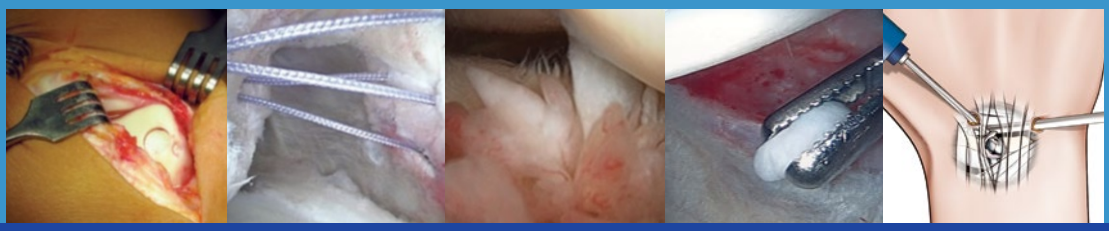
Pietro Randelli
David Dejour
C. Niek van Dijk
Matteo Denti
Romain Seil *Editors*



Arthroscopy

Basic to Advanced

European Society of Sports Traumatology, Knee Surgery & Arthroscopy
ESSKA

Springer

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Editors
Pietro Randelli
San Donato Milanese
Milano
Italy

David Dejour
Lyon
France

C. Niek van Dijk
Academic Medical Centre
Orthopedic Surgery
Univ of Amsterdam
Amsterdam
The Netherlands

ESSKA ASBL
Centre Médical
Fondation Norbert Metz
76, rue d'Eich
1460 Luxembourg
Luxembourg

Matteo Denti
Istituto Clinico Humanitas
Rozzano
Milan
Italy

Romain Seil
Clinique d'Eich
Centre Hospitalier Luxemburg
Luxemburg
Luxembourg

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Preface

Dear colleagues and friends,

Arthroscopy represents a powerful tool in the diagnosis and treatment of a huge range of orthopedic diseases, becoming day by day more indispensable.

The development of newly arthroscopic techniques allows a better treatment of our patients with enormous benefits like pain reduction and faster recovery thus promoting a standard of care that needs to be reached worldwide.

In order to spread this knowledge as much as possible, the ESSKA board has decided to work for 4 years in the creation of this book. The aim of this collection of precious chapters has been to provide the "state of the art" about all available arthroscopic techniques divided per joint.

Some of the most important arthroscopists from different regions of the world have contributed to this book, and I would like to thank these leaders for their precious work.

I would like to quote as well all the editors of the book, for their sustain, and especially David Dejour and Niek Van Dijk, for their help to collect and review the papers of the knee and ankle sections, respectively.

All members of my team deserve to be thanked, especially Paolo Arrigoni and Davide Cucchi who worked very hard on this project.

From the production point of view, I would like to thank Mrs. Gabriele Schroeder and Mr. Claus-Dieter Bachem from Springer, for their support in the achievement of such a huge work.

I think that all the readers will be able to take advantage of this book in their daily practice and that this work will deserve to be quoted as a masterpiece in the field.

This book is dedicated to our families and friends who have made possible to all authors and editors to spend days and weeks to create this book without feeling guilty about the time we spend away from them.

Milano, Italy — Pietro Randelli

Contents

Part I

General Content

History of Arthroscopy

1

Lars Goebel and Henning Madry

The development of arthroscopic surgery can be regarded as one of the milestones in orthopedic surgery within the twentieth century, along with joint arthroplasty and the open reduction and internal fixation of fractures [1–3].

The origin of *arthroscopy* comes from the Greek *arthros* for joint and *scopein* for to look. Physicians have long since attempted to look into body cavities. Its roots can be traced back to the time of the Roman Empire. In the ruins of Pompeii, evidence for the use of vaginal speculums and proctoscopes was made [4, 5].

In modern times it was Philipp Bozzini (1773–1809), a German doctor from Mainz, who first invented a primitive endoscope, his *Lichtleiter*, to inspect body cavities like the mouth, nasal cavity, rectum, or female bladder. When his invention was presented to the *Rome Academy of Science* (Italy) in 1806, the potential of his invention was, however, not acknowledged at all [6] (Table 1.1).

L. Goebel • H. Madry (✉)
Center of Experimental Orthopaedics, Saarland University Medical Center, Kirrberger Straße, Building 37, 66421 Homburg/Saar, Germany

Department of Orthopaedic Surgery, Saarland University Medical Center, Kirrberger Straße, Building 37, 66421 Homburg/Saar, Germany

Cartilage Net of the Greater Region, University of the Greater Region, 66421 Homburg/Saar, Germany
e-mail: henning.madry@uks.eu

Half a century later, Antoine Desormeaux (1815–1882), a French physician from Paris, developed in 1853 a *gazogene cytoscope*, which used a mixture of gasoline and turpentine to illuminate and a system of mirrors to visualize the bladder. Today, his invention is regarded as the first instrument for endoscopy [7].

In 1860 Julius Bruck (1840–1902), a German dentist from Breslau (now Wrocław, Poland), transluminated the bladder with a *diaphanoscope* from the rectum to remove bladder stones [8].

The German urologist Maximilian Nitze (1848–1906) from Berlin introduced a cystoscope in 1876 which already used a heated platinum loop for illumination [9]. One year later, his first public demonstration took place at the *Institut für Pathologie* at the *Stadtkrankenhaus Dresden-Friedrichstadt* (Germany), the same place where 50 years later Michael Burman performed his arthroscopic cadaver studies [10] under the supervision of the German pathologist Christian Georg Schmorl (1861–1932).

After the invention of Thomas Edison's light bulb, Maximilian Nitze and Josef Leiter (1830–1892), an Austrian surgical instrument maker from Vienna, designed the first cystoscope with an incandescent light bulb for illumination in 1886 [11]. Maximilian Nitze was also the first to take a photograph of the inside of a human bladder 4 years later.

The Swedish physician Hans Christian Jacobaeus (1879–1937) from Stockholm invented, together with the *Georg Wolf company*

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Table 1.1 Selected milestones of the history of arthroscopy within the past two centuries

Milestones in the history of arthroscopy	
1806	Philipp Bozzini invents his *Lichtleiter*, the first primitive endoscope
1853	Antoine Desormeaux develops a *gazogene cytoscope* to visualize the bladder
1860	Julius Bruck uses a *diaphanoscope* to transluminate the bladder from the rectum
1876	Maximilian Nitze introduces his cystoscope with a heated platinum loop for illumination
1886	Maximilian Nitze and Josef Leiter design the first cystoscope with an incandescent light bulb
1890	Maximilian Nitze takes the first photograph of the inside of a human bladder
1910	Hans Christian Jacobaeus invents his *laparo-thoracoscope*
1912	Severin Nordentoft, the first *arthroscopist*, presents his results on endoscopy of the knee joint in Berlin
1918	Kenji Takagi uses a cystoscope to examine cadaver knees and later patients with tuberculous knees
1921	Eugen Bircher started to perform *arthroendoscopies* to diagnose meniscal pathologies
1925	Philip Kreuscher publishes his remarkable article on *Semilunar Cartilage Disease*
1931	Michael Burman performs cadaver studies and publishes his historical paper on *Arthroscopy or the Direct Visualisation of Joints*, including the first arthroscopic pictures ever published
1939	Ernst Vaubel publishes *Die Arthroskopie*, the first book on arthroscopy
1954	Harold Hopkins introduces the principle of glass fiber cold light
1955	Masaki Watanabe, the *father of modern arthroscopy*, develops the concept of *triangulation* and removes the first tumor arthroscopically
1957	Masaki Watanabe publishes his first *Atlas of Arthroscopy*
1959	The *Watanabe No. 21* arthroscope is produced in series
1960	Harold Hopkins develops rod lens systems for arthroscopes
1962	Masaki Watanabe performs the first arthroscopic meniscectomy
1964	Robert Jackson is the first foreign doctor to visit Watanabe acquiring his technique of arthroscopy
1967	The *Watanabe No. 22* arthroscope is the first arthroscope to use cold light
1968	Robert Jackson gives first instructional course on arthroscopy at the *American Academy of Orthopaedic Surgeons*
1972	John Joyce is the first to organize private arthroscopy teachings
1973	Jan Gillquist promotes the *central approach* to the knee
1974	Richard O'Connor performs the first partial meniscectomy in North America
1974	The *International Arthroscopy Association* (IAA) is founded
1975	Harold Eikelaar receives the first PhD degree on arthroscopy
1976	Robert Jackson and David Dandy publish the first textbook in English on arthroscopy of the knee
1976	Lanny Johnson develops the first motorized shaver instrument
1982	The North American chapter of the IAA is converted to the *Arthroscopy Association of North America* (AANA)
1984	The *European Society of Sports Traumatology*, *Knee Surgery and Arthroscopy* (ESSKA) is founded
1985	AANA's journal *Arthroscopy*: *The Journal of Arthroscopic and Related Research* (Arthroscopy) is launched
1993	ESSKA's journal *Knee Surgery*, *Sports Traumatology*, *Arthroscopy* (KSSTA) commences
1995	The IAA and the *International Society of the Knee* (ISK) assemble to the *International Society of Arthroscopy*, *Knee Surgery and Orthopaedic Sports Medicine* (ISAKOS)
2014	The *Journal of Experimental Orthopaedics* (JEO), ESSKA's basic science journal, is introduced

(Berlin, Germany), his *laparo-thoracoscope* in 1910. He used this technique for diagnostic purposes in undefined abdominal complaints and functional impairment and as well to treat pleural adhesions caused by tuberculosis [12].

In 1912 Severin Nordentoft (1866–1922, Fig. 1.1), a Danish surgeon and radiologist born in Aarhus, presented his work on *Endoscopy of Closed Cavities by the Means of My Trokart-Endoscope* at the *41st Congress of the German Society of Surgeons* in Berlin (Germany) [13]. He described a *trocart-endoscope*, which was similar to the Jacobaeus *laparo-thoracoscope*, consisting of a 5 mm diameter trocart, a fluid

Fig. 1.1 Severin Nordentoft (1866–1922), today acknowledged as the first *arthroscopist* (Are reprinted with permission)

valve, and an optic tube. Of note, he reported about its application for endoscopy of the knee joint, besides suprapubic cystoscopy and laparoscopy [14]. It was thus Severin Nordentoft who first coined the term *arthroscopy* for visualization of joint cavities, and, today, he is considered as the first *arthroscopist*. Nevertheless, in his presentation no evidence can be found that he ever applied his instrument to patients. At that time, only 90° optic lens systems were available. Moreover, the lens systems allowed only for a relatively poor overview of the joint because of sparse illumination as only about 10 % of the light of modern optics was transmitted. Severin Nordentoft already chose sterile saline as optical medium and advised the use of arthroscopy for the early diagnosis of meniscal lesions [14]. Interestingly, in the decades thereafter, other

Fig. 1.2 Kenji Takagi (1888–1963) (Are reprinted with permission)

arthroscopic pioneers never referred to him in their publications.

Kenji Takagi (1888–1963, Fig. 1.2), a Japanese orthopedic surgeon from Tokyo, applied in 1918 a cystoscope to look inside cadaver knees and later to examine knees affected by tuberculosis. His first arthroscope, build in 1920, was 7.3 mm in diameter, thus relatively big and impracticable for a use within the knee. He continued sophisticating his cystoscope and developed a total of 12 different arthroscopes, with smaller diameter and different angels of view, that became the very prototypes for modern arthroscopes. Also, simple operations, such as biopsies, could be performed with operative instruments he invented. He also discussed distension of the knee with saline solution to enlarge the joint cavity and to improve visualization [4, 5].

The Swiss surgeon and politician Eugen Bircher (1882–1956, Fig. 1.3) started to perform arthroscopies in 1921 as an attempt to diagnose meniscus pathologies [15]. He was the first to publish several papers on the topic of what he called *arthroendoscopy* and approximately performed 60 cases until 1926. Eugen Bircher used this procedure only in advance to arthrotomies.

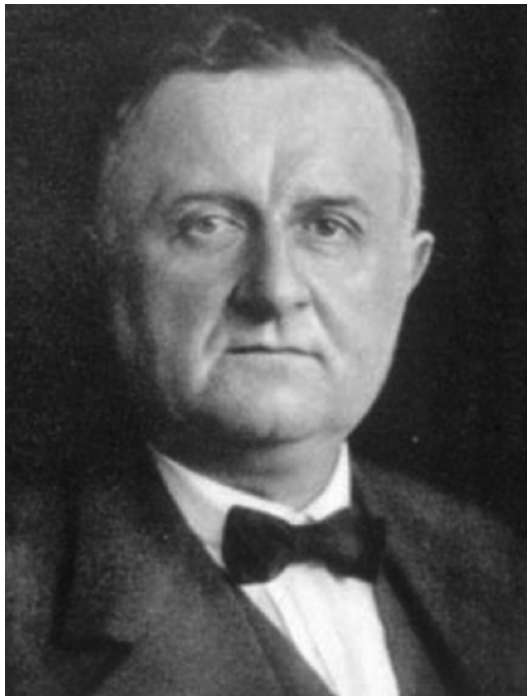

Fig. 1.3 Eugen Bircher (1882–1956) (Are reprinted with permission)

Fig. 1.4 Michael Burman (1896–1974) (Are reprinted with permission)

Interestingly, Severin Nordentoft and Eugen Bircher never referred to each other despite both had presented their results at the annual congresses of surgery in Berlin. Eugen Bircher also used a 90° optic with a very limited field of view, a little illumination, and a long dead end of the arthroscope. By 1930, Eugen Bircher quitted the use of his *arthroendoscopy* in favor of air arthrography, a radiographic technique expecting better visualization of joint contours.

Phillip Heinrich Kreuscher (1883–1943), a son of German immigrants, from Chicago (Illinois, USA) was the first arthroscopist in Northern America. After initial studies about the *collapsed lung treatment* for pulmonary tuberculosis, his academic focus shifted from 1917 onto athletic injuries and especially to the menisci, the *semilunar cartilages* of the knee. In 1925, his remarkable article on *Semilunar Cartilage Disease*: *A Plea for the Early Recognition by Means of the Arthroscope and the Early Treatment of this Condition* was published where he most likely used a Jacobaeus *laparo-thoracoscope* [5, 16]. In a letter to Michael Burman in 1931, he reported 25–30 cases where he applied his arthroscope, although later he did no longer perform arthroscopies. Perhaps like Eugen Bircher, not acknowledged in his time and possibly frustrated by the technical difficulties, he instead focused on arthrography as well.

Michael Burman (1896–1974, Fig. 1.4) was a young American registrar for orthopedics [17]. He started to work with an arthroscope designed by Reinhold Wappler (1870–1932), a designer of electrosurgical instruments, in the anatomy laboratory of the *New York University* (New York, USA). In 1931 he succeeded to gain a travel scholarship that allowed him to extend his research at the *Institut für Pathologie* at the *Stadtkrankenhaus Dresden-Friedrichstadt* [10]. Here, he applied different dyes to visualize articular cartilage degeneration and extended his cadaver studies. Also the first hip arthroscopy is attributed to him, while Kenji Takagi in 1939 performed the first hip arthroscopy in patients. Michael Burman published in 1931 his historical paper *Arthroscopy or the Direct Visualisation of Joints* [18]. The 20 colored aquarelles of arthroscopic findings in different joints that were included are the first

Fig. 1.5 Ernst Vaubel (1902–1989) (Are reprinted with permission)

Fig. 1.6 Masaki Watanabe (1911–1994), the *father of modern arthroscopy* (Are reprinted with permission)

arthroscopic pictures ever published. The images were painted by Frieda Erfurt in Dresden, the institute's medical artist. In the 1950s Burman collected arthroscopic images, but, unfortunately, he never found an editor who was willing to publish his *Atlas of Arthroscopy* [19].

Ernst Vaubel (1902–1989, Fig. 1.5) was a rheumatologist from Wiesbaden (Germany). Together with the *Georg Wolf company*, he improved with an oblique 45° optic the Jacobaeus *laparo-thoracoscope* that was then called *Arthroskop nach Dr. E. Vaubel* [20]. In 1939, the first book ever published on arthroscopy, *Die Arthroskopie*, was published by Ernst Vaubel [21].

Unfortunately, the Second World War (1939–1945) delayed advancements in medical science, and for 16 years no paper on arthroscopy was published [4, 22].

Masaki Watanabe (1911–1994, Fig. 1.6) was an orthopedic surgeon from Nagano, Japan, who graduated from Tokyo Imperial University in 1937. He was a scholar of Kenji Takagi [23]. After World War II, he developed and sophisticated endoscopic instruments. His *Watanabe No. 21* arthroscope (Fig. 1.7) was produced in series from 1959. Today, he is considered as the father of modern arthroscopy, and the *Watanabe No. 21* arthroscope was the first model widely accepted and used. Nevertheless, it had some disadvantages. For example, the incandescent light bulb sporadically broke within the knee joint, and the light carrier was susceptible for short circuit. Notably, Masaki Watanabe also developed the concept of *triangulation* in 1955, and it was also him who first applied knee arthroscopy as therapeutic tool to remove a giant cell tumor in 1955 from the *recessus superior*. In 1962, he performed an arthroscopic partial meniscectomy. Also he was the first to obtain color photographs from the inside of a knee joint (Fig. 1.8). Yet, a color movie on arthroscopy presented at the *Société Internationale de Chirurgie Orthopédique et de Traumatologie* (SICOT) congress in 1957 in Barcelona (Spain) attracted only very few people.

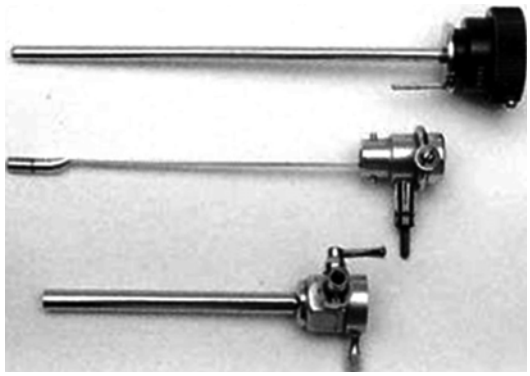

Fig. 1.7 The *Watanabe No. 21* was the first arthroscope produced in series. It had an offset light bulb and an arthroscopic valve (Are reprinted with permission)

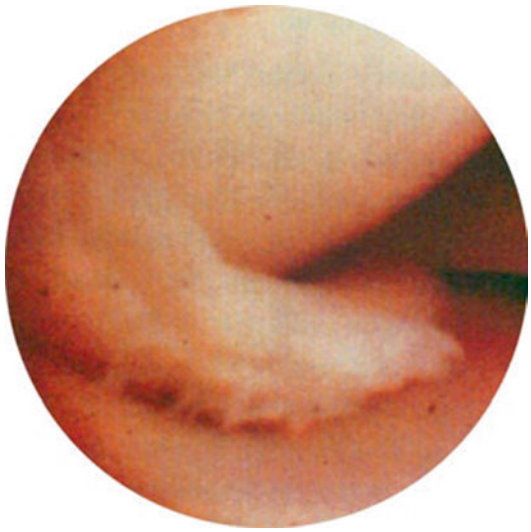

Fig. 1.8 Arthroscopic picture of a torn medial meniscus. The first arthroscopic partial meniscectomy was performed by Masaki Watanabe in 1962 (Are reprinted with permission)

His first *Atlas of Arthroscopy* [24] was published in 1957 in English with illustrations by Fujihashi, followed by a second edition in 1969 containing illustrated color photographs.

Harold Horace Hopkins (1918–1994) was a British physicist born in Leicester, East Midlands. He developed both the principle of glass fiber cold light in 1954 and the optical rod lens system in 1960 [25, 26]. At first glass fibers were used for flexible gastroscopes. The first arthroscope to use cold light was the *Watanabe No. 22* arthroscope built by Tsunekichi Fukuyo in 1967. Interestingly, Masaki Watanabe himself was not convinced and went on using his *Watanabe No. 21* arthroscope with an offset tungsten bulb. While most American pioneers used this conventional arthroscope as well, European arthroscopists used cold light instruments starting from around 1969, produced by German manufacturers *Karl Storz* (Tuttlingen, Germany) and *Richard Wolf* (Knittlingen, Germany). The implementation of rod lenses and cold light significantly improved the visibility, and arthroscopies became safer and more reliable.

Robert W. Jackson from Toronto (Canada) went to Tokyo (Japan) on a traveling fellowship in 1964 to study tissue culture techniques [27]. After many inquiries he found Watanabe at *Tokyo Teishin Hospital*. Curiously, even in his own country, Masaki Watanabe's work was unknown, and Robert Jackson was the first foreign doctor visiting him. For months twice a week, he watched him and acquired the technique of arthroscopy, and, in return, taught Masaki Watanabe English. Before returning to the *University of Toronto* in 1965, he purchased a *Watanabe No. 21* arthroscope. In the first year, he used it already on 25 cases, while frequently being criticized and ridiculed by his colleagues. Despite this challenging environment, 70 cases were accomplished in 1966 and the numbers of case steadily grew thereafter. Other surgeons from North America became aware of this technique. In 1968, Robert Jackson gave the first instructional course on arthroscopy at the *American Academy of Orthopaedic Surgeons* (AAOS) [28]. From 1973 he invited Richard L. O'Connor to join him in these courses. In 1976, together with David Dandy, he published the first textbook in English on arthroscopy of the knee.

Richard L. O'Connor (1933–1980) visited Masaki Watanabe in 1971 and 1972 and learned the technique from him. With *Richard Wolf Medical Instruments Corporation* (Vernon Hills, Illinois, USA), new instruments and arthroscopes were developed. He performed in 1974 the first partial meniscectomy in North America. It was also him who introduced a rod lens-type operation arthroscope [5].

Lanny L. Johnson was one of the leading practitioners and innovators of arthroscopy in North America. He promoted the concept of multiple punctures to explore all regions of a joint and was a pioneer of arthroscopic shoulder surgery and rotator cuff repair, while other diarthrodial joints were also subjected to arthroscopy by him. Lanny Johnson developed many arthroscopic instruments, most notable the first motorized shaver instrument in 1976 in cooperation with *Dyonics* (Andover, Massachusetts, USA). Johnson was also one of the first arthroscopic surgeons videotaping his arthroscopies [5].

In 1972, John J. Joyce III (1914–1991) was the first to organize a private arthroscopy teaching course at the *University of Pennsylvania* (Philadelphia, Pennsylvania, USA) [5].

Harold R. Eikelaar from the Netherlands was the first recipient of a PhD degree on arthroscopy in 1975. Together with the *Storz company*, he developed the first 30° forward oblique arthroscope.

Ejnar Eriksson was the first professor for sports traumatology at the *Karolinska Institute* (Stockholm, Sweden) and hosted, as first one, many arthroscopy courses in European countries.

Jan Gillquist, a Swedish orthopedic surgeon, in 1973 promoted the *central approach* through the patellar tendon to the knee.

Within the last decades, several arthroscopic associations were set up. The *International Arthroscopy Association* (IAA) was founded on April 26, 1974, when there were plans for a second private course on arthroscopy, after the first one was held 1973 by John Joyce in Philadelphia. Masaki Watanabe was elected as its first president, while the IAA's purpose was set *to foster by means of arthroscopy the development and dissemination of knowledge in the fields of orthopedics and medicine in order to improve the diagnosis and treatment of joint disorders*. Initially, the IAA was constituted solely out of two chapters, North America and Japan. At first, every 3 years IAA meetings were held corporately with the SICOT, beginning 1975 in Copenhagen (Denmark), and from 1987 biennial meetings were held with the *International Society of the Knee* (ISK). In 1995 the ISK and IAA joined to form the *International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine* (ISAKOS, Fig. 1.9), with its first meeting being held in Buenos Aires in 1997 [5, 7, 19, 27, 28].

Fig. 1.9 Logo of ISAKOS, the *International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine* (Represents the official logo of the above named society and was taken from the respective official website)

The North American chapter of the IAA was converted into the *Arthroscopy Association of North America* (AANA, Fig. 1.10) in 1982 as it became apparent that a different kind of organization was needed for Northern America to satisfy the educational needs of the increasing number of arthroscopists. Further being closely related to the IAA, meetings were now held annually. Its journal *Arthroscopy*: *The Journal of Arthroscopic and Related Research* (Arthroscopy) was launched in 1985.

In Europe, similar to the AANA, the *European Society of Sports Traumatology, Knee Surgery and Arthroscopy* (ESSKA, Fig. 1.11) was founded 1984 in West Berlin by Ejnar Eriksson from Sweden. Its clinical journal *Knee Surgery, Sports Traumatology, Arthroscopy* (KSSTA) was launched in 1993, with Eriksson serving as editor in chief. ESSKA inaugurated also its basic science *Journal of Experimental Orthopaedics* (JEO) in 2014.

Fig. 1.10 Logo of AANA, the *Arthroscopy Association of North America* (Represents the official logo of the above named society and was taken from the respective official website)

Fig. 1.12 Logo of APKASS, the *Asia-Pacific Knee, Arthroscopy and Sports Medicine Society* (Represents the official logo of the above named society and was taken from the respective official website)

Fig. 1.11 Logo of ESSKA, the *European Society of Sports Traumatology, Knee Surgery and Arthroscopy* (Represents the official logo of the above named society and was taken from the respective official website)

Fig. 1.13 Logo of SLARD, the *Sociedad Latinoamericana de Artroscopia Rodilla y Traumatología Deportiva* (Represents the official logo of the above named society and was taken from the respective official website)

Similarly, the *Asia Pacific Orthopaedic Society for Sports Medicine* (APOSSM) was founded in 1995 together with ISAKOS. In 2012 APOSSM took its progression further to the development of its new society, the *Asia-Pacific Knee, Arthroscopy and Sports Medicine Society* (APKASS, Fig. 1.12). Also, for South and Latin America, the *Sociedad Latinoamericana de Artroscopia Rodilla y Traumatología Deportiva* (SLARD, Fig. 1.13) was established.

Teaching the art of arthroscopy began at first one-on-one with the instructor and the student looking through the same optic. It was later

facilitated by beam-splitting devices, allowing both to look at once into the joint [5]. Nevertheless it was still extremely susceptible for moving the arthroscope away. Later, flexible fiber optics were available, further facilitating teaching [26]. With the implementation of television monitors, slides, or videos, it was possible to better demonstrate pathological conditions, as well as technical processes. Models out of rubber and plastic were developed for teaching, while today cadaver teaching centers represent the state of the art.

In the last decades, indications for arthroscopic therapies have been continuously expanded [29]. Almost every joint may be assessed and treated by arthroscopy. At the same time, techniques and indications are further sophisticated, e.g., for meniscal repair [30, 31] or anterior cruciate ligament reconstruction [32, 33]. Today, arthroscopy has to be regarded as the standard technique for many indications, compared with conventional methods. Its benefits include, but are not limited to, a reduced time of the healing process and a decreased number of complications while a diagnosis and definitive operative treatment are facilitated [3]. Future inventions may lead to three-dimensional arthroscopy, e.g., the invention of manual movable optics allowing the surgeon to turn the optic from 0 to 90°.

While in the early days, innovations by the pioneers of arthroscopy were often met with ignorance and skepticism, arthroscopic operations now represent one of the key technological advancements of the past 100 years in orthopedic and trauma surgery.

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Surgery Set-Up, Instrumentations and Electronic Equipment

2

Pietro Simone Randelli and Davide Cucchi

2.1 Surgical Environment

Arthroscopic surgery might be performed in operative theatre, in outpatient/ambulatory setting or in an office; in any of these settings, basic requirements such as anaesthesia support, electric power and suction for fluid management must be present. Adequate sterilisation of arthroscopic equipment is also crucial [1, 19, 25].

2.2 Arthroscopy Tower

An arthroscopy tower is a vertical cart with various shelves on which electronic equipment for the arthroscopic procedure is placed (Fig. 2.1). Wheels allow moving the tower to the optimal position during surgery. Modern arthroscopy towers have a modular design to conform to any set-up needed. A monitor is placed on the top of the arthroscopy tower. A smaller monitor may be placed on the opposite side of the main one or on another articulating arm to allow vision from other points of the room. The video camera unit and a light source unit are usually placed on the first shelves under the monitor, together with possible external hard drives or documentation system units; a printer may be placed on the bottom shelf. A power box for motorised instruments and one for radiofrequency may be mounted on the arthroscopy tower or on separate carts. If used, the irrigation pump is usually placed also on the arthroscopy tower [1, 18, 19].

2.3 Light Source and Light Cable

A key feature of arthroscopy is to enable visualisation of internal structures with a minimal incision. To obtain this, light must be brought inside the joint with an arthroscope. At the beginning of the arthroscopic and endoscopic era, light was produced by a candle and delivered through rigid instruments. Then, a light bulb was mounted on the tip of the arthroscope; in 1967, fibre optics were introduced in arthroscopy by Masaki Watanabe (Fig. 2.2) [6, 15, 24].

Nowadays light is produced by a 100–300 W xenon lamp or by a LED and delivered to the arthroscope with flexible fibre optics. Light intensity and colour temperature are balanced by

P.S. Randelli (✉) • D. Cucchi
Dipartimento di Scienze Biomediche per la Salute,
Università degli Studi di Milano,
Via Mangiagalli 31, Milan 20133, Italy

IRCCS Policlinico San Donato,
Via Morandi 30, San Donato Milanese 20097, Italy
e-mail: pietro.randelli@unimi.it

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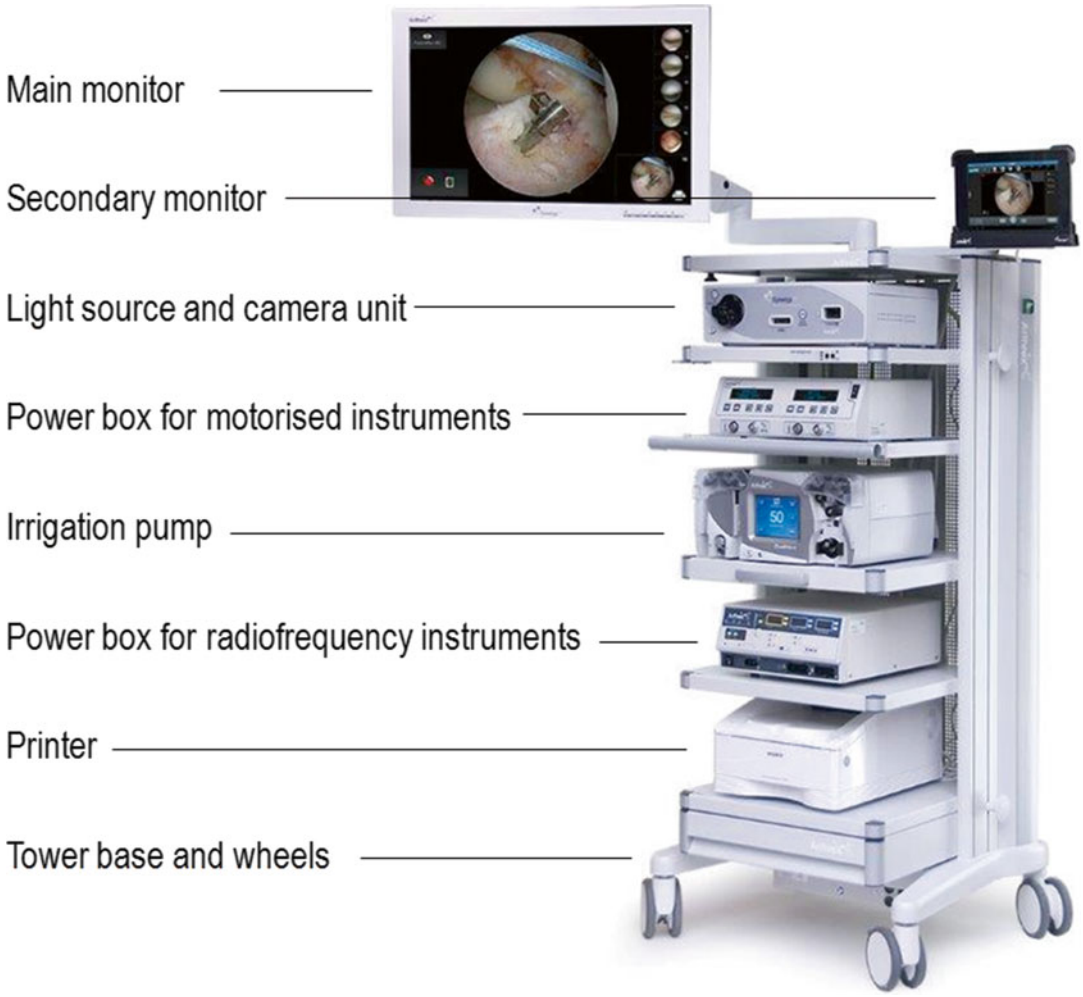

Fig. 2.1 An arthroscopy tower (Courtesy of Arthrex GmbH)

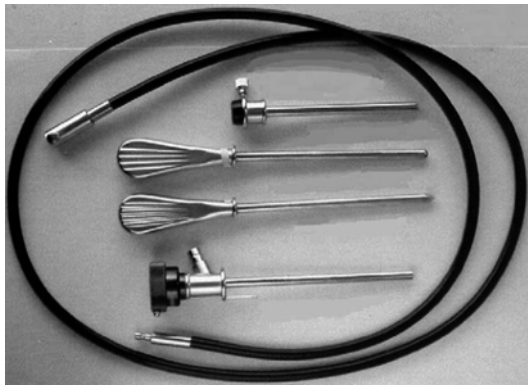

Fig. 2.2 Watanabe's arthroscope No. 22, the first direct-view scope with cold light illumination (Reprinted from: Copyright © 2006 Elsevier Inc., Kieser et al. [15], with permission from Elsevier)

internal feedback sensors and may be controlled on the camera head or on the arthroscopy tower. Filters and diffusion discs might be added to change light quality for special applications. Light loss must be minimal from light source to the joint; the quality of light delivered in the joint is affected by light source's intensity and colour temperature, area of the transverse section of the light cable, light leaking in the connectors of the source-cable-arthroscope unit and possible damages to single fibres; a safety lock system prevents accidental separation of the light cable from the arthroscope. Adaptors may be used to fit cables and arthroscopes from different generations or manufacturers. The light concentration at

the end of the light cable heats the focal point; therefore, this part must never be placed on the patient's skin or on the drape as long as the light source is turned on, because of the risk of fire or burns [1, 18, 19].

2.4 Arthroscopes and Cameras

Arthroscopes are telescopic devices which consist of a magnifying lens system sealed within a rigid tube; the distal (or objective) end contains the end of the fibre optics bundle and the first lens of the optical system. The proximal (or ocular) end is equipped with adapters to be attached to the video camera and the light cable. The image can be transmitted from the objective to the ocular end through two basic optical systems: a rod-lens system, composed by long, cylindrical lenses separated by small spaces, and a single-image fibre system, which is narrower in diameter and contains one image-transmitting fibre bundle. Diameter and length of the arthroscope tube are variable. Diameter and construction materials are important to prevent arthroscope bending, which alters light transmission and image quality.

Important optical characteristics of an arthroscope are focal length, field of view and resolution. Focal length depends on arthroscope length and lens's characteristics and influences depth of field and magnification. The field of view depends on the arthroscope angle or "offset"; increasing the offset, the apparent and real field of view will broaden and the image distortion will increase (Fig. 2.3). Most of the arthroscopes used today have a 30° offset, which allows the surgeon to visualize the articular environment with ease, but 0° and 70°-offset arthroscopes are also available. Resolution depends on light source and light transmission, lens integrity, imaging capturing device and monitor characteristics. The first arthroscopes were designed for direct observation (Fig. 2.4). Nowadays, arthroscopes are routinely connected to a digital video camera, contained in a piece called "camera head". A modern camera head contains usually a three-

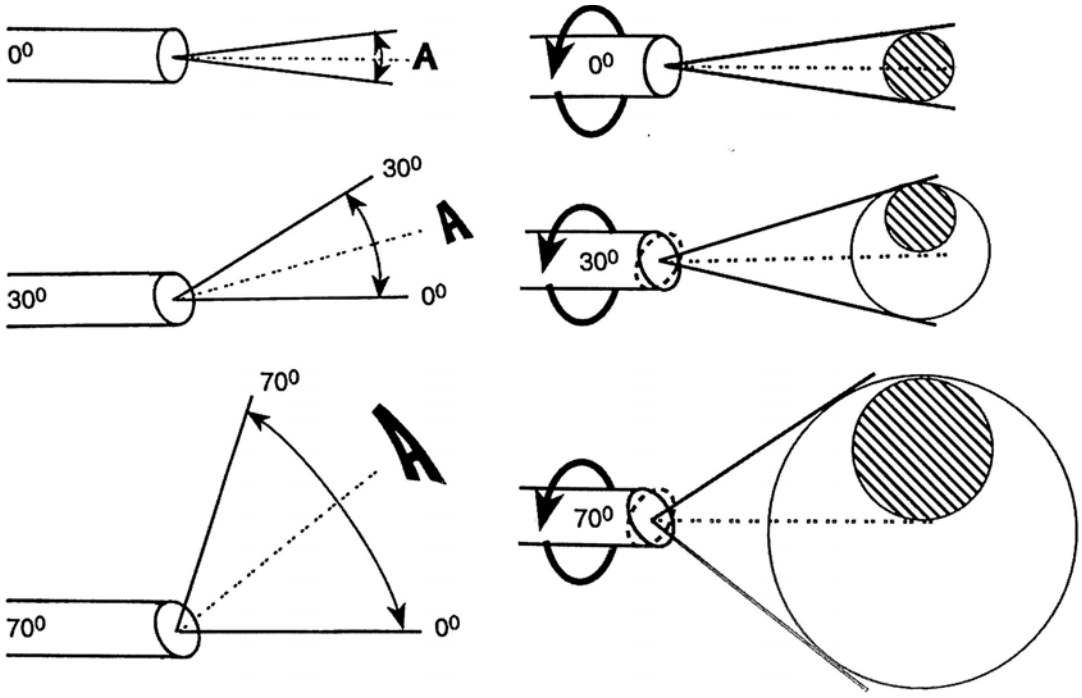

Fig. 2.3 Image distortion and changes in apparent and real field of view using arthroscopes with different offset (Reprinted and modified from: Andrews and Timmerman [1], with permission from Elsevier)

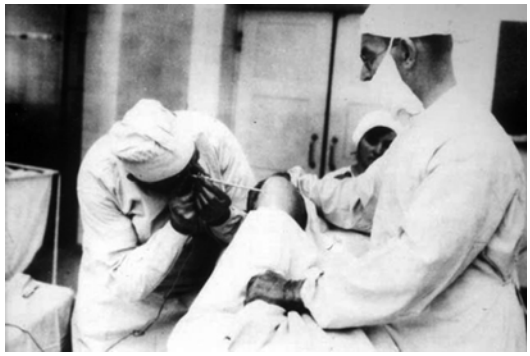

Fig. 2.4 Eugen Bircher performing a knee arthroscopy (Reprinted from: Copyright © 2003 Elsevier Inc., Kieser et al. [30], with permission from Elsevier)

chip CCD sensor; this means that a prism splits the image into the primary colours and projects it to three individual sensors. Multiple-sensor systems enhance sharpness and improve colour balance and resolution. An optical zooming system is built in the camera head and greater image magnification can be digitally obtained by pixel enlargement [1, 18, 19].

2.5 Monitor, Image Capture Devices and Documentation System

The monitor usually sits on top of the arthroscopy tower and it is the device that shows the image created by the arthroscope and the camera head. Monitors have evolved from basic analogue projection boxes to flat panel screens. Image capture devices are commonly found on arthroscopy towers and can be either controlled from the tower or from the camera head. They 'capture' pictures or movies during arthroscopic procedure and save them onto CDs or external hard drives or in a documentation system. This allows to document the procedure digitally and to provide the surgeon and the patient with pictures or movies of the arthroscopic procedure. Documentation systems might also be connected to hospital databases containing radiological and clinical data. Having actual pictures of the injury and the final treatment outcome is important for referral surgeons providing subsequent care and can help patients understand their injuries and their prognosis for recovery. Numerous photo- and video-editing programmes are available from different providers; these are useful to add images to the clinical documentation or to prepare presentations or publications.

2.6 Fluid Management

A clear view is essential to perform an arthroscopic procedure safely and efficiently. Even if the arthroscope, light source and camera are functioning properly, debris and bleeding can block the arthroscopic view. A well-functioning irrigation system helps to widen the joint space and to clear all possible disturbances. Control of bleeding vessels, hypotensive anaesthesia and epinephrine in addition to irrigation fluids are other ways to obtain a clear view.

Irrigation systems can be categorised into three types: gravity infusion, peristaltic volumetric pumps and centrifugal pumps; peristaltic pumps are divided in single and double rollers depending on absence or presence of an outflow pump. No consensus exists about optimal irrigation of joints during arthroscopic operations. Gravity infusion is safe, cheap and easy to prepare but does not allow to accurately control fluid flow and permits to reach only low pressures. In pumps, a computerised console constantly measures fluid pressure and flow within the joint; the surgeon is enabled to optimise flow and pressure using pedals or from the arthroscopy tower. Modern systems automatically adjust for the pressure changes associated with the use of suction devices and shavers [18, 19, 27, 28].

In literature, different values are suggested for the optimal intra-articular pressure, depending on which joint is investigated and the surgeon's preferences. Care has to be taken to avoid high pressure peaks, which can cause fluid extravasation and soft tissue damage; abrupt movements of the joint may rapidly increase intra-articular pressure [1, 7, 8, 26].

Fluid temperature affects core body temperature, perioperative shivering and hypothermia. In endoscopic surgery, strong evidence recommends

the use of warmed irrigation fluid [13]; in arthroscopic surgery, conflicting results have been produced by randomised controlled trials and comparative studies [16, 21, 23].

A saline 0.9% w/v solution and lactated Ringer's solution are the most frequently used fluids for arthroscopy, but is unclear which fluid is the most suitable; in vitro studies have shown that saline may have an inhibitory effect on proteoglycan metabolism in articular cartilage, whilst lactated Ringer's solution causes more elution of proteoglycan from cartilage that renders the cartilage more uneven and rougher [4, 9, 10, 14, 29].

The addition of epinephrine to irrigation fluid significantly improves surgeon-rated visualisation in shoulder arthroscopy but does not affect operative time or volume of irrigation fluid used [2, 12, 22]. Norepinephrine has also been proposed as a substitute of epinephrine in irrigation fluid [5].

2.7 Instrumentations

A vast assortment of hand and motorised instruments is available from different manufacturers.

2.7.1 Hand Instruments

The arthroscope sheath is used to prevent damage to the arthroscope and the tissues whilst changing portals during arthroscopy; it contains the attachment to the irrigation system and can be used to control inflow and outflow.

Blunt-ended trocars and dilators are metal or plastic instruments used to widen arthroscopic portals or penetrate soft tissues, before the entrance of the arthroscope or other instruments.

Wissinger rods and switching sticks facilitate the creation of portals and the exchange between portals and cannulae.

Arthroscopic cannulae are metal or plastic tubes equipped with a blunt trocar to penetrate soft tissues. They can be smooth or threaded, rigid, flexible or semi-rigid; they permit to move the arthroscope, instruments and sutures across different portals without repeated tissue damage, fluid pressure loss and creation of turbulence. The best ones are clear.

A hook palpator or probe is used to assess tissue consistency and stability or move intra-articular structures. Graduated probes help estimate distances and sizes.

Graspers are useful to pick up loose bodies, intra-articular debris or sutures, to pull structures, to assess their resistance or to bring them to correct positions.

Punches and scissors are used to cut unnecessary or damaged tissue; these instruments have substituted in many cases the use of surgical blades, which may break and float in the joint. Different dimensions of straight, angled, reverse and rotary punches exist, which can help the surgeon reach tissues in different positions.

Suture passers are used to penetrate tissues with a suture. Different types exist, which can pass tissue and suture in a single step (direct suture passers) or act with a two-step approach (indirect suture passers): the first step is penetrating the tissue and passing a "shuttle" wire or suture, and the second is retrograde shuttling of the suture back through the soft tissue.

Suture retrievers, pushers and cutters are used to manage intra-articularly sutures and knots.

Chondral pickers that are used to apply a penetrating force on cartilage and rasps can be used to abrade bone, cartilage or capsular tissue.

Special hand instruments are designed to increase accuracy and speed for particular procedures, like ligament reconstruction, meniscal repair and osteochondral transplantation among the most frequently performed.

2.7.2 Suture Anchors

A wide variety of suture anchors has been developed for the fixation of soft tissues to bone. Suture anchors vary in size, shape, composition, method of insertion and fixation, radiopacity and holding strength. New anchors continue to be released as older designs are replaced by newer ones easier to handle, with improved mechanical properties and with a lower rate of failure for

anchor pull-out and suture cut-out. Partially threaded, fully threaded or double threaded screw-in anchors are opposed to non-screw push-in anchors [3, 24].

2.7.3 Powered Instruments

Shavers are instruments that combine rotation of a cutting end with suction to resect large amounts of soft tissue in a short amount of time. They are disposable and differ in size, shape, cutting angle and blade design. Speed, direction and oscillation of the cutting end can be controlled by means of pedals or on the power unit. Although some shavers are more aggressive and can also remove bone, disposable burrs are specifically designed for this task. A power box for motorised instruments is present in most arthroscopy towers, in which different attachments can fit [1, 18, 19].

A radiofrequency ablation instrument may also be part of the tower. The power box uses radiofrequency to generate heat at the tip of a disposable instrument. This heat is used to ablate unwanted or damaged tissues within the joint, to electrocauterise blood vessels or to perform capsular shrinkage. Two types of devices are available: in bipolar tools energy is transferred between electrodes at the site of treatment, whilst in monopolar ones a grounding pad must be used and energy passes through the body. Current controversies include the depth of tissue penetration; the amount of cell death, possible chondral, tendinous and capsular damage; and the ability of each device to monitor and control temperature [1, 11, 17, 19, 20].

2.8 Surgical Positioning

Patient positioning and ease to access joint space determine the success of surgery. Patient positioning must consider surgeon's, anaesthesiologist's and nurse's comfort and possibility to convert the procedure from arthroscopic to open. The arthroscopy tower is usually placed on the contralateral side of the patient. A Mayo stand for sterile instruments can be brought in from the contralateral side or from the foot of the table, according to the surgeon's preference. Numerous devices are available to optimise patient positioning: leg holders, lateral posts and traction units designed to be attached to standard operating tables are available in different models for hip, knee, ankle, shoulder, elbow and wrist arthroscopy and will be described for each joint in the next chapters. Cushions and pads are used to protect delicate structures which can be damaged by prolonged compression or by traction [1, 19, 25].

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Standard Operative Report

3

Petri Sillanpää, Paolo Arrigoni, and Davide Cucchi

3.1 Introduction

The first recorded application of an endoscope to examine a joint occurred in 1912, when the Danish surgeon Severin Nordentoft used a laparoscope to examine the interior of knees. Since then, arthroscopic techniques evolved quickly and were extended to numerous joints.

Small differences between arthroscopy procedures may impact significantly on patient's quality of life and are the main drive for innovation in clinical research. Standard operative reports are a precious tool to store the information on each surgery and compare procedures performed in distant periods and places, which is the basis to single-centre and multicentre registry studies.

Standard operative reports may also be relevant for health care and insurance authorities and could support the surgeon in legal controversies.

Moreover, the availability of a properly filled operative report can be of dramatic importance in planning two-stage and revision surgery; in the end, a standard operative report is an indicator of reliability and high-quality practice.

In this chapter, comprehensive standard operative reports are proposed for arthroscopy procedures in the shoulder, elbow, wrist, hip, knee and ankle.

3.2 Shoulder

The transition from open to arthroscopic surgery has allowed to perform shoulder surgery with smaller skin incisions, reduced inflammatory response and less postoperative morbidity and complications. Arthroscopy permitted also to easily combine procedures extremely demanding with an open approach. Numerous pathologies can nowadays be treated with shoulder arthroscopy: rotator cuff tears, glenohumeral instability, subacromial impingement and instability of the long head of the biceps and of its anchor are some of the most frequently addressed.

Small differences between each surgeon's techniques may impact significantly on patient's quality of life, surgical departments' economics and orthopaedic companies' innovation drive. To compare different surgeons' approaches and assess the value of these small differences, detailed and standard operative reports are needed. Various classifications exist to describe lesions of different structures, but few comprehensive report forms exist. We propose a comprehensive standard operative report for

P. Sillanpää, MD, PhD
Department of Orthopedic, Dextra Koskiklinikka,
Hatanpään valtatie 1, Tampere 33101, Finland

P. Arrigoni, MD • D. Cucchi, MD (✉)
Dipartimento di Scienze Biomediche per la Salute,
Università degli Studi di Milano,
Via Mangiagalli 31, Milan 20133, Italy

IRCCS Policlinico San Donato,
Via Morandi 30,
San Donato Milanese 20097, Italy
e-mail: d.cucchi@gmail.com

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shoulder arthroscopy, which combines the most widely accepted classification schemes and adds few items regarding newer techniques, which will help future researchers.

Shoulder arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Positioning: [ ] Lateral decubitus [ ] Beach chair

Current diagnosed pathology/injuries:

- [ ] Rotator cuff tear
- [ ] SLAP lesion
- [ ] LHB degeneration
- [ ] Anterior instabilty
- [ ] Posterior instability
- [ ] Multidirectional instability
- [ ] Capsular tear
- [ ] Subacromial impingement
- [ ] Calcific tendonitis
- [ ] Adhesive capsulitis
- [ ] Degenerative acromioclavicular disease
- [ ] Glenohumeral arthritis
- [ ] Infective arthritis
- [ ] Humeral fracture
- [ ] Suprascapular nerve entrapment
- [ ] Other (specify): _____

Previous procedures:

- [ ] Rotator cuff repair
- [ ] SLAP repair
- [ ] LHB procedure (specify):_____
- [ ] Labral repair
- [ ] Capsular plication
- [ ] Subacromial decompression
- [ ] Acromioplasty
- [ ] Other (specify): _____

Intraoperative findings

Cartilage status (glenoid)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal
- [ ] ICRS Grade 2 – Abnormal
- [ ] ICRS Grade 3 – Severely Abnormal
- [ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (humeral head)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal
- [ ] ICRS Grade 2 – Abnormal
- [ ] ICRS Grade 3 – Severely Abnormal
- [ ] ICRS Grade 4 – Severely Abnormal

LHB:

- [ ] Agenesia
- [ ] Normal
- [ ] Inflammation
- [ ] Partial tear
- [ ] Complete tear

LHB anchor:

- [ ] Normal
- [ ] SLAP 1
- [ ] SLAP 2 [a][b] [c]
- [ ] SLAP 3
- [ ] SLAP 4

LHB pulley:

- [ ] Normal
- [ ] Isolated SGHL lesion
- [ ] SGHL + partial supraspinatus lesion
- [ ] SGHL + partial subscapularis lesion
- [ ] SGHL + suprasp. + subscap. lesion

Labrum & capsule:

[ ] Normal

[ ] Normal (with anatomical variants) [ ] Sublabral hole [ ] Buford complex

[ ] Other anatomical variants (specify): _____

		indicate position/extension using clock reference method
[ ]	Labral detachment with complete periosteal tearing (Bankart-type lesion)	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
[ ]	Osseous avulsion (bony Bankart-type)	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
[ ]	Labroligamentous periosteal sleeve avulsion (ALPSA/PoLPSA lesion)	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
[ ]	Labral detachment with intact periosteum (Perthes-type lesion)	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
[ ]	Glenolabral articular disruption	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]

[ ] Humeral avulsion of glenohumeral ligaments [ ] Anterior HAGL [ ] Posterior HAGL [ ] Reverse HAGL

[ ] Glenoid avulsion of glenohumeral ligaments

[ ] Other lesion (specify): _____

Rotator cuff (use SCOI classification for posterosuperior cuff, Lafosse classification for subscapularis)

[ ] Normal

[ ] Calcific deposits

[ ] Isolated infraspinatus tear: [A1] [A2] [A3] [A4] [B1] [B2] [B3] [B4] [C1] [C2] [C3]

[ ] Isolated supraspinatus tear: [A1] [A2] [A3] [A4] [B1] [B2] [B3] [B4] [C1] [C2] [C3]

[ ] Posterosuperior cuff (supraspinatus+infraspinatus): [A3] [A4] [B3] [B4] [C2] [C3] [C4]

[ ] Subscapularis tear: [ ] Grade I - Partial lesion of superior one-third [ ] Grade II - Complete lesion of superior one-third [ ] Grade III - Complete lesion of superior two-thirds [ ] Grade IV/V - Complete lesion

Other intraoperative findings (please specify):

_____

_____

_____

Intraoperative procedures

[ ] Articular debridement

[ ] Microfractures: [ ] glenoid [ ] humeral head

[ ] Synovial removal: [ ] with shaver [ ] electrocautery

[ ] LHB tenotomy

[ ] LHB tenodesis: [ ] intraarticular [ ] extraarticular

[ ] SLAP repair

n° of anchors used: ___ name of anchor, company: _____

material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK) [ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)

Anchors' position (clock reference): [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]

Comments: _____

[ ] Labrum/capsule repair
- n° of anchors used: ___ name of anchor, company: _____
- material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK) [ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)
- Anchors' position (clock reference): [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
- n° of capsular plications/retensioning stitches (without anchors): ___
- Plications' position (clock reference): [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]
- Comments:_____

[ ] Rotator interval closure

[ ] Hill-Sachs remplissage
- n° of anchors used: ___ name of anchor, company: _____
- material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK) [ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)
- Comments:_____

[ ] Rotator cuff repair (posterosuperior cuff)
- [ ] Partial-thickness tear [ ] Repaired (PASTA repair) [ ] Completed
- [ ] Full-thickness tear [ ] Partial/functional repair [ ] Complete/watertight repair
- [ ] Side-to-side repair n° of stitches: ___
- [ ] Tendon to bone repair [ ] Single-row [ ] Double-row [ ] Other (specify):_____
  - [ ] Transosseous repair
    - n° of tunnels used:___ name of device, company: _____
  - [ ] Anchor repair
    - n° of anchors used: ___ name of anchor, company: _____
    - material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK) [ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)
  - [ ] Scaffold augmentation name of device, company: _____
  - [ ] Biological enhancing substances (PRP, MSCs) name of product or device, company: _____
  - Comments:_____

[ ] Subscapularis repair
- n° of anchors used: ___ name of anchor, company:
- material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK) [ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)
- Comments:_____

[ ] Subacromial soft-tissue decompression

[ ] Acromioplasty

[ ] Coplaning of the acromioclavicular joint

Other intraoperative procedures (please specify):

_____

_____

_____

Surgeon's signature: _____

3.3 Elbow

The elbow has been investigated arthroscopically for more than 30 years; arthroscopy allowed precise diagnosis and safe treatment with less postoperative complications and faster recovery than any open technique. Fracture osteosynthesis, loose body or osteophyte removal, debridement of osteochondral lesions and synovitis, arthrolysis and joint stabilisation are currently accepted indications for elbow arthroscopy.

New instruments and techniques are developed at a fast pace, which contributes in the progressive widening of indications for elbow arthroscopy. The advent of arthroscopy has also improved the understanding of the pathoanatomical changes associated with elbow pathology. A comprehensive standard operative report for elbow arthroscopy is useful to uniform disease classification systems and to make surgical approaches comparable among different orthopaedic surgeons.

Elbow arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Positioning: [ ] Lateral decubitus [ ] Prone [ ] Supine

Current diagnosed pathology/injuries:

- [ ] Intraarticular loose bodies
- [ ] Synovitis
- [ ] Osteochondritis dissecans
- [ ] Arthrofibrosis
- [ ] Arthritis
- [ ] Instability
- [ ] Impingement
- [ ] Lateral epicondylitis
- [ ] Radial head fracture
- [ ] Coronoid fracture
- [ ] Capitulum humeri fracture
- [ ] Infective arthritis
- [ ] Other (specify): _____

Previous procedures:

- [ ] Fracture osteosynthesis
- [ ] Synovectomy
- [ ] Capsular plication
- [ ] Arthrolysis
- [ ] Collateral ligament stabilisation (medial)
- [ ] Collateral ligament stabilisation (lateral)
- [ ] Other (specify): _____

Intraoperative findings

Posterior compartment:

- [ ] Posterior plica
- [ ] Posterior synovitis
- [ ] Radial head ballottment
- [ ] Annular drive through sign (radiocapitellar laxity)
- [ ] Olecranon fossa osteophytes

Anterior compartment

- [ ] Anterior plica
- [ ] Anterior synovitis
- [ ] Coronoid fossa osteophytes
- [ ] Radial fossa osteophytes

Medial compartment

- [ ] Medial capsular tears
- [ ] Medial collateral ligament elongation

Lateral compartment

- [ ] Lateral capsular tears
- [ ] Lateral collateral ligament elongation

Cartilage status (capitulum humeri, anterior aspect)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal
- [ ] ICRS Grade 2 – Abnormal
- [ ] ICRS Grade 3 – Severely Abnormal

Cartilage status (capitulum humeri, posterior aspect)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal
- [ ] ICRS Grade 2 – Abnormal
- [ ] ICRS Grade 3 – Severely Abnormal

Cartilage status (radial head, prox. R/U joint)

[ ] ICRS Grade 0 – Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (radial head)

[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (U/H joint)

[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Other intraoperative findings (please specify):

_____
_____
_____

Intraoperative procedures

[ ] Articular debridement
[ ] Microfractures:
[ ] Synovial removal: [ ] with shaver [ ] electrocautery
[ ] Capsule repair/plication

n° of anchors used: ___ name of anchor, company: _____

material: [ ] titanium [ ] non-metal, non-biodegradable (PEEK)
[ ] all-suture [ ] biodegradable/biocomposite (PLLA, TCP)

Anchors' position: _____
n° of capsular plications/retensioning stitches (without anchors): ___
Plications' position: _____
Comments:_____

[ ] Arthrolysis

Other intraoperative procedures (please specify):

_____
_____
_____

Surgeon's signature: _____

3.4 Wrist

Wrist arthroscopy originally developed as a diagnostic tool to investigate defects that could be missed by imaging techniques, as ligament tears or cartilage lesions. Advancements in arthroscopy techniques and reduction of the instruments' dimensions permit nowadays to treat a wide array of pathologies, both from degenerative and traumatic causes. Articular debridement, repair of the triangular fibrocartilage complex, ligament stabilisation, fracture osteosynthesis and ganglionectomy are the most frequently performed procedures, and the indications for wrist arthroscopy are growing steadily. Standard operative reports will enable surgeons to share their experiences and describe each of them in a clear, reproducible and comprehensible way. Only few classifications exist for intra-articular wrist lesions. Standard operative reports may stimulate the development of new systems and confirm the used ones as worldwide-accepted references.

Wrist arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Current diagnosed pathology/injuries:

- [ ] Intraarticular loose bodies
- [ ] Synovitis
- [ ] Distal radius fractures
- [ ] Scaphoid fractures
- [ ] Arthritis
- [ ] Instability
- [ ] Lesion of the TFCC
- [ ] Lesions of the SL complex
- [ ] Ganglia
- [ ] Impingement
- [ ] Infective arthritis
- [ ] Other (specify): _____

Previous procedures:

- [ ] Fracture osteosynthesis
- [ ] Synovectomy
- [ ] Debridement/repair of the TFCC
- [ ] Scapholunate stabilisation
- [ ] Bone resection
- [ ] Loose body removal
- [ ] Ganglionectomy
- [ ] Other (specify): _____

Intraoperative findings

Scapholunate Tears (EWAS Classification)

- [ ] I
- [ ] II lesion of membranous SLIOL
- [ ] III A partial lesion involving the volar SLIOL
- [ ] III B partial lesion involving the dorsal SLIOL
- [ ] III C complete SLIOL tear, joint is reducible
- [ ] IV complete SLIOL with SL gap
- [ ] V

TFCC lesions (Palmer Classification)

- [ ] I.a – traumatic, central perforation
- [ ] I.b – traumatic, ulnar avulsion with or without distal ulnar fracture
- [ ] I.c – traumatic, distal avulsion
- [ ] I.d – traumatic, radial avulsion with or without sigmoid notch fracture
- [ ] II.a – degenerative, TFCC wear
- [ ] II.b – degenerative, TFCC wear with lunate and/or ulnar chondromalacia
- [ ] II.c – degenerative, TFCC perforation with lunate and/or ulnar chondromalacia
- [ ] II.d – degenerative, TFCC perforation with lunate and/or ulnar chondromalacia and lunotriquetral ligament perforation
- [ ] II.e – degenerative, TFCC perforation with lunate and/or ulnar chondromalacia, lunotriquetral ligament perforation, and ulnocarpal arthritis

Cartilage status (radius - scaphoid facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (radius - lunate facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (scaphoid - radial facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (scaphoid - midcarpal facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (lunate - radial facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (lunate - midcarpal facet)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (triquetrum)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (capitate)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Cartilage status (hamate)
[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal
[ ] ICRS Grade 2 – Abnormal
[ ] ICRS Grade 3 – Severely Abnormal
[ ] ICRS Grade 4 – Severely Abnormal

Other intraoperative findings (please specify):

_____

_____

_____

Intraoperative procedures

[ ] Articular debridement
[ ] Synovial removal: [ ] with shaver [ ] electrocautery
[ ] Fracture osteosynthesis
[ ] Debridement/repair of the TFCC
[ ] Scapholunate stabilization
[ ] Bone resection
[ ] Loose body removal
[ ] Ganglionectomy

Other intraoperative procedures (please specify):

_____
_____
_____

Surgeon's signature: _____

3.5 Hip

Hip arthroscopy is usually performed in young people suffering labral tears, femoro-acetabular impingement (FAI) or cartilage lesions. Hip arthroscopy has become more common in the past years, and research activity concerning hip arthroscopy procedures is increasing. While arthroscopy of the hip joint is more demanding in regard to patient set-up, it can be assumed that over time similar variety of intra-articular diseases can be treated as in the knee joint. The variety of problems that can be treated with hip arthroscopy is constantly evolving, including treatment of bony and tendon abnormalities around the hip joint.

Standardised operative report for hip arthroscopy includes patient positioning, documentation of intra-articular findings and surgical interventions performed.

Hip arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Current diagnosed pathology/injuries:

- [ ] Cam-type impingement
- [ ] Pincer-type impingement
- [ ] Combined impingement
- [ ] Labral tear
- [ ] Ligamentum teres
- [ ] Ileopsoas tendon
- [ ] Gluteal muscles:_____
- [ ] Acetabular rim fracture
- [ ] Chondrosis/OA
- [ ] Other (specify): _____

Hip dysplasia features:

- [ ] Abnormal CE-angle LCEA
- [ ] Abnormal Tönnis angle
- [ ] Abnormal Femoral shaft-neck angle

Previous procedures:

- [ ] Femoral osteochondroplasty
- [ ] Labral resection
- [ ] Labral reconstruction
- [ ] Microfracture
- [ ] Femoral osteotomy
- [ ] Acetabular osteochondroplasty
- [ ] Labral suturation
- [ ] Acetabular osteotomy
- [ ] ACI
- [ ] FOCA
- [ ] Other (specify): _____

Intraoperative findings and procedures

Cartilage status (ICRS)	0	1	2	3	4
Acetabulum ant med	[ ]	[ ]	[ ]	[ ]	[ ]
Acetabulum ant lat	[ ]	[ ]	[ ]	[ ]	[ ]
Acetabulum cranial med	[ ]	[ ]	[ ]	[ ]	[ ]
Acetabulum cranial lat	[ ]	[ ]	[ ]	[ ]	[ ]
Acetabulum post med	[ ]	[ ]	[ ]	[ ]	[ ]
Acetabulum post lat	[ ]	[ ]	[ ]	[ ]	[ ]
Femur ant med	[ ]	[ ]	[ ]	[ ]	[ ]
Femur ant lat	[ ]	[ ]	[ ]	[ ]	[ ]
Femur cranial med	[ ]	[ ]	[ ]	[ ]	[ ]
Femur cranial lat	[ ]	[ ]	[ ]	[ ]	[ ]
Femur post med	[ ]	[ ]	[ ]	[ ]	[ ]
Femur post lat	[ ]	[ ]	[ ]	[ ]	[ ]

Reference:

ICRS Grade 0 - Normal

ICRS Grade 1 - Nearly Normal (softening)

ICRS Grade 2 – Abnormal (loss <50%)

ICRS Grade 3 – Severely Abnormal (>50%)

ICRS Grade 4 – Severely Abnormal (bone)

Cartilage lesions	<2cm²	>2cm²	Acute	Chronic	Cartilage procedures: specify
Acetabulum ant med	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum ant lat	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum cranial med	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum cranial lat	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum post med	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum post lat	[ ]	[ ]	[ ]	[ ]	_____
Femur ant med	[ ]	[ ]	[ ]	[ ]	_____
Femur ant lat	[ ]	[ ]	[ ]	[ ]	_____
Femur cranial med	[ ]	[ ]	[ ]	[ ]	_____
Femur cranial lat	[ ]	[ ]	[ ]	[ ]	_____
Femur post med	[ ]	[ ]	[ ]	[ ]	_____
Femur post lat	[ ]	[ ]	[ ]	[ ]	_____
Acetabulum ant med	[ ]	[ ]	[ ]	[ ]	_____

Labral procedures

Anterior	[ ] Resection	[ ] Suturation	Autograft: [ ] hamstring - [ ] fascia [ ] other: specify:_____	[ ] Allograft
Cranial	[ ] Resection	[ ] Suturation	Autograft: [ ] hamstring - [ ] fascia [ ] other: specify:_____	[ ] Allograft
Posterior	[ ] Resection	[ ] Suturation	Autograft: [ ] hamstring - [ ] fascia [ ] other: specify:_____	[ ] Allograft

Other (specify): _____

Other procedures

[ ] Cartilage fracture fixation
[ ] Ileopsoas release
[ ] Capsulotomy extended
[ ] Capsule suturation
[ ] Lateral compartment – gluteal tendon suturation
[ ] Posterior compartment –trochanter minor resection
[ ] Infection debridement
[ ] Ligamentum teres reconstruction
[ ] Capsule grafting
[ ] Acetabular osteotomy
[ ] Lateral compartment – fascia lata resection

Other (specify): _____

Other intraoperative findings and procedures (please specify):

_____
_____
_____

Surgeon's signature: _____

3.6 Knee

Knee arthroscopy is one of the most common surgical procedures in orthopaedic world. An arthroscopy of the knee joint is usually performed due to meniscal tears, anterior cruciate ligament rupture or cartilage lesions. During the past two decades, knee arthroscopy has become common when treating patients with more extensive cartilage lesions, posterior cruciate ligament ruptures and intra-articular fractures, referring to our evolving surgical techniques to treat these conditions arthroscopically instead of opening the knee joint. Diagnostic knee arthroscopy and treatment of degenerative meniscal problems are generally not recommended anymore, but the variety of clinical conditions that can be managed arthroscopically will most likely increase. Both the traditional and the modern knee arthroscopic procedures require standardised documentation of surgical findings. Operative reports must be flexible, in order to adapt to different indications and evolving techniques.

Standardised operative report for knee arthroscopy includes documentation of intra-articular findings and surgical interventions performed.

Knee arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Current diagnosed pathology/injuries:

- [ ] ACL
- [ ] PCL
- [ ] LCL
- [ ] PLC
- [ ] MCL and/or POL
- [ ] MPFL
- [ ] Medial meniscus
- [ ] Lateral meniscus
- [ ] Chondrosis/OA
- [ ] Cartilage lesion
- [ ] Patellar tendon
- [ ] Quadriceps tendon
- [ ] Patellar fracture
- [ ] Other (specify): _____

Previous procedures:

- [ ] ACL
- [ ] PCL
- [ ] LCL
- [ ] PLC
- [ ] MCL and/or POL
- [ ] MPFL
- [ ] Meniscectomy (medial)
- [ ] Meniscectomy (lateral)
- [ ] Meniscal repair (medial)
- [ ] Meniscal repair (lateral)
- [ ] Meniscal transplantation (medial)
- [ ] Meniscal transplantation (lateral)
- [ ] ACI
- [ ] Other (specify): _____

Intraoperative findings and procedures

Cartilage status (femur, medial)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal (softening)
- [ ] ICRS Grade 2 – Abnormal (loss <50%)
- [ ] ICRS Grade 3 – Severely Abnormal (>50%)
- [ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (femur, lateral)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal (softening)
- [ ] ICRS Grade 2 – Abnormal (loss <50%)
- [ ] ICRS Grade 3 – Severely Abnormal (>50%)
- [ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (tibia, medial)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal (softening)
- [ ] ICRS Grade 2 – Abnormal (loss <50%)
- [ ] ICRS Grade 3 – Severely Abnormal (>50%)
- [ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (tibia, lateral)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal (softening)
- [ ] ICRS Grade 2 – Abnormal (loss <50%)
- [ ] ICRS Grade 3 – Severely Abnormal (>50%)
- [ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (trochlea)

- [ ] ICRS Grade 0 - Normal
- [ ] ICRS Grade 1 - Nearly Normal (softening)
- [ ] ICRS Grade 2 – Abnormal (loss <50%)
- [ ] ICRS Grade 3 – Severely Abnormal (>50%)
- [ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (patella, medial)

[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal (softening)
[ ] ICRS Grade 2 – Abnormal (loss <50%)
[ ] ICRS Grade 3 – Severely Abnormal (>50%)
[ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage status (patella, lateral)

[ ] ICRS Grade 0 - Normal
[ ] ICRS Grade 1 - Nearly Normal (softening)
[ ] ICRS Grade 2 – Abnormal (loss <50%)
[ ] ICRS Grade 3 – Severely Abnormal (>50%)
[ ] ICRS Grade 4 – Severely Abnormal (bone)

Cartilage lesions

	<2cm²	>2cm²	Acute	Chronic
Patella med	[ ]	[ ]	[ ]	[ ]
Patella later	[ ]	[ ]	[ ]	[ ]
Trochlea	[ ]	[ ]	[ ]	[ ]
Femur med	[ ]	[ ]	[ ]	[ ]
Femur later	[ ]	[ ]	[ ]	[ ]
Tibia med	[ ]	[ ]	[ ]	[ ]
Tibia later	[ ]	[ ]	[ ]	[ ]

Cartilage procedures

	Debridement	Microfractures	OATS	MACI	Allograft
Patella med	[ ]	[ ]	[ ]	[ ]	[ ]
Patella later	[ ]	[ ]	[ ]	[ ]	[ ]
Trochlea	[ ]	[ ]	[ ]	[ ]	[ ]
Femur med	[ ]	[ ]	[ ]	[ ]	[ ]
Femur later	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia med	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia later	[ ]	[ ]	[ ]	[ ]	[ ]

Meniscal procedures

Medial [ ] Resection [ ] Suturation [ ] Implant: name of implant, company: _____ [ ] Allograft

Lateral [ ] Resection [ ] Suturation [ ] Implant: name of implant, company: _____ [ ] Allograft

Other (specify): _____

Ligament procedures: mark "P" for primary; mark "R"for revision

Graft type	ACL	PCL	MPFL	LCL	PLC	MCL	POL	ALL
ST	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
STGR	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
BTB	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
BTB allograft	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
STGR allograft	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
Synthetic	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
Any other:	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]	P[ ]-R[ ]
∟specify:	_____	_____	_____	_____	_____	_____	_____	_____
Primary repair:								

Other procedures

[ ] Cartilage fracture fixation
[ ] Lateral release
[ ] Lateral lenghtening
[ ] Trochleaplasty
[ ] Osteotomy femur
[ ] Infection debridement
[ ] Bone grafting auto/allo
[ ] Plicectomy
[ ] Tibial tuberosity transfer
[ ] Osteotomy tibia
Other (specify): _____

Other intraoperative findings and procedures (please specify):

_____
_____
_____

Surgeon's signature: _____

3.7 Ankle

Ankle arthroscopy is usually performed in patients with cartilage lesion such as OCD, anterior or posterior impingement of the ankle or intra-articular loose bodies. Ankle arthroscopy can also be used to diagnose unexplained ankle symptoms. Ankle arthroscopy became more common during the past two decades, and the list of problems that can be treated with this technology is constantly evolving. Ankle joint arthroscopy can be associated to trauma surgery as well as sports medicine injuries around the ankle joint. The goals of surgery are to reduce ankle pain and improve overall function.

Standardised operative report for ankle arthroscopy includes patient positioning, documentation of intra-articular findings and surgical interventions performed.

Ankle arthroscopy intraoperative report

Hospital: _____

Date of procedure*: _____ /_____ /_____ * : please use day/month/year format (dd/mm/yyyy)

Patient name: _____

Date of birth*: _____ /_____ /_____ Sex: [M] [F]

ID: _____

Side: [R] [L] (in bilateral procedures fill separate forms)

Date of injury*: _____ /_____ /_____ (if not injured, fill the date at onset of symptoms)

Positioning: [ ] Supine decubitus [ ] Prone decubitus [ ] Lateral decubitus

Current diagnosed pathology/injuries:

- [ ] OCD
- [ ] Loose body
- [ ] Acute Cartilage injury
- [ ] Anterior impingement
- [ ] Posterior impingement
- [ ] Chondrosis/OA
- [ ] St post fracture tibia
- [ ] St post fracture talus
- [ ] Tendon injury
- [ ] Achilles tendon
- [ ] Tibialis post tendon
- [ ] Peroneal tendon(s)
- [ ] Other (specify): _____

Previous procedures:

- [ ] Arthroscopy or debridement
- [ ] ACI
- [ ] OATS
- [ ] OCD fixation
- [ ] Microfracture
- [ ] Other (specify): _____

Intraoperative findings and procedures

Cartilage status (ICRS)	0	1	2	3	4
Talus, Anterior	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Center	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Lateral	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Medial	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Posterior	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Anterior	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Center	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Lateral	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Medial	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Posterior	[ ]	[ ]	[ ]	[ ]	[ ]

Reference:

ICRS Grade 0 - Normal

ICRS Grade 1 - Nearly Normal (softening)

ICRS Grade 2 – Abnormal (loss <50%)

ICRS Grade 3 – Severely Abnormal (>50%)

ICRS Grade 4 – Severely Abnormal (bone)

Cartilage lesions					Cartilage procedures				
	<2cm²	>2cm²	Acute	Chronic	Debridement	Microfractures	OATS	MACI	Allograft
Talus, Anterior	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Center	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Lateral	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Medial	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Talus, Posterior	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Anterior	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Center	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Lateral	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Medial	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Tibia, Posterior	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Other procedures

[ ] Anterior spur/synovia resection
[ ] Removal of loose body
[ ] Fracture fixation, talus
[ ] Fracture fixation, tibia
[ ] Tendon repair (specify): _____
[ ] Supramallolar osteotomy for alignment correction
Other (specify): _____

[ ] Cartilage fracture fixation
[ ] Lateral ligament reconstruction
[ ] Posterior/ Os trigonum resection
[ ] Medial malleolar osteotomy
[ ] Tendon reconstruction (specify): _____
[ ] Infection debridement

Other intraoperative findings and procedures (please specify):

_____
_____
_____

Surgeon's signature: _____

Acknowledgements The authors would like to thank Matti Seppänen, MD, PhD, for his commentation for hip arthroscopy documentation.

4 Regional and General Anesthesia, Pain, and Bleeding Control in Shoulder Arthroscopy and Upper Limb Procedures

Paolo Grossi, Emilio Grilli, and Simone Repaci

4.1 Introduction

Shoulder arthroscopic surgery has spread worldwide due to its possibility to treat a huge scenario of pathologies.

Arthroscopy and visualization are the same from a surgical point of view. Thus, it is mandatory to have a perfect control of bleeding, and this is only possible in joints like the shoulder if an anesthesia with blood pressure control is obtained.

Another important issue in shoulder arthroscopy is to control the postoperative pain, thus allowing this surgery in an outpatient facility as mostly done in Western countries.

In this chapter the author focuses on all the strategies to perform an optimal anesthesia, thus controlling pain and reducing bleeding, helping both patients and surgeons.

P. Grossi, MD (✉)
U.O. Anestesia Loco-Regionale e Terapia del Dolore, IRCCS Policlinico San Donato, Milan, Italy
e-mail: pagrossi@libero.it

E. Grilli, MD
Servizio Anestesia Ospedale Beato Matteo, Vigevano, Italy

S. Repaci, MD
Servizio Anestesia Ospedale Maggiore, Bologna, Italy

4.2 Beach Chair Position

The beach chair position was described for the first time in 1988 [37]. It was invented with the aim to avoid neuropathies that may develop during arthroscopy in the lateral decubitus position. To attain the beach chair position, the patient is placed supine on a standard operative table or on the operating table beach chair equipped with a removable posterior portion. The patient is placed in 15° Trendelenburg position, with hips flexed to 45–60° and knees flexed to 30° with a pillow placed under them to protect neurovascular structures at the popliteus groove. The table is then adjusted progressively, raising the trunk and chest, creating an angle of 60° with respect to the pelvis. The head is fixed with a head plate and placed in neutral position, while the chest is secured with straps; the nonoperative arm is placed on a sling; the operative arm can be attached to the Spider [35–46]. The positioning in beach chair takes more time than in lateral decubitus because you have to correctly position the head, neck, and chest; it is possible to reposition the patient during surgery; also it needs at least one assistant washed to keep the arm to operate and to keep the traction if the Spider is not used. Regarding the ease of transition, the beach chair position is faster and easier to be carried out because it does not need repositioning, it having rifar the operative field [35–45]. As regards the effect that the position has on

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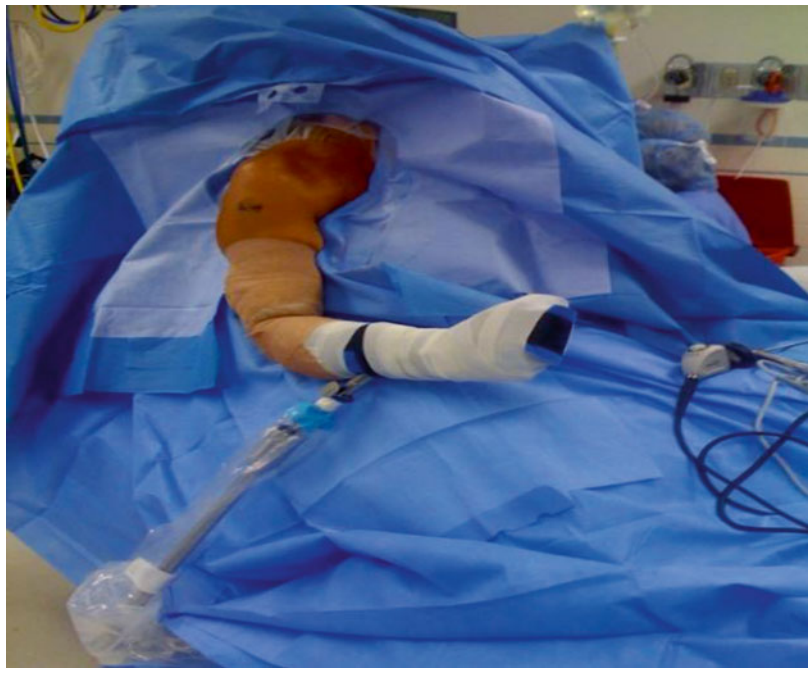
anesthesia, surgeons who prefer the beach chair state that this position may be used without distinction between regional anesthesia with the patient awake and general anesthesia, since the sitting position is tolerated better than lateral decubitus. There is easy access to the airway, when intubation is necessary, in the beach chair position with respect to the lateral decubitus [34–47], although in the lateral decubitus position, a laryngeal mask can be easily placed. The costs for the beach chair are higher than the lateral decubitus, because it requires a dedicated table, a head plate, and the Spider. With respect to orientation, accessibility, and operative visualization, the supporters of the beach chair reported that the sitting position allows the anatomy of the arthroscopic shoulder to be more easily understood [37, 41–45]. The supporters of the sitting position claimed not to have any operative visualization difficulties and were able to work in all portions of the glenohumeral joint and subacromial space using various trocar access. The beach chair position allows to better stabilize the scapula allowing improved diagnostic arthroscopic examination under anesthesia compared to the lateral decubitus [41]. It has been argued that the beach chair is the best position for anterior stabilization and the release and repair of the rotator cuff [41]. Access to the anterior region of the shoulder is easier, and the anterior trocar allows the insertion of anchors at the level of the neck of the glenoid below the 4 o'clock position [37, 41–45]; also the lateral translation of the humerus gives an excellent access to the front-lower portion of the capsule and the axillary region. The beach chair position provides surgeons a better upper limb mobility by ensuring better working dynamic view of the cuff and allows them to treat some minor disorders such as subluxation and the subacromial impingement [34–45].



	Lateral decubitus	Beach chair
Advantages	1. Traction increases space in joint and subacromial space	1. Upright, anatomic position
	2. Traction accentuates labral tears	2. Ease of exam under anesthesia
	3. Operating room table/patient's head not in the way of posterior and superior shoulder	3. Arm not hanging in the way of anterior portal
	4. Cautery bubbles move laterally out of view	4. No need to reposition or redrape to convert to open procedure
	5. No increased risk of hypotension/ bradycardia; better cerebral perfusion	5. Can use regional anesthesia
		6. Mobility of operative arm
Disadvantages	1. Nonanatomic orientation	1. Potential mechanical blocks to use of scope in posterior or superior portals
	2. Must reach around arm for anterior portal	2. Increased risk of hypotension/bradycardia causing cardiovascular complications
	3. Must reposition and redrape to convert to open procedure	3. Cautery bubbles obscure view in subacromil space
	4. Patients do not tolerate regional anesthesia	4. Fluid can fog camera
	5. Traction can cause neurovascular and soft tissue injury	5. Theoretically increased risk of air embolus
	6. increased risk of injury to axillary and musculocutaneous nerves when placing anteroinferior portal	6. Expensive equipment if using beach chair attachment with or without mechanical arm holder

The main risks linked to the beach chair position are attributable to the incorrect alignment of the head relative to axis of the body and to the occurrence of bradycardia/hypotension episodes and cerebral hypoperfusion. Various complications have been reported concerning the correct head positioning in the beach chair, ranging from neuropraxia of cutaneous nerves of the cervical plexus up to the very rare cases of midcervical quadriplegia [48, 49]. Park and Kim [50] have identified three cases of neuropraxia of cutaneous branches of the cervical plexus after arthroscopy in the beach chair position; nerves affected were the small occipital nerve and the great auricular nerve that is thought to have been damaged directly by headrest compression. Mullins [51] and Rhee [52] reported cases of paralysis of the hypoglossal nerve after shoulder arthroscopy in the beach chair position, whose etiology is thought to be due to a change in the position of the neck during the procedure, and so the nerve was compressed to below the angle of the mandible. Haisa and Nitta [48, 49] reported the occurrence of stroke and spinal midcervical quadriplegia after neurosurgical procedures performed in a sitting position. The authors and Wilder [53] have proposed that the extreme flexion of the neck and the stretching of the spinal cord may be sufficient, together with the loss of self-regulating mechanisms induced by drugs of general anesthesia in a sitting position, to compromise the self-regulation of the flow and encourage a spinal cord ischemia.

One of the most common complications that develop in the beach chair position is represented by the appearance of bradycardia/hypotension episodes (BHE), which if not recognized and treated can lead to very serious consequences. The incidence of BHE is about 13–30 % [54–56] of patients who submit to shoulder arthroscopy in the beach chair position with interscalene block. The BHE were defined as a reduction of at least 30 beats/min within 5 min from positioning, or a rate <50 beats/min, and a reduction in systolic BP of more than 30 mmHg in 5 min or a reduction of PAs <90 mmHg. The etiology of BHE is still not well defined, but it is thought that the most common mechanism is the activation of the Bezold-Jarisch reflex [54, 55].This is a cardioinhibitory reflex that originated in

cardiac receptors with unmyelinated vagal C fibers, representing the afferent arm of the reflex. The activation of this reflex starts from an empty hypercontractile ventricle, which causes stimulation of mechanoreceptors (C fiber), producing a sudden interruption of the sympathetic stimulation and thus creating a vagal overtone. D'Alessio [54] reported that during beach chair positioning, increased accumulation and stagnation of blood to the extremities due to the bending of the legs involves an initial sympathetic hyperstimulation that, associated with a reduced cardiac preload, involves a ventricular hypercontractility which triggers the activation of mechanoreceptors, thus mediating vagal fibers, and interruption of sympathetic stimulation. However, Campagna and Carter [57] say that the incidence of BHE in shoulder arthroscopy is not attributed to the activation of the Bezold-Jarisch reflex. There is a bit of discrepancy on the use of epinephrine in the mixture of local anesthetic as a cofactor of BHE. Sia [56] postulated that the use of epinephrine in the anesthetic mixture for interscalenic block increases the incidence of BHE by 25 %, while the study of K Chuo Seo [58] showed no difference in the incidence of BHE between the mixture with adrenaline and that without. The hypothetical mechanism is that adrenaline, when used with a local anesthetic mixture for a regional block, is absorbed slowly into the circulation and so could increase cardiac contractility and heart rate and cause peripheral vasodilation and pooling (decreased afterload), creating ventricular hypovolemia with hypercontractions that predispose patients to BHE. One factor that could contribute to the development of BHE is the site of interscalene block. In fact, in the study of K Chuo Seo [58], it showed that the patients who received a right interscalene block in 92 % of cases experience BHE. The authors think that the blockade of the stellate ganglion caused by right interscalene block may be involved in the etiology of BHE, because the right interscalene block prevents the compensatory response of hemodynamic changes induced by the sitting position due to loss of sympathetic stimulation. Other studies support the hypothesis that the side of the block can be a determining factor in the occurrence of BHE [59–61].

Other studies suggest that the association between general anesthesia and the sitting position can predispose the incidence of BHE, since drugs of general anesthesia can depress the reflex sympathetic response triggered by the supine position, helping to reduce vascular resistance, MAP, and cardiac output [62]. Liguori et al. [63] have developed a protocol of prophylaxis with metoprolol and glycopyrrolate to prevent the development of BHE, since metoprolol can prevent hypercontraction-induced ventricular activation from the sitting position and reduce the Bezold-Jarisch reflex, while glycopyrrolate blocks the Bezold-Jarisch reflex in the effector arm. Their study showed that incidence of BHE was 28 % in the placebo group, 22 % in the glycopyrrolate group, and 5% in the metoprolol group. However, the protection offered by the prior administration of b-blockers in the onset of BHE was not confirmed by the study of Kahn-Hargett [55].

Another complication associated with the beach chair position is the occurrence of cerebral ischemic events, which can occur especially if the technique of controlled hypotension is used. Controlled hypotension is a technique well validated and used in orthopedic surgery, especially for arthroscopic techniques and in the absence of tourniquet, since it permits an improvement of the operating field, increases the speed of the procedure, and reduces intraoperative bleeding [64]. In normal subjects, the cerebral blood flow is maintained constant at mean arterial pressure values between 60 and 140 mmHg, and outside these values, the cerebral blood flow becomes dependent on mean arterial pressure. Since there is a lack of a specific limit pressure safety for controlled hypotension [65] applicable for all patients, the need to monitor indirectly cerebral perfusion using NIRS technology is suggested. NIRS makes possible to estimate the cerebral tissue oxygenation [66] considering both oxyhemoglobin and deoxyhemoglobin concentrations in the brain, thus allowing to detect episodes of cerebral desaturation. The NIRS values are influenced by deep anesthesia, by the type of

anesthetics used, by the levels of $PaCO_2$ from FiO_2 administered, and by the blood pressure. In the study by J. YaDeau [67], the relationship between hypotension and cerebral desaturation was assessed in patients undergoing shoulder surgery anesthetized with interscalene block plus intraoperative sedation with spontaneous breathing. The results of the study [68] showed that hypotension in the sitting position was present in 76 % of patients, while cerebral desaturation, defined as a 20 % reduction in the rSO_2 baseline, was only present in 10 % of patients. Risk factors of correlation between cerebral desaturation and hypotension were represented by hypertension, hyperlipidemia, coronary artery disease, and diabetes. This low value of cerebral desaturation despite the more frequent incidence of hypotension in this study can be explained by the use of regional anesthesia technique in combination or not with sedation associated with spontaneous breathing. In fact, in a recent study, Murphy [68] reported an 80 % incidence of cerebral desaturation in patients in the beach chair position under general anesthesia, while there were no reported events in patients in lateral decubitus under general anesthesia. There are important differences between general anesthesia and regional anesthesia. Volatile anesthetics alter the regulation of the cerebral blood flow unlike propofol [69], even if they have a protective effect on cerebral ischemia; furthermore, mechanical ventilation associated with general anesthesia reduces venous return and cardiac output, causing a right ventricular dysfunction and obstructing the cerebral venous return, thus favoring a reduction in cerebral perfusion [70]. In the awake but sedated patient spontaneously breathing, spontaneous ventilation does not alter the venous return and the distensibility of the left ventricle, while the sympathetic system is active and can prevent the collapse of vascular resistance induced by the sitting position. Despite the high frequency of cerebral desaturation in the study of Murphy [68], there were no recorded neurological events upon awakening and in the succeeding hours. The low incidence of neurological events is related to both the brevity of surgery and to the short duration of cerebral desaturation episodes. In fact, both the severity and the duration of ischemia are critical determinants of brain tissue damage. A data analysis of NIRS conducted in patients undergoing coronary bypass [71] reported a threshold of cerebral desaturation time of 50 min with the occurrence of neurological decline upon awakening and a prolonged hospital stay. In Murphy's study [68], although he did not report any neurological events upon awakening, he found a strong correlation between cerebral desaturation episodes and PONV, which are the result of short episodes of hypoxygenation and cerebral hypoperfusion [72]. The study by Lee [73] found that although the MAP always decreased after induction of anesthesia without any cerebral desaturation, the rSO2 decreases significantly only after placement in the beach chair position. Papadonikolakis [47] in his review focused on the correct interpretation of blood pressure in the sitting position. Because the cerebral perfusion pressure is the difference between average pressure and intracranial pressure, pressure measurement in the sitting position should be made at the level of the brain, because cerebral autoregulation would occur in the intracranial arterioles and capillaries. In the sitting position, there is a hydrostatic pressure gradient between the brain and the normal detection site of Pa. In fact when the MAP is measured from sites other than the brain, it is necessary to apply a correction arithmetic of 1 mmHg for every 1.35 cm difference in height between the brain and the measurement site [74].

4.3 Analgesia for Shoulder Surgery

Shoulder surgery is associated with a high level of intense postoperative pain which may require the use of opioids even for many days [75, 76], sometimes similar to pain treatment for laparotomy and minithoracotomy [77, 78].Therefore, nowadays, opioid-based analgesic technique is no longer feasible due to either the many side effects associated with its use, such as nausea, vomiting, constipation, delirium, pruritus, and light-headedness, or the new findings about the

high use of opioids in the perioperative period, as nociception-induced central sensitization and hyperalgesia secondary to the use of opioids [79], both mechanisms that may be involved in the pathogenesis of pain after surgery. The multimodal analgesia approach [80] prevents postoperative pain and is based on the administration of opioid and non-opioid techniques as well as opioid-sparing techniques, as local regional anesthesia techniques, TENS, physical therapy, and acupuncture that act on different parts of the central and peripheral nervous system to reduce the process of central sensitization and chronic pain [81]. In the outpatient surgery, the multimodal analgesia approach allowed faster discharge of patients; reduced the effects of constipation, urinary retention, nausea, and vomiting; and permitted a more rapid recovery of the patient's functions and psychomotor performance, reducing the costs of hospital stay and the management of side effects. The introduction and diffusion of arthroscopic techniques in orthopedic surgery have reduced hospital stay and the costs of prolonged hospitalization and allowed a quick postoperative course although the pain in the first 24–48 h may be similar in intensity as that of open surgery. For this, different techniques of regional anesthesia have been developed with the intent to spare opioids that you can integrate with or replace general anesthesia.

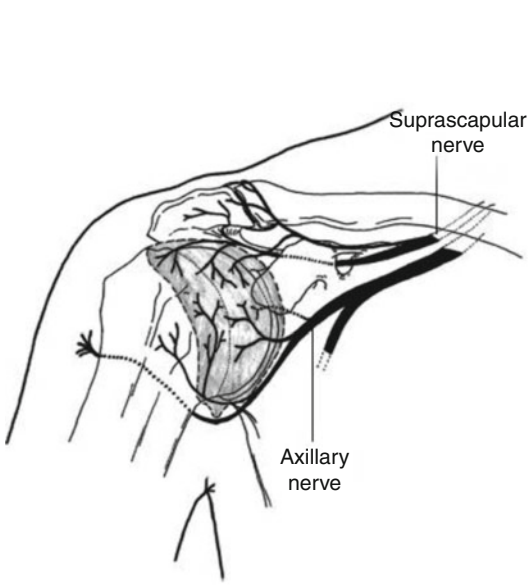
4.3.1 Intra-articular Analgesia

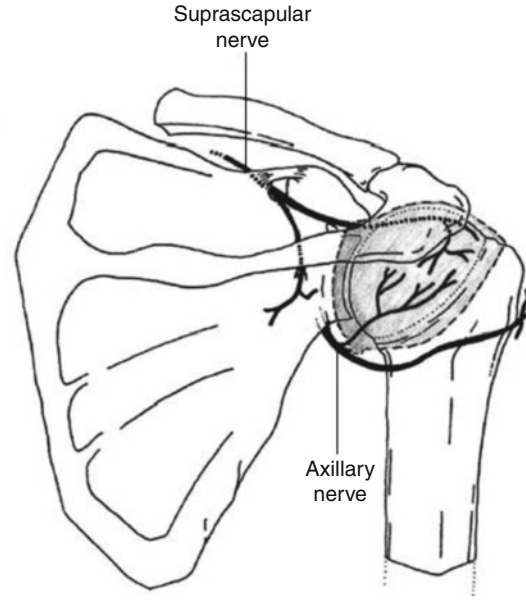
This technique is the administration by the surgeon at the end of the procedure of a variable volume of 25–50 ml of anesthetic solution or local anesthetics and opioids in the joint space or into the subacromial space to which the positioning of a catheter for continuous infusion follows. There are many conflicting opinions in the literature about the real benefit of this analgesic technique. Nisar [82] in a study involving 60 patients, in which rotator cuff repair was a majority, found that this technique can be an alternative to interscalene block in reducing the consumption of postoperative morphine to provide better postoperative pain control. However, other studies as Singelyn [83] and Laurila [84] et al. found a clear superiority of the interscalene block than the intra-articular analgesia that proved only slightly better than placebo. Several studies [85–87] suggest that the combination of local anesthetic + opioid analgesia in intra-articular space provides better analgesic coverage compared to that provided by only using local anesthetic. The initial enthusiasm of this technique, in recent years, has seen poor results especially in extensive arthroscopic shoulder procedures; the use of this technique has been greatly reduced and is limited to minor arthroscopic procedures that do not involve rotator cuff repair, preferring a technical single injection with a mixture of local plus long-acting opioid such as morphine. Besides the limited analgesic coverage, the disuse of this technique can be explained by the increasing emerging concern of damage of chondrotoxicity with chondrolysis induced directly by local anesthetic. In fact, it has been reported in several studies [80, 88, 89] of post-arthroscopic glenohumeral chondrolysis; this was particularly evident with continuous systems of intra-articular infusions, but it appears that the single injection may be associated to a reduced density of chondrocytes at 6 months [89].

4.4 Suprascapular Nerve Block and Circumflex Nerve Block

The suprascapular nerve is a mixed nerve, both sensory and motor, which originates from the roots of C5 and C6 and receives a small contribution from C4 in 50 % of cases. It crosses the posterior triangle of the neck and enters the suprascapular incisure below the superior transverse ligament of the scapula and then continues its descent through the spinoglenoid notch and the inferior transverse ligament of the scapula, ending in the infraspinatus fossa [90]. The motor component innervates the supraspinatus and infraspinatus muscles, with its sensory innervation providing about 70 % of the sensitivity of

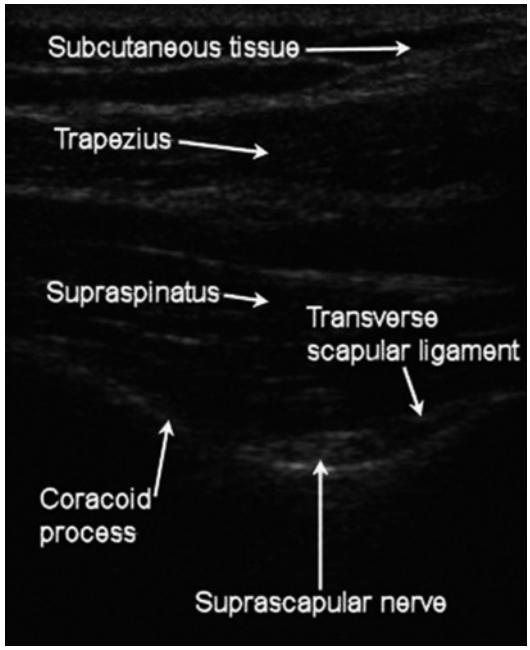
the shoulder joint, because it innervates the upper and posterior parts of the capsule of the shoulder, acromioclavicular joint, the subacromial bursa, and the coracoclavicular ligament. The circumflex or axillary nerve is a mixed nerve that originates from the secondary posterior trunk of the brachial plexus and, from the axilla, exits at the posterior and across the quadrilateral space of Velpeau and then, after surrounding the neck of the humerus, terminates at the posterior loggia of the arm; its motor component innervates the teres minor and deltoid, while the sensory component supplies the anterior and lateral part of the shoulder [91].



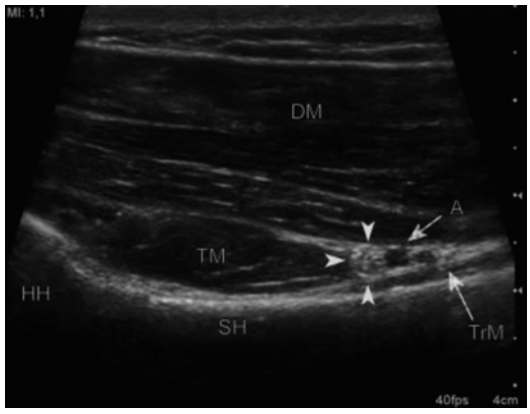


The suprascapular nerve block can be performed with either the peripheral nerve stimulator technique or the ultrasound-guided technique [92]. The ideal approach involves blocking the branches of the nerve proximal to the acromion and subacromial region to ensure better analgesic coverage. Therefore, the best point to perform the block would be at the suprascapular notch, although there is the risk of pneumothorax. Price [93] has described a technique at the level of the supraspinatus fossa, and Checcucci [94] described his block technique by positioning the needle 2 cm medial to the medial border of the acromion and 2 cm cephalad to superior margins of the scapular spine evoking, with nerve stimulation, the abduction and external rotation of the arm (supra- and infraspinatus muscle movements).

For the ultrasound-guided technique [95], the patient is placed in the sitting position; it will use a linear probe placed parallel to the spine of the scapula, scanning in depth the skin, subcutaneous tissue, trapezius muscle, supraspinatus muscle, and suprascapular notch. The location of the suprascapular artery will be identified with the Doppler; the nerve usually lies medial to the pulsation of the circumflex artery over the scapula under the transverse scapular ligament. Eichember and Curatolo [96] described in 2012 a supraclavicular approach for suprascapular nerve block that, according them, ensures a more simple and frequent view of the nerve than the standard approach.



The circumflex nerve block can be done with either the electrical nerve stimulation (ENS) technique or the ultrasound-guided technique. With the ENS technique, the best-known landmarks are those of Price [93] and Checcucci [94]. For the ultrasound-guided technique [97], the ultrasound probe is placed in long axis, about 1.5 cm to 2 cm, below the angle of the acromion parallel to the loggia of the posterior muscles of the arm or the humerus. So you locate, with the Doppler, the pulsation of the circumflex artery in which the nerve is always adjacent, while other landmarks are the deltoid and the teres minor muscles.



In the study of Ritchie [98], the suprascapular nerve block reduces morphine consumption, by 31 % compared to placebo, and the incidence of nausea and vomiting and allows the patient to be discharged earlier. The study of Singelyn [83] compared three analgesic techniques for post-arthroscopic pain shoulder and showed that the suprascapular nerve block alone has better pain control than intra-articular infiltration/subacromial local anesthetic, but provides an analgesic coverage lower than the interscalene block, requiring therefore an integration systemically. Moreover, it is seen that the use of a suprascapular nerve block in addition to a single injection interscalene block prolongs the request for the first administration of analgesic, but does not change the subsequent requests and intensity of pain at 24 h, adding so little benefit compared to interscalene block [99]. When the suprascapular nerve block is used in combination with circumflex nerve block, Price's studies [93–100] suggest that it is possible to obtain a total shoulder analgesia during intra-op, although during surgery opiates or sedative drugs should be used to control pain that could result from stretching of the joint capsule and at the sensitive region of the lateral pectoral nerve that is not blocked by those nerve blocks. In a small number of cases, Checcucci [94] described, as the only anesthetic technique for arthroscopic shoulder, the success of the combined use of suprascapular nerve block, circumflex nerve block, and infiltration of access portals of the trocar without any intraoperative sedation. In the study by Lee [101], different analgesic protocols, such as PCA technique + general anesthesia, PCA plus interscalene block, and PCA plus suprascapular nerve block and circumflex nerve block, were compared. The study showed that in the first 8 h after surgery, the best analgesic coverage was provided by the interscalene block, with mean values of VAS recorded in the recovery room of 1.5 for the interscalene group, 3.6 for the suprascapular nerve block + circumflex nerve block, and 7 for the group of general anesthesia alone. After 8 h from the end of surgery, there has been a rebound pain effect in the interscalene group with a mean VAS of 5.2, while VAS in the double block group was 3.9, and the group

General anesthesia was 5. Even pain control at 16 h–24 h showed a better analgesic and constant coverage in the double block group than in the interscalene group. Lee's study [101] concluded that in the first 8 h, interscalene block is the best postoperative analgesic technique, but suprascapular nerve block plus circumflex nerve block provides analgesic coverage similar if not superior to interscalene block without creating a rebound pain effect that lasts for the first 24 h. The advantages of this combination are that it avoids blocking the motor and sensory function for those parts of the upper limb innervated by the lower roots of the brachial plexus (C7–C8–T1), thus leaving full control of the lower half of the upper limb, and especially avoids paralysis of the phrenic nerve which presents at different degrees, depending on the volume of anesthetic used and on the site of the injection level (C5–C6, C6–C7), especially for those patients who have breathing problems, such as severe COPD and pleural effusion contralateral to the block, patients with one lung, and patients with decreased respiratory reserve contralateral to the block. The disadvantage of this analgesic-anesthetic approach is the need to perform two separate blocking techniques, to have an incomplete block of the shoulder, since it leaves uncovered the lateral pectoral nerve, which may require intraoperative sedation or intraoperative opioid and postoperatively could need integration systemically. Because the single injection nerve block have a limited duration, a continuous infusion is necessary, but for good analgesic coverage, you must use a dual-catheter continuous infusion pump, both for the suprascapular nerve and the circumflex nerve, with some risk of local anesthetic overdose.

4.4.1 Interscalene Single Injection Block

The interscalene single injection block is the procedure most used in shoulder surgery both for open surgery and arthroscopic procedure, since it provides excellent anesthetic and analgesic coverage during the intraoperative period and for the first 12 h postoperatively. It can be used as the only anesthetic technique especially in arthroscopic procedures or in combination with intraoperative sedation with spontaneous breathing or general anesthesia. Hadzic [102] compared interscalene block (ISB) to general anesthesia. Patients in the ISB group have better analgesic coverage, a more rapid recovery of ambulation, and less hospital stay and, more frequently, bypass phase 1 of the PACU without having any unplanned hospital readmission. However, the study of Hadzic [102] also assessed the duration of the analgesic coverage between interscalene block and general anesthesia; upon 24 h, 48 h, and 72 h follow-up, Hadzic did not find any benefit in opiate consumption; and there were no changes in pain intensity after 24 h between the two groups. A similar observation was also made by McCartney [103]. Singelyn's study [83], comparing different analgesic techniques for arthroscopic shoulder, showed a better quality of analgesic coverage for interscalene block, with respect to intra-articular infiltration, and suprascapular nerve block in the first 10–12 h of the postoperative period. Several approaches have been proposed to interscalene block, and its main advantage is that, with a single puncture performed with either the ENS technique or the ultrasound-guided technique, you can get a complete blockage of the shoulder, because the block was performed at the roots of C5–C6, covering, thus, the suprascapular nerve, circumflex nerve, and lateral pectoral nerve and the intra-articular parts. In the ENS technique, the success of research and nerve localization is based on anatomical knowledge through which you can make blocks in different places, limiting complications.

According to some anatomical observations (P. Grossi 2001), it is possible to provide an important aid to ensure the efficiency of the anesthetic block technique, by identifying cutaneous anatomical landmarks that may be some distance from and not directly involved in the area of the block, but lie over the path of the nerve structure and represent an alignment with it in what is a theoretical "anesthetic line."

The concept of an "anesthetic line" reflects only an anatomical virtual observation of the

craniocaudal longitudinal course of the nerve structure, which, when a patient assumes a certain position aimed at identifying various anatomical landmarks, allows to show the nerve structure in a straight manner and therefore in a pattern more accessible from the outside with a needle, allowing it to remain at a greater distance from other structures, such as vessels or organs; this is in order to improve the success of the block through an improved criterion approach thus reducing the time and repeated attempts of punctures, not well tolerated by the patient.

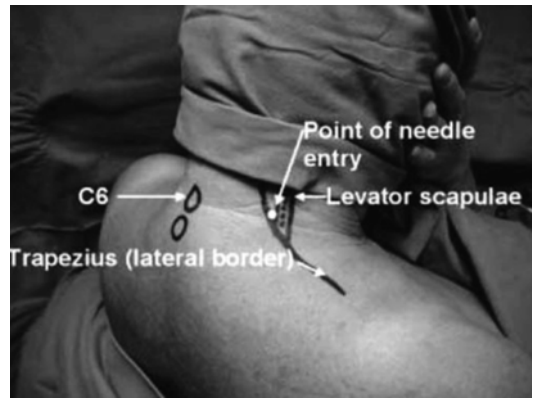
4.4.1.1 Anesthetic Line for the Upper Limb

The patient is placed in the supine position, head turned to the opposite side and the upper limb adducted at 45° to the trunk. Thus, you have a common starting position for all blocks of the upper limb, which allows an excellent visualization of the following landmarks:

- The apex of the scalene triangle (Chassaignac tubercle)
- The midpoint of the clavicle
- Deltoid-pectoral groove, focusing on the coracoid and the profile of the rib cage
- Point of pulsation of the axillary artery at the axilla
- The medial epicondyle of the elbow (in this case the forearm is flexed at 90° on the arm)

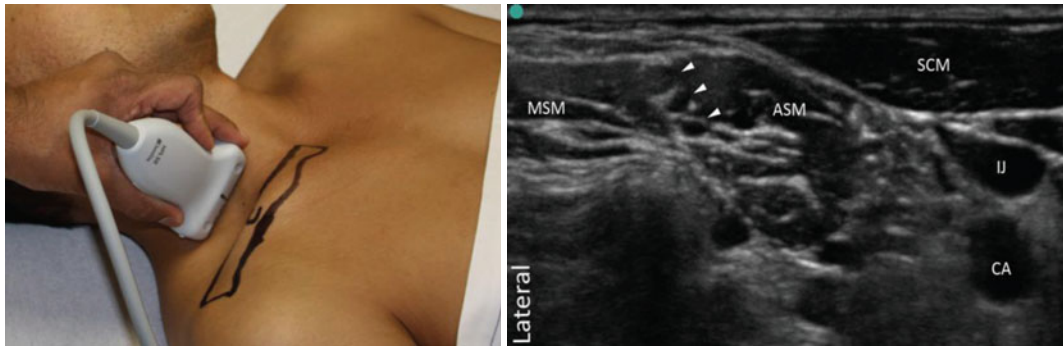
In this situation, we can see that the various cutaneous anatomical landmarks are spread along a line running from the apex of the scalene triangle until the point where the axillary artery is palpated. This line extends up to the medial epicondyle of the elbow and is utilized in the case of blocks at mid-humeral level.

The classic approach of Winnie [104] allows the identification of the interscalene groove, at the level of the cricoid cartilage (C6) with the needle directed medially, slightly caudal, and slightly posterior; Meier [105] changed the approach of Winnie to reduce the risk of complications and to facilitate placement of catheter for continuous infusion; Meier's [105] approach enters the skin at 30° at 2–2.5 cm cephalad to the Winnie approach; Borgeat's [106] lateral approach has a needle insertion 0.5 cm below the level of the cricoid, with a needle orientation of 45–60°. The posterior approach of Pippa [107], an old paracervical approach to the brachial plexus, was recently revisited by Boazaard [108], whose technique involves passing the needle between the levator scapulae and trapezius muscle, thus limiting neck pain and incidence of epidural injection (ref [13] Art Review of blocks and shoulder). Also Boazaard [108] postulated that with this approach, it is possible to have a more selective differential sensory-motor block than the anterior approach, because the block occurs more proximal to the point of fusion of the sensory fibers and motor fibers [109].



The use of ultrasound has enabled us to optimize and improve the block techniques, making them safer and increasing their success rate, through direct visualization of nerve structures and adjacent structures, assessing the progress of the needle and the spread of the anesthetic, and visualizing intravascular and intraneural injections. Liu [110] et al., in a prospective study in which they compared ultrasound with ENS, found that the use of ultrasound reduces the number of needle punctures, increases the

speed of block onset and, in expert hands, can reduce the speed of execution of the block, and improve the success rate of the block. Chan [111], in his ultrasound-guided technique, used both in-plane and out-of-plane approachs to identify the brachial plexus at the interscalene groove, with the difference being that in the in-plane approach, you can display the needle in its entirety and pathway, while the out-of-plane approach provides a shorter path to the target tissue with the needle visualized in the transverse plane [111].



The use of ultrasound permits direct visualization of the spread of anesthetic, allowing to optimize the dose and the volume of anesthetic infusion and minimizing the negative effects of excessive anesthetic volume. Fredrickson [112] conducted a study to estimate the volume and concentration of ropivacaine required to avoid pain in recovery after shoulder surgery. His study found no difference in pain scores between a volume of 20 ml 0.375 % ropivacaine and a volume of 30 ml 0.5 % ropivacaine, but satisfaction was greater in the lower dose group for the shortest effect of motor block. Riazi [113] evaluated the effects of the volume on the phrenic nerve paralysis by comparing a volume of 5 mL of 0.5 % ropivacaine to a volume of 20 mL of 0.5 % ropivacaine during execution of ultrasound interscalene nerve block. He [113] found no difference in pain scores and morphine use between the two groups in the first 24 h, but found a lower incidence of phrenic nerve paralysis (45 % versus 100 %) and better levels of oxygenation and less impairment of FEV1 in the lower-volume group. However, the study of Sinha [114] evaluating intermediate volumes of 10 ml versus 20 ml of 0.5 % ropivacaine using ultrasound-guided technique at the level of the cricoid cartilage (C6) found an incidence of phrenic nerve paralysis in 93 % of patients with no difference between the two groups with different volumes.

Recently Van Geffen [115] and Antonakakis [116] using the ultrasound-guided technique revisited Pippa's posterior approach [107], which, according to them, is very useful in the long-term positioning of the catheter for continuous infusion, thanks to greater stability and better anchorage to the various muscle planes (especially the levator scapulae and trapezius muscle), avoids damage to vascular structures that you may encounter at anterior approach. The major disadvantage of the posterior technique is the increased distance the needle must travel from the entry point to the target nerve; another rare complication is the damage which could be done to the long thoracic and dorsal scapular nerves as the needle has to pass through the middle scalene muscle. The main disadvantage of the single injection interscalene block is its limited duration of action compared to that used during shoulder surgery. Various strategies to minimize this problem have been taken into consideration. One of these is the use of adjuvant drugs with the intent of extending the motor and sensory block. Adjuvant drugs such as adrenaline, clonidine, ketamine, and dexamethasone

were used with varying success. The most promising seems to be the use of dexamethasone. Cummings [117] in his study has found that the use of 8 mg dexamethasone extends the time for the first request of opioids of about 11 h. The specific mechanism of action is not clear but may be related to the glucocorticoid receptor channel activity that would increase K inhibitors on the C fibers [118], although it is possible that this mechanism is mediated by systemic. However, Shaikh [119] et al. think that dexamethasone could have a local action after perineural administration secondary to its action on C fibers, mediated via membrane-associated glucocorticoid receptors and the upregulation of the K channels. Abdallah [120] found that the perineural and intravenous administration of 8 mg dexamethasone has similar effectiveness on time extension of analgesia after supraclavicular single injection block. Recent research by Alemanno et al. [121] found a role of vitamin B1 as an adjuvant drug for time extension after single nerve block. It could be that vitamin B1, at perineural level, ensures the level of synthesis and storage of acetylcholine at presynaptic level thus potentiating analgesia. In his study, the analgesia extension of 1,5–2 ml/kg vitamin B1 was similar with analgesia prolongation offered by buprenorphine after a middle single injection interscalene block.

4.4.2 Continuous Interscalene Nerve Block

Continuous interscalene nerve block was described for the first time in 1987 by Tuominen [77], who had used a similar approach to that described by Winnie, for the single injection block, with a failure rate over 25 %. In 1997, thanks to improved medical devices, Meier [105] revived the continuous technique, with improved effectiveness. In Meier's technique [105], the needle's insertion point is placed slightly higher than at the classic level of C6. This allows to approach the brachial plexus at the interscalene groove along its long axis, supporting that the catheter with its holes be placed to lie more in the vicinity of the roots, thus promoting a greater fixation. Meier's technique is followed then by the lateral technique of Borgeat [106], the posterior approach of Pippa [107], and the modified posterior approach of Antonakakis [116] and Boezaart [109], which favors a greater fixation for the long-term positioning of the catheter. Boezaart [122] used the electrostimulation-guided technique to better confirm the exact location of catheter insertion, prevent malposition, and reduce high failure rate. However, subsequent randomized trials have shown no significant differences between electrostimulation with a stimulating catheter and electrostimulation with a nonstimulating catheter in avoiding second failure and malposition [123–125]. For interscalene catheter placement using a nonstimulating catheter, it is recommended not to insert more than 3 cm from the tip of the catheter once the correct electromotive target is identified. The specific technique for interscalene catheter placement has been associated with a false-negative motor response rate of over 50 % [126]. This high percentage of false-negative motor response was the reason to replace the neurostimulation technique with the ultrasound-guided technique that showed exactly where the catheter was placed and the spread of the anesthetic around surrounding tissues [127].

The ultrasound-guided technique sped up the procedure, improved effectiveness of the block, had a greater opioid-sparing effect, and encouraged a more rapid onset of rehabilitation. The choice between the out-of-plane approach and the in-plane approach remains controversial [128]. Most described is the out-of-plane approach [129], mainly used for cannulation of the internal jugular vein. This approach allows the alignment of the needle and catheter to the long axis of the nerve, promoting catheter advancement. Some authors argue that the orientation of a Tuohy needle bevel along the long axis of the nerve reduces the risk of intraneural positioning. The in-plane approach allows visualization of the entire progress of the needle, thus favoring a better alignment with respect to the long axis of the plexus; nevertheless, the risk of a leak of the injected solution is possible when the tip of the needle is not correctly identified, with the real tip migrating elsewhere or in the intraneural position [130]. Proper placement of interscalene catheter is a real

challenge. The expansion of the perineural space with injected solution can facilitate catheter progression [131]. The solution may be physiological, 5% dextrose, or local anesthetic; among these, 5% dextrose is preferred because it allows to maintain the motor response during stimulation and to reposition the catheter in the most appropriate location during its progression, if the electrostimulation-guided technique is used [132, 133]. Catheter fixation in this area can be a problem especially for the anterior and lateral approach, due to the mobile nature of the surrounding tissues and the presence of hair. In addition to the technique of using tunneled catheter, nowadays securing devices are used such as LockIt Plus that allow to assemble properly the catheter and encourage some small retraction in case of malfunction or kinking. The effectiveness and superiority of continuous interscalene block has been shown by several studies. Borgeat [75], in a randomized study on patients undergoing rotator cuff repair, compared the single injection block with the continuous block showing superiority in the quality and duration of analgesia and greater opioid-sparing effect in patients with catheter. Mariano [134] conducted a randomized trial with 30 patients undergoing major surgery of the shoulder comparing continuous infusion of 0.2% ropivacaine with normal saline, after intraoperative bolus of 40 mL 0.5% ropivacaine. The study showed better analgesia, better sleep quality, low demand for opioids, and improved satisfaction. Even Fredrickson [135] in his study showed the superiority of continuous infusion, compared to control without continuous infusion, in the control of postoperative pain both at rest and during movement, with the continuous infusion group requiring less use of tramadol, but experiencing a greater feeling of heaviness and numbness of the arm. Also Kean [136] and Ilfeld [137] showed a greater superiority of the continuous block compared to single injection block. The right combination of volume and concentration for interscalenic infusion is still not well defined. Klein [138] used high-speed infusions of about 10 ml/h; thereafter it was seen that this dose was not necessary for high-speed infusions because there were always a different degree of motor block, possible reabsorption phenomena, and related risks to intoxication by local anesthetics. With improvement of technology and more accurate placement of the catheter at the site of the block, the volume and concentration of drugs are reduced: Borgeat [139] compared 0.2% ropivacaine with 0.15% bupivacaine via PCA showing a comparable analgesic efficacy between the two types of anesthetics, but low impact motor block offered by ropivacaine. Ilfeld [140] showed that 0,2% ropivacaine 8 ml/h with bolus injection of 2 ml/h provides better analgesic coverage compared to the same drug administered in a speed of 4 ml/h with bolus injection of 6 ml/h; also the study of Le [141] confirmed that a better analgesic coverage is obtained with a continuous higher volume and lower concentration, compared to a lower volume with higher concentration (0.2% ropivacaine 8 ml/h versus 0.4% ropivacaine 4 ml/h). The study of Fredrickson [142] showed that there is good pain control for patients administered with 0.2% ropivacaine at 2 ml/h with boluses of 5 ml/h by means of PCA at the interscalene level after rotator cuff repair procedures and arthroplasty but that a large proportion of the patients experienced a moderate to severe breakthrough pain, which did not subside with increasing concentrations of 0.4% ropivacaine. These studies suggest that to provide adequate analgesia, at least one infusion is needed with a minimum of 4–5 ml/h, which, however, must be associated with an optimal bolus dose of about 4–5 ml/h [143, 144].

The main complications of interscalene block include ipsilateral phrenic nerve paralysis that is always present when the volume injected is above 8–10 ml with different impact on lung function according to the patient's comorbidities, Horner's syndrome, recurrent laryngeal nerve block with dysphonia, hoarseness of voice, accidental puncture of the carotid artery and internal jugular vein. Rare but serious complications are puncture or administration of anesthetic at the level of the intervertebral artery, pneumothorax, subdural injection, intervertebral foramina injection resulting in total spinal anesthesia, cardiovascular shock, and nerve damage of the nerve roots coming out of the foramina, infection at the catheter's point of entry, malposition of the catheter, catheter migration, and transient neurological symptoms.

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Common Nerve Blocks of the Lower Limb

5

Andrea Tognù, Daniele Genco, Luca Josca, Stefano Giarratana, and Paolo Grossi

5.1 Lumbar Plexus Block

The lumbar plexus is formed by the loops of communication between the anterior roots of the first three lumbar nerves, the greater part of the fourth nerve fibres and, in as many as 50 % of cases, by a branch from T12; occasionally a contribution by L5 is possible.

The nerves emerge from the intervertebral foramina running anteriorly to the transverse processes of the lumbar vertebrae, along the medial margin of the quadratus lumborum muscle, splitting and then reuniting again within the compartment of the psoas muscle, and then dividing immediately into their main branches:

- Iliohypogastric nerve (T12–L1)
- Ilioinguinal nerve (L1)
- Genitofemoral nerve (L1)
- Lateral cutaneous nerve of the thigh (L2–L3)
- Femoral nerve (L2–L4)
- Obturator nerve (L2–L4)
- Accessory obturator nerve (L3–L4)

The paravertebral part of the psoas major consists of two muscle layers, one posterior which originates from the transverse processes and one anterior originating for the margins of the vertebral bodies and intervertebral discs; the lumbar plexus is located between these two layers and consequently is "in line" with the intervertebral foramina. The obturator, femoral and cutaneous femoral nerves represent the terminal branches that reach the thigh and leg.

5.2 Procedure

5.2.1 Patient Positioning

The patient is positioned in the lateral decubitus position, with the operative side uppermost and hips and knees only slightly bended for patient's comfort.

5.2.2 Probe and Needle

- A low-frequency (3–5 mHz) semi-convex probe is used.
- One hundred to 150 mm (22 G) needles are used for the single-shot block; 100 mm Tuohy (18 G) needles are used for continuous blocks.

A. Tognù
S.C. Anestesia, Terapia Intensiva Postoperatoria e terapia del dolore, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

D. Genco • L. Josca
Scuola di Specializzazione in Anestesiologia e Rianimazione, Universita' degli Studi di Milano, Milan, Italy

S. Giarratana
Facolta' di Medicina e Chirurgia, Universita' degli Studi di Milano, Milan, Italy

P. Grossi (✉)
Responsabile, U.O. Anestesia LocoRegionale e Terapia del Dolore, IRCCS Policlinico San Donato, Milan, Italy
e-mail: pagrossi@libero.it

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5.2.3 Echographic Exploration

As a general rule, the lumbar plexus roots are not visible with US machines, both because of their usual deep position and for their poor echogenicity due to their thin structure.

The probe should be positioned on the interspinous plane, at the level of the spinous processes of the vertebrae, according to a long axis scan plan, with the marker orientated cranially. A typical "sawtooth" image will be visualized, created by the shadow cones with their hyperechoic margins, generated by the scanning of the spinous processes. Keeping the same plan, one should then move the probe caudally until the sacral promontory will be visualized as a hyperechoic triangular structure. From here, by moving the probe cranially and using the shadow cones generated by the spinous processes as a reference, it will be possible to determine the exact level of the L4–L5 interspace.

Now, by moving the probe in a medial-lateral direction from the spinous processes, it will be possible to visualize the spinal muscles and, right underneath, the transverse process, which will appear as a hyperechoic line with an underlying shadow cone.

From an echographic perspective, the particularly deep anatomical position of the plexus (within the psoas compartment) explains all the difficulties in directly visualizing its roots.

The plexus deepness is related to the patient's weight.

In patients with a regular anatomy, the plexus is 8.5 cm deep in men (range 6,1–10.1 cm) and 7.1 cm in women (range 5.7–9.3 cm) on average. The most interesting feature of the US approach is the possibility to visualize the inferior renal poles which can be located at the L2–L3 level and consequently to avoid all possible complications of a renal puncture (more probable on the right side) and of the ureters.

5.2.4 Technique

Because of its difficult visualization with the US machine, the lumbar plexus block is preferably defined as US assisted, as far as a neurostimulation technique will be complementarily and synergistically employed. After skin disinfection and a subcutaneous local anaesthetic injection, about 2–3 ml of a sterile gel are distributed on the skin, and with the target firmly on the centre of the screen, the needle introduction point will be marked with a dermographic pen, which will correspond to the middle point of the major axis of the probe ($\leq$1 cm laterally).

The needle will be connected to a neurostimulator set to deliver a 2 Hz frequency and a 1.5 mA current and an electric impulse duration of 0.1 ms to confirm plexus localization and will be inserted perpendicularly to the long axis of the probe (OOP access) with an inclination angle of 5–10° in a lateral-medial direction. Its path, in a transverse section, will be visualized as an hyperechoic point; if the needle is not visible, its location will be inferred from the displacement of neighbouring tissues and by injecting pilot boluses. As soon as the tip will be advanced further about 2–2.5 cm from the hyperechoic margin visualized on the screen (apex of the transverse process), the quadriceps femoris twitch will be elicited with an extension movement of the leg on the thigh. Only at this point, after a negative aspiration test, will it be possible to inject 1 ml of a local anaesthetic solution which should not cause any pain or resistance to the injection. As soon as the clonic movement of the quadriceps disappears, a total volume of 20 ml of LA will be injected by visualizing its hypoechoic spreading; if this is not the case, the needle should be gently moved to optimize the diffusion of the LA.

If a continuous block is to be performed, a Tuohy needle is inserted with its open end uppermost.

It is advisable not to deepen the catheter terminal end more than 3–4 cm beyond the needle tip.

5.3 Femoral Nerve Block

The femoral nerve is the main branch of the lumbar plexus, emerging from the psoas muscle and running beneath the inguinal ligament laterally to

the femoral artery, covered by the iliac fascia. From here it splits almost immediately into deeper branches for the innervation of the quadriceps muscle and into superficial branches for the innervation of the skin and of the sartorius and pectineus muscles.

5.4 Procedure

5.4.1 Patient's Positioning

The patient is supine with his limb in a neutral position.

5.4.2 Probe and Needle

- A linear high-frequency probe is set between 10 and 15 MHz.
- Fifty to 100 mm (22 G) needles are used in the case of single-shot blocks; 100 mm (18 G) Tuohy needles in the case of continuous blocks.

5.4.3 Echographic Exploration

At the root of the thigh, the probe has to be positioned at the inguinal fossa level according to a transverse plan.

Conventionally, the probe marker should be kept towards the patient's right side but, to our mind, this is an operator-based choice. From here, the probe should be directed laterally or medially until the femoral artery will be visualized, in a short axis, as a hypoechoic and pulsating structure, with a circular section (to be possibly confirmed with power Doppler). At this level it is often possible to find the origin of the deep femoral artery. The vein will be found in a more medial and deep position and it will be easily compressed with the probe. Lateral to the artery (at about 1 cm on average), the femoral nerve is located, and in the short axis, it will appear as a hyperechoic structure with a triangular or ovular shape.

Superficially to the nerve, two linear hyperechoic structures can be visualized: the lata and iliac fasciae. The posterolateral limit of the femoral nerve is represented by the iliac muscle (IM) which, thanks to its strongly hypoechoic structure, serves as a contrast plan to visualize the nerve.

With an additional lateral displacement, superficially to the IM, the sartorius muscle (SM) is found. With respect to the vascular pole, a slight medial probe displacement will allow us to visualize the pectineus muscle (PM) and, underneath it, the abductor brevis muscle (ABM) and the underlying abductor magnus muscle (AMM).

5.4.4 Technique

After skin disinfection and a subcutaneous local anaesthetic injection, about 2–3 ml of a sterile gel is distributed on the skin, and with the target firmly on the centre of the screen, an in-plane approach will be used to perform the block.

The needle, which can be connected to a neurostimulator to confirm the nerve localization, will be inserted following the long axis of the probe. The insertion point will be at about 2–3 cm from the probe and will correspond to a channel between the sartorius and rectus femoris muscles. Such an approach allows us to get a high-incidence angle so that, by keeping the needle in its entire length on the acoustic window, it can be easily visualized.

The needle will be advanced in a lateral-medial direction until the iliac fascia is pierced. The operator will be aware of the passage through this sheath not only with the US imaging but also by experiencing a characteristic "click" through the needle. Only at this point, after a negative aspiration test, will it be possible to inject 1 ml of a local anaesthetic solution which should not cause any pain or resistance to the injection. A total 15 ml volume of LA will be injected in fractionated boluses by visualizing its hypoechoic spreading; if this is not the case, the needle should be gently moved to optimize the diffusion of the LA.

One of the most common causes of block failure is the failure to pass through the iliac fascia, which determines LA diffusion onto the superficial layers and not around its target.

The same technique is to be used also when performing a continuous block, making sure, in addition, that the distal end of the catheter will be advanced posteriorly to the nerve for about 1–2 cm; in this way it will be kept in place by the tension between the muscle plan and the nerve itself.

5.5 Obturator Nerve Integration

5.5.1 Procedure

5.5.1.1 Patient's Positioning

The patient will be kept in the same position used for performing femoral block.

5.5.1.2 Probe and Needle

- A linear high-frequency probe is set between 10 and 15 MHz.
- Fifty to 100 mm (22 G) needles are used for single-shot blocks.

5.5.1.3 Echographic Exploration

The obturator nerve, through its homonymous canal, enters the thigh, and after 2–3 cm, it splits into an anterior branch (which runs between ALM and ABM) and a posterior one (which runs between ABM and MAM).

Once the femoral nerve is identified, the probe should be directed medially until the pectineus muscle is visualized, and from here, it should be directed caudally for about 2–3 cm until the abductor region is identified. The obturator nerve is small and presents a "tape" shape; these characteristics, in addition to the fact that it is strictly enveloped by the ALM fascia, make it very hard to be visualized.

5.5.1.4 Technique

The needle, which can be connected to a neurostimulator to possibly confirm the nerve localization, will be inserted along the long axis of the probe and will be advanced in a lateral-medial direction until the ALM and ABM aponeuroses are pierced at their intersection point.

The operator will be aware of the needle passage not only with the US imaging but also by experiencing a characteristic "click" through the needle. Only at this point, after a negative aspiration test, it will be possible to inject 1 ml of a local anaesthetic solution which should not cause any pain or resistance to the injection. A total volume of 5 ml of LA will suffice and, thanks to its hypoechoic diffusion, will emphasize the nerve by delimiting its margins.

5.6 Sciatic Nerve Block

The sciatic nerve (or ischiatic) is a mixed nerve and takes its origin from the sacral plexus. It is formed of nerve fibres emerging from every root of the plexus (L4, L5, S1, S2, S3). It is the biggest nerve of the plexus and it is considered its terminal branch. It is formed by two different bundles of fibres which run separately in it and divide at the end of the nerve in two terminal branches.

The nerve roots gather in one trunk behind the sacrum; then the nerve exits from the pelvis passing through the greater sciatic foramen beneath the piriformis muscle. Then it passes in the middle between the greater trochanter and the ischial tuberosity. Once exceeded the buttock, the nerve reaches the thigh and then runs nearby the linea aspera of the femur.

5.7 Gluteal Approach

5.7.1 Procedure

5.7.1.1 Patient's Positioning

Patient is positioned in the lateral decubitus, with the operative side uppermost and half bended, as described in the Sims' position. It is useful to draw a line between the greater trochanter and the ischial tuberosity.

5.7.1.2 Probe and Needle

- A semi-convex low-frequency probe is used, set between 5 and 7 MHz (higher frequency can be used in very lean patients).
- One-hundred-millimetre (22 G) needles are used in single-shot block.

5.7.1.3 Echographic Exploration

It is useful to start the procedure drawing a line connecting the greater trochanter (GT) and the ischial tuberosity (TI).

At this level the sciatic nerve is found at an average depth between 4 and 6 cm; it is appropriate to set up the scanning depth of the ultrasound machine at least 7 cm from the skin.

The probe is placed horizontally on the line traced before with the marker laterally.

The acoustic shadow with hyperechogenic rim seen at the left of the screen is generated by GT; TI is visualized in a similar manner on the other side of the screen.

The articular capsule of the hip is visualized as a curve hyperechogenic structure which connects the two osseous landmarks ("bat sign").

Between the capsule and the gluteus maximus muscle (MGG) above it, another tapered and hyperechogenic structure will be visualized: the sciatic nerve (as soon as it is found, we suggest to lower the maximum gain to optimize the imaging).

The thin hyperechogenic line, visualized between the nerve and the capsula, will be the terminal part of the internal obturator muscle or the quadratus femoris muscle; it will depend upon the probe positioning.

Often, medially to the nerve, there will be noted pulsatile structures, realistically vessels (anteriorly to the ischial tuberosity); these are the inferior gluteal vein and artery which can be better outlined with the Doppler function. The sciatic nerve is almost always seen laterally to the gluteal vessels, seen as a flattened hyperechogenic structure.

5.7.1.4 Technique

After accurate disinfection of the skin and subcutaneous local anaesthetic injection, 2–3 ml of sterile gel is placed on the skin, and once the target is visualized in the middle of the screen, the in-plane approach is used for the block execution.

The needle is inserted along the long axis of the probe in a lateral to medial manner. A neurostimulator can be connected to confirm positioning. The entering point will be 2–3 cm away from the probe. This approach, because of the depth of the sciatic nerve, does not permit a high angle of incidence and then the imaging won't be particularly well defined.

After a negative aspiration test is performed, 1 ml of local anaesthetic is injected without any resistance or pain.

A total volume of 15 ml of LA is injected in different boluses, carefully verifying the hypoechoic spread around the nerve; if this does not happen, move the needle to optimize the spread.

The positioning of a catheter through this way is problematic, not just for technique execution (tight space between probe and GT) but mostly for the discomfort of the catheter for the patient in the postoperative period.

5.7.2 Below Gluteal Approach

At this level, the sciatic nerve emits branches for the posterior thigh muscles and partly for the adductor magnus.

Close to the superior angle of the popliteal fossa, the nerve splits into its terminal branches: tibial and common fibular nerve. The split between these two nerves is often found more cranially along its path in the thigh.

5.7.2.1 Patient's Positioning

Patient is positioned indifferently in Sims' position or prone.

5.7.2.2 Probe and Needle

- A low-frequency semi-convex probe is used, set up between 5 and 7 MHz. In very lean or muscled patient, a high-frequency linear probe can be used.
- One-hundred-millimetre (22 G) needles are used in single-shot block; a 100 mm (18 G) Tuohy needle is used in continuous nerve block.

5.7.2.3 Echographic Exploration

From the point in which the nerve is localized at gluteal level, moving the probe caudally (maintaining the marker laterally), the sciatic nerve

path can be followed all along the "sciatic line" (representing the cleft between the biceps femoris and semitendinosus muscles) until its split can be visualized, at the popliteal fossa apex. In this part the sciatic nerve is covered by a thinner muscular layer and appears to be a hyperechogenic structure with hypoechoic images in it, well defined and in an oval shape.

5.7.2.4 Technique

After accurate disinfection of the skin and after a subcutaneous local anaesthetic injection, 2–3 ml of sterile gel is placed on the skin, and once the target is correctly visualized in the middle of the skin, an in-plane approach is used for the block to be executed.

The needle is inserted along the long axis of the probe in a lateral to medial manner. A neurostimulator can be connected to confirm positioning. The entering point will be approximately 2–3 cm away from the probe (along all the sciatic line); a bigger distance can be used to optimize the angle between the probe and needle, for the latter to be better visualized. After a negative aspiration test is performed, 1 ml of local anaesthetic is injected without any resistance or pain.

A total volume of 15 ml of LA is injected in different boluses, carefully verifying the hypoechoic spread around the nerve; if this does not happen, move the needle to optimize the spread.

It must be underlined that along its path down to the calf, the sciatic nerve is maintained in its anatomic site by connective septa (which depart from lateral and medial poles). In particular, gaining the posterior side of the nerve, the lateral septum, will represent an obstacle to the needle path. Because of this, under direct ultrasound vision, we shall cross this septum, and this will be perceived as a clear "click" through the needle.

If a continuous nerve block is performed, we suggest to leave the terminal tip of the catheter 1–2 cm along the posterior part of the nerve; in this way, it will be stabilized, thanks to the tension between the muscular plane itself and the nerve above. The optimal insertion point of the Tuohy needle, for a better angle and a lesser trauma of muscular tissue, coincides often with the cleft between the vastus lateralis and the long head of biceps femoris muscles.

5.7.3 Lateral Approach

5.7.3.1 Patient's Positioning

The patient is positioned indifferently prone or supine. In patients in supine decubitus (e.g. in trauma patient), the knee will be slightly bended using a wedge under the leg to avoid the posterior part of the thigh to completely touch the bed.

5.7.3.2 Probe and Needle

- A high-frequency linear probe set up between 7 and 12 MHz is used.
- One-hundred-millimetre (22 G) needles are used in single-shot block; a 100 mm (18 G) Tuohy needle is used in continuous nerve block.

5.7.3.3 Echographic Exploration

Place the probe in the middle part of the thigh in a transverse plane along the "sciatic line"[36]. The marker shall be oriented laterally. Scanning down caudally, the sciatic nerve can be followed along all its path, down to its split at the popliteal fossa apex (the split between these two branches is often seen more cranially along its path in the thigh) where it divides into its two terminal branches. The nerve appears to be a hyperechogenic structure with hypoechoic images in it, well defined and with an oval shape.

The popliteal artery, hypoechoic and pulsatile, runs medially to the nerve, giving birth to a neurovascular bundle encircled by the muscle belly of biceps femoris (laterally) and semitendinosus and semimembranosus (medially).

5.7.3.4 Technique

After accurate disinfection of the skin and after a subcutaneous local anaesthetic injection, 2–3 ml of sterile gel are placed on the skin, and once the target is correctly visualized in the middle of the skin, an in-plane approach is used for the block to be executed.

The needle is inserted along the long axis of the probe in a lateral to medial manner.

A neurostimulator can be connected to confirm positioning. The entering point will be approximately 2–4 cm anteriorly from the probe and coincides with the cleft between vastus lateralis and the long head of the biceps femoris muscle.

A total volume of 15 ml of LA is injected in different boluses, carefully verifying the hypoechoic spread around the nerve; if this does not happen, move the needle to optimize the spread.

5.7.4 Anterior Approach

5.7.4.1 Patient's Positioning

In patients with an obliged supine decubitus (for example, in trauma patient), the anterior approach permits to reach a short part of the sciatic nerve nearby the lesser trochanter (PT) of the femur.

5.7.4.2 Probe and Needle

- A low-frequency semi-convex probe set up between 3 and 5 MHz is used.
- One-hundred-millimetre (22 G) needles are used for single-shot block.

5.7.4.3 Echographic Exploration

Place the probe approximately at 8 cm distally to the inguinal plica in the proximal part of the thigh on a transverse scanning plane; the marker is placed laterally. The depth shall be set approximately at least at 7 cm from the skin. At this level the sciatic nerve is found at an average depth between 4 and 5 cm, and because it runs posteriorly to the femur, it is often hard to be visualized with a frontal scanning of the thigh.

Once the shadow of the femur is seen, it is maintained in the middle of the screen, and the probe is moved more medially along the thigh circumference.

The sciatic nerve will appear as an oval or round structure, grossly hyperechoic, placed posteriorly and medially to the lesser trochanter and in the depth of the adductor magnus muscle.

5.7.4.4 Technique

After accurate disinfection of the skin and after a subcutaneous local anaesthetic injection, 2–3 ml of sterile gel are placed on the skin, and once the target is correctly visualized in the middle of the skin, an in-plane approach is used for the block to be executed.

The needle is inserted along the long axis of the probe in a lateral to medial manner and with an anterior to posterior direction. A neurostimulator is connected. The angle obtained with this approach won't allow an optimal visualization of the needle. For this reason its advancement shall be deduced by the movements of the tissues crossed. In a similar fashion, the contact between the needle tip and the nerve will generate a movement of the nerve itself.

A total volume of 15 ml of LA is injected in different boluses, carefully verifying the hypoechoic spread around the nerve; if this does not happen, move the needle to optimize the spread. This is a very difficult operation to do, however, because of muscular plane depth.

Part II

Knee

David Dejour

6 Knee Arthroscopy: General Setup, Portal Options, and How to Manage a Complete Arthroscopic Investigation

Nicolas Pujol and Philippe Beaufils

6.1 Introduction

The cornerstone of arthroscopy performed for diagnosis or treatment is good visualization and palpation of the intra-articular structures to establish an accurate diagnosis, devise the treatment strategy, and work on the target site without damaging the surrounding tissues. Arthroscopists should be conversant not only with the standard portals but also with specific portals that are optimal for a given disorder or surgical technique. Three universal requirements must be met:

- Stringent adherence to surgical principles
- Use of equipment specifically designed for arthroscopic surgery
- Accessibility of the findings to other physicians via a standardized examination whose results are recorded in detail in a standardized report that includes a video recording or photographs (paper or digital)

6.2 Material

In addition to the video system, knee arthroscopy requires the equipment described below.

N. Pujol, MD (✉) • P. Beaufils, MD
Department of Orthopaedic Surgery,
Centre Hospitalier de Versailles,
Versailles-Saint Quentin University,
177, rue de Versailles, Le Chesnay 78157, France
e-mail: npujol@ch-versailles.fr

6.2.1 The Arthroscope

In most cases, a 25–30° wide-angle arthroscope measuring 4.5 mm in diameter is used. A 70° arthroscope is sometimes useful in some indications (to explore the posterior compartments or the anterior portion of the lateral meniscus).

6.2.2 The Standard Instrumentation

6.2.2.1 Mechanical Instruments

Mechanical instruments should be both powerful and precise.

There is no need to have a very large number of instruments. The basic set (Fig. 6.1) is composed of a probe, which is used routinely; a powerful grasping forceps, preferably with serrated jaws; straight and angled 3.5-mm scissors; 3.5-mm and 5-mm punch forceps; and a 90° basket forceps.

6.2.2.2 Motorized Instruments

At the knee, motorized instruments (shavers) are commonly used for specific procedures (e.g., synovectomy or cruciate ligament repair). For meniscectomy, motorized instruments can be helpful in order to remove all foreign bodies at the end of the procedure and to clean the meniscal rim.

6.2.2.3 Bipolar Electrocoagulation and Radiofrequency

This instrument ensures safe electrocoagulation in a saline environment. It has some indications

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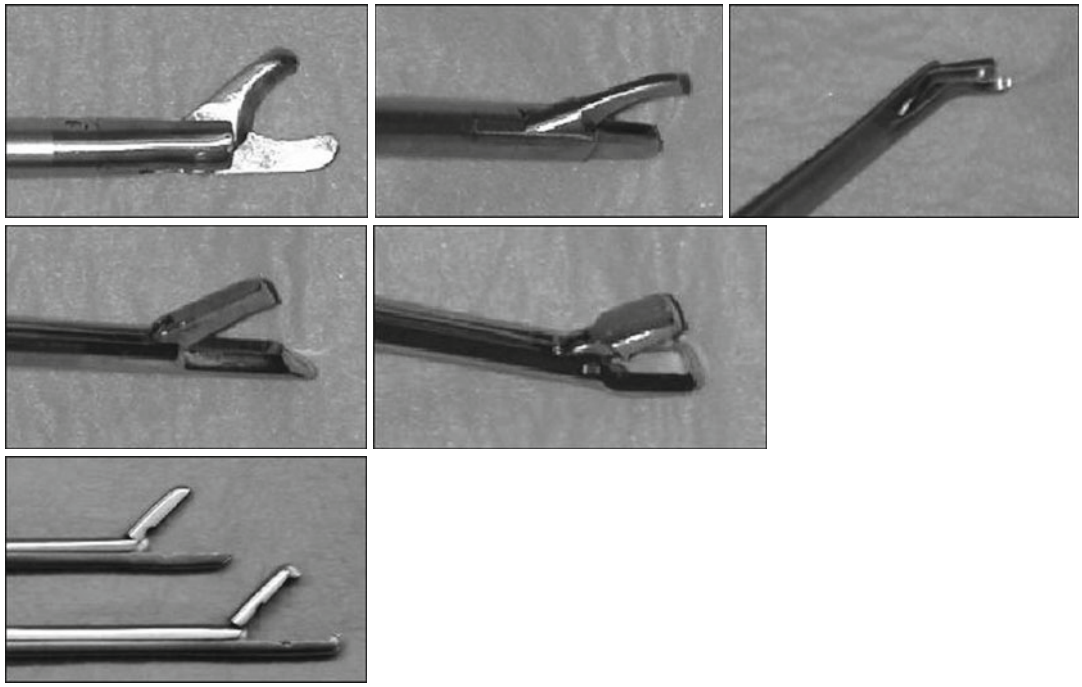

Fig. 6.1 The basic set of instruments comprises a probe, scissors, punch forceps, and grasping forceps

at the knee (lateral retinacular release, coagulation if excessive bleeding despite the use of a tourniquet, cartilage debridement with dedicated wands, synovectomy especially in the posterior compartments). For example, this is not recommended for standard ACL reconstructions in order to preserve the maximum vascularity of the remnants in the intercondylar notch.

6.2.3 Irrigation Cannulas

Irrigation can be obtained by gravity only! A pressure pump that maintains a constant pressure within the knee is useful for sophisticated procedures such as ligament repair and synovectomy. For easy partial meniscectomies, it is not always necessary.

6.3 Anesthesia and Positioning

6.3.1 Anesthesia

General anesthesia and spinal anesthesia are the main techniques for a knee arthroscopy. These two techniques are equivalent for ultrashort outpatient procedures, such as simple arthroscopies [6]. Sometimes, a local anesthesia can be used, with injection at the entry sites of lidocaine 2 % containing 1 % adrenaline (20 ml) [22] and pressure irrigation of the joint with a solution containing 200 mg/L of bupivacaine. At the end of the procedure, a single intra-articular injection of lidocaine hydrochloride can be useful, without any toxic effects on chondrocytes [19].

6.3.2 Positioning

We agree with Jackson [9] that the patient can be positioned supine on an ordinary table with no leg holder. The operator sits on the side of the knee to be treated. One advantage of this position is that it allows full mobility of the hip and knee. The other widely used position involves placing a leg holder at the proximal thigh [24]. The end of the table is folded down and the operator stands along the axis of the lower limb. This position opens up the medial compartment.

6.4 Technique

6.4.1 General Principles

Knee arthroscopy is guided by the following main principles:

- The probe should always be used, and, therefore, an instrument portal is always needed. The probe serves to displace, pull, palpate, or measure the intra-articular structures.
- The principle of triangulation is used to hold the arthroscope and instruments. A larger distance between the two portals makes triangulation easier to achieve. Insertion of a needle whose position is visualized using the arthroscope is often useful to determine the optimal site for the instrument portal.
- If needed, the positions of the arthroscope and instruments should be switched and additional portals used.
- All the main structures should be assessed during a standard arthroscopy, and their aspect should appear in the report of the surgical procedure, even normal.

6.4.2 Anterior Portals (Fig. 6.2)

6.4.2.1 Anterolateral Portal

This is the standard viewing portal. Proper positioning of the portal is crucial to enable high-quality exploration of the joint. The incision is adjacent to the lateral edge of the patellar tendon, 2 mm proximal to the lateral meniscus. The incision site is identified by placing the tip of the thumb in the depression located just above Gerdy's tubercle and creating the incision immediately above the nail.

Arthroscopic examination is performed in a systematic sequence (Fig. 6.3), as detailed below.

The suprapatellar recess and the femoropatellar compartment are examined successively by slowly withdrawing the arthroscope from the extended knee. Rotating the arthroscope provides a very good view of all the structures including the suprapatellar recess with its synovial lining, the suprapatellar or medial plica, the cartilage covering the patella and trochlea, and the proximal portions of the medial and lateral gutters.

The medial compartment is then examined by placing the arthroscope parallel to the joint space then flexing the knee to 30° while applying valgus stress. By rotating the arthroscope, the

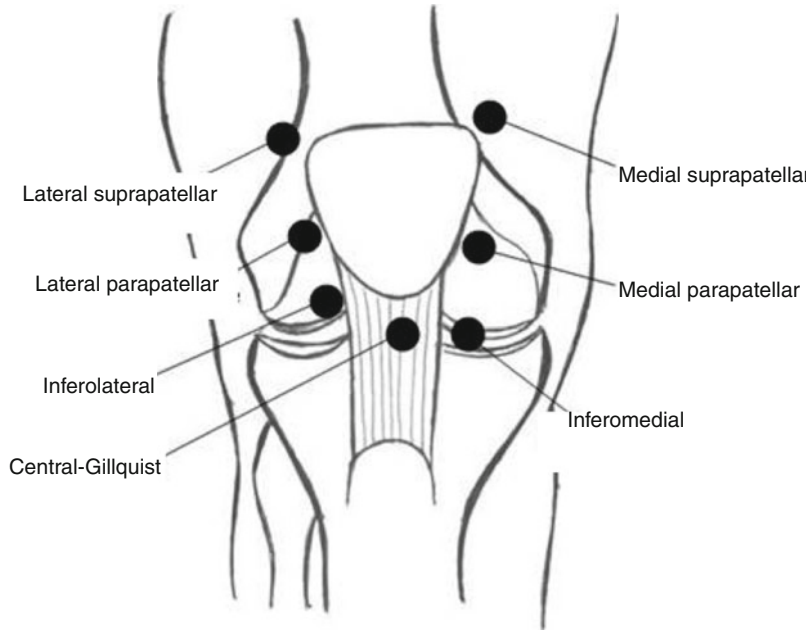

Fig. 6.2 Anterior portals

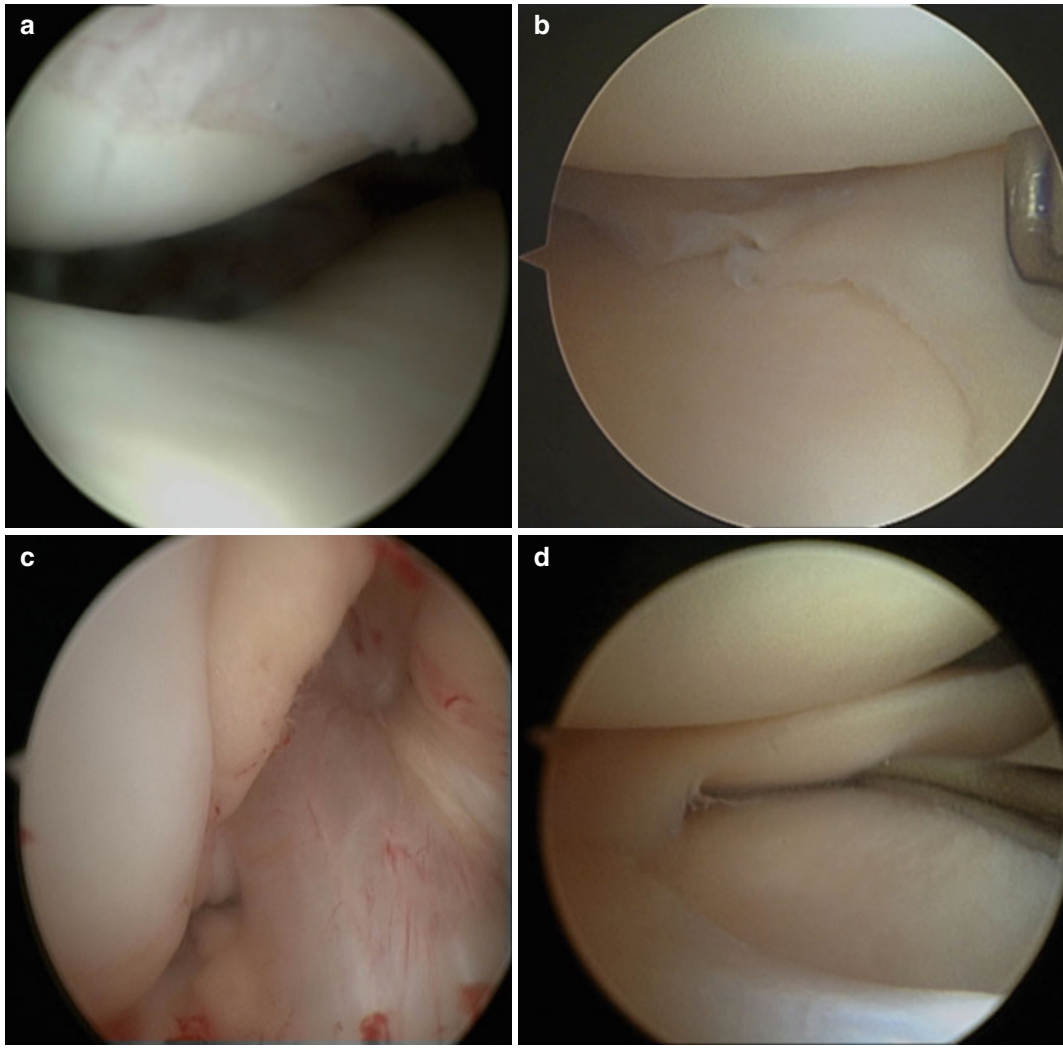

Fig. 6.3 Anterolateral viewing portal (*right knee*). (**a**) Femoropatellar compartment, (**b**) medial femorotibial compartment, and (**c**) intercondylar notch. The posterior crucial ligament is not visible. (**d**) Lateral compartment

following structures can be visualized in succession: distal part of the medial gutter, anterior and medial portions of the medial meniscus, and posterior portion of the medial meniscus. The posterior horn is rarely visible entirely along both aspects, and palpation using the probe is therefore crucial to detect lesions. Then, the medial femorotibial cartilage is inspected and palpated using the probe. If the medial compartment is tight, needle pie crusting of the deep fibers of the medial collateral ligament opens up the medial compartment by 2–3 mm without creating any damage [2, 7]. The additional space thus created allows the operator to work under satisfactory conditions without damaging the cartilage (Fig. 6.4).

The intercondylar region is examined with the knee flexed at 90°. The anterior cruciate ligament is usually clearly visible. The posterior cruciate ligament is concealed by a fat pad that covers its femoral insertion site. A large inferior plica may conceal the cruciate ligaments.

The lateral compartment is examined with the knee in 90° of flexion in Cabot's position and the foot on the table, which opens up the lateral compartment. The following structures are examined

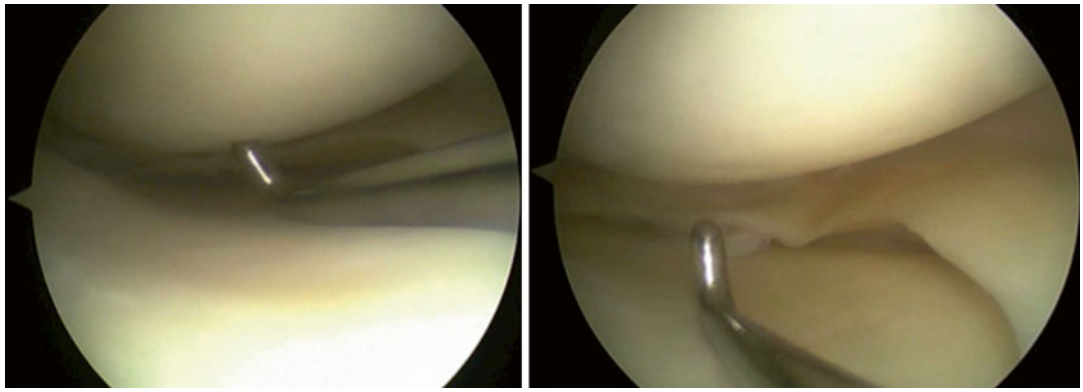

Fig. 6.4 Pie crusting of the deep fibers of the medial collateral ligament under the meniscus to open medial joint space in tight knees

successively: anterior, middle, and posterior portions of the lateral meniscus, lateral femorotibial cartilage, and popliteal tendon (Fig. 6.5) in its supra- and inframeniscal portions and in the distal part of the lateral gutter.

Although the posterior compartments are often accessible via the anterior approach, they are not examined routinely. The posterior compartments should be examined when the clinical or imaging study findings suggest a posterior abnormality or when a therapeutic intervention on posterior structures is needed.

The posteromedial compartment is very often accessible via the anterolateral approach by placing the tip of the arthroscope between the axial aspect of the medial condyle and the cruciate ligaments and then gradually advancing the arthroscope posteriorly, inferiorly, and medially in contact with the posterior meniscal horn with the knee flexed at 90°. The compartment can be examined by rotating the arthroscope, but can be broadened by substituting a 70° arthroscope for the 30° arthroscope (Fig. 6.6). Advantages of this method include the ability to visualize the posteromedial capsule and to provide visual guidance when performing a needle trial to determine the best position for a posteromedial portal. In most of the cases, the inspection of the posteromedial ramp with a 30° arthroscope is sufficient to diagnose the presence of a meniscocapsular lesion. An additional percutaneous needle palpation of the meniscocapsular junction through a

Fig. 6.5 Popliteal fossa through anterolateral portal

posteromedial portal may be helpful to rule out so-called hidden lesions [23]. If in doubt, a 70° arthroscope or a direct visualization of this area through a posteromedial approach may be required. Internal rotation of the tibia and careful extension and flexion movements are helpful to assess this specific region and the behavior of the capsule [15].

The posterolateral compartment is easier to examine. With the knee in 90° of flexion in Cabot's position, the arthroscope is advanced between the axial aspect of the lateral condyle and the anterior cruciate ligament. Then, as described for the medial compartment, the following structures can be examined: posterior capsule, posterior wall of the lateral meniscus, and posterior part of the lateral condyle. The popliteal tendon is not normally visible via this approach.

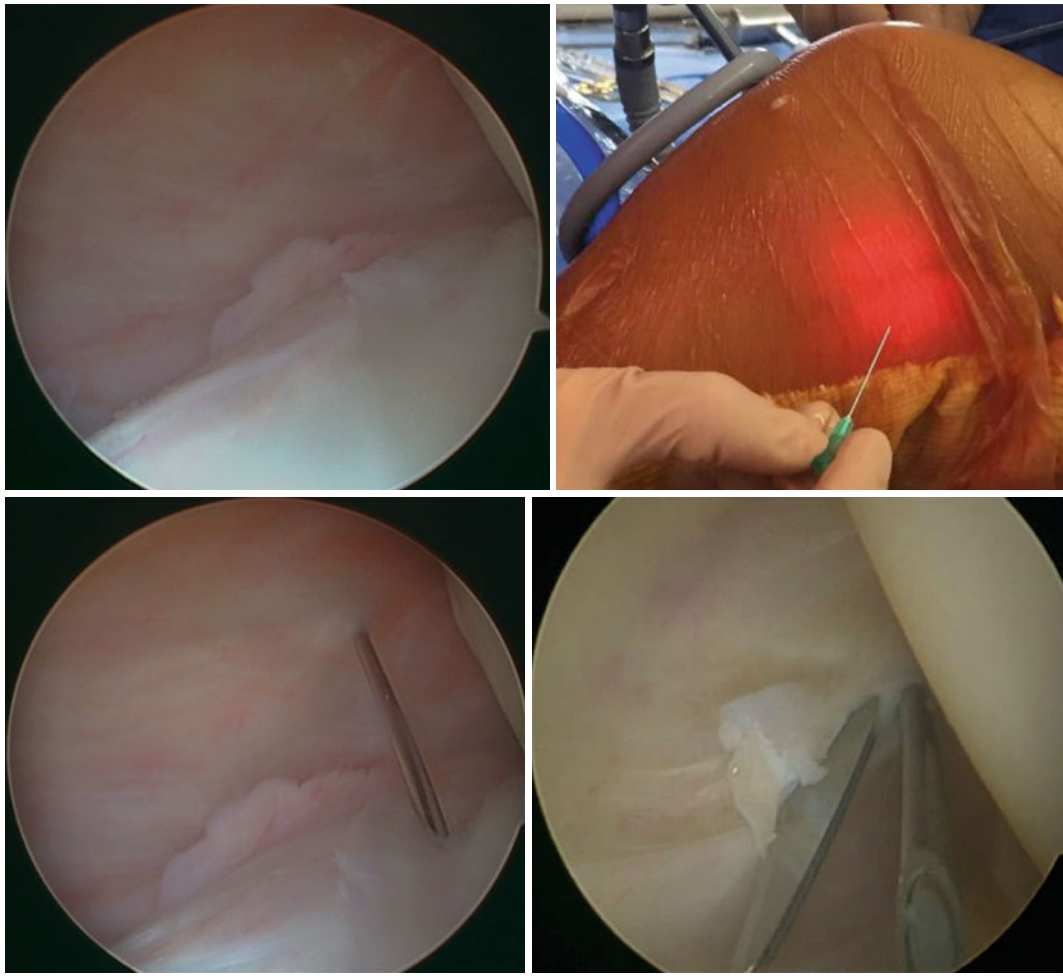

Fig. 6.6 Posteromedial portal

The anterolateral portal is the standard viewing portal and is used routinely for arthroscopy of the knee. This portal offers the largest field of view and has the smallest blind spots [11]. However, it is inadequate for visualizing the anterior third of the lateral meniscus, the medial gutter, the femoropatellar dynamics, and the posterior compartments (unless a 70° arthroscope is used).

6.4.2.2 Anteromedial Portal

The anteromedial portal is the main working or instrumentation portal. The placement of this portal is critical for effectively reaching the various intra-articular structures with the arthroscopic instruments. It is recommended to create this portal under direct vision using the arthroscope. The portal is created just above the wall of the medial meniscus taking care to avoid contact with the patellar tendon in order to ensure sufficient freedom of movement of the instruments. Transcutaneous illumination is also helpful in order to avoid vessels and skin nerves (infrapatellar branches of the saphenous nerve).

Introducing the arthroscope via the anteromedial portal adds to the information obtained via the anterolateral portal by visualizing the medial patellofemoral ramp, the posteromedial compartment, the anterior third of the lateral meniscus, and the femoral insertion of the ACL.

6.4.3 Other Anterior Portals

Each of these portals can serve for the arthroscope or the instruments. Their use is far from routine and depends on the nature of the lesions to be treated (Table 6.1).

6.4.3.1 Central Portal

The central transpatellar tendon portal was first described by Gillquist [13]. The arthroscope is inserted through the patellar tendon, 10 mm above the tibial plateau. This rarely used portal has two main indications, namely, a need for a second instrument portal when performing a difficult meniscectomy, after removal of the middle third of the patellar tendon during ACL reconstruction, and as an accessory portal to reduce anterior tibial spine fractures.

6.4.3.2 Lateral and Medial Suprapatellar Portals

These portals are located 1 cm above the border of the patella on a line prolonging the medial or lateral edge of the patella. For viewing, the superolateral portal is chiefly used to examine the patella (femoropatellar dynamics), trochlea, fat ligament, and plicae [5]. It provides a good view of the proximal part of the lateral gutter (Fig. 6.7). As instrumental portals, the lateral and medial suprapatellar sites are mainly useful for anterior recess synovectomy and for the treatment of lesions located in the anterior knee.

Table 6.1 Viewing portals depending on the lesion to treat

	Anterolateral	Anteromedial	Central	Superior	Posterior
Medial meniscectomy	+++	++	+	0	+
Lateral meniscectomy	++	++	0	0	+
Repair of the medial meniscus	+++	+++	0	0	++
Repair of the lateral meniscus	+++	+++	0	0	0
Foreign bodies	+++	++	0	+	++
Femoropatellar compartment	++	0	0	+++	0
Synovectomy	+++	+++	0	+++	+++
Anterior cruciate ligament reconstruction	+++	++	0	0	0
Posterior cruciate ligament repair	+++	+++	+	0	+++

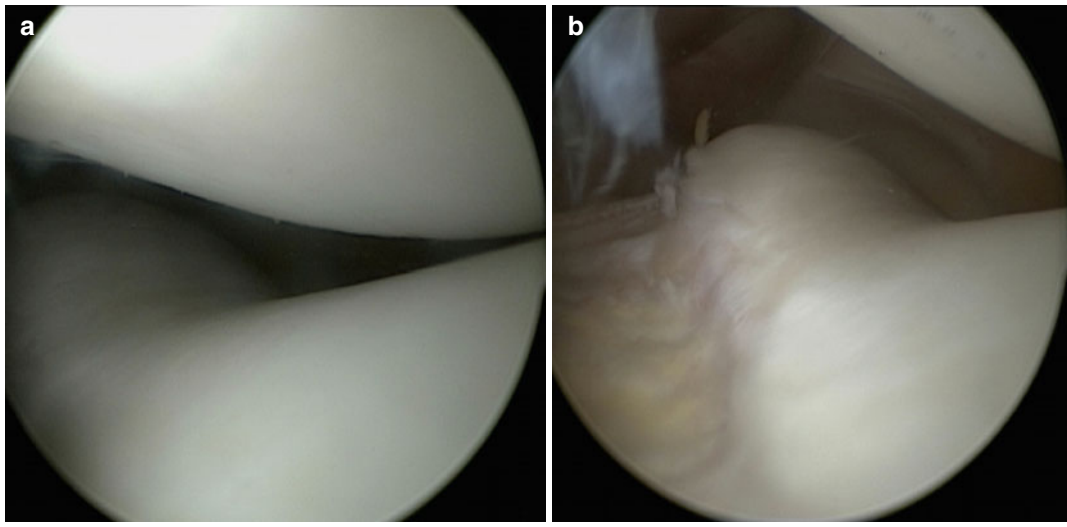

Fig. 6.7 (**a**) Femoropatellar compartment examined via the lateral suprapatellar portal. (**b**) Top of the trochlea is well visible through suprapatellar portal

6.4.3.3 Lateral Midpatellar Portal

D. Patel [18] routinely uses the lateral midpatellar portal for viewing. This portal is in a high anterolateral location. Compared to the standard anterolateral portal, it provides a better view of the anterior portions of both menisci. However, visibility of the posterior structures is decreased compared to the standard anterolateral portal.

6.4.4 Posterior Portals

Posterior portals are difficult to create, and special care is required to avoid injuring the major blood vessels and nerves located behind the knee, not only the popliteal neurovascular bundle but also the peroneal nerve laterally and the medial saphenous nerve medially. The posteromedial portal is located at the posterior angle of the condyle, which is easily felt when the knee is flexed, 1 cm proximal to the femorotibial joint space (Fig. 6.6). There are three crucial requirements: the knee must be flexed at 90° and distended, and the portal must be created under visual guidance after introduction of the arthroscope into the relevant compartment via the anterolateral portal. The entry site is then identified by introducing a needle or no. 11 scalpel posteromedially. The arthroscope is then introduced into the portal. The posterolateral portal is located symmetrically to the posteromedial portal and is created according to the same principles.

The posterior portals can be used for the arthroscope or instruments, which can be switched from the anterior portals. They provide a better view of the posterior structures than do the anterior portals [10]. Thus, the posterior aspect of the condyles is entirely visible, as well as the posterior meniscal wall, condylar cartilage, and base of the posterior cruciate ligament.

Louisia and Beaufils described a combined posteromedial and posterolateral portal established using a back-and-forth technique [14]. This portal can be used to collapse the septum located above the posterior cruciate ligament in order to create a single posterior cavity (Fig. 6.8). It is particularly valuable for extensive posterior synovectomy but should be reserved for experienced arthroscopists [1].

6.5 Intraoperative Complications

Overall, arthroscopy is associated with some complications [3, 8, 25], around 1 % for simple arthroscopies such as meniscectomies [12].

6.5.1 Instrument Breakage

Despite improvements in instrument design, breakage continues to occur, at a rate of less than 0.1 % [20]. To ensure the early diagnosis and to avoid subsequent malpractice suits, the instruments should be examined carefully after each procedure [17].

6.5.2 Vascular Injuries

Vascular injuries are exceedingly rare (the incidence after arthroscopic meniscectomy is 0.003 %) [4]. Injury to the popliteal blood vessels can have devastating consequences.

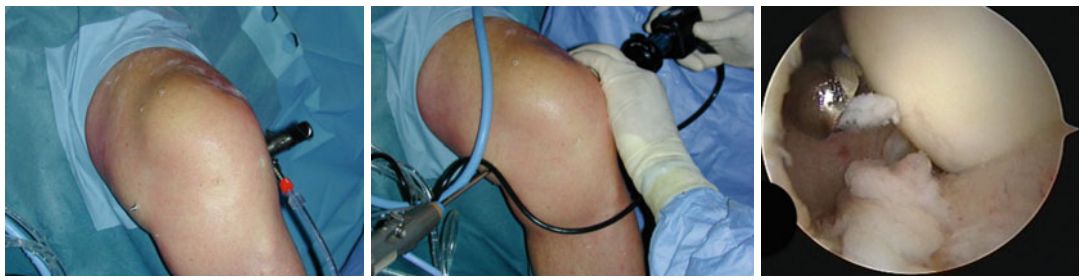

Fig. 6.8 Back and forth posterior portal (outer appearance, arthroscopic view)

A few simple precautions help to prevent vascular injuries: instruments should be used only under visual guidance, aggressive motorized instruments should not be used in the posterior compartments, the drainage fluid should be examined at the end of the procedure to check that it is clear, and the vascular supply to the limb should be checked in the operating room after releasing the tourniquet.

6.5.3 Nerve Injuries

Nerve injuries occur in 0.4–0.6% of cases [11]. The most common form of nerve injury is neuroma of the infrapatellar branch of the medial saphenous nerve, which has been reported during medial meniscectomy or medial meniscus repair (out-in technique). Injury to the popliteal nerve or fibular nerve is exceedingly rare but devastating.

6.5.4 Other Complications

Many complications can occur after arthroscopy. Examples include ligament injury after valgus or varus stress application [16]; complete or partial section of the anterior cruciate ligament during lateral meniscectomy; damage to the cartilage while inserting the instruments or doing a meniscectomy [21], which may be extensive if the joint is tight; damage to a meniscus during portal creation; and burns during electrocoagulation.

The prevention of complications involves the use of appropriate equipment, proper portal positioning, the development of a well-defined treatment strategy, and gentleness.

6.6 Postoperative Care

The portals are closed with resorbable sutures or adhesive strips. Drainage is unnecessary after diagnostic arthroscopy or simple arthroscopic interventions (e.g., meniscectomy). Postoperative analgesia can be obtained by injecting a morphine-bupivacaine mixture into the joint or around the wounds [22].

Conclusions

Arthroscopy of the knee is one of the most common procedures that orthopedic surgeons perform. Although minimally invasive, arthroscopic knee surgery is a surgical procedure that involves pre-, intra-, and postoperative constraints. This technique is routinely used and requires specific instruments and training. Rigorous standard exploration and positioning of the portals are essential steps to start always the surgical procedure in perfect conditions.

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Traumatic and Degenerative Meniscus Lesions: Diagnosis and Classification

7

Michael Hantes, Vasilios Raoulis, and Roland Becker

7.1 Clinical Diagnosis

7.1.1 Introduction

Injury of the knee joint meniscus is one of the most prevalent injuries in the human body. The prevalence of an acute meniscal injury has been estimated of being 60 out of 100,000 patients. Analysis of 19,530 sports injuries over a 10-year period showed knee involvement in 39.8 %. Anterior cruciate ligament (ACL) injuries occurred in 20.3 %, while medial and lateral meniscus lesions in 10.8 % and 3.7 % respectively [1].

Acute meniscal tears occur most often from twisting injuries, while chronic degenerative tears can occur in older patients with minimal twisting or stress. However it remains unclear whether the degenerative meniscus lesion develops first and initiates the progression of osteoarthritis or vice versa. There is a 2.8 times higher incidence of meniscus tears in male than female patients. Acute meniscus injuries in male patients occur predominantly between 31 and 40 years of age. Acute ACL injuries produce more frequently lateral meniscus tears, while chronic ACL tears cause medial meniscus tear more frequently. In addition, the medial meniscus functions as a secondary stabilizer for the knee and reduces anterior subluxation of the tibia when the anterior cruciate ligament is torn [2, 3].

The combination of a comprehensive history, multiple physical tests, and diagnostic imaging is necessary for confirmation of a meniscal lesion, whereas the gold standard remains the arthroscopic procedure itself. A thorough subjective history can help the examiner to choose the appropriate clinical tests and include them in the physical examination. Several provocative maneuvers or tests have been described to elicit symptoms from a torn meniscus, such as the McMurray's test, tenderness to palpation along the joint line, the Apley compression test, and the Thessaly test. Early, clinical examination, appropriate investigation, and final treatment of meniscal injuries may prevent later degenerative disease and inappropriate surgical treatment that can predispose to later degenerative changes. This chapter presents the basic approach to the physical examination of the knee with a particular focus on the evaluation of meniscus pathology.

M. Hantes, MD (✉) • V. Raoulis, MD
Department of Orthopaedic Surgery and Musculoskeletal Trauma, Faculty of Medicine, School of Health Sciences, University of Thessalia, Larissa, Greece
e-mail: hantesmi@otenet.gr

R. Becker, MD
Department of Orthopaedic and Traumatology, Centre of Joint Replacement, University Hospital of Brandenburgc "Theodor Fontane University", Brandenburg, Germany

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7.1.2 History

Before the physician performs a physical examination, it is essential that he obtains a focused full history and the chief complaint should be elicited. History-taking should be performed carefully and patiently. Good history-taking is the most important and significant medical procedure, highly related to the capability and the experience of the physician. A history is mostly indicative of the disease itself and thus essential to lead to the final diagnosis. The age of the patient and the time that has passed since the onset of symptoms should be noted, while a traumatic painful knee in a young patient should be distinguished from a nontraumatic chronic knee pain in a patient over 40 years of age.

The next step is to clarify whether there was an acute injury of the knee and the mechanism of the injury. Patients with a sudden onset of pain without reporting an antecedent trauma may have underlying articular cartilage degeneration, a degenerative meniscus lesion, or other pathology [4]. The presence of chronic recurrent pain and swelling after exercising could be indicative of a meniscal tear irritating the joint. The mechanism of the injury plays its role, in that a sudden twist or repeated squatting can cause meniscus tear. A contact injury means that the knee has absorbed enough energy and all the structures of the knee should be examined (bones, ligaments, meniscus). Most patients report an acute onset of sharp pain following a twisting injury with the knee flexed and the foot planted on the ground. The combination of torsional and axial loading appears to be the cause of most meniscal injuries [5–8]. A mechanism of injury that includes a varus or valgus stress to the knee with a resultant sensation of instability may be associated with lateral collateral ligament (LCL) or medial collateral ligament (MCL) injuries, respectively. The timing of the injury is important to note, although patients often cannot describe a specific event.

Significant historical questions should include the location and duration of pain, a change in activities, an audible "pop" at the time of injury, swelling around the knee joint, a feeling of give-way weakness or buckling, locking or catching of the tibiofemoral articulation, instability sensation, and possibly associated, hip, back, or thigh pain [6, 9]. In particular, an audible "pop" and the immediate onset of pain and swelling are associated with anterior cruciate ligament (ACL) tears, often being a result of a noncontact pivoting injury. Patients may report pain while going down the stairs, with directional change during walking, as well as pain with bending of the knee. A sudden pain localized to the joint line when catching one's foot on an irregular surface is also indicative of meniscal pathology. Mechanical symptoms such as clicking or locking accompanied with a localized pain in the joint line are often associated with meniscus lesions.

Intra-articular loose bodies from cartilage injuries or from abnormal patella-femoral mechanics can also produce mechanical symptoms such as locking and catching. Physicians should keep a high clinical suspicion for meniscus tears in combination with other knee injuries. Approximately one-third of all meniscus tears are associated with ACL injuries [10]. After an acute ACL tear, lateral meniscus lesions occur more frequently than medial meniscus lesions. Unlike lateral meniscus injuries, medial ones are more common in knees with a chronic ACL deficiency due to the role of the posterior horn of the medial meniscus [11–13]. Previous knee injuries and surgeries should be taken into account, as well as previous knee injections. Finally, the occupation of the patient (worker, athlete) and sport participation could play a role for the treatment (prolonged rehabilitation period after meniscus repair).

7.1.3 Clinical Examination

The clinical examination is the most important part of patient's assessment, and the indication for MRI should be given after that and when additional information is required for the treatment. The clinical examination should be standardized as much as possible and therefore a strict algorithm is recommended including inspection (*LOOK*), palpation (*FEEL*), joint

movement (*MOVE*), and the joint specific test (*SPECIFIC TESTS*).

7.1.3.1 Inspection (LOOK)

The general physical examination starts with observation of the knee, i.e., detecting any swelling or obvious deformity. The patient should be wearing shorts and both knees should be examined. Inspection of the skin and the muscle tone of the knee joint is very important. Skin abnormalities such as excoriations, wounds, ecchymosis, and erythema can provide important information regarding the causality of knee pain. Atrophy of the quadriceps may indicate disuse after injury and can help the clinician to determine chronicity. The calculation of the patient's body mass index (BMI) is important since the knee joint is affected by body weight and characteristic meniscus tears occur more often in portly individuals [14]. Weight-bearing alignment is assessed in each leg with the patient standing straight with his feet together. Varus or valgus of the knee should be noted as it alters normal knee kinematics by shifting the load-bearing axis medially or laterally, respectively. Evaluation of the gait should follow next, since patients with meniscus tears or degenerative changes in the knee such as osteoarthritis often experience pain during the standing phase of gait.

7.1.3.2 Palpation and Range of Motion (FEEL and MOVE)

The physician should methodically palpate the bony and soft tissue structures first of the unaffected and then of the affected knee, paying particular attention to areas of focal tenderness and swelling. The patient is lying supine on the examination table to allow for full, unrestricted range of motion during the palpation. Intra-articular effusion is estimated by palpating, with one hand compressing fluid from the supra-patellar pouch to beneath the patella while the second hand is squeezing fluid from the inferior aspect of the joint to beneath the patella. A finger can then be used to depress the patella, which will feel as if it is bouncing on the underlying effusion [15]. The clinician should continue with palpation of the extensor mechanism of the knee including the quadriceps tendon, the patella, and the patellar tendon, checking for tenderness or palpable defects. While palpating the anterior structures of the knee, warmth or tenderness overlying the regions of the supra-patellar, prepatellar, or infrapatellar bursas should be taken notice of. The clinical assessment of the patella and the extensor mechanism finishes with checking for J sign (lateral patella subluxation), the apprehension test (indicative of dislocation/subluxation), measurement of the Q angle, and the quadriceps active test.

The palpation of the medial aspect of the knee should include the medial meniscus at the upper edge of the medial tibial plateau; the MCL extending from the medial femoral epicondyle to the medial proximal tibia; the insertion of sartorius, gracilis, and semitendinosus tendons into the anteromedial proximal region of the tibia; and the pes anserinus bursa. Tenderness to palpation along the posterior medial joint line can indicate a medial meniscus lesion, an MCL injury, or a medial compartment degenerative disease.

Just like the medial aspect of the knee, the palpation should continue to the lateral knee. The lateral meniscus can be palpated at the upper edge of the lateral tibial plateau, and the LCL can be palpated as it extends from the lateral femoral epicondyle to the fibular head by bending the knee or using the "figure of four" position. The differential diagnosis except for lateral meniscus tear, include LCL injury, osteoarthritis, popliteus tendonitis, and iliotibial friction band syndrome. When palpating the lateral and medial meniscus, a physician should always bear in mind that parameniscal cysts could be discovered.

The normal range of motion of the knee ranges from 0 to 140°, which should always be compared with the contralateral side. Patellofemoral crepitus with a range of motion may correlate with patellofemoral osteoarthritis. Crepitus and/or pain in early flexion indicate a more distal patella disease. Joint pain that is present during both active and passive range of motion is often associated with intra-articular pathology, while pain that is present only with active range of motion has a higher likelihood of being related to an extra-articular soft tissue disorder [15].

7.1.3.3 Joint Stability

The evaluation of joint stability is extremely important in every orthopedic knee examination. The physician should perform a series of maneuvers to both the affected and unaffected knee to test the collateral and cruciate ligaments for laxity. The MCL is examined with the patient in supine position by applying a valgus stress to the knee joint with the knee in 30° of flexion and in full extension. The LCL can be evaluated in a similar manner by applying a varus stress to the knee joint in 30° of flexion and full extension. Laxity to valgus or varus stress with the knee in 30° of flexion indicates an isolated injury to the MCL or LCL, respectively. Laxity in full extension indicates an injury to one or both cruciate ligaments in addition to a collateral ligament injury [16]. During the evaluation of the collateral ligaments, the examiner should also consider meniscus pathology.

The assessment of joint stability should continue with the evaluation of ACL and PCL. The Lachman-Noulis test, anterior drawer test, and the pivot shift test are the main tests for evaluating the ACL. The Lachman-Noulis test is the most sensitive and specific physical examination maneuver for detection of an ACL injury [17, 18]. An instrument called "KT-1000" (a knee arthrometer) can be used to determine the magnitude of movement in mm.

The PCL can also be evaluated by a variety of clinical tests, which are the posterior sag sign, the posterior drawer test, and the active quadriceps test. First, the knee should be inspected for a posterior sag sign, which is indicative of a PCL tear. An undetected posterior sag of the tibial plateau can lead to a falsely negative posterior drawer test secondary to the lack of additional posterior translation of an already posteriorly subluxed tibia.

7.1.3.4 Specific Meniscal Tests

Numerous tests are available with a moderate to high sensitivity and specificity for identifying meniscus tears [19–26]. The examiner should choose the tests which he/she feels most comfortable and reproducible with. Meniscal tests can be distinguished in compression and dynamic tests.

Compression tests:	1. Joint line tenderness
	2. Hyperflexion and extension test
	3. Böhler test
	4. Krömer test
	5. Payr test
Dynamic tests:	6. McMurray test
	7. Apley (grinding and distraction) test
	8. Bounce home test
	9. Thessaly test
	10. Merke's test
	11. Steinmann I test
	12. Steinmann II test
	13. Bragard test
	14. Anderson (medial/lateral grinding) test
	15. Pässler – rotational grinding – test
	16. Fuche test
	17. Ege test
	18. Finochietto test
	19. Cabot's sign
	20. Childress test

Joint Line Tenderness

The joint line tenderness is one of the most reliable tests with a positive predictive value of 60–80 %. The test is performed in different flexion positions of the knee. Palpation of the medial and lateral joint line is performed to identify also a meniscus ganglion, or swelling except pain. The sensitivity and specificity of joint line tenderness for meniscal pathology range from 55–85 % to 29.4–67 % respectively [19–21].

The clinician can begin by evaluating for medial or lateral joint line tenderness to palpation, which is the most basic procedure of the meniscal assessment. Flexing the knee and adding tibial rotation, either internally or externally, allow for easier palpation of the periphery of the medial and lateral meniscus, respectively. The most important finding in patients with a meniscal tear is localized tenderness along the joint line (Fig. 7.1). It is estimated that 60–80 % of patients with meniscal lesions will have a joint line that is painful upon palpation.

Hyperflexion and Hyperextension Test

Hyperextension of the knee causes compression of the anterior horn and a bucket handle tear or

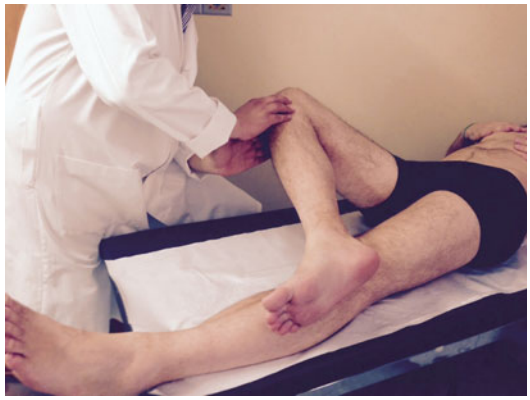

Fig. 7.1 Medial joint line palpation with the patient's knee flexed 90° to evaluate joint line tenderness

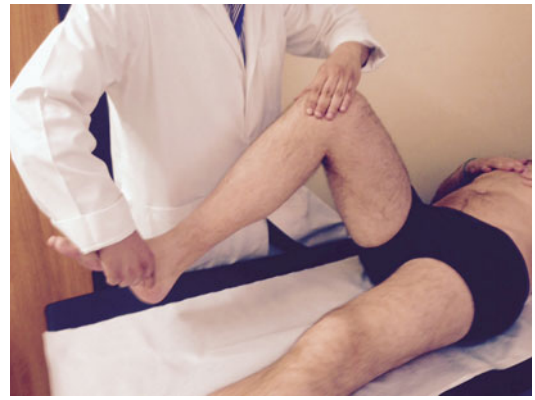

Fig. 7.2 McMurray test for medial meniscus; the examiner palpates the medial aspect of the knee while extending the knee and externally rotating the tibia

flap tear may impinge. Hyperflexion causes stress on the posterior part of the meniscus. It might be aggravated by performing rotation at the same time. The patients also complain frequently about pain or discomfort during deep squatting.

Böhler Test

Varus or valgus stress of the knee causes compression of the medial or lateral joint space, while the opposite joint space is under distraction. The compression of the compartment may become painful when the meniscus is torn.

Krömer Test

The test is similar according to Böhler tests, but varus and valgus stress are performed at different knee flexion angles in order to evoke pain sensation.

Payr Test

The test is used to examine the medial meniscus. The patient lies back. The knee is flexed to 90°. In the figure-of-four position, the foot is elevated and during the same time compression is performed at the medial joint line with the other hand. This will increase the compression at the medial compartment. When the test is performed under knee flexion of less than 90°, the intermediate region of the meniscus is examined. Knee flexion of more than 90° addresses the posterior horn of the meniscus.

Mc Murray Test

This test was first described in 1940 by McMurray. The McMurray test is one of the most widely used clinical exam maneuvers for the evaluation of meniscus lesions. This test is performed with the patient positioned supine. The physician first brings the knee into full flexion while stabilizing the knee with one hand at the lateral side providing valgus stress and grasping the foot by the sole with the other hand. The knee is then brought to 90° of flexion, first with full internal rotation of the tibia and then with full external tibial rotation. An appreciable click in association with a torn meniscus that reproduces the patient's previous painful sensations is a positive test. Both menisci, lateral and medial, can be assessed with this test: pain or clicking with internal rotation suggests the presence of a lateral meniscus injury, while pain or clicking with external rotation is indicative of medial meniscus injury (Fig. 7.2).

The McMurray test has modest sensitivity for detection of meniscus tears with reported values ranging from 16 % to 58 % [19–22]. On the other hand, it is highly specific for meniscus tears, particularly tears of the posterior horn, with specificity values ranging from 77 % to 98 % [20, 21, 23]. Consequently, this provocative test has continued to be utilized in combination with other physical examination maneuvers for the diagnosis of meniscus injury.

Apley Test

The Apley compression test was originally described by Apley in 1947. Since then the test has been known as "Apley test." According to Apley, the patient lies in prone position with the knee flexed to 90°. The tibia is compressed into the distal femur, and external rotation follows to assess the medial meniscus and internal rotation for the evaluation of the lateral meniscus. If during this maneuver the patient feels pain, which is less severe or relieved when the maneuver is repeated with distraction of the tibia, the test is considered positive (Fig. 7.3).

The Apley grind test has been shown to have a relatively low sensitivity (13–16%) and high specificity (80–90%) [20, 21].

Bounce Home Test

The Bounce home test evaluates for a possible limitation in the ability of the knee to fully extend it. Loss of full ROM at the knee joint may indicate a torn meniscus fragment or other intra-articular pathology such as a loose body or joint effusion. The test is performed with the patient lying supine and the physician holding the heel of the foot in his hand. After passively flexing the knee, the knee is then allowed to passively extend. If full extension of the joint is not complete or has a rubbery end feel, there is probably a torn meniscus (in most cases a bucket handle tear) or some other blockage present [25].

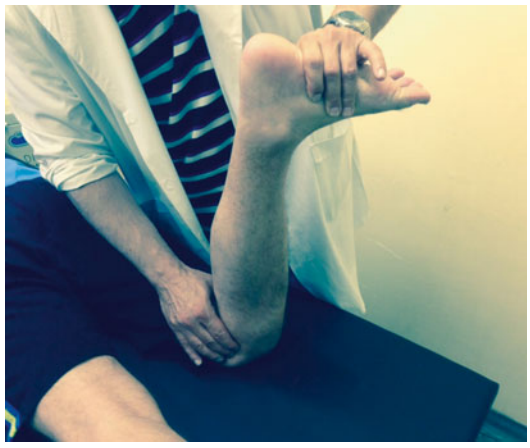

Fig. 7.3 Apley test for medial meniscus; the patient lies in the prone position with the knee flexed to 90°. The examiner medially and laterally rotates the tibia using compression and distraction. If rotation plus compression is painful, a meniscus injury is possible

Thessaly Test

The Thessaly test is a relative new test in comparison with other tests for meniscus evaluation and it is a weight-bearing test. It attempts to reproduce dynamic load transmission into the knee joint [26]. The examiner supports the patient by holding his outstretched hands. The patient then rotates his knee and body both internally and externally three times, keeping the knee in slight flexion at 5°. The same testing procedure is then repeated with the patient maintaining the knee in more flexion at 20°. A positive test results in joint line discomfort or locking or catching (Fig. 7.4).

Fig. 7.4 The Thessaly test. The examiner supports the patient by holding his or her outstretched hands while the patient stands flatfooted on the floor. The patient then rotates his or her knee and body, internally and externally, three times, keeping the knee in slight flexion (5°). The same procedure is then carried out with the knee flexed at 20°

When the Thessaly test is performed at 20° of knee flexion, it has been shown to have high sensitivity for detection of both medial and lateral meniscus tears (89 % and 92 %, respectively). The 20° Thessaly test has also been reported to have high specificity rates, i.e., 97 % and 96 %, for the detection of medial and lateral meniscus tears, respectively. This test has lower sensitivity and specificity when performed at 5° of knee flexion.

Merke's Sign

A similar loading test has been described by Merke in 1940. The patient stands upright having the load on both of the legs. Rotation of the upper body will cause automatically rotation in the knee. Internal rotation serves for testing the lateral meniscus and external rotation the medial one.

Steinmann I

Forced rotation is performed at different flexion angles. External rotation is used to test for the medial meniscus and external rotation for the medial meniscus. The menisci will be caught between the tibia and femur, causing pain in the affected compartment.

Steinmann II

Pain sensation moves from anterior to posterior during knee flexion. The varus and valgus stress test will help to distinguish meniscus pathology and collateral injuries.

Bragard Test

The pain occurs at the anterior part of the joint line during pressure by the index finger. The other hand forces the foot into external rotation while extending the knee. The same test is repeated in internal rotation during knee flexion and will decrease the pain.

Anderson Test (Medial and Lateral Grinding)

The patient is lying back for the test. The examiner fixes the lower leg and performs circling movements at the level of the knee. During knee flexion, valgus stress is applied in addition and during extension varus stress.

Pässler Test (Rotational Grinding Test)

The patient sits on a chair while the examiner sits in front of the patient and fixes the lower limb. The examiner positions his/her thumbs at the level of the medial joint space. The circular motion of the lower leg with internal and external rotation and varus and valgus stress is applied at the same time. Pain will be caused at the joint line.

Fouche Test

In contrast to the McMurray test, the knee is internally positioned during extension. Unstable meniscus fragment of the medial meniscus will be caught during extension. The same will happen with the lateral meniscus during external rotation.

Ege's Test

The test was first described by Akseki in 2004. Basically it is a kind of McMurray test under loading. The patient stands having his/her feet positioned in external rotation in order to test the medial meniscus. The patient is asked to squat. The test is repeated in internal rotation in order to examine the lateral meniscus. A specificity and sensitivity of 67 % und 81 % respectively has been reported.

Finochietto Test

The test can be applied when the anterior cruciate ligament is torn. An anterior drawer in 90° of flexion is performed. The anterior movement of the tibial plateau may cause some catching sensation or pain.

Cabot Sign

The Cabot sign is positive when there is a "hiatus popliteus syndrome" meaning a lesion at the posterior horn of the lateral meniscus. Typically the patient is complaining about pain at the lateral joint space and in the popliteus region with radiation into the calf. Pain can be caused by putting the affected leg over the contralateral one. During the maneuver, the lateral joint space is palpated. The second hand fixes the ankle and the patient is asked to extend the knee against resistance.

Childress Sign

The patient is asked to perform deep squatting until the heel touches the buttock. The duck gait will cause pain and locking when there is a symptomatic meniscus tear. The patient is even unable sometimes to get into the squatting position.

7.1.3.5 Conclusion

Often the diagnosis of a meniscus tear is challenging even for the experienced clinician. The physician relies upon an accurate history and a variety of physical examination procedures to arrive at a diagnosis of a lesion of the meniscus. It is from the results of these tests that the clinician then formulates a treatment plan, while imaging techniques play an important role in confirming the diagnosis of meniscus injury. But it is important that clinicians utilize their physical examination skills to determine when to obtain advanced imaging if necessary.

According to Lowery [27], the composite score of five clinical criteria (see below) can accurately detect meniscal pathology.

1. History of locking or catching
2. Pain during hyperextension
3. Pain during maximal flexion
4. Positive McMurray test
5. Pain over the joint line

In case all five criteria are positive, there seems to be a 92% probability of a meniscus lesion [27–29].

7.2 Diagnostic Imaging

7.2.1 Introduction

After clinical examination, radiological assessment will determine and confirm the diagnosis of a meniscus tear. Diagnostic imaging techniques include X-rays, computed tomography (CT) scans, and magnetic resonance imaging (MRI). The aim of the physical and radiological examination is to accurately diagnose a meniscal lesion and define its characteristics, to search for any concurrent lesions, and to provide guidelines for the appropriate surgical treatment, depending on the abovementioned findings. Some of these imaging tests can also be used for the follow-up after an arthroscopic surgery, such as meniscal repair or meniscus transplantation. This chapter discusses the value of various radiological tests commonly used for assessing meniscal lesions prior to the final treatment.

7.2.1.1 Plain Radiographs: Standard Views

Radiographs are considered the most appropriate first imaging modality in the workup of both traumatic and nontraumatic knee pain. After a reported knee injury, X-rays are obtained in search of a fracture that occurred during the injury. Anteroposterior (AP) and lateral views of the injured knee are recommended. Apart from a proximal tibia, distal femur, and patella fracture, the clinician should look for a Segond fracture (an avulsed fragment from the proximal lateral tibia), which refers to an ACL lesion. In an older patient, over 40 years of age, with nontraumatic knee pain, X-rays are used for the assessment of the cartilage and the presence of any degenerative articular changes. In an osteoarthritic knee with a degenerative meniscus, bilateral weight-bearing X-rays including AP, lateral, schuss [30] or Rosenberg [31], and skyline views at 30° of flexion are systematically required. Joint space narrowing should be assessed on the AP view in extension and on the schuss or Rosenberg view, since the most frequently involved zones of articular cartilage are the contact areas of knees between the distal femur and proximal tibia positioned in between 30 and 60° of flexion [31]. By use of X-rays, the physician could also spot osteochondral lesions, loose bodies, calcification of the meniscus, and a possible Pellegrini-Stieda lesion (calcification of femoral insertion of MCL, chronic MCL injury). If the clinician's suggestion is that the weight-bearing alignment should be assessed, long cassette radiographs could be used.

7.2.2 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is the gold standard imaging method for the assessment of meniscal lesions [32, 33]. The development of new sequences, improvements in image quality, and more powerful magnets in association with excellent contrast resolution and multi-planar capability allow an accurate diagnosis of meniscal lesions. With the help of MRI, many of the essential characteristics of meniscal tears that are critical to management, such as their location, shape, length, and depth, can be described. This is very important for the assessment of stability, the likelihood of tear propagation, and the determination of reparability of the torn meniscus. It is advantageous to know ahead of time whether a given meniscal tear can be repaired, as in this way, the additional equipment, surgical assistants, and time needed for the repair can be anticipated. Patients also benefit from knowing early on whether surgery is necessary and also the options of treatment. A treatment plan may be developed by assessing the need for and timing of surgery and by determining the type of surgery (meniscal debridement, rasping, repair, partial or total resection, or meniscal transplantation). The rehabilitation time for meniscal repair is longer than that for partial meniscectomy (PM), and patients want to know the exact rehabilitation plan to fit with their other obligations (job or sports timing issues) [32–34]. MRI can be used to identify other injuries, such as cartilage injury and ligament tears, especially ACL tears, the presence of which may also influence the decision whether to perform surgery [32, 34, 35]. The sensitivity and specificity for detection of medial meniscal tears are both estimated to be approximately 90 %. The same applies to the specificity for lateral meniscus tears, but here the sensitivity is lower (approximately 80 %) [36, 37]. The accuracy of detecting meniscal lesions in a nonoperated or postoperative knee is not significantly improved by using direct or indirect MR arthrography [38]. However, direct MR arthrography is useful after meniscal repair. The classification system [39] for MRI refers to meniscal lesions, regardless of whether they are degenerative or traumatic. A healthy meniscus is triangular and prismatic in shape, producing a low-intensity signal in all sequences, with a homogeneous and weaker signal than that of cartilage. Meniscal tears appear as linear areas of high signal intensity located within the normal low-intensity zones on both T1- and T2-weighted images (Fig. 7.5a–c). Degenerative changes related to the presence of local mucoid degeneration are seen as areas of high signal intensity on T1- and particularly T2-weighted scans. A displaced bucket handle meniscus tear can occur in the sagittal MRI with the "double PCL sign" (meniscus within the notch) and in the coronal view with the meniscus displaced in the notch (Fig. 7.6). Meniscal lesions have been classified into three grades:

- *Grade 1*: a small focal area of hyperintensity, no extension to the articular surface
- *Grade 2*: linear areas of hyperintensity, no extension to the articular surface
- Grade 2 tears were found to be associated with a meniscal tear on arthroscopy. Therefore, they were subdivided into 2a, 2b, and 2c. (Fifty percent of patients with grade 2c had meniscal tears upon arthroscopy [40].)
  - *2a*: linear abnormal hyperintensity with no extension to the articular surface
  - *2b*: abnormal hyperintensity reaches the articular surface on a single image
  - *2c*: globular wedge-shaped abnormal hyperintensity with no extension to the articular surface
- *Grade 3*: abnormal hyperintensity extends to at least one articular surface (superior or inferior) and is referred as a definite *meniscal tear* [40]

At last it is important to be aware of anatomic variants and pitfalls that can mimic a tear, including discoid meniscus, meniscal flounce, a meniscal ossicle, and chondrocalcinosis. When a meniscal tear is identified, accurate description and classification of the tear pattern can guide the referring clinician in patient education and surgical planning. For example, longitudinal tears are often amenable to repair, whereas horizontal and

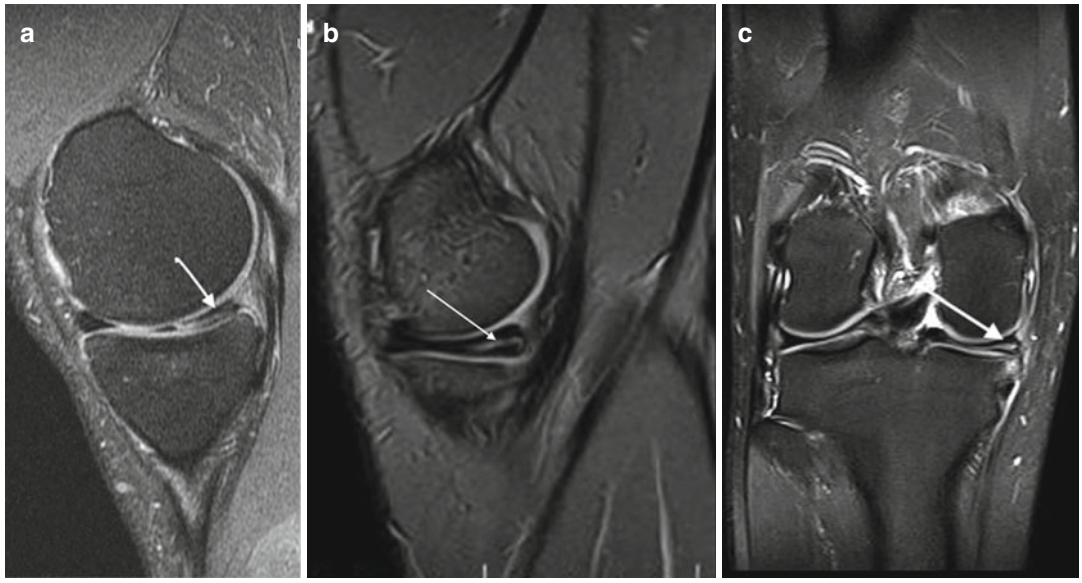

Fig. 7.5 (**a**–**c**) Sagittal (**a**, **b**) and coronal (**c**) magnetic resonance images showing abnormal (*high*) signal intensity (*arrows*) into the meniscus extending to the articular surface

radial tears may require partial meniscectomy. Tear patterns include horizontal, longitudinal, radial, root, complex, displaced, and bucket-handle tears. Occasionally, meniscal tears can be difficult to detect at imaging; however, secondary indirect signs, such as a parameniscal cyst, meniscal extrusion, or linear subchondral bone marrow edema, should increase the suspicion for an underlying tear. Awareness of common diagnostic errors can ensure accurate diagnosis of meniscal tears.

7.2.3 Computed Tomography: Arthrography

Although MRI is the preferred imaging method for the evaluation of the meniscus and the knee in general, CT and especially CT arthrography have become a powerful imaging tool. CT arthrography and MR imaging have a similar level of accuracy when used for the detection of meniscal tears. A CT scan without a previous intra-articular iodinated contrast injection is no longer considered a good practice for the assessment of the meniscus [41–43]. The spiral acquisition mode has increased the spatial resolution of CT arthrography. In additional multi-detector technology has also increased the speed of this imaging examination. Dual-detector spiral CT arthrography has been shown to be accurate for detection of unstable meniscal tears (Fig. 7.7a, b) and displaced meniscal fragments that are smaller than one-third of the meniscus [44]. The limitations of this imaging technique include a possible allergic reaction, infection (invasive technique), the use of ionizing radiation, and the inability to detect ligamentous lesions (particularly lesions of the posterolateral corner, the lateral collateral ligament, and PCL) [45, 46]. CT arthrography is, nonetheless, a valuable alternative when MR imaging is not available, in the presence of orthopedic hardware or in patients with contraindications for MR imaging (overweight patients, claustrophobia).

7.3 Classification of Meniscal Injuries

7.3.1 Introduction

Basic science and clinical studies have substantiated the crucial role of the menisci in maintaining knee joint homeostasis.

Biomechanical studies have shown that the menisci have important functions of load transmission, shock absorption, joint lubrication, and knee stability. Clinical studies have clearly demonstrated that loss of meniscal function (especially the lateral meniscus) causes early osteoarthritis. Consequently, it is important to know the outcomes of different treatments for meniscal tears that may include partial meniscectomy, meniscal repair, or transplantation. In the last years, the meniscus tears have been classified in terms of morphology, reparability, symptomatology, and type of injury. A reliable, international classification by morphology was formed by the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) Knee Committee in 2006 [47].

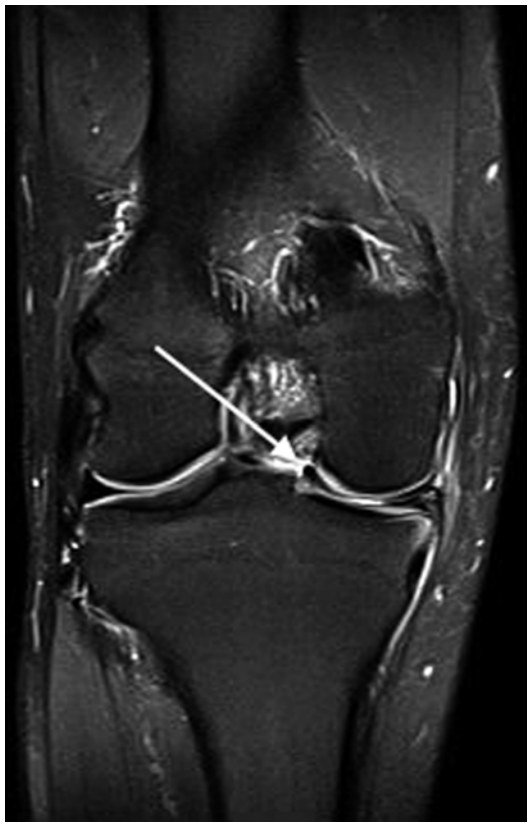

Fig. 7.6 Coronal magnetic resonance image showing a displaced (*arrow*) bucket-handle meniscus tear in the notch

7.3.2 International Classification of Meniscal Tears

The International Society of Arthroscopy, Knee Surgery and ISAKOS Knee Committee formed a Meniscal Documentation Subcommittee in 2006 with the objective of developing a reliable, international meniscal evaluation and documentation system to facilitate outcome assessment [47]. After 5 years the interobserver reliability of the ISAKOS classification of meniscal tears was reported with acceptable results for grading tear depth, location, tear pattern, length, tissue quality, and percentage of the meniscus excised (Fig. 7.8). The ISAKOS classification of meniscal tears provides sufficient interobserver reliability for pooling of data from international

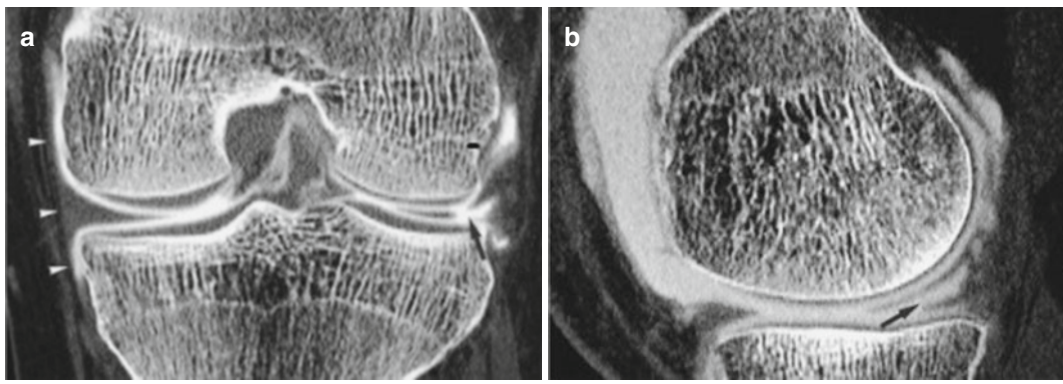

Fig. 7.7 (**a**, **b**) Coronal (**a**) and sagittal (**b**) CT arthrography showing a tear (*arrow*) of the lateral meniscus

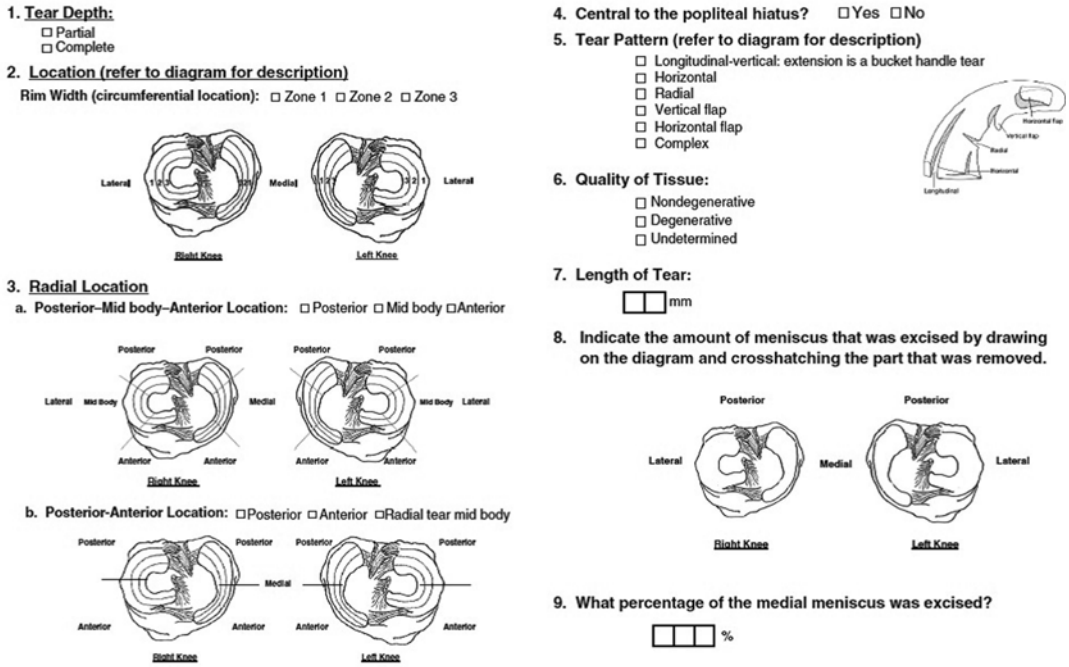

Fig. 7.8 Questionnaire of ISAKOS classification for meniscal tears

clinical trials designed to evaluate the outcomes of treatment for meniscal tears [48].

7.3.2.1 Tear Depth

The partial tear extends through either the superior or inferior surface of the meniscus. A horizontal tear may also be a partial tear. The complete tear extends through both the superior and inferior surface of the meniscus [40].

7.3.2.2 Rim Width

In the zone classification, tears may involve more than one zone. The tears should be graded based on how far the tear extends into the meniscus. For example, a complete radial tear that extends through zones 3, 2, and 1 should be graded as a zone 1 tear [49–52].

Zone 1 tears have a rim width of less than 3 mm.
Zone 2 tears have a rim width of 3–5 mm.
Zone 3 tears have a rim width of more than 5 mm.

7.3.2.3 Radial Location

Grade location of the tear with two formats:

(a) Indicate whether the tear is posterior, mid body, or anterior in location. Tears should be graded according to all the zones in which they are located. For example, a complete bucket-handle medial meniscus tear might be in the posterior, mid body, and anterior zones [51].
(b) The posterior-anterior classification is demonstrated on the diagram. Indicate whether the tear is anterior, posterior, or both. A radial tear in the middle lateral meniscus from anterior to posterior should be marked as radial tear mid body [52].

7.3.2.4 Tear Pattern

The tear should be graded according to the following patterns [53]:

(a) Longitudinal-vertical: extension is a bucket-handle tear
(b) Horizontal
(c) Radial
(d) Horizontal flap
(e) Vertical flap
(f) Complex

Tears should be graded on the predominant tear pattern. Complex tears include two or more tear patterns. A tear in the lateral meniscus that extends partially or completely in front of the popliteal hiatus should be graded as central to the popliteal hiatus.

Classification of meniscus tears is very important for the assessment of the tear, and consistency in documentation is essential for valid assessment of the treatment for meniscal tears. An international classification can make the life of orthopedic surgeons around the world easier as it improves the communication between them.

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8 The Role of Meniscectomy in the Treatment of Traumatic Meniscus Tears: Technique Results Indications

Philippe Beaufils and Nicolas Pujol

8.1 Definition

Traumatic meniscus tear is defined as a tear that is in general associated with an adequate knee injury. Among the different types of tears (Fig. 8.1), vertical tears such as longitudinal (including bucket handle tears) and radial tears belong to this group [48]. Flap tears can belong to it, too, if they are secondary to a vertical longitudinal tear and not a horizontal cleavage.

8.1.1 Location

Vascularity of the meniscus has important implications regarding possibility of healing process and thus indications [9]. It is thus very important to exactly locate the tear, according on one hand to the periphery of the meniscus and on the other hand to the segment of the meniscus. Cooper et al. [21] described one of the most commonly used classification systems (Fig. 8.2). In this system the meniscus is divided into circumferential zones. Zone 0 is the synovial meniscal junction, zone 1 includes the outer third of the meniscus, zone 2 includes the middle third, and zone 3 is the central third of the meniscus. In the meniscus of adults, capillaries penetrate no deeper than 10–25 % of the width of the lateral meniscus and 10–30 % width of the medial meniscus [9, 10, 21].

In 2006, the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) Knee Committee presented a standardized international classification of meniscal tears. For the rim width classification, the committee adopted a modification of the Cooper classification system. Zone 1 (outer third of the meniscus) tears have a rim width within 3 mm of the synovial meniscal junction (SMJ). Zone 2 (middle third of the meniscus) tears have a rim width within 3–5 mm from the SMJ. Zone 3 (central third of the meniscus) tears have a rim width of 5 mm or more from the SMJ. In the zone classification, tears may involve more than one zone. The tears should be graded based on how far the tear extends into the meniscus. For example, a complete radial tear that extends through zones 3, 2, and 1 should be graded as a zone 1 tear.

Despite the lower interobserver reliability, the consensus of the ISAKOS Committee was that having three radial zones was better for descriptive purposes because certain tears reside in specific zones. Consequently, the historic standard anterior, middle, and posterior classification was recommended [7]. Clearly, this classification is recommended for clinical practice and study purposes.

P. Beaufils (✉) • N. Pujol
Orthopaedic department, Centre Hospitalier de Versailles, Le Chesnay 78150, France
e-mail: pbeaufils@ch-versailles.fr; npujol@ch-versailles.fr

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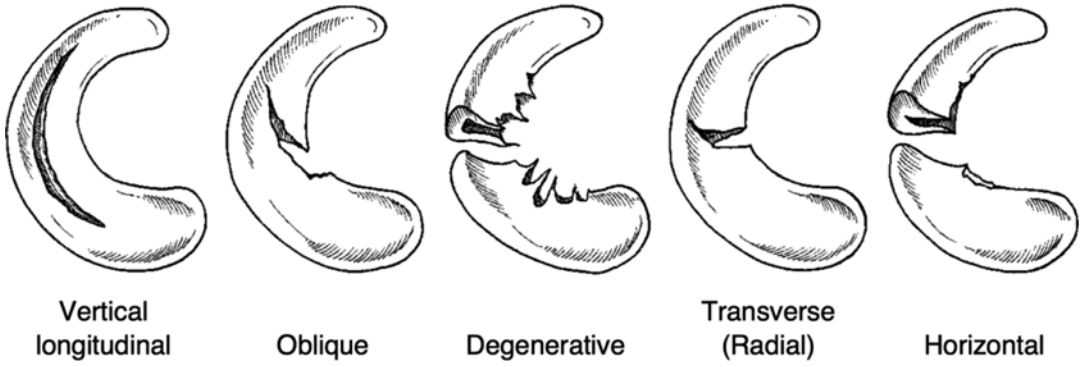

Fig. 8.1 Classification of meniscus tears. According to Fu [27]

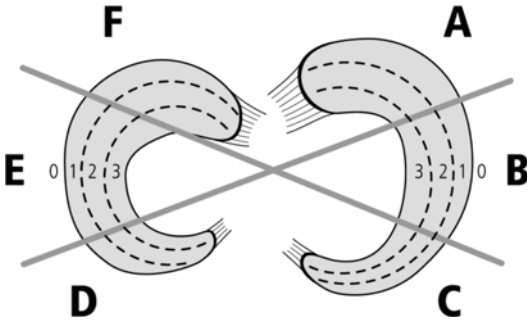

Fig. 8.2 Classification of meniscal lesions according to Cooper et al. [21]

Tears located at the peripheral attachment sites (meniscofemoral and meniscotibial), or zone 1, are also commonly referred to as outer third, or red-red (R/R), tears. Tears located in the middle third (zone 2) are classified as red-white (R/W) tears, and tears in the inner third (zone 3) are termed white-white (W/W) tears [11].

8.1.2 Stability

It is very important to assess the stability of the meniscus.

8.1.2.1 Longitudinal Tears

In unstable meniscus tears, the central part of the lesion can be dislocated into the joint space until the center of the femoral condyle thus evoking locking and sudden pain or it engages or is able to engage between the tibia plateau and the MCL or into the notch. A typical example is a longitudinal tear that temporarily changes to a bucket handle tear as well as a flap tear that engages between the femoral condyle and tibial plateau [25]. In terms of partial or very short meniscus tears, a stable tear is defined as a tear that is not displaceable with the probe [22].

8.1.2.2 Radial Tears

Radial tears are in general defined as unstable [62].

8.2 Technique

Arthroscopic meniscectomy is one of the most difficult arthroscopic knee procedure.

The cornerstone of arthroscopy performed is good visualization and palpation of the intra-articular structures to establish an accurate diagnosis, devise the treatment strategy, and work on the target site without damaging the cartilage.

The goal is to resect the part of the meniscus which is torn and not to extend the meniscectomy to the whole meniscus. This is usually easy in a traumatic tear where the fissure is well defined.

The definition of the amount of resected meniscus needs to be precise. The term arthroscopic partial meniscectomy is commonly used, meaning not the whole meniscus has been resected. In reality, the amount of resection should not refer to the whole meniscus but to each segment of the meniscus (according to Cooper and ISAKOS classifications). For

example, resection of the posterior segment of the medial meniscus should not be called partial meniscectomy of the medial meniscus but subtotal or total meniscectomy of the posterior segment. In the same way, a meniscectomy for extended bucket handle lying in the avascular zone is called partial extended meniscectomy. In both cases the amount of resected meniscus is the same, but the first one has more detrimental consequences than the second one (Fig. 8.3).

8.2.1 Positioning

We agree with Jackson [32] that the patient can be positioned supine on an ordinary table with no leg holder (Fig. 8.4). The operator sits on the side of the knee to be treated. One advantage of this position is that it allows full mobility of the hip and knee. The other widely used position involves placing a leg holder at the proximal thigh [6]. The end of the table is folded down and the operator stands along the axis of the lower limb. This position opens up the medial compartment.

In most cases, a 25–30-wide-angle arthroscope measuring 4.5 mm in diameter is used. There is no need to have a very large number of instruments. The basic set (Fig. 8.5) is composed of a probe, which is used routinely; a powerful grasping forceps, preferably with serrated jaws; straight and angled 3.5-mm scissors; 3.5-mm and 5-mm punch forceps; and a 90° basket forceps.

Portals are standard [23]: anterolateral and anteromedial. In a tight joint, needle pie-crusting of the deep fibers of the medial collateral ligament opens up the medial compartment by 2–3 mm without creating any damage. Pie-crusting can be done at the joint line or at the distal insertion of the medial collateral ligament [52]. There is no specific morbidity, and the additional space thus created allows the operator to work under satisfactory conditions without damaging the cartilage (Fig. 8.6). Two portals (one for the scope, one for the instruments) are usually sufficient. In some complex cases, three anterior portals may be required. Posterior portals are sometimes necessary: flipped flap in the posterior compartment and loose meniscal body. Scope is introduced in the posterior compartment via the anterior approach: anterolateral for the posteromedial compartment and anteromedial for the lateral one. The posterior instrumental portal is then done under visual control.

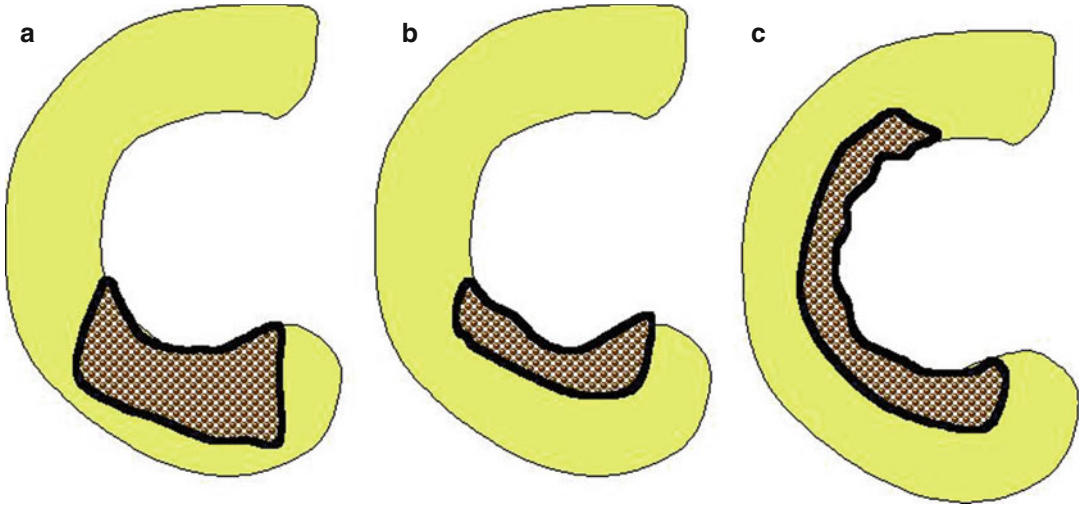

Fig. 8.3 Characterization of a meniscectomy. Amount of resection is defined according to the segment which is torn: (**a**) subtotal meniscectomy of the posterior segment; (**b**) partial meniscectomy of the posterior segment; (**c**) partial extended meniscectomy. Note that the amount of resection is the same in (**a**, **c**), but the functional consequence is much more important in (**a**)

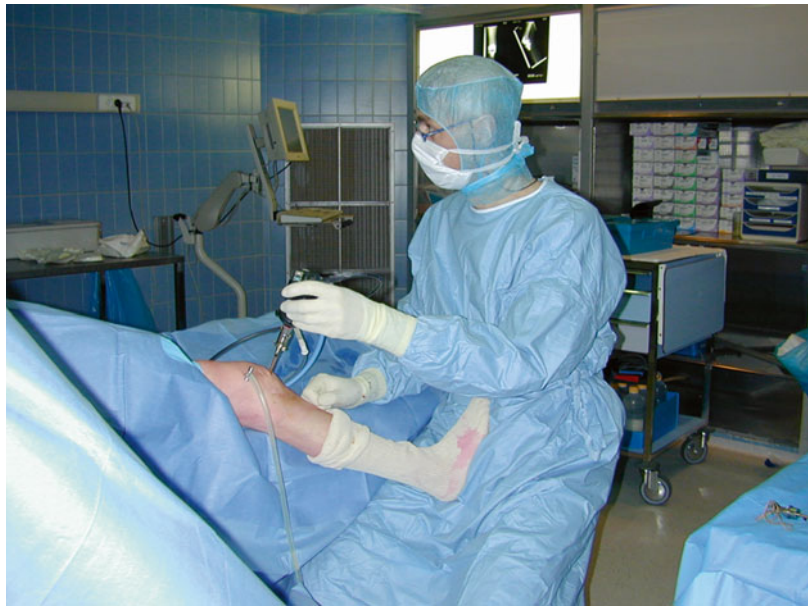

Fig. 8.4 Positioning of the patient on a standard table without knee holder

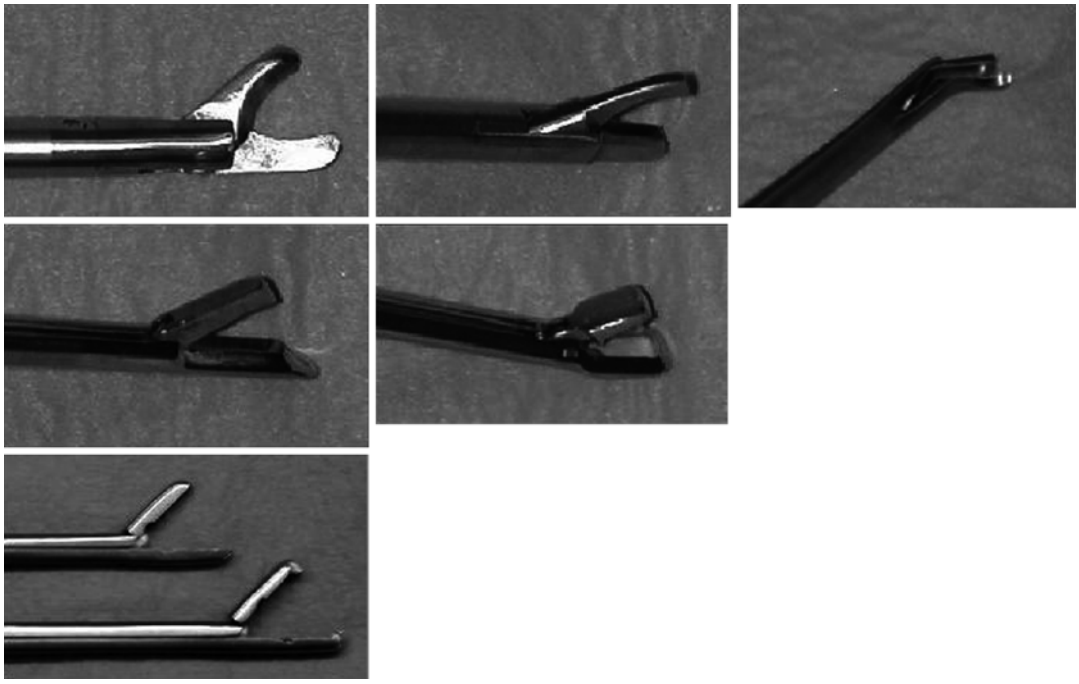

Fig. 8.5 Instruments which are useful for meniscectomy

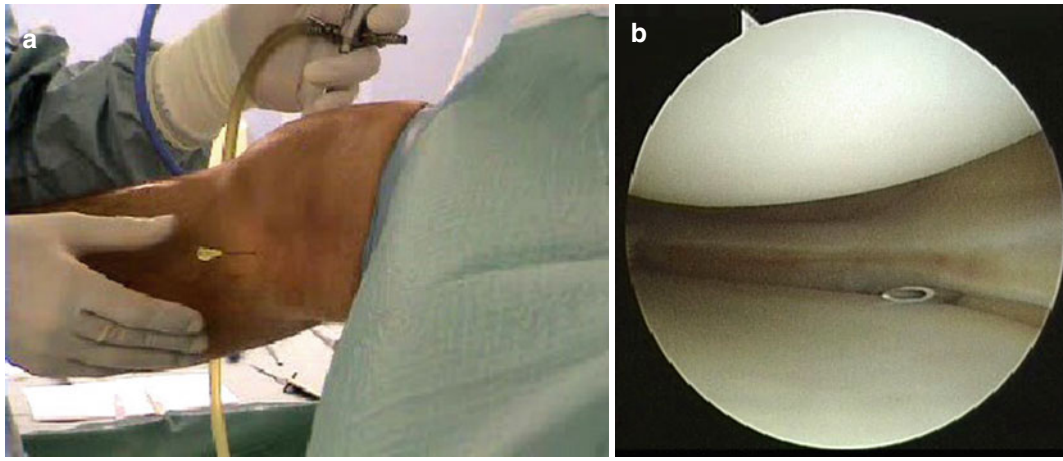

Fig. 8.6 Pie-crusting is sometimes necessary when the medial compartment is very tight. (**a**) External view; (**b**) Arthroscopic view. The needle cuts the menisco tibial collateral ligament

8.2.2 Vertical Longitudinal Tear

Rather than morcellization, we propose in traumatic tear one-piece resection. Scope is inserted through the anterolateral portal and instruments through the medial portal.

The successive steps are:

Section of the posterior attachment with scissors (Fig. 8.7).

Section of the anterior attachment (do not start with anterior attachment because of the risk of posterior displacement of the meniscus fragment in the posterior compartment during the posterior cut (Fig. 8.8)).

Removal of the loose meniscal piece.

Control of the stability of the meniscus remnant.

In case of bucket handle, the first step must consist of reducing the displaced meniscus.

This allows a better assessment of the characteristics of the tear (location, extent), a better visualization of the posterior attachment, and thus a more precise cut of this attachment. In chronic displaced tears, it is not always possible to reduce the meniscus. There are two possibilities:

- Cut first the posterior attachment, using curved scissors. But this cut is often too anterior and secondary morcellization of the posterior horn is necessary.
- Cut first the anterior attachment which allows to reduce the meniscus and then cut the posterior attachment with the risk of displacement in the posterior compartment.

8.2.3 Flaps

Attachment of the flap is usually located at the junction of posterior and midsegments. It can be in place or displaced either in the femoral gutter which is easy to visualize or in the tibial gutter under the meniscus which necessitates the use of the probe to extract it.

Flaps resection is easy, starting with the section of the attachment and followed by removal of the loose meniscus peace.

Radial tears are treated using the so-called saucerization.

Morcellization is carried out around the radial tear.

8.3 Lateral Meniscal Tears

Lateral meniscal tears have several specificities: the anterior segment is more often involved than on the medial meniscus. Visualization of the anterior segment is difficult even by inferomedial portal. A more proximal medial portal is some-

times useful. In the vast majority of the cases, it is necessary to alternate instruments and scope.

The posterior horn is cut through the instrumental inferolateral portal. For the anterior cut, the portal depends on the extent of the tear. In case of limited tear to the midpart, the anterior cut is carried out through inferomedial portal. In case of far anterior extended tear, anterior cut is done by inferolateral portal using an 11° blade.

8.4 Results

Stable knee and ACL knees must be distinguished.

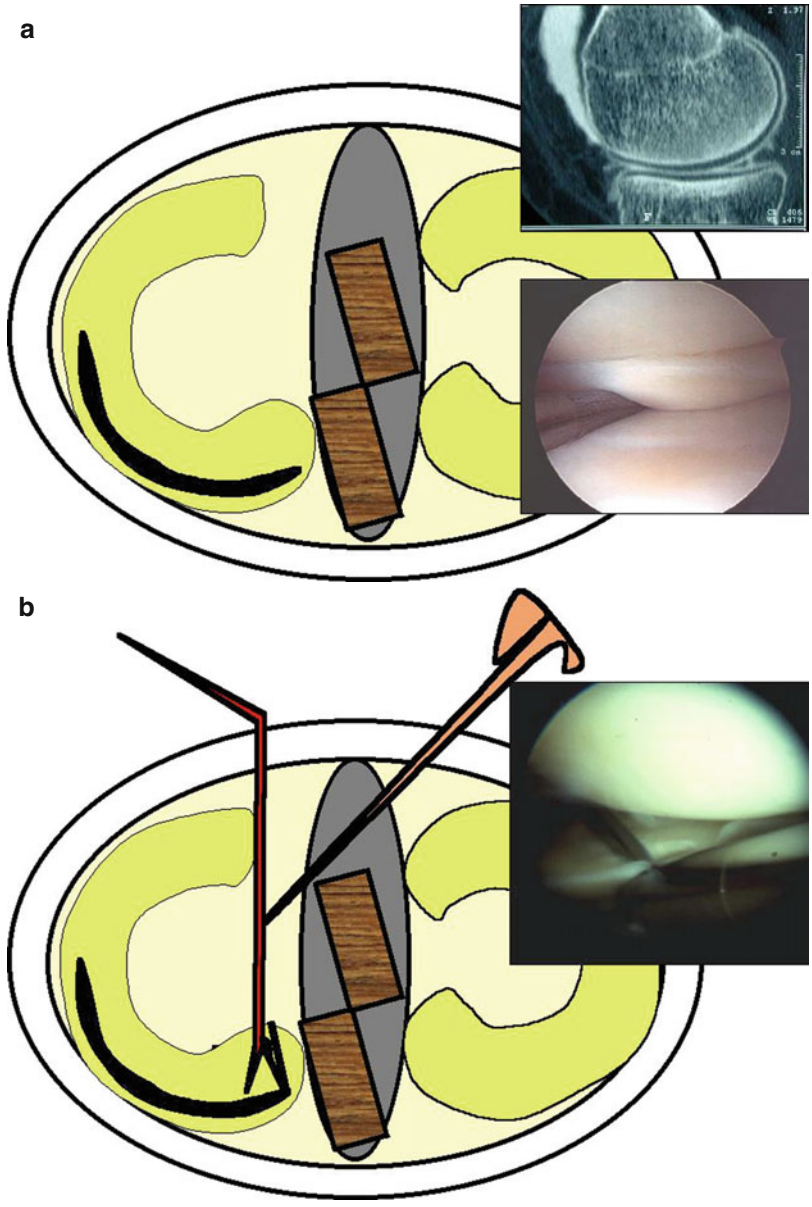

Fig. 8.7 (**a**) Technique of meniscectomy in vertical longitudinal tears; (**b**) first step: section of the posterior attachment; (**c**) second step: section of the anterior attachment; (**d**) third step: removal of the loose meniscus

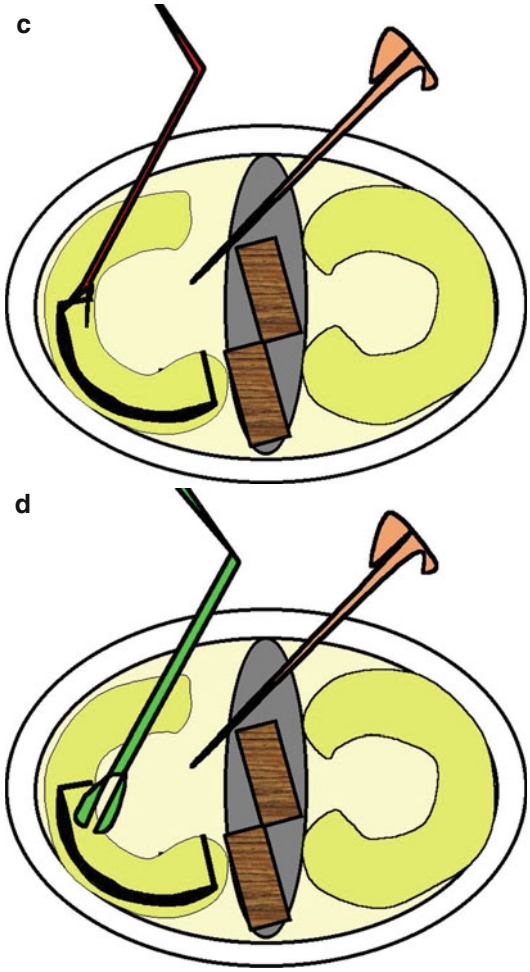

Fig. 8.7 (continued)

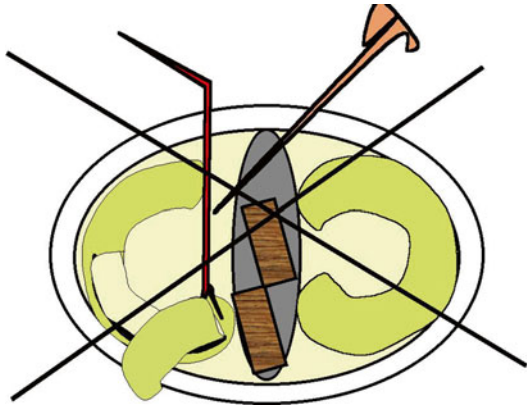

Fig. 8.8 If the meniscectomy starts with the anterior attachment section, there is a risk of posterior subluxation of the meniscus flap during posterior section

8.4.1 Stables Knees

Pujol et al. [51] did a review of the literature, including long-term (more than 8 years) outcomes on stable knees in young patients (less than 40 years) with traumatic tears. Eleven studies (level IV) have been identified (Table 8.1).

At a mean 11.8-year follow-up, functional outcomes of medial meniscectomy are good or very good in 84–95 % of the cases, but a joint narrowing is present on X-rays in 19–60 % of cases (Table 8.1). Lateral meniscectomies provide good or very good results in 58–95 %, and joint narrowing is present in 33–65 % of cases.

Factors of bad prognosis are:

- Side: medial meniscectomies have better outcomes than lateral ones [19, 29, 31, 33]. Rate of iterative procedure is higher. Rate of osteoarthritis is much higher [15]. Rapid lateral chondrolysis can be observed after lateral meniscectomy even in traumatic tears [17].
- Amount of resection: the incidence of arthrosis is less important after partial meniscectomy [18, 51, 63].
- Status of the cartilage at the time of surgery.

In a multicenter study within French Arthroscopy Society, Lutz et al. demonstrated better outcomes in a repair group than in a meniscectomy group at 10.6-year follow-up. All procedures were proposed for vertical longitudinal tears in zone 1 or 2. All subitems of the KOOS score were better in the repair group, except quality of life. The risk of secondary osteoarthritis was significantly reduced in the repair group [38].

8.4.2 Anterior Cruciate Ligament Tears

The prime passive restraint to anterior displacement of the tibia on the femur is the ACL. Secondary meniscal lesions are frequent after anterior cruciate ligament rupture. The cyclic recurrence of instability accidents exposes

Table 8.1 Outcomes according to Pujol's Review of the literature [51]

Ref	*N*	Meniscus	Meniscectomy	Age	FU	Narrowing >50% (%)	Narrowing mm	Score	Excellent and good results (%)
Fauno (1992)	136	Med & Lat	Partial	23	8.5	23.5			83
Rockborn (1986)	60	Med & Lat	Partial or subtot	30	13	42		99 Lysholm	72
Burks (1997)	111	Med & Lat	Partial	35.8	14.7		0.7	94 Lysholm	
Higuchi (2000) [29]	37	Medial	Partial or subtot	26.7	12.2	60			84
	30	Lateral	Partial or Subtot	26.7	12.2	33			73
Scheller (2001)	29	Lateral	Partial	39.9	12.3	65		82 Lysholm	
Hulet (2001)	49	Medial	Partial	36	12	19			95
Hoser (2001) [30]	29	Lateral	Partial	33.5	10.3	42		80.5 Lysholm	58
Anderson-Molina (2002)	18	Med & lat	Partial	29	14	22.2		95 Lysholm	
	18		Subtotal	28	14	39		99 Lysholm	
Bonneux (2002) [15]		Lateral	Partial	25	8	49		74.5 IKDC	
Chatain (2003) [19]		Medial	Partial	38.5	11	21.50			95
		Lateral	Partial	35	11	42.20			95
Shelbourne (2006)		Medial	Partial	18.2	11.8		1.2±0.5	86.3 IKDC	

the meniscus to increased risk of new meniscal tears and also degradation of the previous.

Isolated meniscectomy on ACL-deficient knee is not a benign procedure in terms of the following:

- Return to sports activities [2, 44]: only about 30 % are able to return to their previous competitive activity.
- Subjective results [2, 28].
- Radiographic changes.

Neyret et al. [44] reported long-term outcomes after isolated open meniscectomy in non-reconstructed ACL tears. Incidence of osteoarthritis was 67 % at 27 years and 86 % at 30 years, much more frequent than on stable knee (34 % and 50 %, respectively). Von Porat et al. [60] reported 59 % of osteoarthritis after meniscectomy on ACL-deficient knees compared to 31 % when the menisci were intact. Nebelung et al. [42] found more than 50 % of total knee replacement at a mean 35-year follow-up after ACL tears in high sport level athletes. All the patients sustained meniscectomies. Isolated meniscectomy is at high risk.

Meniscectomy associated with ACL reconstruction is also a factor of bad prognosis in terms of function, laxity, and secondary arthrosis.

According to Kartus et al. [34], Aglietti et al. [1], Dejour [24], Mc Conville [39], and Shelbourne [54] knee pain and swelling with daily activities after ACL reconstruction were more frequent in the group that underwent meniscectomy comparing to those who were not submitted to such procedure.

In the 2014 SOFCOT symposium (Ch Hulet and N Graveleau), 674 ACL reconstructions were reviewed at 10 years follow-up. Comparing a meniscectomy group with an intact meniscus group, this review demonstrated a significant difference in terms of IKDC: 25 % of C+D in the meniscectomized group versus 14 % in the intact meniscus group at 10 years.

8.4.2.1 Laxity

Objective residual laxity (KT-1000, Telos) after ACL reconstruction is affected by associated meniscectomy [14] (Table 8.2). But these findings must be ponderated since initial preoperative laxity is often higher in case of combined meniscal tear.

Table 8.2 Results on laxity of ACL reconstruction

Studies	Laxity with intact meniscus	Laxity after meniscectomy
Bouattour et al. (2002) [16]	1.57 mm	5.18 mm
Ait Si Selmi et al. (2006) [4]	3.9 mm	4.2 mm
Laffargue et al. (1997) [36]	29 % rated A (IKDC ligament item)	0.9 % rated A
Kartus et al. (2002) [34]	78 % negative Lachmann test	64 % negative Lachmann test

After Fayard et al. [26]

8.4.2.2 Osteoarthritis

In SOFCOT review [31] tibiofemoral arthrosis was more frequent on the medial side (28 % versus 8 %) and the lateral side (5 % versus 3 %) in the meniscectomized group. These results correspond to Salata's review [53] with an incidence of joint narrowing varying from 22 to 44 % at 10 years.

In a systematic review of 7 prospective and 24 retrospective studies, Oiestad et al. [45] compared the rate of osteoarthrosis between isolated reconstructed knees (0–13 %) and ACL-reconstructed knees + medial meniscectomy (21–48 %).

Meniscectomy appears to be the main factor of bad prognosis regarding secondary osteoarthrosis.

8.5 Complications

Complication rates range from 0.56 to 8.2 % [20, 57].

8.5.1 Short Term

Infection rate varies from 0.04 to 0.42 % [8]. The Arthroscopy French Society Symposium of 2001 reported infection in 0.04 % of cases.

Intraoperative material breakage is now an uncommon complication [40]. The latest improve of materials and the growing technical experience has diminished these events.

Cartilage iatrogenic injury during instrument handling is not always avoidable. Lubowitz et al. [37] described 28 % of "mild" cartilage damage and 3 % of "moderate and severe" cartilage damage associated to posteromedial assessment of the posterior horn of medial meniscus using the transcondylar notch view. The incidence of this complication is directly connected to the adequacy of material and the residual laxity of the operated knee and the surgeon's experience.

Ligament injuries are not frequent complications in arthroscopic surgery. The studies of Small [56, 57] reported two medial collateral ligament stretching out of 1,184 knee arthroscopic procedures, without consequences.

Vascular complications are extremely rare. The Committee on Complications of North America [20] declared 0.005 % of vascular complications.

The most serious and prevalent lesions concern the popliteal artery resulting in pseudoaneurysms or arteriovenous fistulas.

The risk for neural lesions associated to meniscal surgery is known to be higher during meniscal repair than meniscal excision [35] but is possible specially when using posterior portals. Portal placement and unaware management of instruments may injure the most exposed neurological structures around the knee. Sherman et al. [55] documented 0.6 % of postoperative hyperesthesia or paresthesia in the distribution of the sartorial or infrapatellar branch of the saphenous nerve.

Synovial fistula is often observed on posterior portals. This will increase the risk of infection. Posterior portals must be closed with special attention.

Deep vein thrombosis is possible events after any inferior limb surgery or arthroscopy. The incidence of pulmonary embolism (PE) following arthroscopic knee surgery has not been well established.

8.5.2 Middle Term

8.5.2.1 Rapid Chondrolysis

The clinical set of early chondrolysis is more often related to lateral meniscectomy [5, 17]. Pathogenesis is not known, and rapid chondrolysis has been even observed on nonoperated lateral meniscus tear [59]. It develops even in young patients without any previous cartilage defects. Clinically patients present pain over the lateral side and effusion within 1 month after surgery.

X-rays demonstrate early joint narrowing, especially on the schuss view.

The adequate treatment is based on articular lavage, steroids infiltrations, and articular rest, expecting an arrest of the process after several months.

8.5.2.2 Postmeniscectomy Osteonecrosis

Postmeniscectomized osteonecrosis has been mainly described after treatment of meniscal degenerative lesions. It is a controversial issue [46]. Diagnosing a postmeniscectomy osteonecrosis supposes to eliminate a pre-op spontaneous osteonecrosis (SPONK): this is a very important argument for a systematic pre-op MRI. Sudden medial pain may be an argument for medial meniscus tear and also for SPONK. Medial condyle is mainly involved, and osteonecrosis always appears on the meniscectomized compartment of the knee. Some authors state that the removal of the protective effect of the meniscus on load transfer (as it increases surface for forces transmission dictates lower femorotibial pressure) will lead to subchondral bone injury and finally osteonecrosis.

Diagnosis is confirmed on the absence of osteonecrosis on preoperative MRI, the presence of bone marrow edema on postmeniscectomy MRI, and radiological signs of osteonecrosis.

8.6 Indications

There is not just one but many methods of treatment.

When an orthopedic surgeon is faced with a meniscal lesion that is assumed to be responsible for the patient's symptoms, two fundamental questions need to be answered: (1) "Is it necessary to treat this lesion surgically?" (refraining from operative treatment must be seriously

considered) and (2) "If there is a need for surgical treatment, should meniscectomy or meniscal repair be performed?" [13].

The most important guideline in the decision-making process is the principle of meniscal preservation and not sparing. It means that meniscus repair or leaving the torn meniscus alone is the treatment of choice, and meniscectomy as partial as possible must be proposed when it is not possible to save the meniscus. Saving the meniscus is the key point. Taking the risk of meniscus repair failure is preferable to an immediate meniscectomy. Pujol et al. [50] demonstrated that the secondary meniscectomy in case of meniscus repair failure is not more important than the primary meniscectomy, which is a strong argument to push indications for meniscus repair.

The treatment obviously also depends on other factors, such as epidemiologic criteria, e.g., patient age, activity level, time since injury, or coexistent lesions, particularly to ligaments and joint cartilage, and anatomical criteria, e.g., medial or lateral meniscus, type of lesion, its localization, and extension.

With regard to the anatomical criteria, it should be emphasized that indications for meniscal repair and for meniscectomy are not contradictory but rather complementary. Meniscectomy is recommended primarily for lesions within the avascular zone of the meniscus, requiring only partial resection of meniscal tissue, which is relatively harmless to the cartilage. Meniscal repair on the other hand is indicated for lesions within the vascularized zone, which would lead to total or subtotal meniscectomy if affected meniscal tissue is removed and therefore to an increased risk of cartilage degeneration. In some lesions associating peripheral tear and more central tear, it is possible to combine partial meniscectomy and peripheral repair in order to avoid total or subtotal meniscectomy.

8.6.1 Longitudinal Vertical Lesion in a Stable Knee

Surgical removal of the torn fragment is most commonly performed because in the vast majority of cases the tear is located in the avascular zone of the meniscus. Patients usually recover rapidly and uneventfully. The long-term prognosis is favorable, provided that the meniscus has not been totally removed (which would mean excision of meniscal tissue as far as the peripheral zone) and that the resection has not been extended too far anteriorly or posteriorly [63]. As a rule, asymptomatic lesions should be left alone.

Meniscal repair should always be considered when the anatomical conditions are favorable (lesion located within the red-red or red-white zone), when the time from injury is less than 3 months, especially if the patient is young and also if the patient's morphotype is disadvantageous (varus knee for medial meniscectomy and valgus knee for lateral meniscectomy). Long-term studies comparing meniscectomy and meniscus repair demonstrate better functional results after meniscus repair [43, 47, 58, 63]. Particular attention must be paid to the possible detrimental effect of lateral meniscectomy on the affected joint as secondary cartilage degeneration is common, not to mention rapid chondrolysis in a young and active patient. Indications for repair should therefore be widened for the lateral meniscus (hypermobile meniscus, true traumatic lesion).

8.6.2 Traumatic Meniscal Lesion in an ACL-Deficient Knee

Every effort should be made to avoid subsequent meniscectomy, which is known to compromise functional performance, joint stability and cartilage, whether it is associated with ACL reconstruction or not. Masterly neglect and surgical repair are considered to be the best solution, the more so since these lesions are most often located in the peripheral vascularized zone of the meniscus and have the best chance to heal.

The risk of secondary meniscectomy after leaving alone small meniscal tears is 0–7 % (mean 4 %) for the lateral meniscus and 0–21 % (mean 15 %) for the medial meniscus [49]. It means that meniscus repair indications should be pushed for the medial meniscus.

Meniscectomy should only be considered when repair or leaving the meniscus alone is not possible:

- Extended unstable longitudinal tears in white-white zone
- Damaged meniscus tissue or complex nonrepairable tears, even in vascularized zone

In the other cases which represent the majority, meniscus preservation must be proposed. Time between injury and surgery is not an argument itself for meniscectomy in this context of ACL lesions; it is in fact often difficult to exactly establish the time of the meniscus tear in the ACL history.

Posterior meniscocapsular or even intracapsular lesions have been described in conjunction with ACL tears especially on the medial side. Natural history is not well known, but the risk of tear extent and the low morbidity of meniscus repair are strong argument for a repair during ACL reconstruction. It needs a posterior approach to recognize the tear and repair it using a hook as first described by Morgan [41] and popularized by Ahn et al. [3].

Traumatic root avulsions are rare, frequently associated with ACL tears. These meniscal tears correspond to a total functional meniscectomy and must be repaired by a transosseous tibial reinsertion [62].

Meniscal tears in conjunction with ACL injury fall into one of the three following diagnostic circumstances [12]:

1. Symptomatic anterior laxity of the knee (functional instability) in an active individual practicing sports, in whom ACL reconstruction is strongly indicated. In this situation the meniscal lesion is treated simultaneously. The postoperative protocol is not altered, regardless of the treatment of the meniscus, which may involve surgical repair or masterly neglect. The ACL surgery is aimed at optimally restoring joint function and protecting the cartilage thanks to meniscal tissue preservation.
2. Anterior laxity of the knee associated with minor symptoms in an active individual who is not engaged in high-demand sports activities. In this case the indications for ACL reconstruction are not straightforward considering the functional limitation of the patient. A diagnosis of a reparable meniscal lesion may be an important argument in favor of surgery. The goal of ACL reconstruction then is to protect the articular cartilage and to improve the natural history of the knee joint. Meniscal treatment is indicated according to the above-mentioned rules.
3. An isolated meniscectomy without ACL reconstruction can only be considered in case of symptomatic meniscal lesion (excluding frequent stable asymptomatic tears which are diagnosed during an arthroscopic exploration for ACL tear) and nonrepairable meniscal tear by a sedentary middle-aged nondemanding patient who does not present functional instability.

Conclusion

Long-term follow-up studies after meniscectomy demonstrate a high rate of poor results especially in terms of secondary osteoarthritis. Main factors of bad prognosis are lateral side injury, combined ACL injury, and extent of meniscectomy. Complications are rare but sometimes severe such as infection, rapid chondrolysis, and secondary osteonecrosis. Meniscus preservation is the key point in the management of traumatic meniscal tears. Meniscus repair or leaving the meniscus alone is the first line of choice whenever possible. Meniscectomy remains possible when the tear lies in the avascular zone, when it is a complex tear, when the meniscal tissue is badly damaged, or when the demand of the patient is low, especially in the middle age.

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9 The Role of Arthroscopy in the Treatment of Degenerative Meniscus Tear

Hélder Pereira, Ibrahim Fatih Cengiz, Joana Silva-Correia, Joaquim Miguel Oliveira, Rui Luís Reis, and João Espregueira-Mendes

9.1 Introduction

Several classification methods of meniscal lesions have been proposed over the years, aiming to define the best course of action in treatment as well as assessment of outcome [2]. The ISAKOS classification of meniscal tears provides sufficient inter-observer reliability for determining factors which help to choose the adequate management as well as assembling data from clinical trials designed to evaluate the outcomes of treatment for meniscal tears [2]. This should be kept in mind once not all the prognostic factors rely on the division between acute and degenerative meniscal injuries. Moreover, a degenerative meniscus injury (Fig. 9.1), previously

H. Pereira (✉)
3B's Research Group – Biomaterials, Biodegradables and Biomimetics, Univ. Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, Avepark – Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco Guimarães 4805-017, Portugal

ICVS/3B's – PT Government Associated Laboratory, Braga, Portugal

Clínica do Dragão, Espregueira-Mendes Sports Centre – FIFA Medical Centre of Excellence, Porto, Portugal

Orthopedic Department Centro Hospitalar Póvoa de Varzim, Vila do Conde, Portugal

Ripoll y De Prado Sports Clinic – FIFA Medical Centre of Excellence, Murcia-Madrid, Spain
e-mail: helderduartepereira@gmail.com

I.F. Cengiz • J. Silva-Correia • R.L. Reis
3B's Research Group – Biomaterials, Biodegradables and Biomimetics, Univ. Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, Avepark – Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco Guimarães 4805-017, Portugal

ICVS/3B's – PT Government Associated Laboratory, Braga, Portugal

J.M. Oliveira
3B's Research Group – Biomaterials, Biodegradables and Biomimetics, Univ. Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, Avepark – Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco Guimarães 4805-017, Portugal

ICVS/3B's – PT Government Associated Laboratory, Braga, Portugal

Ripoll y De Prado Sports Clinic – FIFA Medical Centre of Excellence, Murcia-Madrid, Spain

J. Espregueira-Mendes
3B's Research Group – Biomaterials, Biodegradables and Biomimetics, Univ. Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, Avepark – Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco Guimarães 4805-017, Portugal

ICVS/3B's – PT Government Associated Laboratory, Braga, Portugal

Clínica do Dragão, Espregueira-Mendes Sports Centre – FIFA Medical Centre of Excellence, Porto, Portugal

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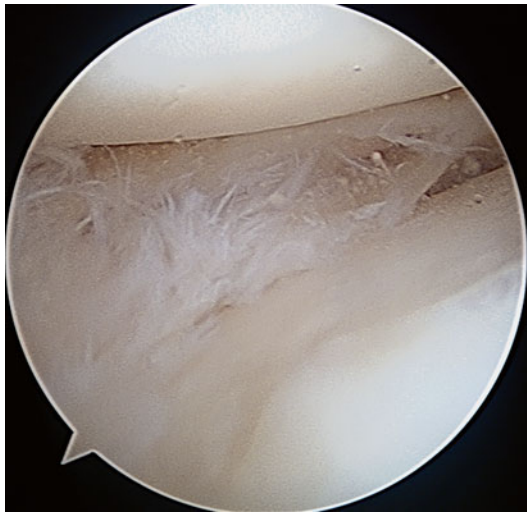

Fig. 9.1 Degenerative medial meniscus

asymptomatic, might change and become symptomatic after an acute traumatic event, thus representing a challenge for surgeons [3].

Degenerative meniscus lesions typically comprise a slow progression of symptoms (asymptomatic most of the time), and they can be associated to cavitations, several tear patterns, softened meniscal tissue, fibrillation, and/or other degenerative changes [2, 11].

Typically, a degenerative meniscus comprises signal changes observed in MRI with a horizontal cleavage in the knee of a middle-aged or older person.

Intrameniscal linear signal changes are often reported, sometimes communicating with the inferior meniscal surface. Progressive mucoid degeneration and weakening of the meniscus ultrastructure are often described [25].

Degenerative meniscal matrix changes are possibly related to early stage osteoarthritis. Such changes, in combination with progressive malalignment and overload on the affected compartment, could thus lead to meniscal fatigue, rupture, and extrusion [10, 24, 28].

Once the meniscus loses a part of its critical function in the knee joint, the increased biomechanical loading patterns on joint cartilage may result in accelerated cartilage which further contributes to accelerating the global join disease (osteoarthritis) [7].

In many cases what should be addressed is the multifactorial condition of an osteoarthritic joint and not considers the isolated meniscal injury per se as the only cause of the patient's symptoms.

This is the most critical and probably most difficult decision when dealing with such patients. This is the "key to success" in treatment of patients with degenerative meniscal tears. Herein we will describe some treatment possibilities for specific tear patterns; however one must understand that any decision is made always after considering this "golden rule."

Opposing to degenerative tears, weight-bearing trauma is an important risk factor for acute meniscal tears [36].

Horizontal tears (Fig. 9.2) are frequently not traumatic and have a degenerative nature (even in younger patients) [35]. Vertical or longitudinal tears, bucket handle, and radial tears usually (but not always) are associated to the traumatic group [26]. Flap tears are another type of meniscal tear which frequently arises after a traumatic event but can also be observed in complex degenerative tears.

Joint laxity is known to be a risk factor for meniscal tears (acute or degenerative). Despite being not modifiable, patients with such characteristics might be a subject of specific prevention programs before enrolling specific sports activities [36]. ACL injuries are also a very important concomitant and/or etiologic factor to consider for several types of meniscus tears [36].

Traumatic meniscus tear (TMT) can be defined as a tear that happens as a consequence of a knee injury which is capable to tear a meniscus which could previously be considered as healthy and without relevant changes. The patient can often remember a specific trauma or movement implicated in the tear, opposing to the natural history of degenerative menisci. Traumatic injuries are more prone to cause mechanical symptoms such as clicking, catching, or locking of the knee [27]. However the possibility for mechanical complaints cannot be immediately erased when dealing with degenerative tears.

Some patients with meniscus presenting slowly progressive degenerative meniscus

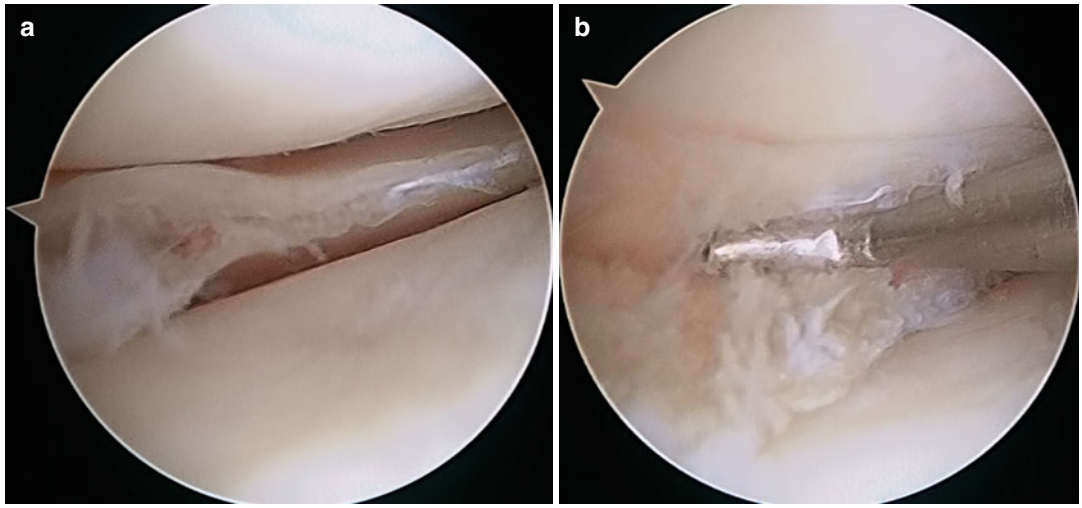

Fig. 9.2 Horizontal cleavage tear (**a**); the hook probe is used to separate superior and inferior components (**b**)

changes might experience sudden onset of symptoms after an acute trauma. The challenge in such cases is: *How much can be done in such patients to preserve the meniscus* (*as much as possible*) *while also addressing their* "*new*" *symptoms*?

Not everything is clarified in this field. There is not a straight line dividing traumatic from degenerative meniscus tears, and ESSKA has gathered in 2015 a Meniscus Steering Group aiming to provide guidelines combining the best available knowledge in the field. Herein we share some of this experience combined with our own clinical practice.

We will briefly comment the most frequent types of meniscal tears from the perspective of degenerative meniscus approach.

9.2 Treatment, Indications, and Techniques

9.2.1 Conservative Treatment

The primary choice in the treatment of a patient with knee pain and probably correlated to degenerative meniscus tear (DMT) is nonsurgical therapy including physiotherapy and medication, regardless if there is evidence of osteoarthritis or not. Overweight and sedentary life style should also be addressed [3].

The functional rehabilitation program should include progressive neuromuscular and strength exercises over a minimum of 12 weeks (two to three sessions per week) [37]. Movement and progressive strengthening is mandatory.

9.2.2 Arthroscopic Partial or Subtotal Meniscectomy

There are no evidence-based guidelines for the best surgical approach concerning meniscectomy of an irreparable DMT (Fig. 9.3). Meniscectomy can always be considered for irreparable complex tears, but it is currently considered as a "last option" given the awareness of the deleterious long-term consequences [20]. Moreover, the amount of resected tissue seems to be implicated in the consequences of meniscectomy [19]. In some cases it can be combined to partially resect the unstable part of the meniscus but still preserve or even repair the remaining [1].

For this reason we favor limited resection of any meniscal tears to the unstable component, and whenever possible, we try to repair and preserve meniscus suture. The French Arthroscopy Society Group has reported favorable outcome irrespective on the type of meniscectomy [9]. Identified risk factors of poor results included the presence of degenerative cartilage lesions (OR 2.8),

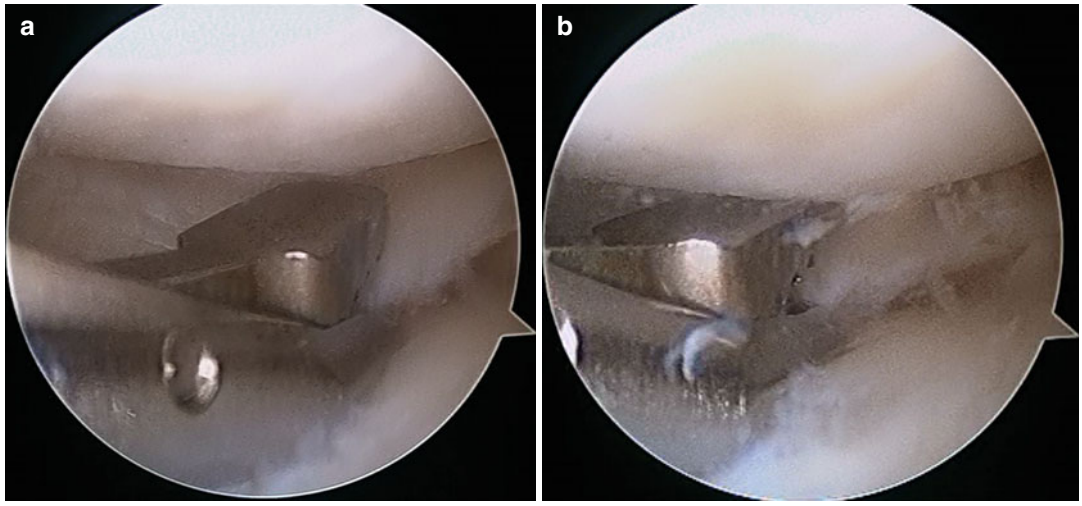

Fig. 9.3 Partial meniscectomy (**a**); notice that in degenerative meniscus, it is frequent that the arthroscopic view is diminished by the debris released by the degenerative menisci (**b**)

resection of the meniscal wall (OR 2.2), and age >35 (OR 5.0).

In summary, meniscectomy is thus proposed when mechanical symptoms are present and fail to respond to conservative treatment and a meniscal tear is identified on MRI which is suitable for improvement by standard arthroscopic two-portals two-portals approach.

9.2.3 Meniscal Repair

According to the best available knowledge, the healing rate after meniscal repair is: complete healing in 60 %, partial healing in 25 %, and failure in 15 % of cases [32]. On the other hand, partially or incompletely healed menisci are many times asymptomatic at least in the short term [29, 31].

There has been a remarkable development of suture techniques derived from improved biological and anatomical knowledge as well as development of surgical techniques and devices [23].

According to literature, the failure rate after arthroscopic meniscal repair ranges from 5 % to 43.5 % (mean, 15 %) [29]. The volume of subsequent meniscectomy after failed meniscal repair is not increased when compared with the volume of meniscectomy that would have been performed if an attempt of repair had not been performed at the first approach [29].

Arthroscopic meniscal repair provides long-term protective effects, even if the initial healing is incomplete [32].

Obviously degenerative meniscal tears have inherently even more limited possibility for healing. However, it has been shown that repair horizontal cleavage tears might have favorable outcome in open or arthroscopic repair with a low rate of secondary meniscectomy [31].

Methods of repair can use all-inside, inside-out, or outside-in techniques alone or in combination. Rasping, trephination, or augmentation with fibrin clot may assist in increasing the healing rate in properly selected cases of DMT (Figs. 9.4 and 9.5). Repair of degenerative meniscal root tears has also shown to provide favorable outcome and should be considered [1].

9.2.4 Surgical Treatment of Parameniscal Cysts

Parameniscal cysts are typically associated with a horizontal meniscal lesion (Fig. 9.6). If surgical treatment is indicated, it is very important not only to treat the meniscal injury but also to evacuate the content of the cyst. This can be done

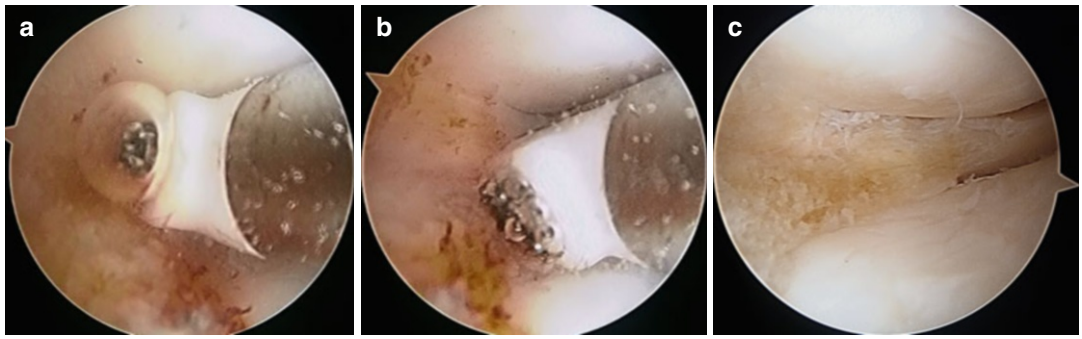

Fig. 9.4 Effect of radiofrequency on removing and stabilizing meniscus remnants (**a** and **b**); final result (**c**)

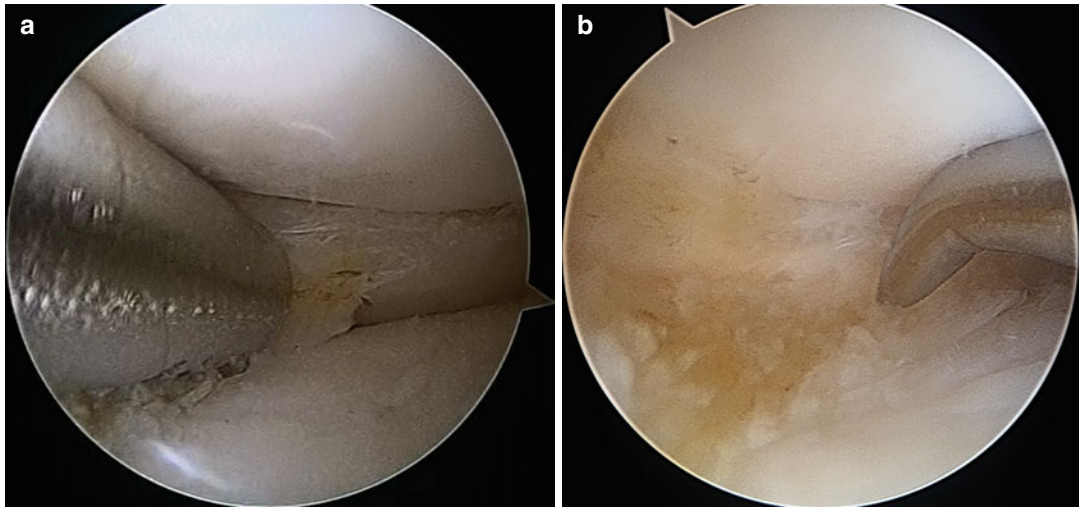

Fig. 9.5 Effect of shaver blade (**a**) to resect and achieve vascularized part of meniscus remnant followed by trephination to improve healing (**b**)

arthroscopically, evacuating such content into the joint after adequate resection of the affected meniscus up to the menisco-synovial junction at the level of the cyst and afterward to enlarge the tract of the cyst. Sometimes, particularly in large cysts, open excision of the cyst combined with arthroscopic meniscectomy might be required.

9.2.5 Surgical Treatment of Different Types of Degenerative Tears

Radial tears these are often related to trauma but sometimes are also described in degenerative meniscus. Radial tears can be complete or incomplete. They are oriented extending from the inner edge of the meniscus toward its periphery where there might be some healing capacity (Fig. 9.7). Radial tears are in general defined as unstable [38]. They were generally considered as non-repairable because the circumferential hoop fibers are disrupted and the majority of the tear is avascular. However, repair of complete radial meniscal tears is a key to restoring the mechanical integrity necessary to maintain hoop tension in the meniscus. Repair of radial tears is currently considered a challenge and represents a difficult decision for the surgeon [23]. The major goal is to achieve a primary stable meniscal repair. This is considered crucial in order to provide a chance for meniscal healing [23]. The

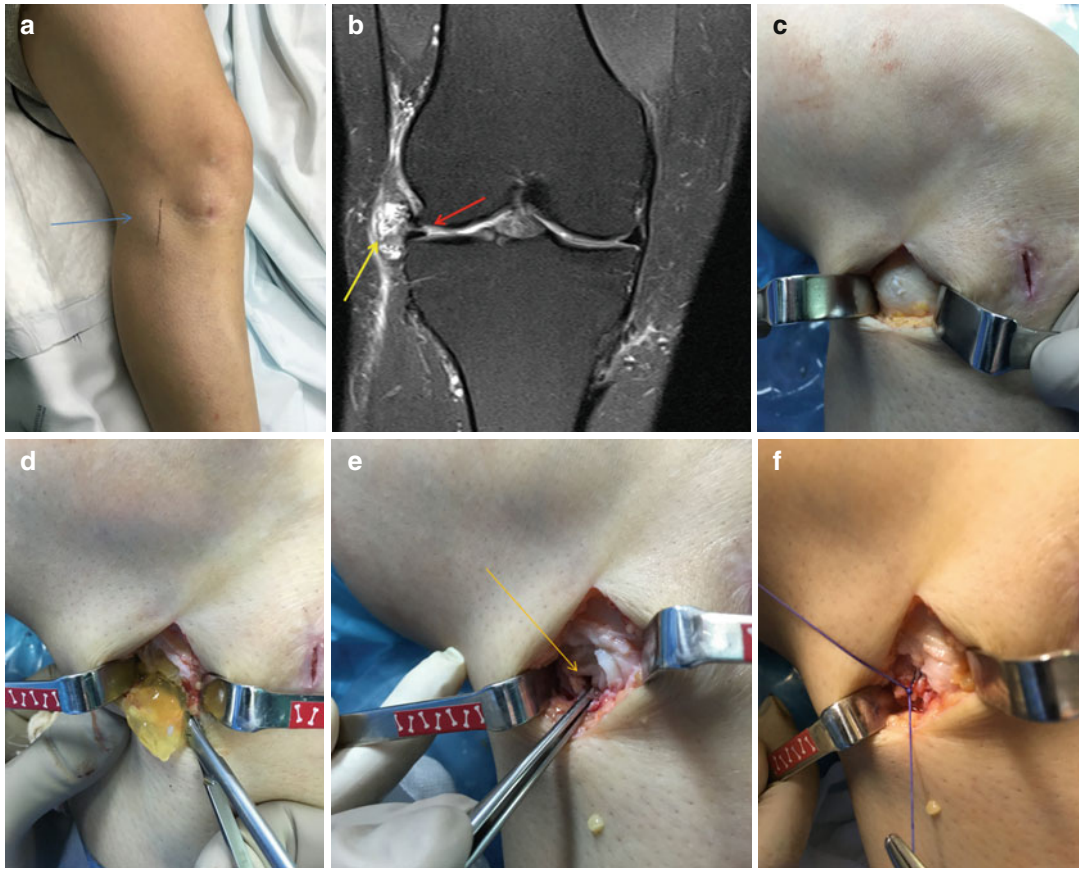

Fig. 9.6 Surface anatomy view of large parameniscal cyst (**a**); MRI view of the cyst (*yellow arrow*) and horizontal cleavage tear (*red arrow*); open view of the cyst (**c**) and its content (**d**); horizontal cleavage of the lateral meniscus (*orange arrow*) (**e**); suture of the meniscus and capsule (**f**)

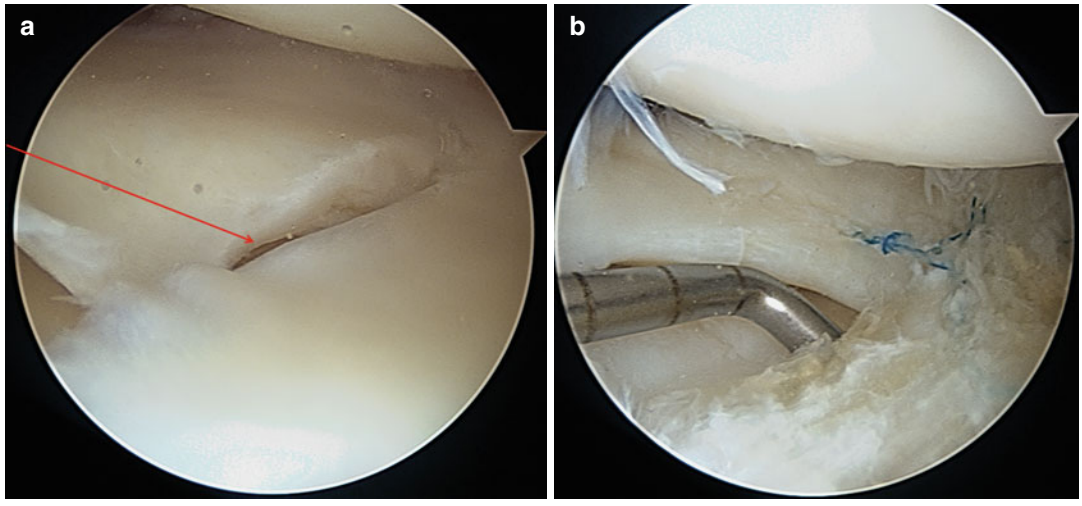

Fig. 9.7 Radial tear (**a** *red arrow*); final look after radial tear repair with multiple sutures (**b**)

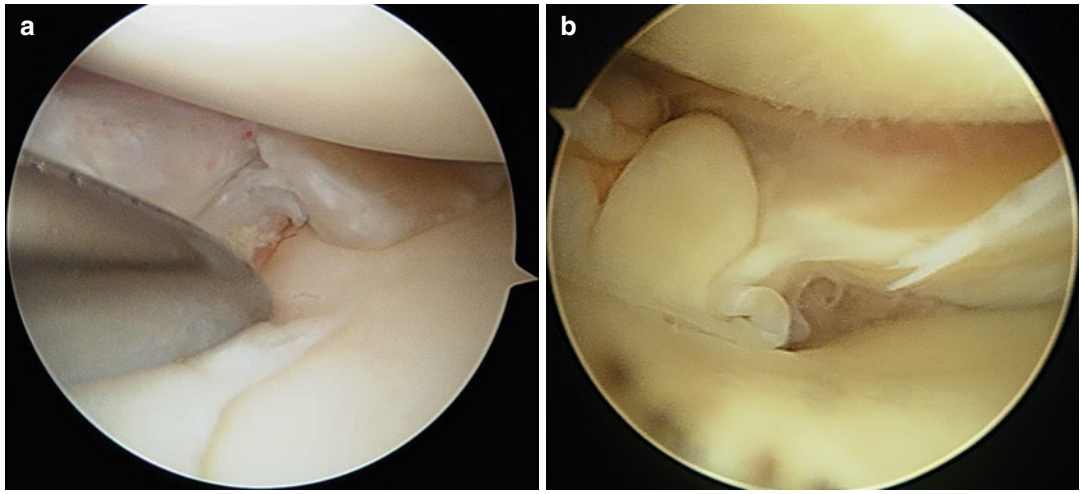

Fig. 9.8 Meniscal flap under the body of the meniscus entrapped between the capsule and the tibia (**a**); flap near the posterior horn (**b**)

combination of sutures enhanced by fibrin clot has allowed positive results for treatment of radial tears [21, 33].

Flap or parrot-beak tears They might be radial tears with a circumferential extension creating a flap of meniscal tissue (Fig. 9.8). Sometimes this flap can be dislocated "under" the body of the meniscus and lodged/compressed between the joint capsule and the bony surface. This might be the cause of persistent pain and it is strongly advisable, when there are changes in the normal structure of meniscus, to use the hook probe to search for such fragments thoroughly throughout all meniscus.

Peripheral, longitudinal tears This kind of tears is usually vertically oriented parallel to the edge of the meniscus. Longitudinal tears are often related with trauma and are rarely degenerative. Usually these are the most suitable meniscal lesions for repair.

Horizontal cleavage tears In this type of tear the superior and the inferior surfaces of the meniscus are divided. It is in the most times degenerative tear and most frequently occurs in older people. Symptomatic horizontal meniscal tears in young patients are a particular condition which often presents as an isolated severe meniscus lesion. A complete resection of such tear would subsequently result in a subtotal meniscectomy. Arthroscopic repair of such lesions (Fig. 9.9) is sometimes possible and has provided fair results [21]. Open meniscal repair of complex horizontal tears (Fig. 9.6) even extending into the avascular zone has proven to be effective at midterm follow-up in young and active patients with a low rate of failure [31, 34].

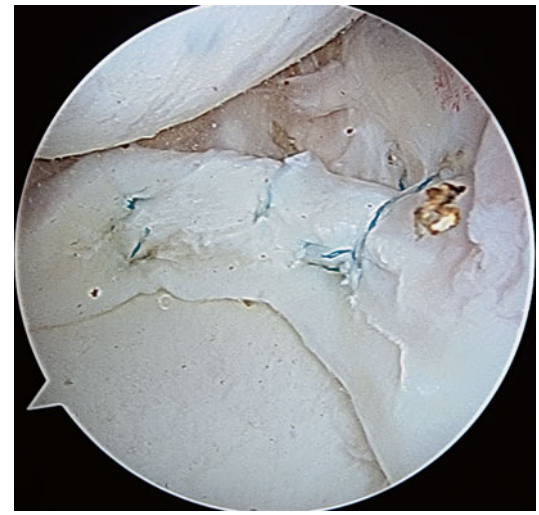

Fig. 9.9 Final look after repair of complex meniscal tear with horizontal cleavage component combining horizontal and vertical sutures

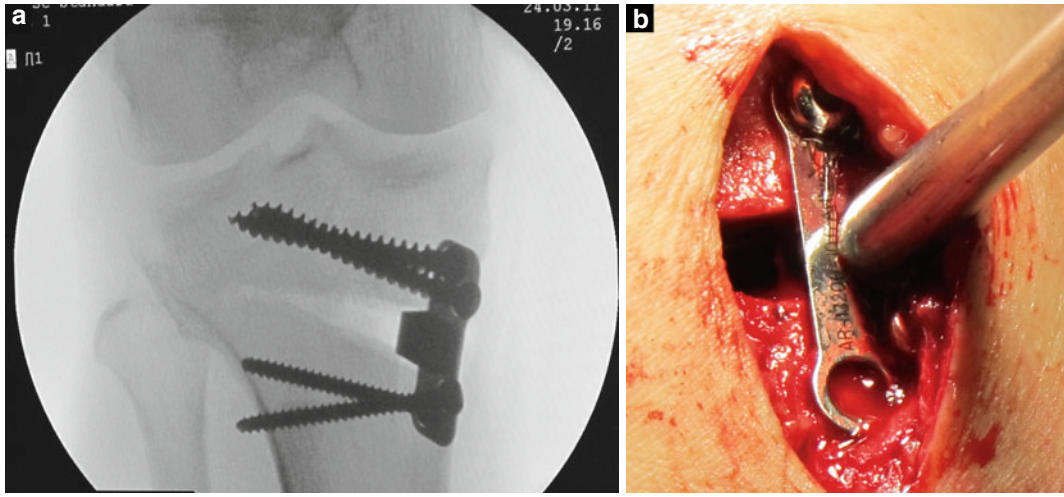

Fig. 9.10 Osteotomy for unloading the medial compartment (radioscopy view – **a**) and intraoperative view of step plate fixation (**b**)

Complex degenerative tears Complex tear is a combination of other tears that occurred in multiple planes. They appear more frequently in older patients and in the posterior horn. Generally the complex tears are non-repairable. Tears should be graded on the predominant tear pattern. Complex tears include two or more tear patterns. A tear in the lateral meniscus that extends partially or completely in front of the popliteal hiatus should be graded as central to the popliteal hiatus.

Meniscal root lesions (MRTs) This type of meniscal tears is receiving increasing attention [8]. Most regularly, root tears are degenerative in nature and must be differentiated from true traumatic root tears which are rare. These traumatic root tears are frequently associated with an ACL tear particularly on the posterior horn of the lateral meniscus. They can be treated by tibial re-fixation, using a transtibial tunnel [1] if the remaining tissue is found to be adequate for repair.

The possibility to repair a meniscal injury is multifactorial [6]; thus, several factors must be considered, including age, activity level, tear pattern, chronicity of the tears, combined injuries (anterior cruciate ligament injury), and healing potential/vascularization.

It is still somewhat debatable if an ACL injury associated with minor symptoms in patient involved in low-demand sports activities should undergo ACL repair. The diagnosis of a concomitant meniscal lesion represents an important argument in favor of surgery.

Pujol and Beaufils have defended that the indications for surgical repair can be widened for the medial meniscus (increased risk of secondary meniscectomy if left alone), even for small stable lesions [30]. On the other hand, for the lateral meniscus with small stable lesions, "let the meniscus alone" can be the preferred approach given the low risk of subsequent meniscectomy [4]. An overall *odds ratio* of 3.50 for medial meniscal tears has been described when ACL surgery is performed more than 12 months after the ACL injury when compared to less than 12 months after ACL injury [36]. On the other hand, concerning lateral meniscus tears, minimal to no evidence was found for the amount of time between ACL injury and reconstruction surgery as a risk factor [36].

These findings are somewhat in line with the recognized different roles of medial and lateral menisci within the knee joint.

Another very important factor to consider is alignment. Osteotomy (Fig. 9.10) might be an adequate option in selected cases with unicompartmental overload combined with degenerative meniscus changes.

9.3 Complications

The rate of surgical complications considering partial meniscectomy is low (1–2 %). However, the risk of subsequent osteoarthritis after surgical treatment is three times greater (30 %) than functional treatment regardless of the type of resection performed [3, 13, 14].

The data support the important distinction between a DMT and a traumatic meniscal tear. A patient with a traumatic meniscal tear has a better long-term prognosis after partial maniscectomy when compared to DMT. Some observational studies have examined the long-term outcome of meniscectomy [3, 12–15].

What must be brought to attention is that surgery is a tool for treatment. Dealing with degenerative injuries is completely different than dealing with traumatic tears. Unnecessary procedures represent unnecessary risks, a waste of resources, and an economic burden to society.

The prevalence of degenerative meniscal lesions in the general population increases with increasing age, ranging from 16 % in knees of 50–59-year-old women to over 50 % in the knees of men aged 70–90 years [12]. A prevalence of meniscal tear of over 90 % has been reported in knees of patients with symptomatic knee osteoarthritis [16, 22].

These epidemiologic studies demonstrate the high prevalence of meniscal lesions in the general population. Probably, meniscal degeneration to some extent should be considered as part of normal aging. Moreover, most of these meniscal tears do not directly cause knee joint symptoms as over 60 % of tears were seen in knees of the study participants completely free of knee pain, aching, or stiffness [12]. It is important to point out that this study was population-based and study subjects were randomly sampled, i.e., not sampled on the basis of the presence or absence of any knee joint symptoms.

9.4 Results and Literature Review

According to the best available evidence, when dealing with DMT, outcomes are similar after conservative treatment and arthroscopic partial meniscectomy [3–5, 15, 16].

According to literature review, an algorithm has been proposed as guidelines to the French orthopedic community in 2009 [4] which we will try to summarize below.

So far, no differences in outcome for DMT have been shown regardless of the severity of other osteoarthritic changes in the joint or absence of such changes [4]. Moreover, meniscectomy may lead to increased risk of osteoarthritis progression if functional meniscus tissue is removed [3, 4].

When conservative treatment fails, arthroscopic partial meniscectomy or even repair in limited and properly selected cases may be considered as an alternative treatment option [3, 4].

This algorithm remains globally valuable, in the light of recent publications [3]. Conservative treatment is always the first line. If it fails, arthroscopic treatment can be considered. Information to the patient and dealing with their proper expectations is crucial.

When should surgery be proposed? There is no evidence in literature supporting a definitive answer to this question.

However, we agree with the course of action proposed by other several experts in this field:

Surgery may be considered for patients with frequent mechanical symptoms (joint catching or locking) for more than 2 weeks over the past 2 months.

After 3–6 months of persistent pain/mechanical symptoms correlated with a degenerative meniscus with normal X-rays/abnormal MRI signal (grade III) suggestive of an unstable lesion, surgery can also be considered [3].

Meniscectomy should be limited to the minimum possible once partial meniscectomy has been reported to be associated with less radiographic osteoarthritis than total meniscectomy [17, 18]. Moreover, degenerative meniscus injuries was associated with a higher risk of developing symptomatic knee osteoarthritis than a traumatic meniscal tear (risk ratio 7.0 and 2.7, respectively; risk ratio versus non-operated reference subjects without clinical meniscal tear and knee surgery randomly recruited from the general population) [18].

Take-Home Message

There is a high prevalence of degenerative meniscus tears in asymptomatic patients. Conservative treatment should always be the first option. Arthroscopic partial meniscectomy can be considered for mechanical symptoms which fail to respond to functional treatment. Meniscectomy in degenerative tears has also been connected to faster development of osteoarthritis. Some horizontal and root tears in meniscus with some degenerative changes have provided favorable outcome and should be considered in properly selected cases. Classification of meniscus tears is very important for the assessment of the tear. Quite often, what should be considered is the multifactorial condition of an osteoarthritic joint, and not the isolated approach of a meniscal injury as the only/main cause of the patient's symptoms. This is the most critical and probably most difficult decision when dealing with such patients. This is the "key to success" in treatment of patients with degenerative meniscal tears. The ACL-deficient knee presents a different topic demanding specific care. Several advances in the field of surgical treatment have recently aroused. The current trend favors repair over meniscectomy even in some types of injuries previously considered as irreparable.

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Arthroscopic Meniscectomies for Congenital Meniscus Lesions

10

Romain Seil, Tracey Gillman, Georges Assad, Klaus Dueck, and Dietrich Pape

10.1 Introduction

The knowledge and treatment on congenital meniscal problems in children and adults have undergone important changes over the last decades [1, 2, 5, 9, 11, 19, 25, 27, 36, 39, 41]. Most of them are related to the lateral discoid meniscus, which has been initially described in 1889 by Young [45]. It is bilateral in approximately 25 % of the cases. Medial discoid menisci [14, 18] and other congenital deformities like ring-shaped menisci [6, 35] are anecdotal (Fig. 10.1). A lateral discoid meniscus should therefore be the first hypothesis to consider in an extension deficit or a snapping knee with no trauma history in a child. MRI is the best diagnostic tool to confirm the diagnosis and to rule out other potential knee problems. It has been established that discoid menisci are more frequent in Asiatic populations [13, 40]. Therefore, it is not surprising that the most used classification system comes from Japan ([43; Table 10.1) and that the newest findings in the field originate from South Korea (Ahn ref n°4) [4, 24].

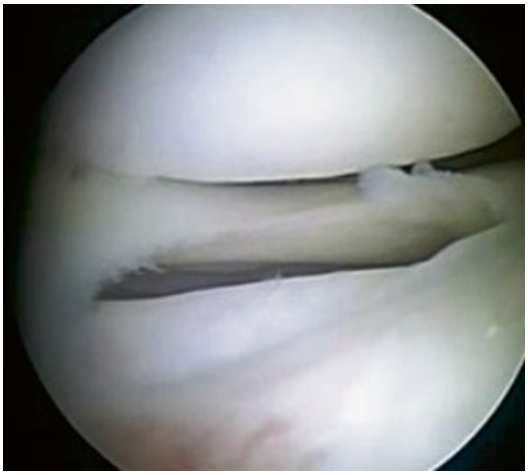

Fig. 10.1 The circular lateral meniscus in the right knee of a 10-year-old girl. It was associated with a dysplastic ACL. The latter was not attached on the tibia. Instead, it inserted on the anterior horn of the ring-shaped meniscus

R. Seil, MD, PhD (✉)
Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg-Clinique d'Eich, 76, rue d'Eich, Luxembourg 1460, Luxembourg

Sports Medicine Research Laboratory, Luxembourg Institute for Health, 76, rue d'Eich, Luxembourg 1460, Luxembourg

Service de Chirurgie Orthopédique et Traumatologique, Centre d'Orthopédie et de Médecine du Sport, Centre Hospitalier – Clinique d'Eich, 78, rue d'Eich, Luxembourg 1460, Luxembourg
e-mail: seil.romain@chl.lu

T. Gillman • G. Assad • K. Dueck
Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg-Clinique d'Eich, 76, rue d'Eich, Luxembourg 1460, Luxembourg

D. Pape
Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg-Clinique d'Eich, 76, rue d'Eich, Luxembourg 1460, Luxembourg

Sports Medicine Research Laboratory, Luxembourg Institute for Health, 76, rue d'Eich, Luxembourg 1460, Luxembourg

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Table 10.1 Watanabe classification of discoid menisci

Type I: complete disc-shaped meniscus covering the entire tibial plateau
Type II: incomplete semilunar-shaped meniscus with partial tibial plateau coverage
Type III: (also called Wrisberg-type) meniscus with a deficient posterior meniscotibial attachment

It is now well established that the best treatment of discoid menisci should not be total meniscectomy anymore. Meniscus preservation is key and the optimal treatment consists of partial meniscectomy, meniscoplasty (saucerization) and peripheral meniscocapsular reattachment [8, 22, 31, 38, 46]. This chapter assesses the indications, technique and results of arthroscopic treatment of discoid menisci.

10.2 Indications

Discoid menisci are very often incidental findings on MRI. If they are asymptomatic, the patient should be informed about the prognosis of the lesion which should be left alone. Complete or incomplete discoid menisci predispose to mucoid degeneration but are often not causing symptoms. Symptomatic discoid menisci cause either pain or recurrent locking phenomena. A palpable or even audible snapping is not rare. It results either from impingement of the thicker, central part of the meniscus against the femoral condyle during motion or from instability of the horns.

It is often associated with an extension deficit and joint line pain. Radiographs are generally normal. In some cases, a widening of the lateral joint space, a flattening of the lateral femoral condyle, a hypoplastic lateral intercondylar eminence or a concavity and obliquity of the lateral tibial plateau as well as different heights of the fibular head can be identified [15]. The diagnosis on MRI is sometimes difficult. This is especially true for paediatric knees where MRI signals are often abnormal. Ahn et al. [4] proposed a new MRI classification with four types of discoid menisci: normal discoid menisci, anterocentrally dislocated discoid menisci, posterocentrally dislocated discoid menisci and centrally dislocated discoid menisci (Fig. 10.2). In the latter, the rate of subtotal meniscectomies exceeded 50 %, whereas the second and third categories frequently required peripheral capsular attachments. This is in line with the 28–77 % of peripheral detachments described by Good [22] and [31], which are more frequent in complete discoid menisci and in the anterior horn (47–53 %) than in the posterior horn (39 %) or body segment (11 %). By differentiating between stable and unstable as well as complete and incomplete discoid menisci, Good et al. added an important functional aspect to the Watanabe classification.

10.3 Technique

An intact and asymptomatic discoid meniscus which is discovered as an incidental finding during arthroscopy should be left in place. Surgical management of a symptomatic discoid meniscus is an advanced arthroscopic procedure including the different surgical steps of meniscoplasty, meniscal repair and/or meniscal attachment for peripheral instability. Meniscoplasty is also called saucerization. It represents a resection of the centre of the meniscus and peripheral debridement in order to recreate the shape of an original meniscus. Partial resection is therefore recommended if ever possible, especially in children's knees [21], and a total meniscectomy should be avoided by all means.

In order to achieve a better visualization of the anterior horn, the lateral arthroscopic portal should be placed more proximal and lateral than for a classic meniscectomy [10]. The medial working portal should be made after needle palpation. If the discoid meniscus is complete, it is sometimes difficult to resect it with classical instruments in its central part, because the tissue is often harder than in the normal meniscus (Fig. 10.3). Therefore, the initial central resection may be performed with electrocautery or a blade. Once this central part has been resected, the tissue becomes softer which corresponds to the disorganized and inhomogeneous distribution of the circumferential collagen fibre bundles as described

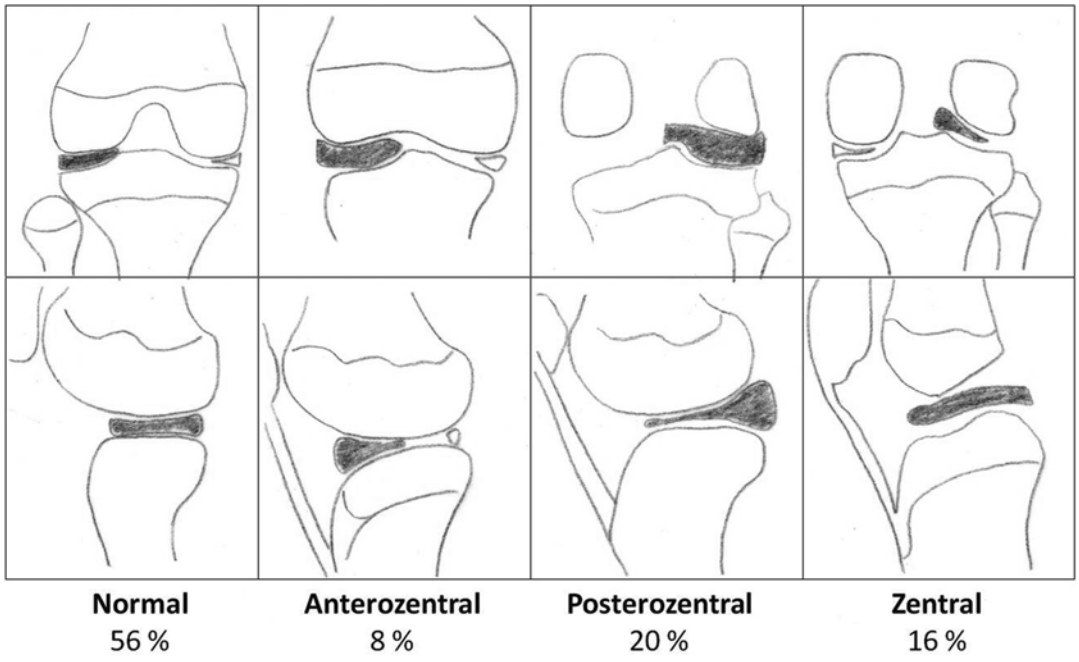

Fig. 10.2 Schematic drawing of the appearance of lateral discoid menisci according to a novel MRI classification by Ahn et al. [4] (*left* coronal views, *right* sagittal views)

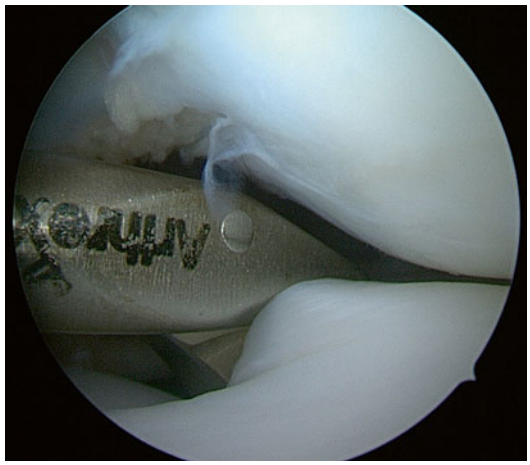

Fig. 10.3 Incising a complete discoid meniscus in its central part can be difficult due to the hard tissue

by Papadopoulos [37]. This can be performed by using a regular basket forceps. A semicircular resection should then be made starting from the anterior to the posterior horn. Care should be taken not to force the resection into the popliteal hiatus, which would result in a complete functional meniscectomy. Tears of the discoid menisci are often not visible at the first sight and only become apparent once the central part has been resected (Fig. 10.4) [1]. This is especially true if they are located at the undersurface of the discoid meniscus. In order to allow for a better visualization of the anterior horn, it is recommended to switch the arthroscope to the anteromedial portal (Fig. 10.5). In some cases of narrow knees, a transmeniscal or inframeniscal working portal may be useful to allow for a better access.

A peripheral rim of 8–10 mm should be preserved. It can either be made of a thick and compact tissue or, which is more frequent, of a superficial and a deep layer separated by a horizontal tear. This leaves the option either to resect one of these layers or to reassemble them after thorough interstitial debridement and vertical repair. A final peripheral testing is done to verify the stability of the newly shaped meniscus. In case of instability of the remaining tissue, a repair can be done using either outside-in sutures in the area of the anterior horn or by all-inside sutures (i.e. Meniscal Viper®, Arthrex) or hybrid devices

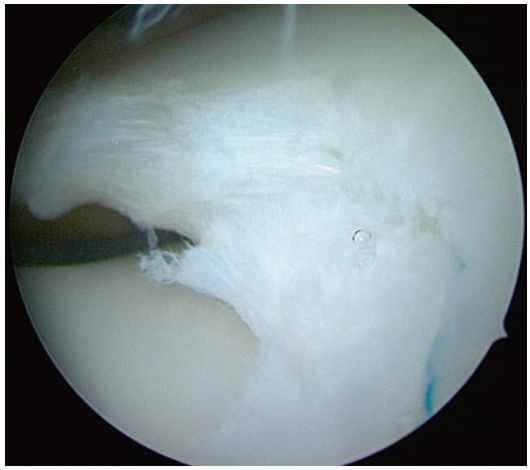

Fig. 10.4 The partially resected lateral discoid meniscus in a left knee: the undersurface flap tear became only visible after resection of the central part of the discoid meniscus (same patient as in Fig. 10.3)

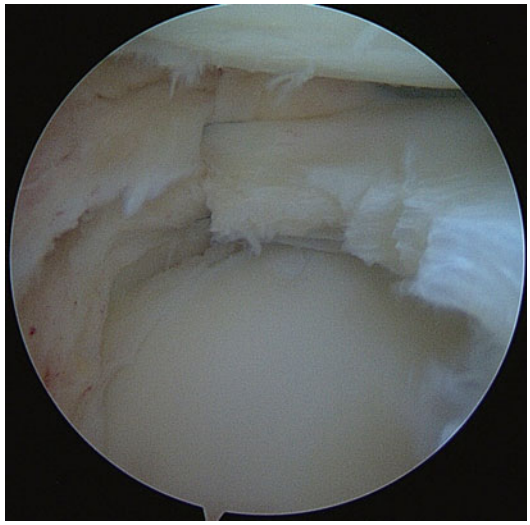

Fig. 10.5 View of a posterocentrally dislocated lateral discoid meniscus in a right knee of a young female patient. Visualization of the anterior meniscocapsular separation was best visible from the anteromedial portal

(i.e. Fast-Fix®, Smith & Nephew) for the middle and posterior segments (Fig. 10.6).

10.4 Complications

The main intraoperative complication is the excessive resection of the meniscus into the popliteal hiatus. From a biomechanical point of view,

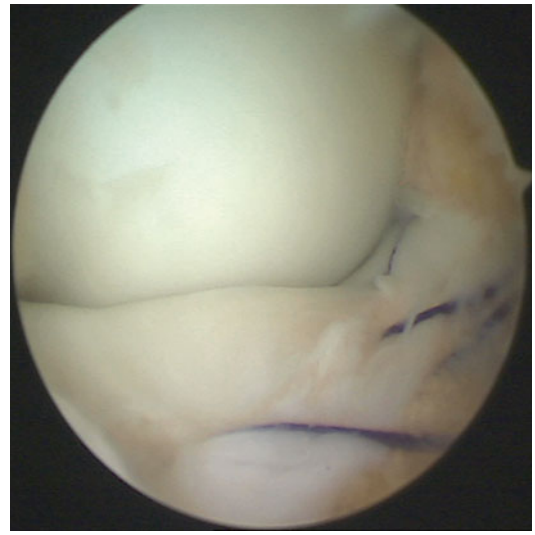

Fig. 10.6 Anterior meniscocapsular reattachment

this situation would create a functional complete meniscectomy. The second intraoperative problem is related to the narrow joint space, which favours the appearance of iatrogenic cartilage lesions. Instrument breakages have been reported due to thickness of the discoid portion [10]. An insufficient resection of the anterior horn can lead to residual anterolateral pain. A persistent instability can cause a recurrent snapping and pain. In the long term, surgery of discoid menisci has been associated with the appearance of an osteochondritis dissecans in the lateral femoral condyle [17, 23, 33, 34].

10.5 Results

Short-, mid- and long-term results have shown that arthroscopic meniscoplasty and saucerization with repair of the unstable meniscus rim is an effective procedure [30]. Several studies found that young age was the most important prognostic factor for a good clinical outcome [32]. In female patients, patients with a BMI greater than 23.0 kg/m^2 or patients with a time course of greater than 6 months, discoid menisci were associated more frequently with cartilage lesions [20]. Less satisfactory outcomes have been observed in children aged 10 years and older or when a reoperation became necessary [44]. In the long term,

some authors have observed signs of osteoarthritic changes in the lateral knee compartment in up to 40 % of patients [3, 7, 12]. A recent study highlighted the influence of torn discoid menisci on the axial alignment of the lower limb in adolescents and young adults. Varus deformity was significantly reduced, and a valgus inclination developed in some of these patients [42].

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Meniscal Repair: Indications, Techniques, and Outcome

11

Hélder Pereira, Ibrahim Fatih Cengiz, Joana Silva-Correia, Pedro L. Ripoll, Ricardo Varatojo, Joaquim Miguel Oliveira, Rui Luís Reis, and João Espregueira-Mendes

11.1 Introduction

"Nothing has changed so much in recent years of orthopaedics as the treatment algorithm of meniscus lesions" [77]. We moved from the "recommendation" during the 1970s to remove what was then considered a useless structure [73] to the current trend favoring preservation, repair, or even replacement of the menisci [77].

H. Pereira (✉)
3B's Research Group–Biomaterials, Biodegradables and Biomimetics, University of Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, AvePark, Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco, Guimarães 4805-017, Portugal

ICVS/3B's–PT Government Associate Laboratory, Braga/Guimarães, Portugal

Clínica do Dragão, Espregueira-Mendes Sports Centre – FIFA Medical Centre of Excellence, Porto, Portugal

Orthopedic Department Centro Hospitalar Póvoa de Varzim, Vila do Conde, Portugal

Ripoll y De Prado Sports Clinic – FIFA Medical Centre of Excellence, Murcia, Madrid, Spain
e-mail: helderduartepereira@gmail.com

I.F. Cengiz • J. Silva-Correia • R.L. Reis
3B's Research Group–Biomaterials, Biodegradables and Biomimetics, University of Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, AvePark, Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco, Guimarães 4805-017, Portugal

ICVS/3B's–PT Government Associate Laboratory, Braga/Guimarães, Portugal

P.L. Ripoll
Ripoll y De Prado Sports Clinic – FIFA Medical Centre of Excellence, Murcia, Madrid, Spain

R. Varatojo
Descobertas: Knee, Ankle, Arthroscopy and Sports Trauma Unit, Hospital CUF, Lisbon, Portugal

J.M. Oliveira
3B's Research Group–Biomaterials, Biodegradables and Biomimetics, University of Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, AvePark, Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco, Guimarães 4805-017, Portugal

ICVS/3B's–PT Government Associate Laboratory, Braga/Guimarães, Portugal

Ripoll y De Prado Sports Clinic – FIFA Medical Centre of Excellence, Murcia, Madrid, Spain

J. Espregueira-Mendes
3B's Research Group–Biomaterials, Biodegradables and Biomimetics, University of Minho, Headquarters of the European Institute of Excellence on Tissue Engineering and Regenerative Medicine, AvePark, Parque de Ciência e Tecnologia, Zona Industrial da Gandra, Barco, Guimarães 4805-017, Portugal

ICVS/3B's–PT Government Associate Laboratory, Braga/Guimarães, Portugal

Clínica do Dragão, Espregueira-Mendes Sports Centre – FIFA Medical Centre of Excellence, Porto, Portugal

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Nevertheless, meniscectomy is still one of the most frequent orthopedic procedures [68] despite the latest results favor meniscal repair over partial meniscectomy concerning either clinical outcome or risk for osteoarthritis [57].

It is well known that different patterns of meniscus lesions have different clinical evolution and implications [48]. Recognizing the specificity of different meniscus tears is critical in order to determine the best choice for treatment. Several classification methods of meniscal lesions have been proposed over the years aiming to define the best course of action for treatment as well as prognosis and assessment of outcome [4]. The ISAKOS classification of meniscal tears provides sufficient interobserver reliability for decisive factors, which assist surgeons in the choice of the most adequate management, as well as collecting data from clinical trials designed to evaluate the outcomes [4]. This should be kept in mind once not all the prognostic factors rely on the division between acute and degenerative meniscal injuries.

Methods of repair can use all-inside, inside-out, or outside-in techniques, alone or in combination. Rasping, trephination, or augmentation with fibrin clot may assist in increasing the healing rate in properly selected cases including some degenerative meniscus tears [29]. Meniscal repair is not exclusive of acute traumatic tears, once some selected cases of degenerative injuries (including some horizontal cleavage tears) might also be considered as reparable [37]. Moreover, repair of degenerative meniscal root tears has also shown to provide favorable outcome [2].

Horizontal tears are frequently not traumatic and have a degenerative nature (even in younger patients) [72]. Vertical or longitudinal tears, bucket-handle tears, and radial tears usually (but not always) are associated with the traumatic group [61]. All these can be considered as possibly reparable depending on the classification, zone, and surgeon's experience. Flap tears are another type of meniscal tear which frequently arises after a traumatic event and is frequently irreparable. This type of lesion can also be observed in complex degenerative lesions.

Complex tear is a combination of other tears occurred in multiple planes. They appear more frequently in older patients and in the posterior horn. Generally the complex tears are non-repairable. Tears should be graded on the predominant tear pattern. Complex tears include two or more tear patterns. A tear appearing in the lateral meniscus that extends partially or completely in front of the popliteal hiatus should be graded as central to the popliteal hiatus.

Furthermore, a degenerative meniscus injury, previously asymptomatic, might change and become symptomatic after an acute traumatic event, thus representing a challenge for surgeons [10].

The possibility to repair a meniscal injury is multifactorial [12]; thus, several factors must be considered including age, activity level, tear pattern, chronicity of the tears, combined injuries (ACL injury), and healing potential/vascularization.

It is still somewhat debatable if an ACL injury associated with minor symptoms in patient involved in low-demand sports activities should undergo ACL repair. The diagnosis of a concomitant meniscal lesion represents an important argument favoring the surgical procedure.

Pujol and Beaufils have defended that the indications for surgical repair can be widened for the medial meniscus (increased risk of secondary meniscectomy if left alone), even for small stable lesions [63]. On the other hand, for the lateral meniscus with small stable lesions, "let the meniscus alone" can be the preferred approach given the low risk of subsequent meniscectomy [11]. An overall *odds ratio* of 3.50 for medial meniscal tears has been described when ACL surgery is performed more than 12 months after the ACL injury when compared to less than 12 months after ACL injury [74]. On the other hand, concerning lateral meniscus tears, minimal to no evidence was found as a risk factor, at least for the period of time comprised between ACL injury and reconstruction surgery [74].

These findings are somewhat in line with the recognized different roles of medial and lateral menisci within the knee joint.

There have been remarkable developments of suture techniques derived from improved biological and anatomical knowledge accompanied with advances in surgical techniques and medical devices [49].

This work aims to summarize the most frequent indications for meniscal repair and describe technical options as well as results and possible complications.

11.2 Indications for Meniscal Repair

According to recent advances in suture devices and surgical techniques, several injuries previously considered as irreparable are now potentially repairable (Table 11.1). Posterior capsular avulsions are considered out of the scope of this chapter and are dealt separately. Regardless of the used technique, vertical or horizontal mattress sutures are usually possible (Fig. 11.1). Vertical sutures have higher pullout resistance and are perpendicular to the circumferential fibers of the meniscus [70]. Both points of the suture can be put in the meniscus tissue or one in the capsule and another in the meniscus. Horizontal sutures are parallel to the same fibers.

11.2.1 Longitudinal and Bucket-Handle Tears

A vertical or longitudinal tear (Fig. 11.2) occurs in line with the circumferential fibers of the meniscus. If such tear reaches enough length, it is classified as a bucket-handle tear. The bucket-handle tear may be described as being attached anteriorly and posteriorly with high instability in the middle. It can progress and become detached at either end or transected in the middle thus creating unstable anterior and posterior flaps. A bucket-handle tear may displace into the intercondylar notch, where it may cause true locking of the knee joint.

The longitudinal tears, particularly those occurring closer to the peripheral vascular zones, have always been considered as the most direct indication for repair either by horizontal sutures, vertical sutures, or combinations of both [7, 56, 57].

Concerning bucket-handle tears, in case of a dislocated/unstable bucket handle, the first step will be to bluntly reduce the meniscus to its native site (using the hook probe or similar tool) [26].

If the meniscus is stable after reduction, the surgical procedure becomes easier, and the chances for successful repair are increased [1, 26].

11.2.2 Radial Tears

These are often related to trauma but sometimes have been also observed in degenerative meniscus. Radial tears can be complete or

Table 11.1 Injury types and possibility to repair

Injury types and possibility to repair	
Injury type	Potential for repair
Horizontal tear	Potentially repairable
Longitudinal tear	Repairable
Radial tear	Potentially repairable
Bucket-handle tear	Potentially repairable
Root tears	Potentially repairable
Oblique (flap or parrot beak) tears	Irreparable
Complex degenerative tears	Irreparable

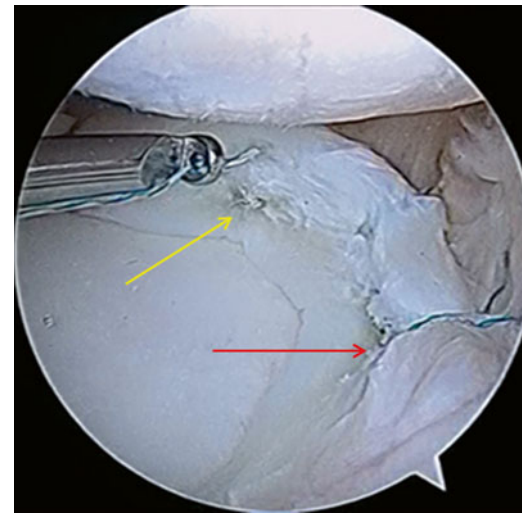

Fig. 11.1 Vertical (*red arrow*) and horizontal (*yellow arrow*) mattress sutures are visible

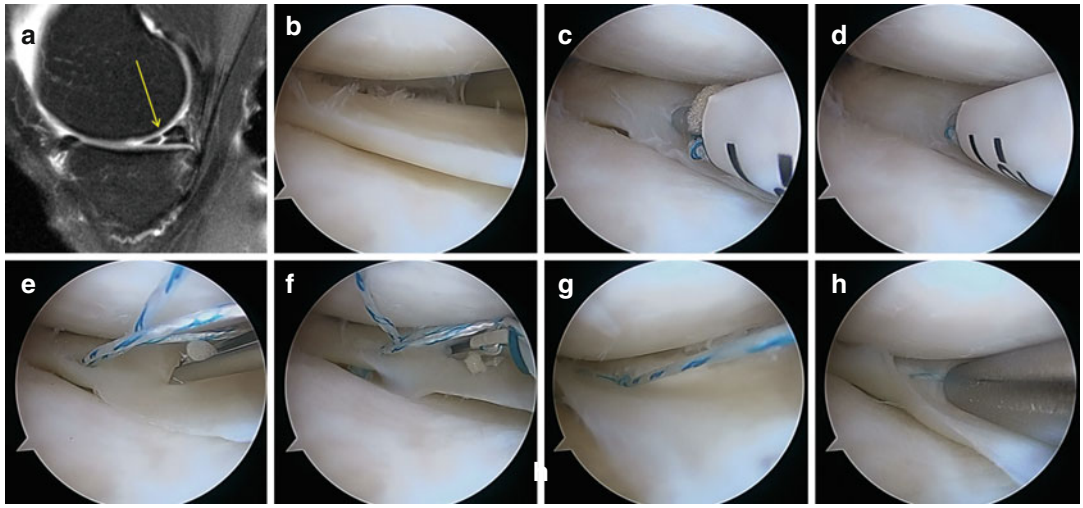

Fig. 11.2 MRI of longitudinal tear (**a**) and arthroscopic view (**b**); all-inside repair sequence with the first anchor introduction (**c**, **d**); the second anchor is deployed (**e**, **f**). The suture is finally tensioned by pulling the suture (**g**) and then by the use of a knot pusher (**h**)

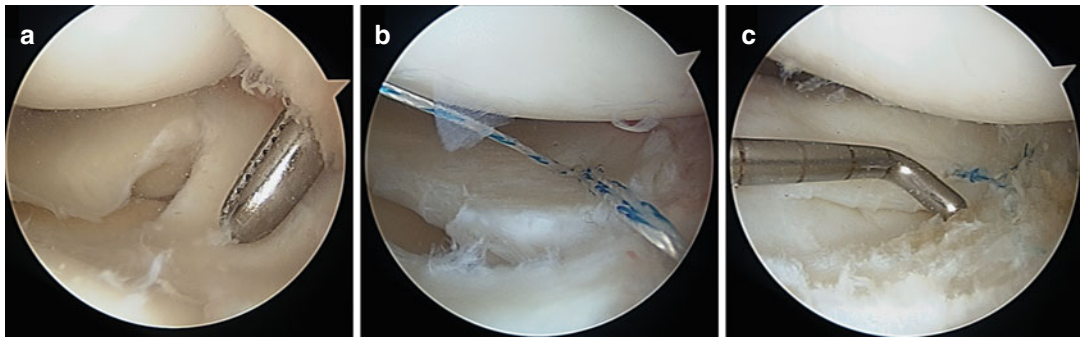

Fig. 11.3 Radial tear arthroscopic view (**a**) repaired by suture (**b**). Stability of the repair is confirmed by tensioning with the hook probe (**c**)

incomplete. They are oriented extending from the inner edge of the meniscus toward its periphery, where there might be some healing capacity (Fig. 11.3). Radial tears are in general defined as unstable [79]. They were generally considered as non-repairable because the circumferential hoop fibers are disrupted and the majority of the tear is avascular. However, repair of complete radial meniscal tears is a key to restoring the mechanical integrity necessary to maintain hoop tension in the meniscus. Repair of radial tears is currently considered a challenge and represents a difficult decision for the surgeon [49]. The major goal is to achieve a primary stable meniscal repair. This is considered crucial for providing a chance to efficiently heal meniscus [49]. Sometimes, the combination of sutures enhanced by fibrin clot has also allowed positive results for treatment of radial tears [37, 67].

11.2.3 Horizontal Cleavage Tears

In this type of tear, the superior and the inferior surfaces of the meniscus are divided (Fig. 11.4). It is typically a degenerative tear and most

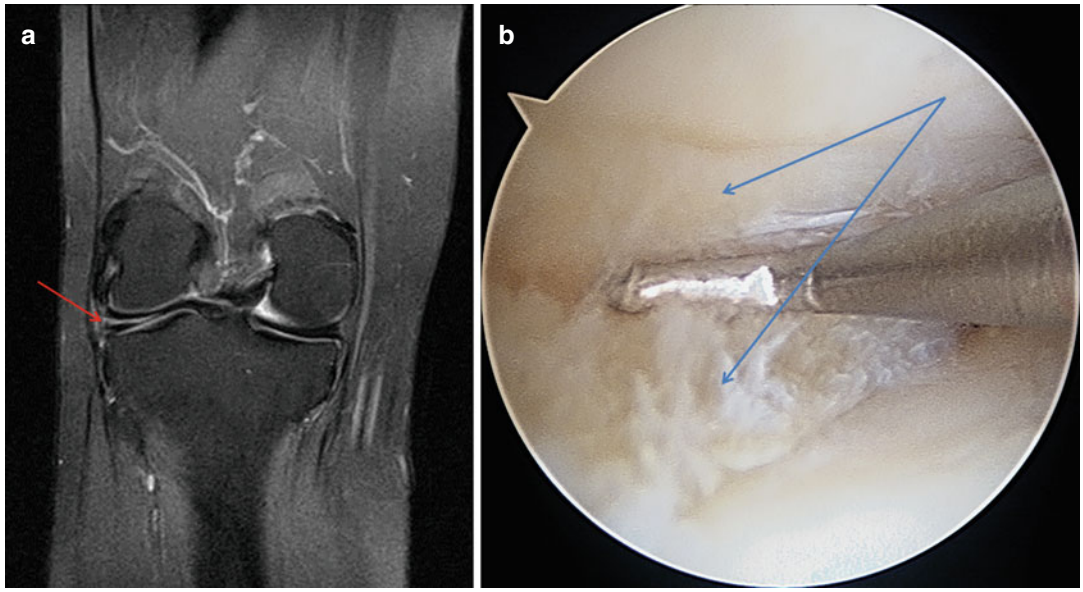

Fig. 11.4 Horizontal cleavage tear on MRI (**a**) and arthroscopic view (**b**) demonstrating the superior and inferior components of the tear (*blue arrows*)

frequently occur in older people. Symptomatic horizontal meniscal tears in young patients are a particular condition which often presents as an isolated severe meniscus lesion. A complete resection of such tear would subsequently result in a subtotal meniscectomy. Arthroscopic repair of such lesions is sometimes possible and has provided fair results [37]. A recent systematic review (level IV) concluded that horizontal cleavage tears show a comparable success rate to repairs of other types of meniscal tears [43].

Open meniscal repair of complex horizontal tears, even those extending into the avascular zone, have proven to be effective at midterm follow-up in young and active patients with a low rate of failure [64, 69].

11.2.4 Meniscal Root Tears (MRTs)

This type of meniscal tears is receiving increasing attention [13]. Most regularly, MRTs are degenerative in nature and must be differentiated from the rare true traumatic root tears. The traumatic root tears are frequently associated with an anterior cruciate ligament (ACL) tear, particularly on the posterior horn of the lateral meniscus.

They can be treated by tibial re-fixation, using a transtibial tunnel [2], if the remaining tissue is found to be adequate for repair.

The repair of root tears (Fig. 11.5) has been done by tibial tunnel [42] (namely, posterior horns) and all-inside techniques (more frequently on anterior horns) [55].

11.3 Techniques

Several techniques have been described and can be chosen according to the injury pattern, surgeon's experience, and available resources (Table 11.2).

11.3.1 Inside-Out

Henning [33, 34] was the first to describe the inside-out technique of arthroscopic meniscal repair.

Inside-out techniques use specific long flexible needles connected to suture wire and zone-specific cannulas to pass sutures through the joint and across the tear (Figs. 11.6 and 11.7). A small posterior joint line incision is used to retrieve the sutures and tie them directly onto the capsule. The use of a posterior retractor is important in order to protect the posterior neurovascular structures when this technique is selected for posterior tears (Fig. 11.6).

11.3.2 Outside-In

The outside-in techniques have been described by Warren [78] and Morgan and Casscells [53]. This is a cheap method to provide sutures particularly to the body and anterior segments of menisci. Outside-in techniques involve passing sutures percutaneously through spinal needles at the level of joint line, across the meniscus tear, and then initially retrieving the sutures intra-articularly (Figs. 11.8 and 11.9).

Knots can then be tied on the intra-articular free ends of the suture. A small incision is then made at the joint line, where the protruding suture ends are retrieved and tied directly on the capsule.

More frequently, the sutures are pulled outside the skin using one of the needles as a suture passer. A small incision is made and both ends of the suture brought together subcutaneously and

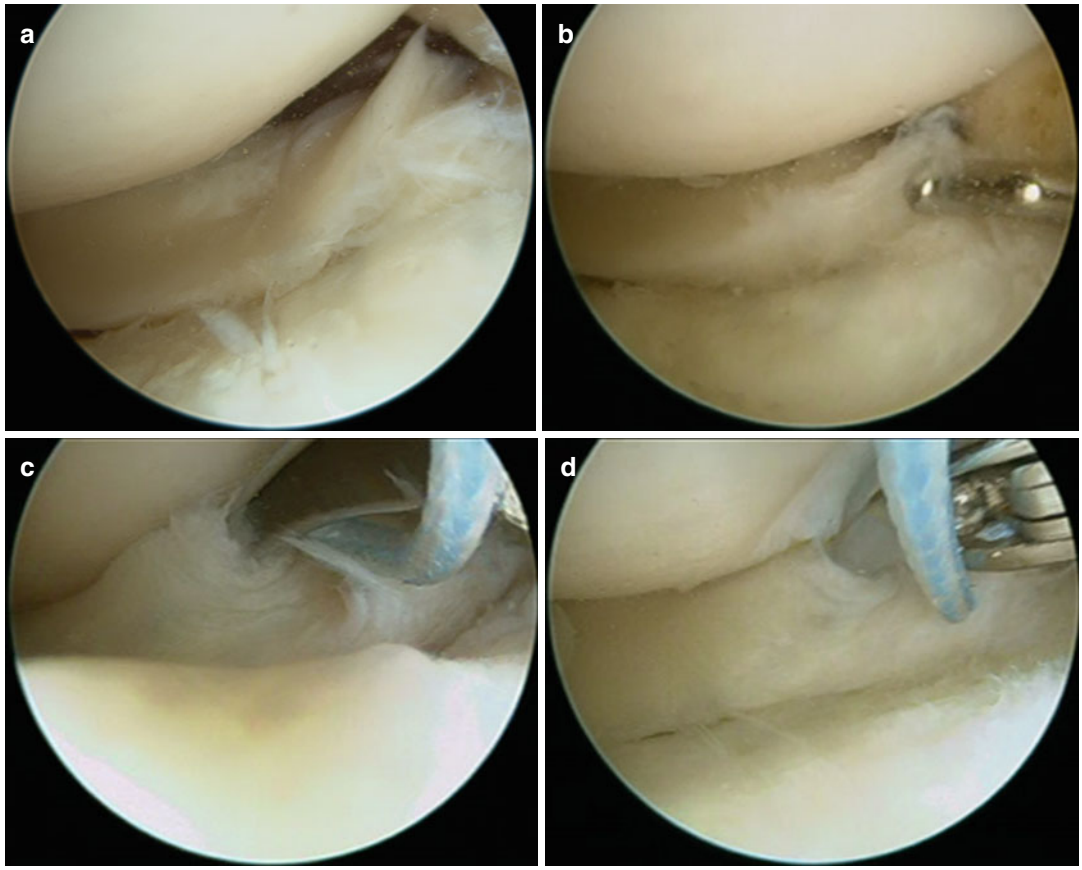

Fig. 11.5 Posterior root tear on arthroscopic view (**a**, **b**). Sutures are passed through the meniscus tissue by the use of shoulder instruments (**c**, **d**). After drilling a tunnel, the sutures are passed through and tensioned (**e**–**g**). Achieved stability is checked (**h**)

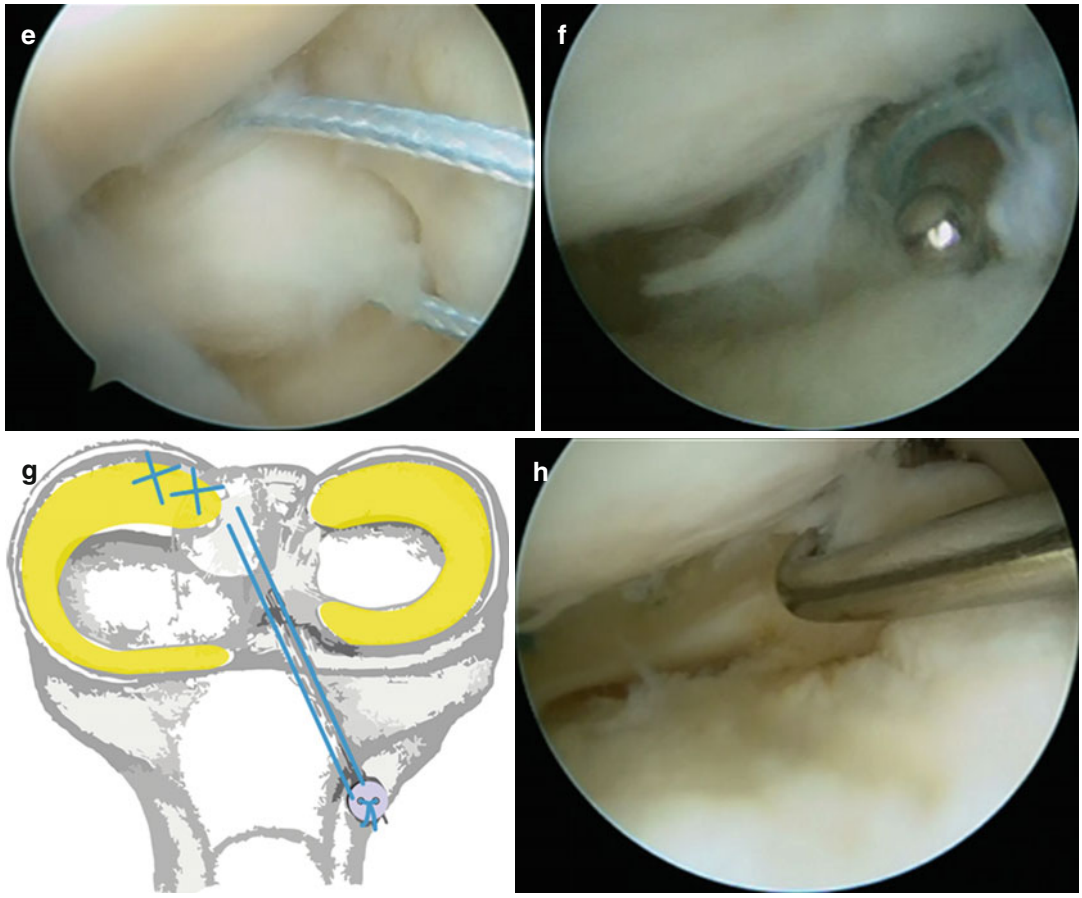

Fig. 11.5 (continued)

tied over the capsule. This avoids bulky knots inside the joint.

A potential disadvantage of the outside-in technique is difficulty in reducing the tear and opposing the edges while passing the sutures.

11.3.3 All-Inside Meniscus Repair

In recent years, there has been a huge development in all-inside techniques (Figs. 11.2 and 11.10) and related devices resulting in increased ease of use and reduced surgical times. Moreover such development also enabled to lower the iatrogenic risk to the neurovascular structures [32, 47]. Suture techniques exhibited biomechanical superiority over biodegradable flexible and rigid anchor devices for meniscus repair [18].

Several generations have been described.

Table 11.2 Repair techniques and most frequent indications

Repair techniques and most frequent indications	
Inside-out technique	Posterior horn tears
	Middle-third tears
	Bucket-handle tears
	Peripheral capsular tears
	Meniscal allograft
Outside-in technique	Anterior horn tears
	Middle-third tears
	Bucket-handle tears
	Peripheral capsular tears
	Radial tears
	Meniscal allograft
All-inside technique	Posterior horn tears
	Middle-third tears
	Bucket-handle tears
	Peripheral capsular tears
	Radial tears
	Meniscal allograft

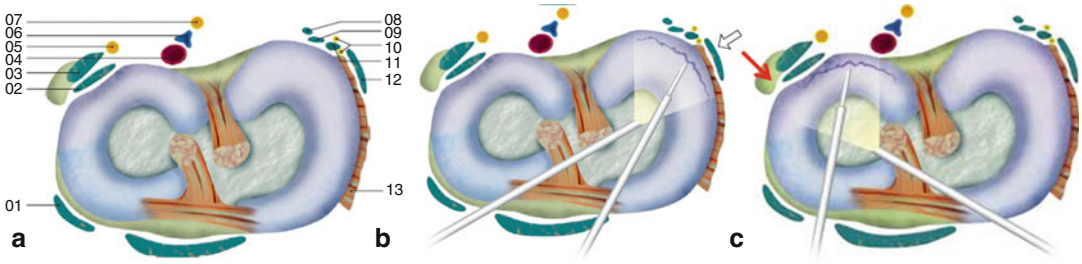

Fig. 11.6 Anatomical structures at risk during posterior horn of both meniscus repairs (**a**): *1* iliotibial band; *2* popliteus tendon; *3* biceps tendon; *4* popliteal artery; *5* peroneal nerve; *6* popliteal vein; *7* tibial nerve; *8* semitendinosus tendon; *9* semimembranosus tendon; *10* saphenous nerve; *11* gracilis tendon; *12* sartorius tendon; and *13* medial collateral ligament. (**b**) Structures at risk when repairing the medial meniscus (*white arrow* represents posteromedial approach). (**c**) Structures at risk when repairing the lateral meniscus (*red arrow* represents posterolateral approach) (From Katabi et al. [38])

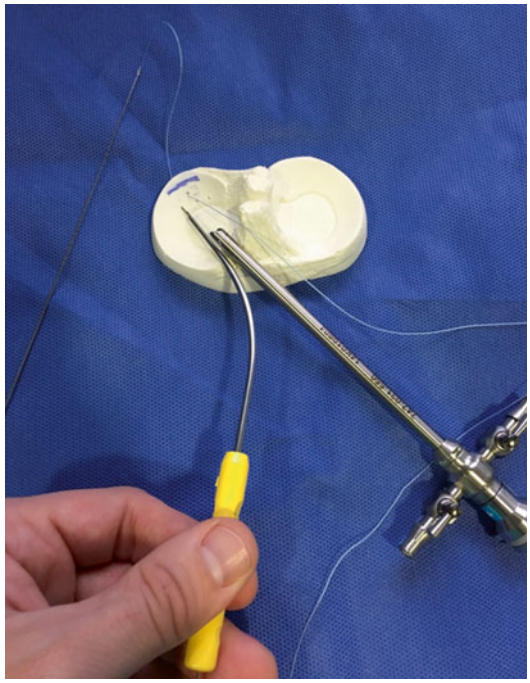

Fig. 11.7 Model representing inside-out suture by means of using a curved cannula and a system composed of two long needles connected by 2.0 suture

11.3.3.1 First-Generation All-Inside Repairs

The first generation of all-inside repairs was described in 1991 by Morgan [52] and required the use of curved suture hooks through accessory posterior portals to enable passing the sutures through the tear. Sutures were then retrieved and tied arthroscopically. The technique was technically demanding and had inherent considerable risk to the neurovascular structures at risk. It was consequently abandoned with the development of second-generation repairs.

11.3.3.2 Second Generation of All-Inside Meniscal Repairs

The second generation of all-inside meniscal repairs introduced the concept of technique-specific devices placed across the tear and anchored peripherally. The prototype of this generation was the T-Fix (Smith and Nephew, Andover, Massachusetts), which consisted of a polyethylene bar with an attached No. 2-0 braided polyester suture, deployed through a sharp needle or cannula in order to capture the peripheral meniscus or capsule. Adjacent sutures were then secured with arthroscopic knots pushed onto the meniscal surface.

This system enabled repair through the standard anterior arthroscopic portals without the need for accessory incisions and with lower risk to neurovascular structures.

However, the technical limitations of the device were the need for arthroscopic knots with potential chondral abrasion and the difficulty to tension the knots after placement.

Despite good early results, the acknowledgment of its limitations led to the development of third-generation devices [9, 24].

11.3.3.3 Third Generation of All-Inside Meniscal Repairs

The third generation consisted of an explosion of bioabsorbable meniscal repair devices, including arrows, screws [76], darts, and staples

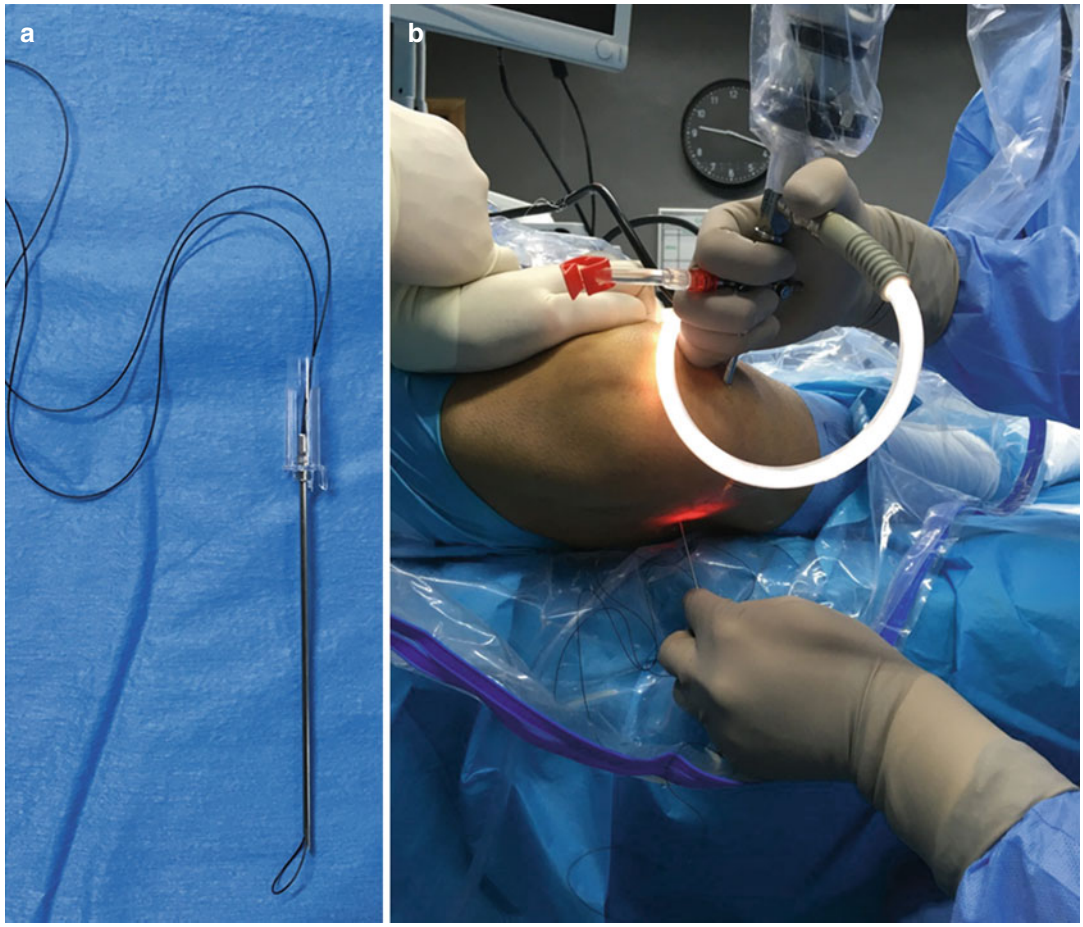

Fig. 11.8 Needle with nylon loop used to retrieve sutures for outside-in repair (**a**). Introduction from outside to the inside of the joint at the level of joint line by transillumination (**b**) and direct arthroscopic view

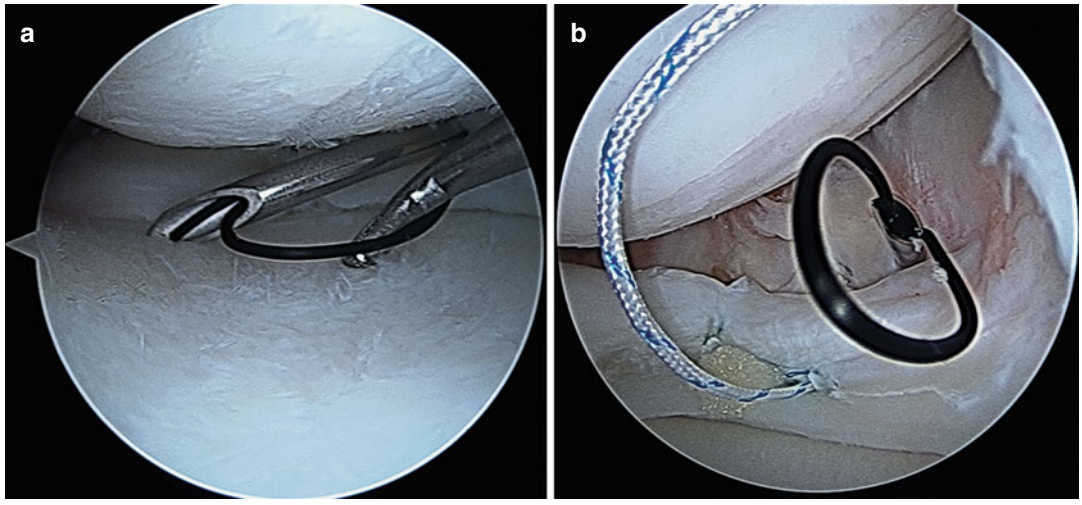

Fig. 11.9 Arthroscopic view of outside-in technique. The nylon loop (**a** and **b**) is used to bring the suture outside the joint percutaneously before final suture which requires a small stab skin incision

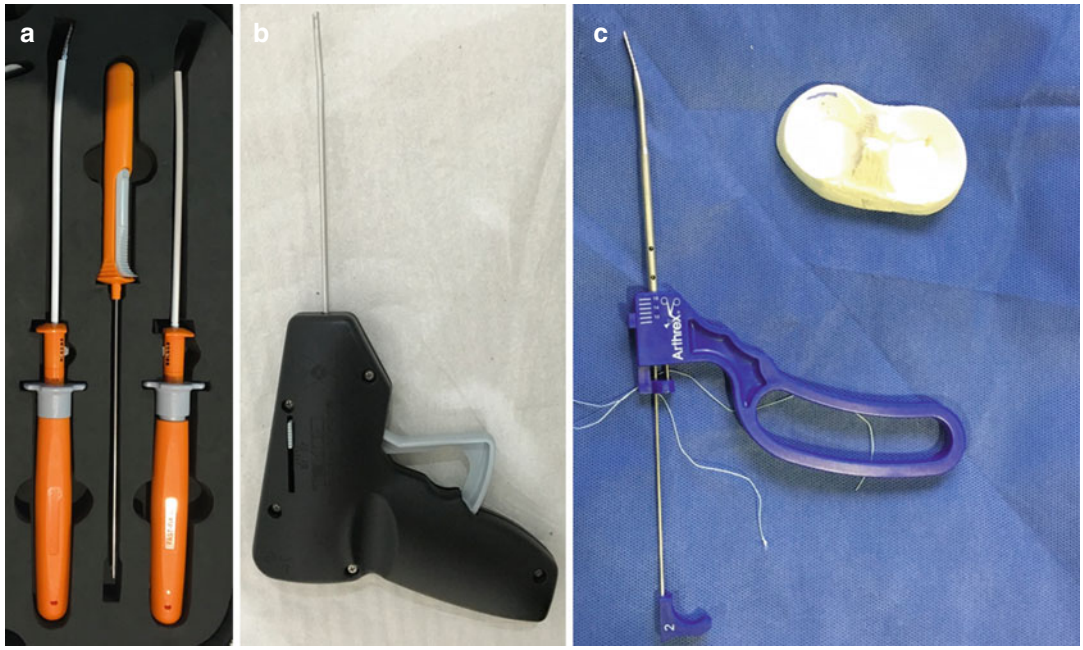

Fig. 11.10 Three common examples of all-inside devices: Fast-Fix® (Smith and Nephew) (**a**); MaxFire® (Biomet) (**b**); Meniscal Cinch® (Arthrex) (**c**)

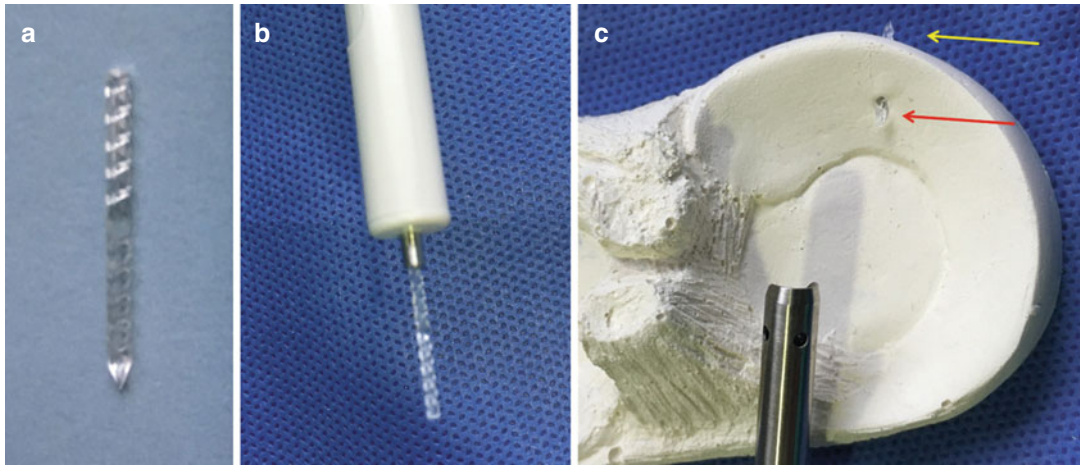

Fig. 11.11 Meniscal darts made of polylactic acid for meniscal repair (**a**). Introduction device (**b**) and final aspect of fixation on a rubber model (**c**). Notice that this hard structure has inherent risk for periarticular (*yellow arrow*) and/or chondral damage (*red arrow*)

(Fig. 11.11). Most of these devices were composed of the rigid poly-L-lactic acid (PLLA) which has been linked to some problems of erratic degradability. Despite some authors describing good results [3, 60], these devices were linked to higher failure rates [30, 44] and higher number of complications.

Numerous device-specific complications have also been reported, including synovitis, inflammatory reaction, cyst formation, device failure/migration, and chondral damage [44]. If these devices are placed too proud or if they loosen/migrate, significant chondral damage can result, often consisting of grooving of the adjacent

femoral condyle. Given the deterioration of results and considerable prevalence of complications, the rigid third-generation devices have gradually lost popularity.

11.3.3.4 Fourth Generation of All-Inside Meniscal Repairs

The previously described limitations and complications, combined with the lack of adjustable tensioning, led to the development of the fourth and current generation of all-inside meniscal repair devices. These devices are flexible and suture based and have lower profile, and they allow for variable compression and retensioning across the meniscal tear. They are usually composed of suture combined with small anchors (serving as blocks) and a pre-tied slipknot [18]. Several devices exist according to different brands (e.g., Fast-Fix®, Smith and Nephew; Meniscal Cinch®, Arthrex; RapidLoc®, Depuy; Maxfire, Biomet®; Sequent®, Linvatec; etc.)

A depth-limiting sleeve on the inserter is used to avoid excessive penetrations of the needle with higher risk of iatrogenic complications (neurovascular structures) [51]. It may be precut to any desired length, and shorter length is usually required in the posterior horn of lateral meniscus [51]. The curved or straight inserter, with both anchors loaded, is introduced into the joint and advanced across the tear.

After deploying the first anchor, the needle inserter is withdrawn from the meniscus but kept inside the joint. The second anchor is advanced to the tip of the inserter, which is then advanced once more across the meniscus and arrayed. The anchors and the resultant suture bridge may provide a vertical or horizontal mattress configuration. The pre-tied slipknot is advanced with a push-pull technique to apply variable compression across the tear. The suture is then cut.

There are also other devices currently available.

The Meniscal Viper Repair System (Arthrex, Naples, FL) (Fig. 11.12) has been developed for repair of peripheral meniscal lesions located within 1–2 mm of the periphery [17]. For lesions located in zone 2 (within the central 50 %), careful assessment of their distance from the periph-

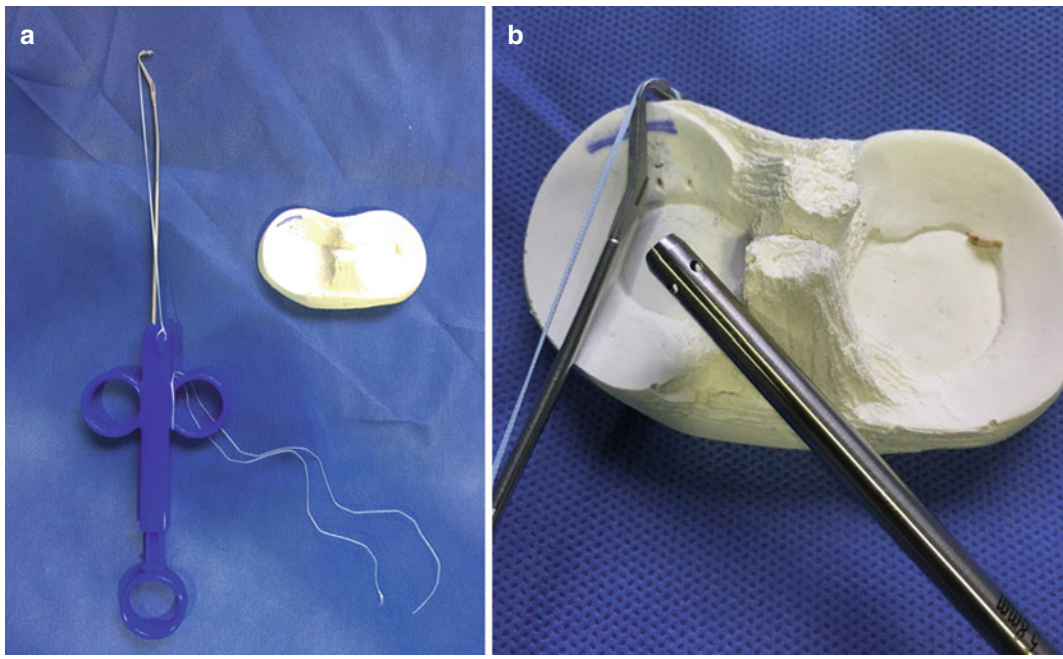

Fig. 11.12 The Meniscal Viper Repair System® (Arthrex, Naples, FL) has been developed for repair of peripheral meniscal lesions located within 1–2 mm of the periphery (**a**, **b**)

ery is recommended. For lesions located more than 3–4 mm away from the periphery, alternative repair systems or augmentation with other devices may be prudent.

This system provides all-inside, all- suture repair without using hard pieces (blocks) inside or in the periphery of the joint [17].

11.3.4 Biologic Augmentations

Other means of assisting the repair of avascular meniscal tears, including fibrin clot [6, 34], fibrin glue [39], meniscal rasping, growth factors [31], and cell-based therapies, have been attempted [59]. A method using a bioabsorbable conduit has been also tried to augment the healing of avascular meniscal tears in a dog model by improving vascularization [21]. Further attempts by biomaterials such as porous polyurethane [40], porcine small intestinal submucosa [22], fascia sheaths [41], collagen scaffolds, and growth factors have been reported with variable outcomes [58]. Tissue engineering and regenerative medicine strategies promise future possibilities, but this goal has not yet been completely achieved and requires ongoing research [58].

11.4 Results

According to the best available knowledge, the healing rate after meniscal repair is complete healing in 60 % of cases, 25 % of partial healing, and 15 % of failure [65]. On the other hand, partially or incompletely healed menisci are many times asymptomatic, at least in the short term [62, 64]. According to literature, the failure rate after arthroscopic meniscal repair ranges from 5 % to 43.5 % (mean, 15 %) [62]. The volume of subsequent meniscectomy after failed meniscal repair is not increased when compared with the volume of meniscectomy that would have been performed if an attempt of repair had not been performed at the first approach [62].

Arthroscopic meniscal repair provides long-term protective effects, even if the initial healing is incomplete [65].

It seems obvious that degenerative meniscal tears have inherently even more limited possibility for healing. However, it has been shown that repair horizontal cleavage tears might have favorable outcome in open or arthroscopic repair with a low rate of secondary meniscectomy [64].

Paxton et al. concerning radiographic changes observed that 78 % of meniscal repairs had no radiographic degenerative changes compared with 64 % of partial meniscectomies; one grade change or less was found in 97 % of meniscal repairs compared with 88 % of partial meniscectomies [57] (systematic review levels I–IV).

Another level III study concluded that meniscal repair for isolated traumatic meniscal tears provided significantly better results in long-term follow-up concerning prevention of osteoarthritis and sports activity recovery compared with partial meniscectomy [75]. No progression for arthritis was observed in 80.8 % after repair compared with 40.0 % after meniscectomy, and return to sports activity was 96.2 % after repair compared with 50 % after meniscectomy [75].

On level I–IV systematic review and meta-analysis, at minimum 5 years follow-up, mild (grade I) degenerative changes were reported in five studies and ranged from 8 % to 25 % [54]. Failure rate was reported from 22.3 % to 24.3 %, but these results do not reflect the experience with the most recent all-inside devices [54].

Some authors reported higher failure rates for medial meniscus repair comparing to lateral [45]. However, a more recent study could not identify significant differences comparing success or failure rate of medial comparing to lateral meniscus [57].

Moreover, despite traditionally it has been stated that meniscal repair combined to ACL reconstruction provides better outcome, this fact was not confirmed in a study at more than 5 years follow-up [45]. The failure rate was 22.7 % in the eight studies reporting on meniscal repairs in ACL-intact knees compared with 26.9 % in the three studies reporting on repairs in ACL-reconstructed knees [45].

On another recent (level IV) study, Pujol et al. have shown at a mean follow-up of 114 ± 10 months that 23 patients displayed no

signs of osteoarthritis when compared to the non-injured knee, 6 patients had grade 1 osteoarthritis, and two had grade 2 [66].

The initial meniscal healing rate did not significantly influence clinical or imaging outcomes, and only 12.9 % of patients underwent subsequent meniscectomy [66].

Moreover, the risk for subsequent meniscectomy after meniscal repair is low (8.9 %), which also supports the fact that repairing a meniscus is a safe and effective procedure in the long term [46].

The risk for undergoing subsequent meniscectomies was decreased in patients undergoing a concomitant ACL reconstruction and in patients over 40 when compared to patients under 20 years old [46].

Moreover, it has been shown that the volume of subsequent meniscectomy after failed meniscal repair is not increased when compared with the volume of meniscectomy that would have been performed if not initially repaired [62].

For traumatic lateral meniscus tear approached during ACL reconstruction procedures [71] (level III), it seems plausible to provide the general recommendation to leave small (<1 cm) tears alone, repair large tears in vascular zone, and excise unstable tears in avascular zone [23] (level I).

The red-white (zone 2) (rim width 3 to <5 mm) of menisci has been considered the "gray" area for healing. A recent systematic review that addressed this topic could identify 767 repairs in zone 2 among a universe of 1,326 meniscus repairs [7] (systematic review levels I–IV). An acceptable midterm clinical healing rate was found for zone 2 meniscus repairs which might be connected to the development of surgical techniques and implants enabling more stable repairs. So, when indicated, repair in the zone 2 of menisci is possible and provides good results.

Another interesting topic is the combination of both approaches: combined meniscectomy and repair. Preserving as much tissue as possible through repair while resecting only what is considered irreparable, and a possible risk factor for mechanic problems or further aggravating the lesion. Limited related literature reports are available so far which impairs further conclusions.

The preservation of peripheral rim and the largest possible amount of meniscus tissue have positive implications in load transmission and contact area [5, 35, 66].

Ahn et al. [2] (level IV) described that in 6 of 78 cases, a partial medial meniscectomy in the avascular zone was performed, while the remaining tissue on the vascular zone was preserved by repair.

Another case reported described that after limited partial meniscectomy of unstable fragments of a radial tear while leaving alone the more peripheral part of the lesion in the vascular area resulted in self-healing (confirmed by second look arthroscopy) [28]. No evidence-based guidelines are possible, but the rationale for such approach can be discussed. The preservation of the meniscal rim is of paramount relevance in keeping the structure and biomechanical features. Moreover, if future replacement approaches are to be considered, preservation of meniscal rim is of critical relevance [14]. On the other hand, an unstable tear in the avascular zone, considered as irreparable, could be implicated in subsequent aggravation of the tear caused by repetitive motion in the site of injury. In such cases, it might be arguable that limited resection could help to preserve the meniscus and that the remaining tissue is still appropriate for repair. For practical purposes, it seems advisable (although debatable), in such cases, to first perform the repair and after stabilization of the meniscal tear remove the unstable part.

In general, the most recent meta-analysis concludes and reinforces that meniscal repairs have better long-term patient-reported outcomes and better activity levels than meniscectomy. Furthermore, meniscal repair had a lower failure rate than meniscectomy [80].

11.5 Complications

Arthroscopy meniscal repair shares some risks of complication which are common to any surgical procedure, namely, any arthroscopic procedure. These are considered out of the scope of this

work, and herein we will focus on specific complications of meniscal repair.

11.5.1 Neurovascular and Soft Tissue Complications

Meniscal repair of the posterior horn of both medial and lateral menisci is associated with risk of iatrogenic damage to neurovascular structures given the local anatomy (Fig. 11.6) [38].

The popliteal artery and common peroneal nerve are at some degree of risk during repair of the posterior horn of lateral meniscus.

On the other hand, the saphenous nerve (mainly its infrapatellar branch) is at risk during repair of medial meniscus posterior horn. To our best knowledge, there are no reports of injury of popliteal vein or tibial nerve with currently available repair devices.

Popliteal artery injury (fistulas, pseudoaneurysm, or even laceration) is extremely rare but has been reported [15, 16, 34].

This has been reported with all techniques, including all-inside [20]. When inside-out technique is used, a posterolateral approach (Table 11.3) is recommended to control the exit of the needles and lower the risk for injury.

All-inside or inside-out needles placed in the posterior horn of lateral meniscus are very close to the peroneal nerve [36].

Neuropraxia of the saphenous nerve (and its infrapatellar branch) is the most common neural injury with some authors reporting 22 % of transient saphenous neuropraxia in inside-out techniques [8].

Espejo-Baena et al. recommend a medial incision with the knee around 70–90° of flexion to reach a "safe zone" located between the surface of the fascia cruris and the medial collateral ligament [25].

Other soft tissue injuries reported during meniscal repair include entrapment of popliteal tendon and iliotibial band (during lateral meniscus repair) [25, 50].

Table 11.3 Posteromedial and posterolateral approach for protection of structures during posterior horn repair

Posteromedial approach	Knee around 70–90°
	3–4 cm below joint line
	Bucket-handle tears
	"Safe zone" located between the fascia cruris and the medial collateral ligament
	Pass sutures around 20° flexion
Posterolateral approach	3–4 cm made with knee at 90° flexion
	Stay posterior to lateral collateral ligament and keep short head of biceps femoris posterior
	Retractor anterior to the lateral gastrocnemius head
	Pass sutures around 90° flexion

Entrapment of the saphenous vein, medial collateral ligament, sartorius, gracilis, and semimembranosus tendons have been observed during medial meniscus repair [19, 25].

11.5.2 Complications Related to Meniscal Implants and Repair Devices

Several rigid meniscal repair devices are made of polylactic acid or derivates. The structure and integrity of such polymers decrease with time, and fragments might become loose inside (Fig. 11.13) or outside the joint [27]. As abovementioned, such device-specific complications include synovitis, inflammatory reaction, cyst formation, device failure/migration, and chondral damage [44].

Concerning all-inside devices, mainly during the learning curve period, some related complications include intra-articular loosening of the implant, intra-articular deployment of the device, suture failure or cutting during tensioning, or bending of the device itself during application. These might result in meniscal and/or chondral damage [51].

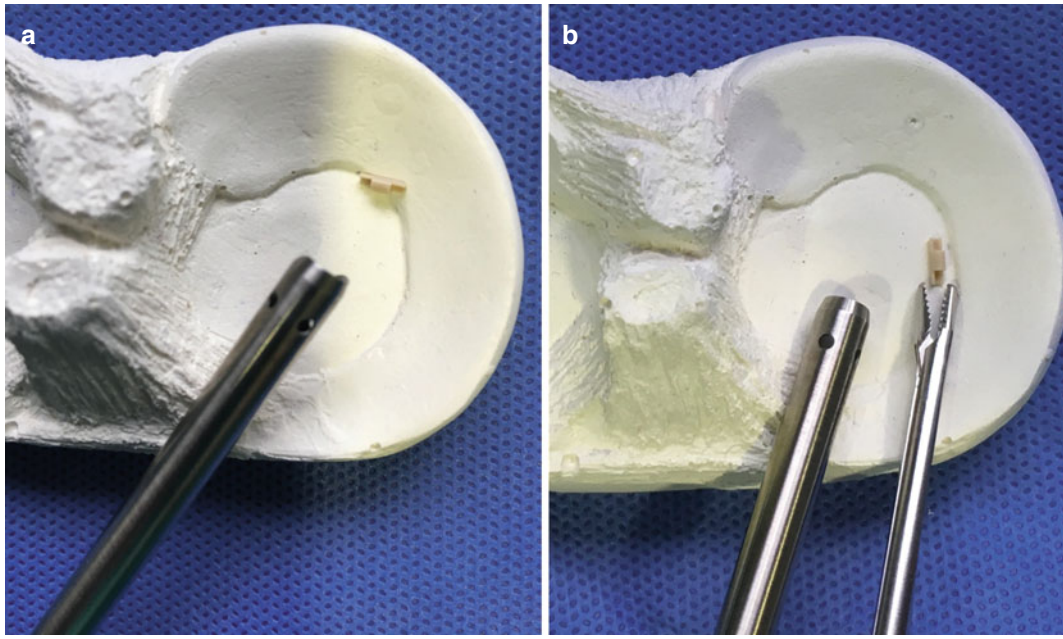

Fig. 11.13 Model demonstrating removal of a hard PEEK part of an all-inside device which can migrate intra-articularly (**a** and **b**)

Take-Home Message

Meniscal repair has proven to be effective, reproducible, and reliable if proper techniques and indications are respected. Some injuries previously considered as irreparable are currently found to be potentially reparable (e.g., horizontal cleavage tears, radial tears, root tears). There is a demanding learning curve for some techniques, and, in this sense, previous training and cadaver laboratory training courses are crucial. Preoperative planning relies on proper classification of tears, and, frequently, surgeons must be prepared with several repair options when dealing with some cases.

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12 Meniscal Allograft Transplantation: Indications, Technique and Results

Peter Verdonk, Nick Smith, Rene Verdonk, and Tim Spalding

12.1 Introduction

It is now recognised that menisci are important structures in the knee. Their primary role is load distribution, which is achieved by increasing the congruency of the tibiofemoral joint [6, 12, 27]. In the loaded knee, the lateral meniscus transmits 70 % and the medial meniscus 50 % of the load through the respective compartments of the knee [26]. The menisci have also been shown to provide secondary constraint to the knee [15–17].

Meniscal tears are common; a recent review of NHS knee operations in the UK found that the yearly incidence of meniscus-related surgery was 35 per 100,000 population [10]. Throughout the last century, treatment has shifted from complete excision to meniscal-preserving surgery where possible [2, 8]. Despite this, many tears are irreparable and there is a high failure rate of repaired tears [20]. The consequences of meniscectomy are now well understood. Biomechanical studies have shown that meniscectomy decreases the tibiofemoral contact area by 50–75 % and increases the peak contact pressure by 200–300 % [3, 19, 38]. Clinical studies have shown a high risk of OA following meniscectomy, with a recent meta-analysis finding a mean prevalence of knee OA of 53.5 % (range 16–92.9 %) at 5–30 years following meniscectomy [22].

Meniscal allograft transplantation was first performed in humans in 1984 and has been advocated for the treatment of patients with a symptomatic knee following a meniscectomy. Since then it has undergone a number of refinements and a large number of studies have been published in recent years.

This chapter presents, firstly, the indications for meniscal transplant; secondly, the surgical technique used by the authors; and, thirdly, the published clinical outcome results and data on the chondroprotective effect to support the advised indications.

12.2 Indications

The primary indication for meniscal allograft transplantation is a patient with a symptomatic knee and a history of meniscectomy in the

P. Verdonk, MD, PhD (✉)
Orthopaedic Surgery, Antwerp Orthopaedic Center, MoRe Foundation, Stevenslei 20, Deurne 2100, Belgium

Department of Orthopaedic Surgery, Antwerp University, Antwerp, Belgium
e-mail: pverdonk@yahoo.com

N. Smith
Clinical Sciences Research Laboratories, University of Warwick, Clifford Bridge Road, Coventry CV2 2DX, UK

R. Verdonk, MD, PhD
Orthopaedic Surgery, Maaltebruggestraat 260, Ghent 9000, Belgium

T. Spalding, MD
University Hospitals Coventry and Warwickshire, 5th floor UHCW, Clifford Bridge Road, Coventry CV2 2DX, UK

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symptomatic compartment. Symptoms may range from exercise-related pain to constant pain, swelling and/or stiffness. The upper age limit is usually 50–55 years of age but has occasionally been performed in older people [30]. It is generally agreed that alignment and stability of the knee should be normal or corrected at the time of surgery [30]. The amount of articular cartilage damage or OA is controversial, with the majority of surgeons reporting moderate or severe degeneration to be an exclusion criterion [30]. However this is not universal, and some studies have reported reasonable results in these patients. Stone et al. reported a failure rate of 22.4 % of 49 patients with moderate to severe articular cartilage damage, with a mean follow-up time of 8.6 years [33]. Kempshall et al. found a higher failure rate in patients with exposed bare bone at the time of transplantation compared to preserved articular cartilage, although patient-reported outcome measures (PROMs) in patients that did not fail were similar in both groups [11].

12.3 Surgical Technique

12.3.1 Overview of Surgical Technique Principles

The technique essentially involves dissecting the meniscus off the donor tibial plateau and preparing each end with nonabsorbable sutures which are then lead through carefully placed bone tunnels emerging in prepared insertion sites. The graft is passed into the knee through a slightly extended portal and fixed in place with a combination of all-inside devices and 'in-to-out' suture loops tied over the capsule. Sutures for the anterior and posterior sutures are tied over a bone bridge on the proximal tibia.

The key stages are:

1. Graft preparation
2. Arthroscopic set-up
3. Recipient preparation
4. Posterior and anterior horn tunnel preparation
5. Posteromedial or posterolateral 'middle' traction suture insertion
6. Insertion of the meniscal graft – 'parachuted in' using the leading sutures
7. Fixation of graft
8. Wound closure and post-operative rehabilitation

12.3.1.1 Patient Set-up

The procedure is performed under general anaesthesia with appropriate prophylactic antibiotics. The patient is supine on the operating table with a thigh tourniquet, single thigh side support and a footrest with the knee positioned at 90°.

12.3.1.2 Graft Preparation (Fig. 12.1)

The meniscus allograft is usually supplied as a medial or lateral hemi plateau with the meniscus attached. The graft is confirmed to be of the correct side and limb prior to the initiation of anaesthesia and is thawed to room temperature as per the tissue banks' specific instructions (usually about 15 min in warm water or 1 h in room temperature). The graft can be opened and prepared on the back table prior to the start of the surgery to reduce tourniquet time or can be prepared by an assistant whilst the knee arthroscopy is performed.

The periphery of the meniscus needs to be trimmed to the true margin of the meniscus and freshened with a sharp blade or needle to aid integration and healing once inserted.

The superior surface of the meniscus is marked to aid in orientation. In the case of the lateral meniscus, the most anterior margin of the popliteal

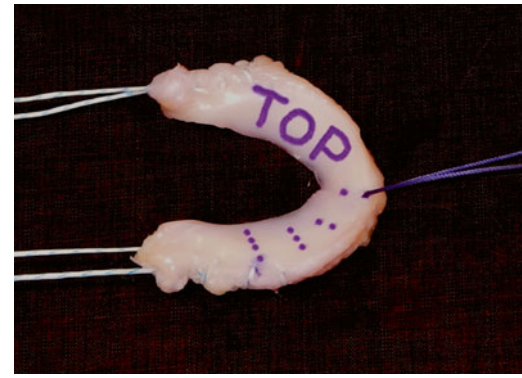

Fig. 12.1 Final preparation of a meniscus allograft showing high-strength sutures at the anterior and posterior horn and a middle traction suture

hiatus is also marked, and a number 2 nonabsorbable suture is placed as an oblique vertical mattress. For the medial meniscus, a point is marked at 40% of the circumference from posterior to anterior, and a number 2 nonabsorbable suture is placed as a vertical mattress. These sutures represent the middle traction suture.

The meniscus is sharply dissected off the plateau, and care is taken to debulk the attachment point of the meniscal horns of any excess soft tissue.

The anterior and posterior horns of the allograft are then prepared. Number 2 Ultrabraid sutures (or equivalent) are placed into the posterior and anterior roots using a modified whip stitch, passing the suture a minimum of three times along the meniscus and back again to ensure a good hold. It is important to ensure the sutures emerge on the inferior aspect of the footprint of the meniscal horn. The graft is then wrapped in a vancomycin-soaked swab (500 mg in 100 ml saline) and placed securely on the scrub table awaiting implantation.

12.3.1.3 Knee Arthroscopy

The thigh tourniquet is inflated after all the draping and preparation has been performed in order to maximise tourniquet time for the surgery. Longitudinal anteromedial and anterolateral arthroscopy portals are made just next to the patella tendon. Longitudinal incisions are preferred to allow extension of 1–2 cm for insertion of instruments and the graft.

A complete knee arthroscopic examination and assessment is then performed documenting the state of the joint surfaces and treating any coexistent pathologies. Particular attention should be paid to the integrity of the opposite compartment if a concomitant offloading osteotomy is to be performed.

A decision is made as to management of chondral lesions in the affected compartment, noting that the optimal indication for transplantation is chondral surfaces showing changes of ICRS grade 3b or less. Small areas of bare bone can be treated by the microfracture procedure. Treatment options for larger cartilage defects include microfracture and cartilage transplantation.

12.3.1.4 Recipient Preparation

The host meniscus is assessed and prepared by resecting remaining meniscal tissue using a combination of arthroscopic punches and a shaver to leave a 1–2 mm peripheral vascular rim of native meniscal tissue that will support the meniscal allograft. The recipient bed and synovium is rasped using the diamond tip rasp and fenestrated with a microfracture awl to assist with healing and vascularization of the graft.

12.3.1.5 Posterior and Anterior Horn Tunnel Position and Preparation

The tunnel positions for meniscal horn attachment points are identified in the knee. This is prepared using a combination of an angled punch to resect the remaining meniscus, the meniscal shaver and a closed cup curette, exposing subchondral bone.

Care is taken to ensure an adequate bone bridge is created anteriorly for the transosseous suture. The shaver is used to remove soft tissue, and with appropriate force on the blade, it is often possible to expose bleeding subchondral bone at this point.

To prepare the bone tunnels for the meniscal horn sutures, a 2 cm horizontal skin incision is made on the proximal tibia, on the contralateral side, just below the flare of the tibia. A 1 cm area of bare bone is exposed and marking the periosteum with cautery.

12.3.1.6 Posterior and Anterior Horn Tunnel Creation

The meniscal allograft transplantation drill aimer guide is inserted through the contralateral portal and positioned in the posterior horn insertion point. The drill guide sleeve is then inserted into the handle and positioned onto the tibia through the prepared incision.

The posterior horn suture tunnel is drilled with a long 2.4 mm-diameter beath pin, visualising the tip emerge through the bone. The guide wire is overdrilled with the endobutton 4.5 mm drill (Smith and Nephew), carefully positioning the tip just proud of the tibial plateau surface (Fig. 12.2). A closed curette can be used during the drilling

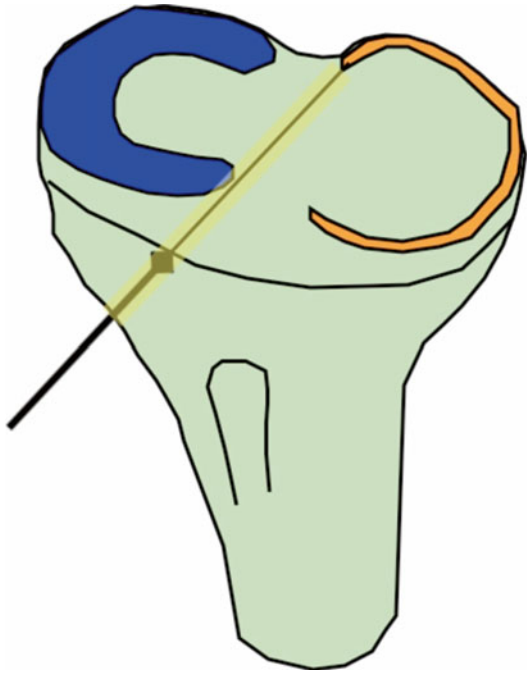

Fig. 12.2 The guide wire located in the posterior horn insertion area of the native meniscus is overdrilled with the 4.5 mm drill, carefully positioning the tip just proud of the tibial plateau surface

process to help protect inadvertent damage to articular surfaces and to help retract meniscal tissue, aiding visualisation. The guide wire is removed, leaving the endobutton drill bit in situ. A looped end of a 2-0 Prolene is passed through the endobutton 4.5 mm drill bit on a suture passer (Suture Retriever, Smith and Nephew), and the suture loop is retrieved through the ipsilateral portal using a suture manipulator. The free end of this lead suture is passed through the loop and clipped so that it hangs unsupported out of the way.

The meniscal transplantation drill aimer guide is reintroduced through the contralateral portal. The tunnel for the anterior horn is drilled in the centre of the attachment footprint, using a 2.4 mm guide wire and 4.5 mm endobutton drill, followed by insertion of a loop of 2-0 Prolene suture on the suture retriever, in a similar manner to the posterior horn tunnel. The suture is brought out through the ipsilateral portal, next to the posterior horn suture. Once again care needs to be taken to avoid twisting the suture loops, and the orientation is checked with the suture manipulator.

12.3.1.7 Middle Traction Suture

The next stage is insertion of two loops for the posteromedial or posterolateral traction and fixation suture. An 18 gauge needle is used to localise the correct insertion point. An ACCU-PASS suture device (Smith and Nephew) preloaded with No 1 PDS is then used, from outside-in, to position two loops of sutures on the superior and inferior aspect of the meniscal bed directly above each other. Each loop is then gathered through the ipsilateral portal and clipped to one side, once again checking with the suture manipulator. Care is given to clearly identify the inferior and superior suture loops separately by, for example, clipping the inferior one with a large clip and the superior one with a smaller clip.

12.3.1.8 Graft Passage

All sutures on the graft are then pulled into position using the preplaced shuttle sutures, and the graft is delivered into the joint through the lateral portal by traction on the posterior and middle sutures. Sometimes it is necessary to 'persuade' the meniscus into position under the femoral condyle using the arthroscopy blunt obturator. The anterior and posterior horn sutures are then held temporarily over the bone bridge using a single knot throw and a clip. The graft is inspected arthroscopically to assess graft size and position, ensuring it is snug against the meniscal bed.

12.3.1.9 Graft Fixation (Fig. 12.3)

The graft is fixed using a hybrid technique of all-side, inside-out and outside-in suture systems. The first all-inside meniscal repair device is introduced using a slotted cannula. Holding tension on the middle sutures, the posterior third is fixed to the prepared meniscal rim using the all-inside system by inserting sutures on the superior and inferior surfaces in a stacked vertical mattress pattern to the capsule. Portals can be switched to ensure adequate fixation. A minimum of three suture devices are recommended, and by joysticking with the needle, the allograft can be optimally placed on the rim.

The mid- and anterior thirds are sutured using an inside-out technique with 2-0 Ultrabraid (Smith and Nephew), or similar, loop sutures inserted

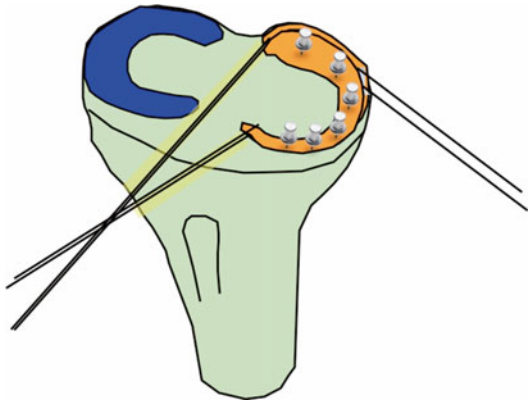

Fig. 12.3 The meniscus allograft is fixed by an anterior and posterior horn traction suture, a middle traction suture and multiple all-inside (posterior horn), inside-out (middle segment) and outside-in (anterior horn) sutures. The first suture should be located in the posteromedial or posterolateral corner, subsequently fixing the posterior segment and then progressing the fixation in the middle and anterior segment

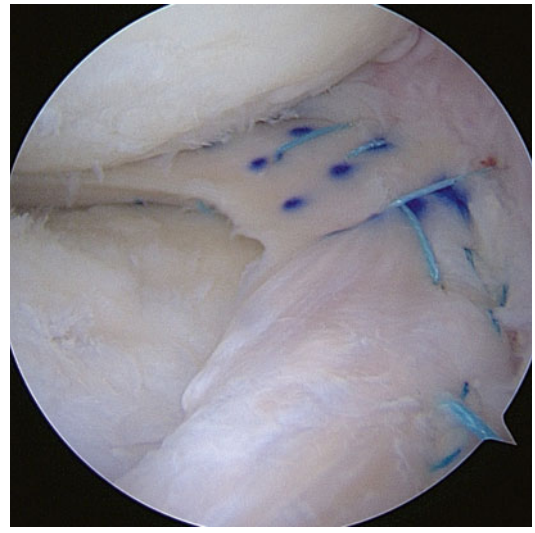

Fig. 12.4 Meniscus allograft is well fixed within the native rim of the meniscus. Clear vertical and horizontal sutures are visible

from the opposite portal in a vertical loop pattern. A curved cannula system such as the Meniscal Stitcher system (Smith and Nephew) is used preferably achieving at least six loops in the body and anterior third. If there is inadequate suture hold on the anterior 1–2 cm, then outside-in needle suture placement is required, using the Meniscal Mender suture system (Smith and Nephew).

12.3.1.10 Final Suture Fixation

The inside-out sutures initially emerge directly through the skin. Once the fixation is complete, a 2 cm longitudinal incision is made between the sutures on the knee, taking care to avoid damaging the suture threads. Dissection scissors are used to spread the subcutaneous sutures in a longitudinal direction down to the capsule. With a langenbeck-style retractor elevating the skin, the sutures can be seen and retrieved using an arthroscopic hook.

12.3.1.11 Tying the Sutures

When tying the sutures, it is important to evaluate the position of the meniscus in the knee. Sutures should be tied so the meniscus fits snuggly against the capsule (Fig. 12.4). In general, the capsule sutures are tied first and the order determined by the visual assessment of the meniscus. Finally, the anterior and posterior horn sutures are tied under strong tension over the bone bridge. This has the effect of pulling the meniscus and capsule into the correct position and thus minimising radial displacement extrusion.

Wounds are irrigated with saline. All sharps and instruments are retrieved and confirmed and the wounds closed. Local anaesthetic infiltration is performed according to personal preferences.

12.4 Patient-Reported Outcomes

Virtually all case series evaluating meniscal allograft transplantation reported in the literature show an improvement in PROMs at latest follow-up [30, 37]. The Lysholm score [34] has been the most commonly used PROM to evaluate the outcome following meniscal allograft transplantation [30]. In 2015, a systematic review showed a pooled baseline score of 55.7 and latest follow-up score of 81.3 (out of 100), across 25 studies [30]. The mean follow-up length for the papers in the systematic review was 5.1 years. The same systematic review also found a weighted mean IKDC subjective knee scores [9] of 47.8 and 70 (across 12 studies) and

Tegner scores [34] of 3.1 and 4.7 (across 10 studies) at baseline and final follow-up, respectively. Similar scores have been found in other recent systematic reviews, although some different studies were included, depending on the research question of the paper [24, 37]. Most studies report PROMs at short- to midterm follow-up. One study with one of the longest follow-up periods (mean 13.8 years) showed a baseline Lysholm score of 36 (range 5–86) and latest follow-up of 61 (range 21–91) [35]. One systematic review ordered PROMs by length of follow-up, showing a trend towards worsening PROM scores with time, although still higher than baseline scores [7].

12.5 Return to Sports

It is not universally agreed whether patients should be allowed to return to full sporting activities following meniscal allograft transplantation. Some surgeons place lifelong limits on pivoting/cutting sports due to stress on the transplant and potential risk of failure. However in published studies, it is more common for surgeons to allow return to full sporting activities by 6–12 months [30]. One study specifically analysed whether return to sporting activities resulted in increased complications or failure, finding no correlation [32]. A limited number of case series have reported return to sports in elite and professional athletes, finding that the majority were able to get back to preoperative sporting levels [25].

12.6 Radiological Outcomes

There have been relatively few studies reporting the radiological outcome following meniscal allograft transplantation. The most commonly reported outcome is change in joint space width. A recent systematic review found 16 studies (428 knees) that had reported change in joint space width over a mean of 4.5 years [31]. They found a weighted mean narrowing of 0.03 mm over the entire follow-up period. Other studies that used the contralateral knee for comparison found no significant differences, although sample sizes were usually small [23, 28].

A limited number of studies have looked at other radiological tools of OA progression, including the Kellgren and Lawrence classification, IKDC radiological scores and Fairbank classification, showing variable outcomes from limited to advanced OA progression [31]. A few studies have reported changes in articular cartilage on MRI scans following meniscal allograft transplantation [31]. Verdonk et al. reported changes on patients at an average follow-up of 12.1 years, finding no further progression of articular cartilage degeneration on the femoral condyle and tibial plateau in 47 % and 41 % of patients, respectively, including 35 % of patients with no progression on both sides of the joint [36].

Graft extrusion has been extensively reported following meniscal allograft transplantation, although there are wide variations in the timing, method of measurement and measures themselves. A recent systematic review on meniscal transplant extrusion found 23 studies (814 transplants) reporting graft extrusion but was unable to draw conclusions due to the variability of reporting within these studies [21]. Another systematic review reported that in studies reporting absolute extrusion, the mean extrusion was between 1.7 and 5.8 mm [31]. Where studies had reported the relative percentage extrusion, the rates were between 19.4 % and 56.7 %.

A number of studies have looked for a correlation between clinical scores and the amount of extrusion, with most studies finding no correlation [31]. Other studies have reported correlations between graft extrusion and other measures: Lee et al. found a more anterior allograft placement correlated with the degree of extrusion [14], Abat et al. found a suture-only technique resulted in higher extrusion compared to bone plugs [1], and Choi et al. found an association with meniscal extrusion to increased lateral positioning of the bone bridge [5]. However, the clinical relevance of these findings is not known.

12.7 Complications and Failures

Reporting of complications is highly variable across reported case series. The weighted mean complication rate has been reported as between 11 % and 14 % following meniscal allograft transplantation, but this is likely to be an underestimate of the true complication rate [24, 30]. A recent large case series of 172 meniscal allograft transplantations reported a reoperation rate of 32 %, which may reflect a more accurate complication rate [18]. The most common complication is retear of the allograft; other complications include synovitis or effusion and superficial infection.

Failure rates, defined as conversion to arthroplasty or removal of the allograft following a tear or failure to integrate, also vary considerably, with the weighted mean failure rate across case series being reported as 10.9 % at 4.8 years [30]. A recent large case series reported a 95 % survival at a mean of 5 years [18]. Case series with longer follow-up show less promising results, with a 33–36 % midterm failure rate being reported across a number of studies [13]. This is also supported by Verdonk et al. who found a 70 % survival at 10 years to be supported by current evidence [37]. It is difficult to know the survival past 10 years, especially as changes in graft type, operative technique and rehabilitation make inferences from historical studies difficult. One of the studies with longest follow-up reported a 29 % failure rate at a mean of 13.8 years following 63 open transplantations [35].

12.8 Discussion

The high risk of symptomatic OA following meniscectomy has been consistently shown over the last few decades in many publications. Meniscal allograft transplantation has been shown to at least partially restore normal contact forces across the knee, suggesting that it may be able to restore knee biomechanics [19]. Case series have consistently shown that patients have an improvement in PROMs at all follow-up time points, although there is a lack of controlled studies in the literature. These results are encouraging in a patient group with otherwise very limited treatment options. The retear and failure rates are not low, but they must be considered in the context of the severity of symptoms and the lack of effective alternative treatment options.

It is scientifically plausible that meniscal allograft transplantation is chondroprotective, but direct evidence of this is currently limited [29]. The negligible loss of joint space width reported across a number of studies is encouraging. Although direct comparisons to the native knee cannot be made, the relative risk for OA has been shown to be low in patients with joint space narrowing of less than 0.7 mm over 3 years [4]. However it is not known what effect the allograft itself has on the joint space measurement. Animal model studies have shown meniscal allograft transplantation to be chondroprotective, but these studies have not been replicated in humans to date.

From this data the evidence appears to justify the stated indication for meniscal allograft transplantation – pain and symptoms in the affected compartment in a young patient with a meniscal-deficient knee. This indication seems to be universal. It is also commonly accepted that alignment and stability should be normal or corrected at the time of surgery. From the evidence, it is not clear whether patients should be offered meniscal allograft transplantation in the presence of moderate or severe articular cartilage damage. It is likely that the success rates are lower, but in the absence of alternative treatments, meniscal allograft transplantation may be a reasonable treatment option for these patients.

Conclusion

Meniscal allograft transplantation is an effective treatment for patients with a symptomatic meniscal-deficient knee. At present there is not enough evidence to determine whether it is chondroprotective, although some studies support this hypothesis. Whilst alternatives such as tissue engineering may supersede meniscal allograft transplantation in the future, it currently provides the best chance of a functional improvement in carefully selected patients.

Take Home Messages

- Meniscal allograft transplantation has now been performed for over 30 years.
- Based on current evidence in the literature, meniscus allograft transplantation is a safe procedure with an acceptable complication rate.
- Current evidence clearly quantifies the clinical benefit observed after MAT but evidence for the chondroprotective effect remains indirect
- The evidence supports meniscal allograft transplantation as the treatment of choice for the symptomatic post-meniscectomy knee not responding to conservative therapy.

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Implantable Devices for Cartilage Repair in the Knee: Scaffolding

13

Stefano Zaffagnini, Alberto Grassi,
Tommaso Roberti di Sarsina,
Giulio Maria Marcheggiani Muccioli,
Margherita Serra, and Maurilio Marcacci

13.1 Introduction

The most actual and effective method to substitute the meniscus with synthetic devices is the scaffolding. The concept of a meniscal scaffold was introduced in the early 1990s to prevent or delay the deleterious effects of meniscal deficiency. The rationale behind the use of a meniscal scaffold was to replace meniscal deficiency with a three-dimensional structure capable of supporting the production of a meniscus-like fibrocartilaginous tissue. At the time of this writing, two scaffolds are approved and available for clinical use in humans: the CMI® and the Actifit®.

13.2 The Scaffolds

The *CMI*® (Ivy Sports Medicine GmbH, Gräfelfing, Germany) is a porous collagen-glycosaminoglycan (GAG) matrix of defined geometry, density, thermal stability, and mechanical strength [14] composed of about 97 % purified type I collagen, the most commonly found protein in the body. The remaining portion of the CMI consists of GAGs, including chondroitin sulfate and hyaluronic acid. The type I collagen is isolated and purified from bovine Achilles tendon, and then the collagen-GAG complex is chemically cross-linked to improve in vivo stability and implant handling characteristics.

After in vitro studies that supported cellular ingrowth, the CMI® was tested on animal models showing initially no evidence of cartilage wear or damage with evidence of meniscal tissue regeneration [24, 25]. Latter animal studies confirmed these findings showing healing of the implant with regenerated tissue at the host meniscus and increasing amounts of tissue invasion with associated resorption of the CMI over serial time points. In a canine model, there was complete CMI resorption and replacement at 6 months. Furthermore, MRI provided excellent correlation with the gross and histological observations, supporting the findings of continued tissue ingrowth and maturation over time.

The CMI, already available for the European market, recently received FDA approval for the clinical use in the United State.

The *Actifit*® (Orteq Ltd, London, UK) is a synthetic polymeric scaffold of which 80 % consists of a biodegradable polyester (polycaprolactone) and the remaining 20 % made of polyurethane. The polyester portion provides flexibility and controls the degradation rate, while the semidegradable stiff polyurethane portion provides mechanical strength. To obtain a material with excellent mechanical proprieties,

S. Zaffagnini (✉) • A. Grassi • T.R. di Sarsina
G.M.M. Muccioli • M. Serra • M. Marcacci
Clinica Ortopedica e Traumatologica II, Istituto Ortopedico Rizzoli, Bologna, Italy

Laboratorio di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Bologna, Italy
e-mail: stefano.zaffagnini@biomec.ior.it

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the polyurethane is made without a catalyst contributing to polymer biocompatibility and uniformity [4].

The Actifit® scaffold underwent extensive animal testing. Canine studies revealed fully integrated scaffolds following implantation into meniscectomized joints with evidence of meniscus-like tissue ingrowth and very mild signs of immunological response [27]. Further studies confirmed the safety of the scaffold, showing no deleterious effects on the articular cartilage and a friction coefficient similar to native meniscus after 3 months [16, 28].

The Actifit® at the moment of the present chapter is available for clinical use only in countries outside the United States.

13.3 Patient Selection

Surgery for the symptomatic meniscus-deficient knee should be considered only after exhausting all nonsurgical measures. Accurate patient selection and both clinical and radiological evaluation is mandatory in order to obtain a good result and prevent early failure.

The main *indications* to meniscal replacement with scaffolds are:

- Prior loss of meniscus tissue.
- Irreparable meniscus tears requiring partial meniscectomy, either traumatic or chronic posttraumatic meniscus tear.
- Meniscus damage requiring greater than 25 % removal.
- With intact anterior and posterior attachments and intact rim over the entire circumference (except for the area of popliteal hiatus for lateral meniscus).
- In case of ACL deficiency, it should be corrected within 12 weeks of scaffold implant.
- Compliance with postoperative rehabilitation program.

Treatment of acute meniscal lesion with meniscal scaffold remains controversial as a multicentric study published by Rodkey et al. using medial CMI® [21] reported no differences when compared to partial meniscectomy in acute meniscal lesions at midterm follow-up. However, currently no analogous studies are available with Actifit®, and the long-term cartilage protection of these implants has been properly studied.

The main *contraindication* for meniscal replacement with scaffolds are:

- Concomitant PCL insufficiency of the involved knee
- Diagnosis of untreated grade IV degenerative cartilage disease in the affected joint
- Uncorrected malalignment
- Systemic or local infection and evidence of osteonecrosis in the involved knee
- Conditions like rheumatoid arthritis, relapsing polychondritis, severe degenerative osteoarthrosis, and inflammatory arthritis

Generally, advanced chondral degeneration is the most common contraindication; however, it may be addressed concomitantly with chondrocyte transplantation, osteochondral grafting, or synthetic scaffolds in case of localized chondral defects. Also malalignment is reported to cause abnormal pressure on the affected compartment; therefore, a corrective osteotomy should be considered when properly indicated. The absence of symptoms remains a controversial issue, as prophylactic meniscus scaffold implantation is not routinely recommended.

13.4 Preoperative Evaluation

Obtaining an accurate history of knee trauma, injuries, and surgical procedures is mandatory when initially evaluating the patient. Knee pain, swelling, and mechanical symptoms exacerbated by physical activity are typical complaint after several years of adequate knee function postmeniscectomy. A targeted physical examination should be performed and height, weight, and BMI collected as well. With the patient standing, lower limb alignment is evaluated. The range of motion and ligamentous stability are assessed both for affected and contralateral knee. Pain and tenderness should be reported exclusively in the

affected compartment, and ipsilateral quadriceps strength and circumference reduction can be noted as consequence of knee pain.

Radiological evaluation should be obtained as well pre-surgically. Weight-bearing anteroposterior (AP) radiographs of bilateral knees in full extension and a non-weight bearing at 45° of flexion lateral radiograph are required. Roseberg views (45° flexion weight-bearing posteroanterior radiograph) are also helpful to detect subtle joint space narrowing, while long-view mechanical axis radiography is necessary to assess for limb malalignment. MRI is helpful to evaluate the meniscal defect, ligament lesions, subchondral bone pathologies, and cartilage status.

13.5 Surgical Technique

Meniscal replacement with scaffold is a surgical procedure that is mainly performed arthroscopically; therefore, surgical skills are required in order to achieve good placement and device fixation. Although medial and lateral scaffolds are different in shape and size, the surgical technique is almost the same.

13.5.1 Patient Position

The patient is positioned supine with tourniquet insufflated to 300 mmHg, and the knee is flexed to 90°. A leg holder is placed 5 cm proximal to the superior pole of the patella in order to allow valgus stress to open the medial compartment, while opening of lateral compartment is achieved flexing the leg over the contralateral knee in the "figure-of-four" position.

13.5.2 Arthroscopic Setting

A medial suprapatellar portal is usually performed for the water inflow, while routine anteromedial (AM) and anterolateral (AL) portals are made for scope and instruments. The AL portal is placed distal to the pole of the patella at the soft spot, about 1–2 cm lateral to the patellar tendon; the AM portal is placed at the same level, about 1–2 cm medial to the patellar tendon. Then a thorough arthroscopic examination is performed to verify if all the indications to meniscal replacement are fulfilled. ACL and cartilage status are assessed to correctly plan if additional procedures are required.

13.5.3 Preparation of the Implant Bed

A full-thickness defect with a stable meniscal rim over the entire length is obtained removing any degenerated or unstable meniscal tissue using basket and motorized shaver (Fig. 13.1). When the defect reaches the white/red zone, a microfracture awl is used to obtain bleeding at the meniscal rim. The anterior and posterior attachment points should be trimmed square (radially) to better match the scaffold and improve device stability. A medial release with outside-in needle punctures and varus stress can be performed without leading to residual laxity if the medial compartment is too tight for proper visualization. Alternatively, lateral compartment tightness and difficulty placing the scaffold into the defect represent an intraoperative contraindication implantation as poor healing and lateral laxity are a significant problem when lateral collateral ligament release is performed.

13.5.4 Preparation of the Scaffold

The previously prepared defect is measured using a specially designed measuring device through the ipsilateral portal starting from the posterior aspect of the lesion (Fig. 13.2a). The implant is oversized by 10 % in order to obtain a good press fit with improved stability. When popliteal hiatus is included in the meniscal defect, it could be necessary to oversize the scaffold by 15–20 % since it may recess into the hiatus during fixation.

Once the correct size has been established, the scaffold is removed from the sterile package and trimmed using a fresh scalpel with an effort to match the angle of obliquity of the anterior and posterior aspect of the implant to the recipient site (Fig. 13.2b).

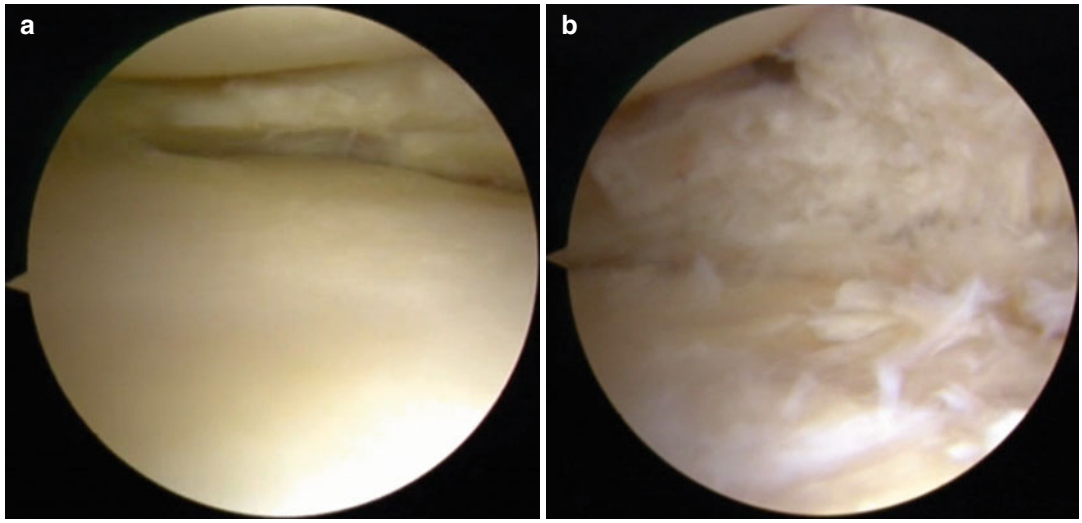

Fig. 13.1 The meniscal lesion is identified arthroscopically (**a**), and any degenerate or unstable meniscal tissue is removed in order to obtain a full-thickness defect with a stable meniscal rim over the entire length (**b**)

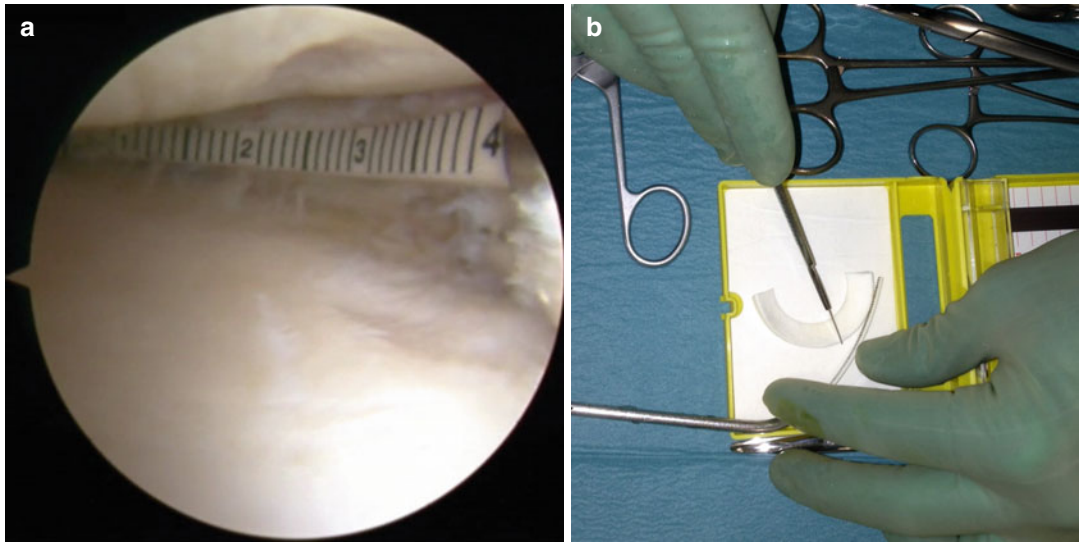

Fig. 13.2 A specially designed measuring device is inserted in the knee joint in order to exactly measure the length of the meniscal defect (**a**). With a scalpel the CMI is then trimmed according to the correct size previously measured (**b**)

13.5.5 Scaffold Fixation

The prepared scaffold is mounted on a curved atraumatic vascular clamp and directly inserted into the joint through the corresponding portal that should be enlarged enough to accommodate the tip of the fifth finger (Fig. 13.3a). It is then released and manipulated to reach the correct position with a blunt probe (Fig. 13.3b). Then the scaffold is sutured to the capsule standard suturing technique or, alternatively, with all-inside sutures. This new-generation meniscal repair takes advantages of both all-inside technique and biomechanical suture properties

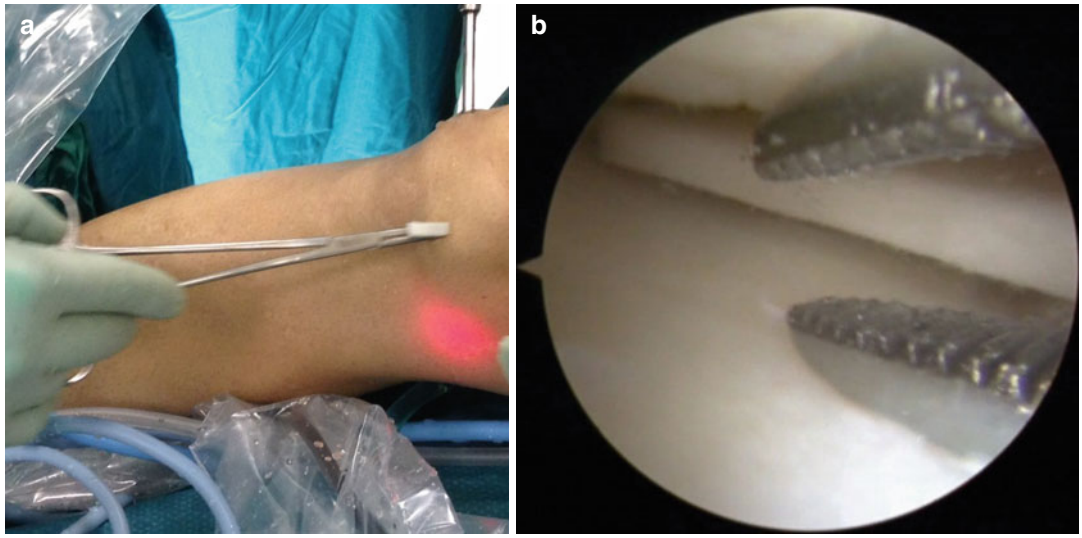

Fig. 13.3 The CMI is mounted on a curved clamp and directly inserted into the joint through the corresponding portal (**a**) and then released in the proper position (**b**)

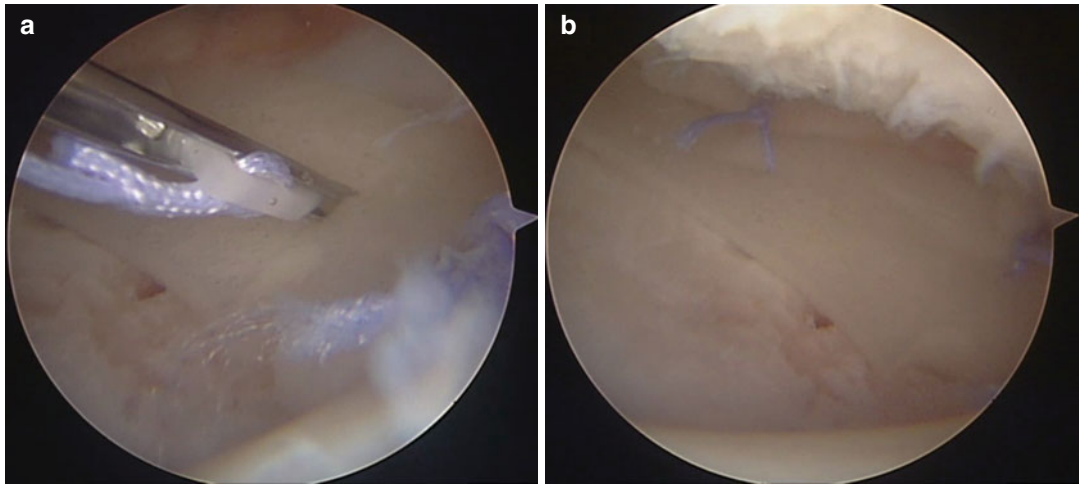

Fig. 13.4 The tip of the FasT-Fix device is inserted through the CMI (**a**) and the first "anchor" is released. Then the capsule is pinched just above the first passage of the stitch. After the release of the second "anchor" of the device, the stitch is pulled and the remaining suture is cut, obtaining a vertical stitch (**b**)

(Fig. 13.4). Sutures are placed vertically using a standard technique every 5 mm along the periphery of the device, while anterior and posterior borders are fixed with two horizontal/oblique sutures. An inside-out suture placed every 5 mm could be used alone or in combination with this all-inside approach, although requiring the execution of posterolateral or posteromedial portals is required to accesses and retrieve sutures. When a lateral scaffold is implanted, care should be taken to avoid placing sutures directly through the popliteal tendon, because the physiological micromotion of this tendon might damage the still immature scaffold. Once the scaffold is sutured, stability is checked with a probe, tourniquet is released, and a drain (if used) is positioned with no suction.

13.5.6 Concurrent Procedures

ACL reconstruction is the most frequent procedure associated with meniscal replacement. As ACL reconstruction has been reported to create a more favorable environment for meniscus healing after repair [13], combined ACL reconstruction and scaffold implantation is recommended, when indicated. Scaffold insertion and fixation should be performed before definitive fixation of the ACL graft, in order to allow better medial or lateral joint opening during stress maneuvers. Similarly, when staged procedures are planned, meniscal replacement should be performed first. However, ACL reconstruction should be delayed for no more than 12 weeks after scaffold implantation as knee instability could jeopardize the healing of the scaffold.

Knee osteotomy is a frequently combined procedure as well, as neglected lower extremity malalignment represents a contraindication to scaffold implantation. We recommend a closing wedge lateral high tibial osteotomy (HTO) [17] to correct for varus deformity as it has been demonstrated to reduce tibial slope reducing stress on the native or reconstructed ACL [5, 6, 30]. Valgus deformity is instead addressed through a closing wedge medial distal femoral osteotomy (DFO). When combined scaffold implant and HTO or DFO are performed, the arthroscopic device implantation should be performed first.

As advanced cartilage damage represents an explicit contraindication to meniscal replacement, no clear indications on cartilage treatment and scaffold implantation are available. Cartilage damage could be addressed through microfracture, osteochondral transplantation, or autologous chondrocyte implantation (ACI) according to the cartilage status; however, these procedures should be performed before scaffold implantation in order to try to preserve the device. Therefore, if performed in sequence, meniscal replacement should be planned at least 3 months after the cartilage procedure. Some surgeons may choose to perform the procedures concurrently.

13.6 Rehabilitation

The rehabilitation after scaffold implantation resembles the protocol after meniscal repair or meniscal allograft transplantation. Therefore, extreme care is mandatory in order to allow scaffold healing and good outcome. The program usually covers a period of 6 months and offers a balanced combination of strengthening and motion exercises providing protection of the newly formed tissue throughout the delicate process of regeneration.

The program starts with 1 month of non-weight bearing and full-time extension knee brace that is removed only to allow progressive passive joint mobilization. Complete weight bearing should be allowed after 6–8 weeks after the implantation, while full range of motion (ROM) should be obtained at the sixth week postoperatively. Light exercises, including isometric quadriceps exercises, mobilization of the patella, heel slides, quad sets, anti-equinus foot exercises, and Achilles tendon stretching are advised from week 1. Increased open and closed exercises, jogging on level ground, and sport-related exercises without pivoting could be performed since the third month. Gradual resumption of sport activity is allowed at the sixth month; however, contact sports should be delayed until the ninth month. In order to optimize the outcome, strict adherence to the program is mandatory, even when the patient feels able to return to his accustomed activities sooner than expected. In case of concurrent procedures, the rehabilitation program should be tailored accordingly.

13.7 Risks and Complications

There have been no reported risks specific to the CMI® and Actifit® implants. Most reported complications are related to the surgical technique. Saphenous nerve injury has been reported after medial scaffold implantation as a possible consequence of suture placement [2]. Knee instability could theoretically represent a drawback of excessive medial or lateral release performed to allow the compartment opening [21], while

popliteus tendon entrapment could be caused by improper scaffold fixation when the popliteal hiatus is involved. Other complications like pain, swelling, wound infection, and deep vein thrombosis have been with the incidence ranging from 0 to 32 %, depending on the length and detail of follow-up.

Failures and reoperation rate are about 10 % at midterm, and the causes include persistent pain, swelling, infection, or mechanical failure of the scaffold.

13.8 Results

Outcomes following CMI® implantation have been extensively studied. A recent systematic review [9, 32] reported improvement of clinical scores, sport activity, and pain relief after the implantation, with stable results also at long term. Satisfactory outcomes were achieved in about 70 % of patients [10]. The pivotal study of CMI® surgery is a multicenter randomized controlled trial performed by Rodkey et al. [21] enrolling about 300 patients comparing medial CMI® implantation to medial meniscectomy at 5 years of follow-up. The authors reported better results and lower reoperation rates in patients with chronic meniscal deficiency treated with CMI implantation. Regarding acute meniscal lesions, no significant differences have been found compared to the control group, and the primary indications for CMI® remain for patients following previous meniscectomy and proper symptoms. The potential long-term chondroprotective effect of the scaffold have been studied by [9, 35] with a controlled clinical trial revealing reduced signs of knee osteoarthritis and better clinical results (pain and function) in patients treated with medial CMI®. Good results have been reported also in lateral CMI® [11, 33, 34]. Overall, the clinical results appear to improve after 6 months and peak at 1-year follow-up and to remain generally stable at 10 years of follow-up [9].

Regarding combined procedures, Hirschmann et al. [11] reported a case series of 67 patients where 53 of them were treated with medial or lateral CMI combined with ACL reconstruction showing a wider area of bone marrow edema and inferior clinical results compared to isolated CMI® at 1-year follow-up. [1, 2] compared the long-term outcomes of combined medial CMI® and ACL reconstruction with partial medial meniscectomy and ACL reconstruction. The authors reported improvements in both groups, with significantly better pain reduction in the chronic patients treated with the scaffold. Linke at al. [15] performed a controlled study involving 60 patients with varus alignment and medial meniscus deficiency showing no significant difference at short term between patients that underwent high tibial valgus osteotomy (HTVO) plus medial CMI® and isolated HTVO. Other authors reported good results after combined CMI® implantation and microfractures or MACI [7, 22, 26, 31].

Histologic specimens obtained from second-look arthroscopy revealed the presence of regenerated tissue similar to the fibrous composition of meniscal cartilage after 6 months [26]. Other studies have reported inhibition of osteoarthritic degeneration at 24 months follow-up [20] and progressive resorption of the scaffold with complete absence of the implant at 5 years [3]. MRI evaluation showed an early progressive reduction of scaffold size, followed by a slower change of signal intensity toward an isointense signal analogous to normal meniscus (Fig. 13.5) [3, 8, 9, 19, 33].

The clinical experience with Actifit® is still limited due to its more recent European Union regulatory clearance allowing distribution and implantation in July 2008. However, the results are promising and not inferior to CMI®. The main clinical data is derived from one single multicentric European study of 52 patients with both medial and lateral meniscal defects following previous meniscectomy. The clinical evaluation showed significant improvements in knee function, pain, and sports activity after 6 months with maintenance of the results at 12 and 24 months. Two-year reoperation and failure rate was 17.3 %, mostly due to the surgical procedure and not to the scaffold itself, while only 7 % of the adverse events registered during the follow-up were

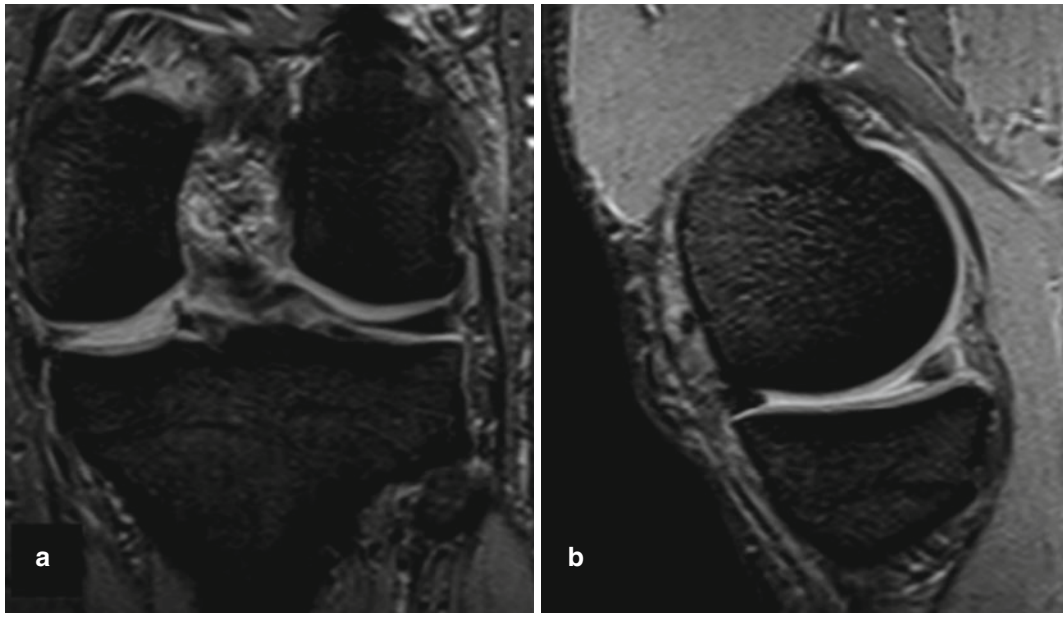

Fig. 13.5 Magnetic resonance appearance of a medial CMI 10 years after the implant on coronal (**a**) and sagittal (**b**) view. The scaffold is still clearly visible but with a reduced size and slightly higher signal compared to native meniscus

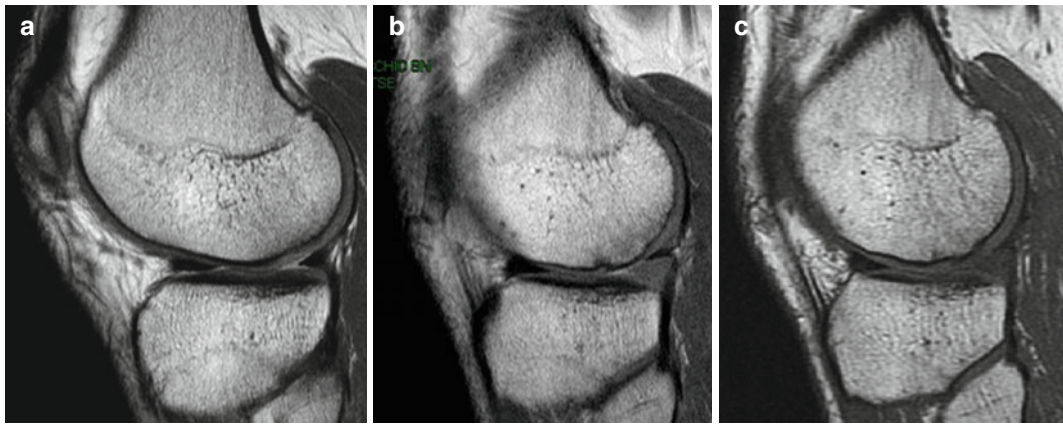

Fig. 13.6 Sagittal MRI slice before medial Actifit® implant (**a**), after 6 months (**b**), and after 12 months (**c**). Posterior horn defect filling and progressive enhancement of scaffold signal is present

related to the scaffold; these were mostly knee pain, effusion, and swelling. Lateral meniscus implantation appeared to be associated with higher rate of failures. The cartilage status at the 24-month follow-up MRI evaluation was stable or improved in 92 % of cases. The MRI evaluation showed also a significant enhancement of the scaffold signal over time resembling tissue ingrowth and vascular proliferation in 82 % of patients (Fig. 13.6) [28]. Furthermore, the second-look arthroscopy showed good integration of the scaffold with the native meniscus, with no suture loosening (Fig. 13.7), while histological examination at 12 months revealed fully vital material, no adverse reaction to scaffold material, and a regenerated tissue composed by type I collagen, fibroblasts, and fusiform fibrochondroblast-like cells [29]. Other reports

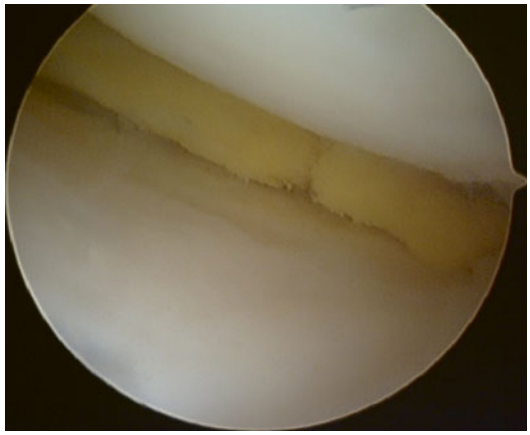

Fig. 13.7 Arthroscopical appearance of medial Actifit® 7 months after the implant. The scaffold appears in place, with good integration with the native meniscus

[1, 12] with probable overlapping bias demonstrated similar results; Kon et al. [12] showed good knee function and return to sport activity in a single-center cohort of 18 patients, while Bouyarmane et al. demonstrated similar improvements in patients who underwent lateral scaffold implantation [1]. Regarding combined procedures, it has been demonstrated it has not any superiority than medial Actifit® implantation compared to partial medial meniscectomy when combined with HTVO in case of symptomatic varus knee [7].

The short-term results of both CMI® and Actifit® have been reported in a small prospective study showing no substantial differences [23]. Moreover, both scaffolds have been used by Marcacci et al. [18] to treat unicompartmental osteoarthritis through an integrated biomechanical and biological approach alternative to metal resurfacing involving combined ACL reconstruction, knee osteotomy, and cartilage reconstruction with an osteochondral biomimentic scaffold.

Conclusions

Meniscal scaffolds represent an attractive surgical option for irreparable meniscal lesions in appropriately symptomatic patients. Although a wide range of conditions could be potentially treated, good results are strictly dependent upon adherence to proper surgical indications. Good to excellent results have been reported ranging from 70 to 90%. Both CMI® and Actifit® have been reported to undergo resorption and substitution with a meniscus-like tissue with the potential of chondroprotection. Despite the clinical benefits of these scaffolds, further long-term studies are needed to confirm outcomes over time and the protective effects on articular cartilage, especially for the Actifit® scaffold.

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Cartilage Lesions

14

Peter Angele, Giuseppe M. Peretti,
and Johannes Zellner

14.1 Diagnosis

Since hyaline cartilage is not innervated, even large defects can remain completely symptomless for a long time. Chondral defects often become noticeable on the appearance of secondary symptoms like swelling, joint locking, or effusion due to synovitis. These simple and common symptoms or persistent pain could draw attention to the possibility of a cartilage defect [1].

14.1.1 History

Chondral injuries are present in 10–12 % of individuals [2]. Widuchowski et al. reviewed 25,124 knee arthroscopies to quantify the prevalence, location, and grade of the chondral lesions. Sixty percent had chondral lesions, of which 67 % were supposed to be focal. The main locations were retropatellar and medial [3]. In their series of more than 30,000 arthroscopies of the knee, Curl et al. found high-grade cartilage lesions (Outerbridge grades III and IV) in over 60 % of the patients [4]. As 14 % of osteoarthritis patients had a knee trauma in adolescence [5], medical history should particularly include past specific traumas. A knee distortion – even a couple of years ago – may lead to the source of the knee problems. Especially in athletes, full-thickness chondral defects are more common than among the general population [6]. Familiar dispositions (OCD, metabolic disorders) should also be recorded. Patients should be asked for loose-body symptoms, intermittent or activity-related pain, or swelling. Pain with prolonged sitting, kneeling, or stair climbing may indicate cartilage problems behind the patella. Previous operations, e.g., meniscal resections, ligament replacements, etc., are also important due to possible subsequent cartilage damage. Increased age, male sex, and increased surgical delay all increase the frequency and severity of articular cartilage injuries after ACL tears [7]. Twenty three percent after acute ACL injury and 54 % with chronic laxity of the ACL have chondral lesions [8].

14.1.2 Clinical Evaluation

A systematic physical examination should be performed in every patient with careful observation of gross morphology, effusion, palpation,

P. Angele (✉)
Sporthopaedicum Regensburg, Regensburg, Germany

Department of Trauma Surgery, University Medical Center Regensburg, Regensburg, Germany
e-mail: peter.angele@ukr.de

G.M. Peretti
Department of Biomedical Sciences for Health, IRCCS Galeazzi Orthopaedic Institute, University of Milan, Milan, Italy
e-mail: gperetti@iol.it

J. Zellner
Department of Trauma Surgery, University Medical Center Regensburg, Regensburg, Germany
e-mail: johannes.zellner@ukr.de

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range of motion assessment, stability testing, and alignment. In acute traumatic cases, up to 50 % of patients with lateral patellar dislocation show evidence of osteochondral lesions of the lateral femoral condyle, the medial patellar facet, or both [9]. These patients complain about tenderness at the insertion of the medial patellofemoral ligament at the medial epicondyle or along the medial retinaculum. In chronic cases of cartilage injuries, patients show tenderness at the joint line, limited weight bearing, or recurrent effusion.

Physical examination should focus on the following pathologies:

- Limited range of motion
- Effusion
- Instability
  - Clicking, grinding, or any other pathological sounds
  - Catching or locking
- Malalignments (valgus or varus deformities)
- Maltracking or tilt of the patella

14.2 Exploration

14.2.1 Radiological

14.2.1.1 X-Ray Examination

Cartilage cannot be seen directly in X-rays. Nevertheless, X-rays of the knee in two planes and sometimes with special techniques like patella défilé or others are still necessary, as they give useful information about posttraumatic changes and overall joint conditions [1]. In acute cases osteochondral injuries especially with large underlying bony fragments and osteochondritis dissecans lesions can be detected. By plain X-rays arthritis of the knee can be diagnosed or at least excluded. Especially X-ray evaluation under weight bearing like the Rosenberg view can help to detect joint space narrowing and other (pre) arthritic conditions. In most cases long-leg standing radiographs are mandatory for the analysis of the alignment, as axis deviation might change the therapeutic algorithm for the treatment of chondral injuries.

X-ray examination should focus on the following pathologies:

- Joint space narrowing
  - Calcification of cartilage and meniscus
- Osteophytes
- Patella maltracking or tilt
  - Malalignments (varus or valgus deformities)
  - Signs of inflammatory diseases
  - Trauma-related pathologies

14.2.1.2 Magnetic Resonance Imaging

Improvements in MRI technique continue, so that modern magnetic resonance tomographs give a detailed view of the articular cartilage itself and can help to detect even smaller articular cartilage pathologies and osteochondral injuries. MRI is also useful in detecting (osteo)chondral loose bodies and chondral fragments. Although the field intensity plays a major role in terms of image resolution and quality, in the hands of a skilled examiner, even devices with 1.5 or 1.0 tesla can bring out reasonably explicit images of the articular cartilage. However, clinicians should be aware that MRI tends to underestimate articular chondral lesion size compared to intraoperative arthroscopic findings after cartilage debridement. This should be considered when surgeons plan treatment strategies.

The main factor is the appropriate MRI sequence, which can only be chosen when the clinical objectives are precisely described.

The most widely used MRI cartilage-sensitive sequences are fast spin echo (FSE) and 3D fat-suppressed gradient echo (GRE). T2-weighted FSE sequence is accurate in detecting intrachondral pathologies and tissue structure abnormalities and has some additional advantages: high-spatial resolution images, low artifact sensitivity, and short scan time. 3D GRE sequences highlight cartilage surface and thickness; they are characterized by higher out-of-plane resolution and contrast-to-noise resolution than 2D images and allow for volume measurements [10, 11]. Magnetic resonance arthrography can reveal minimal fibrillation or fractures of the articular

surface, and it is particularly useful in defining the integrity of the interface between native cartilage and repair tissue. Other isotropic 3D-GRE-based acquisitions have been recently developed [12]: fast low-angle shot (FLASH), volumetric interpolated breath-hold examination (VIBE), and sampling perfection with application optimized contrast using different flip angle evolutions (SPACE). They can potentially be promising in cartilage imaging, providing high-resolution images of the cartilage and the surrounding tissues, with a voxel (volumetric picture element) size inferior to 0.5 cm^3 for 1.5 Tesla.

MR imaging should focus on the following pathologies:

- Characteristics of the cartilage defect (size, depth, localization)
- Status of the subchondral plate
- Pathologies of the subchondral bone (OCD, edema, bone bruise)
- Secondary pathologies (meniscal tears, ACL ruptures, etc.)

Even if some of those questions will nevertheless be answered during later arthroscopy, MRI remains a useful tool for a detailed therapy planning and enables assessment of the joint status and subchondral structures.

14.2.2 Arthroscopy

Diagnostic arthroscopy is indicated on suspicion of an articular cartilage defect or in persistent, unclear disorders of the knee [13]. It is accepted as the most accurate and reliable method to assess chondral injury size, depth, surface appearance, and location in order to determine therapeutic options. Only arthroscopy enables a direct view of the cartilage surface and palpation of its stiffness with a probe hook. Softening of the articular cartilage and partial delamination can be discovered that way. However, the evaluation of the cartilage quality stays subjective and depends on the surgeon's experience. Objective methods, e.g., near-infrared spectroscopy (NIRS) [14] for intraoperative cartilage evaluation or navigated defect size assessment [15], have not become daily routine in arthroscopy. The probe hook with its defined length can be used for the assessment of the defect size. However, it has been shown that especially smaller defects and inexperienced surgeons are factors that make an overestimation of the cartilage lesion size more likely [16]. However, arthroscopic examination of the knee by experienced surgeons is the gold standard for exact determination of the defect characteristics and is essential in terms of differential diagnosis and classification of a cartilage lesion.

14.3 Rating

14.3.1 Classification

A couple of classifications have been published for the grading of articular cartilage defects, and a few of them are in clinical use. In 1961 Outerbridge et al. introduced the first classification, initially developed to describe cartilage defects behind the patella [17].

- Outerbridge Grade I: Softening and swelling
- Outerbridge Grade II: Fragmentation/fissuring <1/2 in.
- Outerbridge Grade III: Fragmentation/fissuring >1/2 in.
- Outerbridge Grade IV: Erosion with exposed subchondral bone

To address some deficiencies of the existing classification systems, the International Cartilage Repair Society (ICRS) developed a clinical evaluation system [18]. By dividing the articular surface into 21 femoral, 18 tibial, three trochlear, and nine retropatellar zones, it is possible to map chondral lesions precisely. Direct measurement of the size and depth of the defect is also performed and scored. So the International Cartilage Repair Society (ICRS) offers a sophisticated but still pragmatic classification that is increasingly recommended for use [13].

Basically, ICRS distinguishes between osteochondritis dissecans (OCD) lesions and (post) traumatic cartilage defects.

Isolated cartilage defects are classified as follows:

- Grade 0: Normal.
- Grade I: Nearly normal. Superficial lesions, soft indentation (A), and/or superficial fissures and cracks (B).
- Grade II: Abnormal. Lesions extending down to <50 % of cartilage depth.
- Grade III: Severely abnormal. Cartilage defects extending down to >50 % of cartilage depth (A) as well as down to the calcified layer (B) and down to but not through the subchondral bone (C). Blisters are also included in this grade as subgroup (D).
- Grade IV: Severely abnormal. Defects include the subchondral plate (A) and also the adjacent cancellous bone (D) (Fig. 14.1).

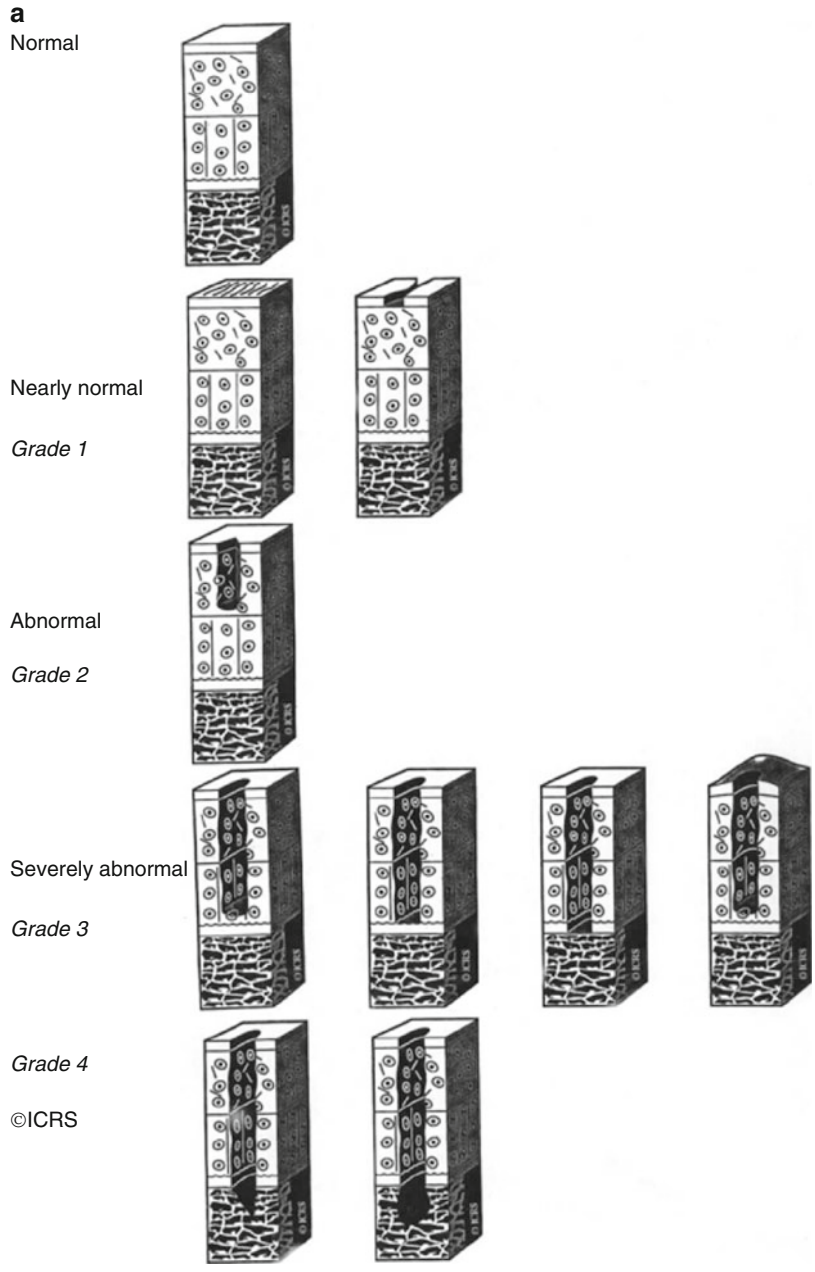
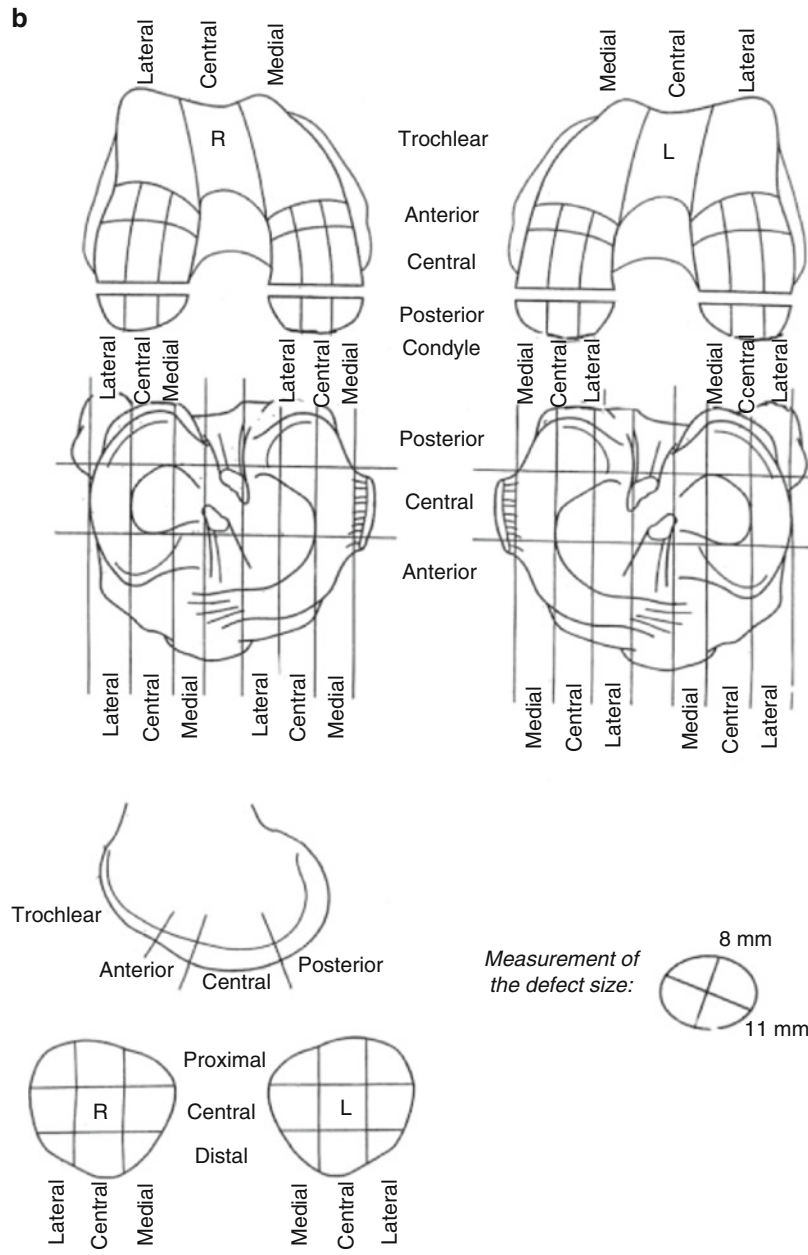


Fig. 14.1 ICRS classification system for cartilage lesions (**a**) and localization (**b**)

Fig. 14.1 (continued)



In the ICRS classification system, OCD is divided into four categories [18]:

- OCDI: Stable continuity, softened area covered by intact cartilage
- OCD II: Partial discontinuity, stable on probing
- OCD III: Complete discontinuity, "dead in situ," not dislocated
- OCD IV: Dislocated fragment, loose within the bed or empty defect

More than 10 mm in depth is B subgroup (Fig. 14.2).

For the juvenile OCD lesions, Hefti et al. (1999) introduced a MRI classification system [19]:

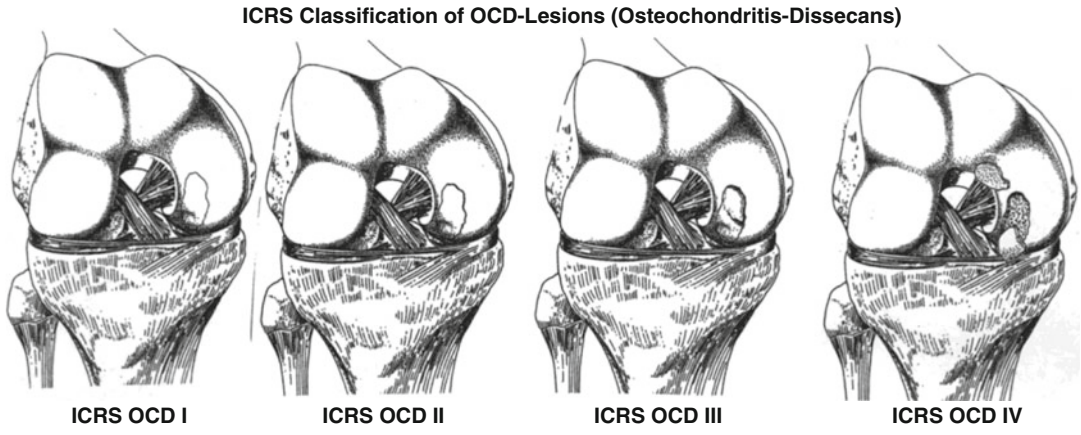


Fig. 14.2 ICRS classification of OCD lesions

- Stage 1: Small change of signal without clear margins of fragment.
- Stage 2: Osteochondral fragment with clear margins but without fluid between fragment and underlying bone.
- Stage 3: Fluid is visible partially between fragment and underlying bone.
- Stage 4: Fluid is completely surrounding the fragment, but the fragment is still in situ.
- Stage 5: Fragment is completely detached and displaced (loose body).

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Cartilage Repair: Autograft Osteochondral Grafting

15

Tim Spalding

15.1 Indications

Autograft osteochondral grafting (OCG) is a technique to repair articular cartilage defects by transplanting healthy articular cartilage with the underlying bone from one area of the knee to the damaged area. The earliest work was undertaken by Matsusue in Japan, expanding on work from Yamashita [30] and Matsusue [24], and this was followed separately by Hangody and Bobic who helped promote the use of small diameter osteochondral cylinders to resurface damaged chondral surfaces [5, 14, 16]. The technique has now been in use for many years and is well established.

There are three main commercially available instrumentation systems to enable the surgery:

- OATS Osteochondral Autograft Transfer System (Arthrex, Naples FL) (Fig. 15.1)
- COR Chondral Osseous Replacement (DePuy Synthes Mitek Sports Medicine, Raynham, MA)
- Mosaicplasty (Smith and Nephew PLC, London UK)

Indications have evolved since inception and OCG is currently indicated for defects with maximum size 2–2.5 cm^2. Defects should be on one surface of the joint and should be in a position where it is possible to get perpendicular access – which makes it inappropriate for tibial defects and lesions of the posterior condyle.

The concept of the operation is to fill a chondral or osteochondral defect. The minimum size for treatment is considered as 9–10 mm diameter, based on the observation that pressure only increases on the edge of defects that are greater than 10 mm in diameter [13].

The maximum appropriate size of the defect is more determined by the shape than the physical area, as the critical factor is the potential for donor-site morbidity. More than two plugs are considered to lead to a higher risk of morbidity with increased tendency for bleeding, pain and mechanical symptoms from the donor sockets. If the harvest sockets are too close together, then there is a risk for coalescence of the base due to natural convergence from the convex surfaces, and this limits the graft availability.

15.2 Surgical Technique

The surgical technique for implanting osteochondral grafts is essentially similar for the three main commercially available instrumentation systems. A level core or plug of healthy articular cartilage is harvested from a lesser-used area in the knee and transplanted into a prepared recipient donor socket.

T. Spalding
Department of Orthopaedics and Trauma, University Hospital Coventry, Coventry, UK

Hospital of St Cross Rugby, Coventry, UK
e-mail: tim@timspalding.com

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Fig. 15.1 OATS instrumentation packaged as single use kit (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München)

The goal of surgery is to effect a repair of the defect with articular cartilage of equal thickness and surface shape as the recipient area. Care needs to be taken to ensure that the harvested core is perpendicular to the surface and that the recipient socket is also perpendicular. Instrumentation allows this to be performed arthroscopically, but to enable this to be performed accurately, the surgeon needs to consider using a mini-open approach rather than persist with arthroscopic viewing which is technically challenging. The depth of harvest and preparation must be accurate to avoid the need for impaction on the graft creating cell death. Proud grafts can cause catching symptoms but over recessed grafts may not see sufficient load and can fail.

The key decisions to be made at the beginning of surgery include:

1. *Patient positioning*? It is important that the knee is held still during the harvest of the graft cores and the surgeon must choose a familiar technique to allow this, as discussed in the sections below.
2. *Is the lesion suitable for the procedure*? The lesion should be repairable with one or two plugs or a maximum of three as discussed in order to avoid donor-site morbidity.
3. *What is state of the surrounding articular surface*? The implanted plugs should be level with healthy normal surface, and if the remaining surface is degenerate, then this may be beyond the ideal indication for the procedure.
4. *Arthroscopic or mini-open procedure*? It is much easier and quicker to achieve reliable perpendicular grafts through a mini-open approach involving a 4–5 cm incision rather than struggling with an arthroscopic approach in a tight knee, especially when two or more plugs are required. Postoperative discomfort is not significantly different when using appropriate volumes of local anaesthetics. The arthroscopic approach may have been shown to have less incongruence in a study by Keeling et al. [21], where grafts of 7 mm diameter had a prominence of less than 1 mm in 69 % of arthroscopic cases and 57 % of open cases, but this challenge has to be weighed up against the degree of surgical difficulty.
5. *Single larger plug or multiple smaller plugs*? Usually one to three plugs are used noting that it is easier to insert smaller diameter plugs than larger as the smaller plugs are more forgiving if not entirely perpendicular.
6. *Incisions longitudinal or transverse*? Longitudinal incisions allow for extension for access and possible conversion to mini-open arthrotomy.

7. *Where to harvest the donor graft*? The superomedial and superolateral trochlea surfaces have similar contour and thickness to the weight-bearing part of the medial condyle. If not appropriate due to wear, then the margin around the notch can used, but harvest diameter is limited to 6 mm due to the contour of the area. Contact pressures are lowest on the medial trochlea and the lower lateral trochlea, but the width of these two areas are different; therefore, it is optimal to harvest small grafts from the medial trochlea and larger grafts from the low lateral trochlea [8]. The medial and lower lateral trochlea, above the intercondylar groove, have been shown to provide the best curve for condyles. For the trochlea the best donor site is the rim of the groove, as it is flat [1, 2] and thickness is also similar in this area to the femoral condyle.

15.2.1 Surgical Steps for Repair of Defect on Medial Femoral Condyle

The steps below relate to the approach and technique for lesions on the medial femoral condyle (MFC), and for illustration purposes, the OATS instrumentation is used. Alterations in the technique for other areas in the knee, and using other instruments, are summarised later in the chapter.

15.2.2 Step 1: Arthroscopic Evaluation and Preparation

To allow for accurate preparation of the defect and harvest of grafts, it is important that the knee is sufficiently stable on the operating table. A side post and foot support are used to allow such control in knee flexion when approaching the MFC during impaction of the instruments. The leg can be supported in variable amounts of near extension by supporting the thigh on the table with the calf over the edge of the operating table (Fig. 15.2). This is preferred to holding the leg free over the end of the table when there may be insufficient hold to maintain perpendicular graft harvest and insertion.

Longitudinal incisions for the arthroscope and working portal are preferred in order to allow appropriate extension for insertion of the instruments and conversion to a mini-open procedure if needed.

The defect is inspected and evaluated BEFORE making the working anteromedial portal, and once a decision is made, then the site for the longitudinal portal is identified using a needle to ensure it will be possible to achieve perpendicular access (Fig. 15.3a–d).

The defect is debrided with the shaver to help make the decision as to the number and configuration of the plugs, but it is not necessary to prepare down to the bone as the damaged area will be removed by the coring device.

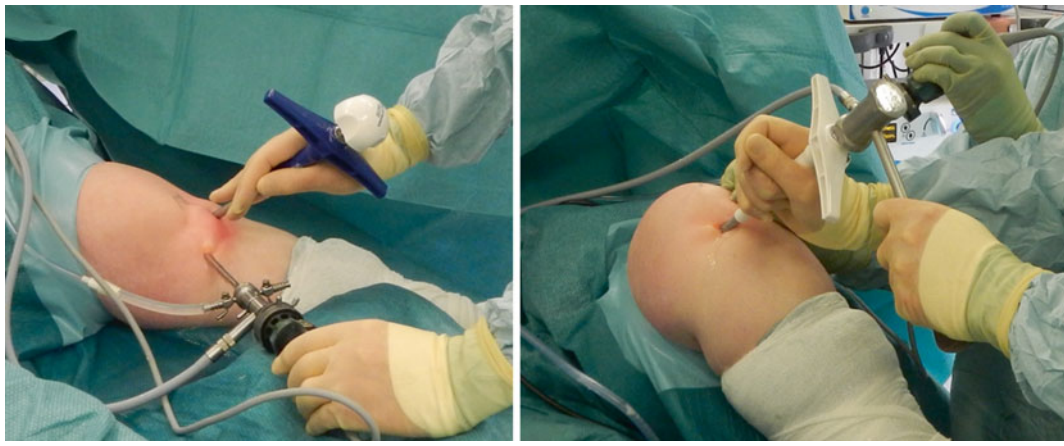

Fig. 15.2 Set-up and positioning so that the knee can be rigidly held at 90° flexion for femoral condyle lesions and near extension for harvest

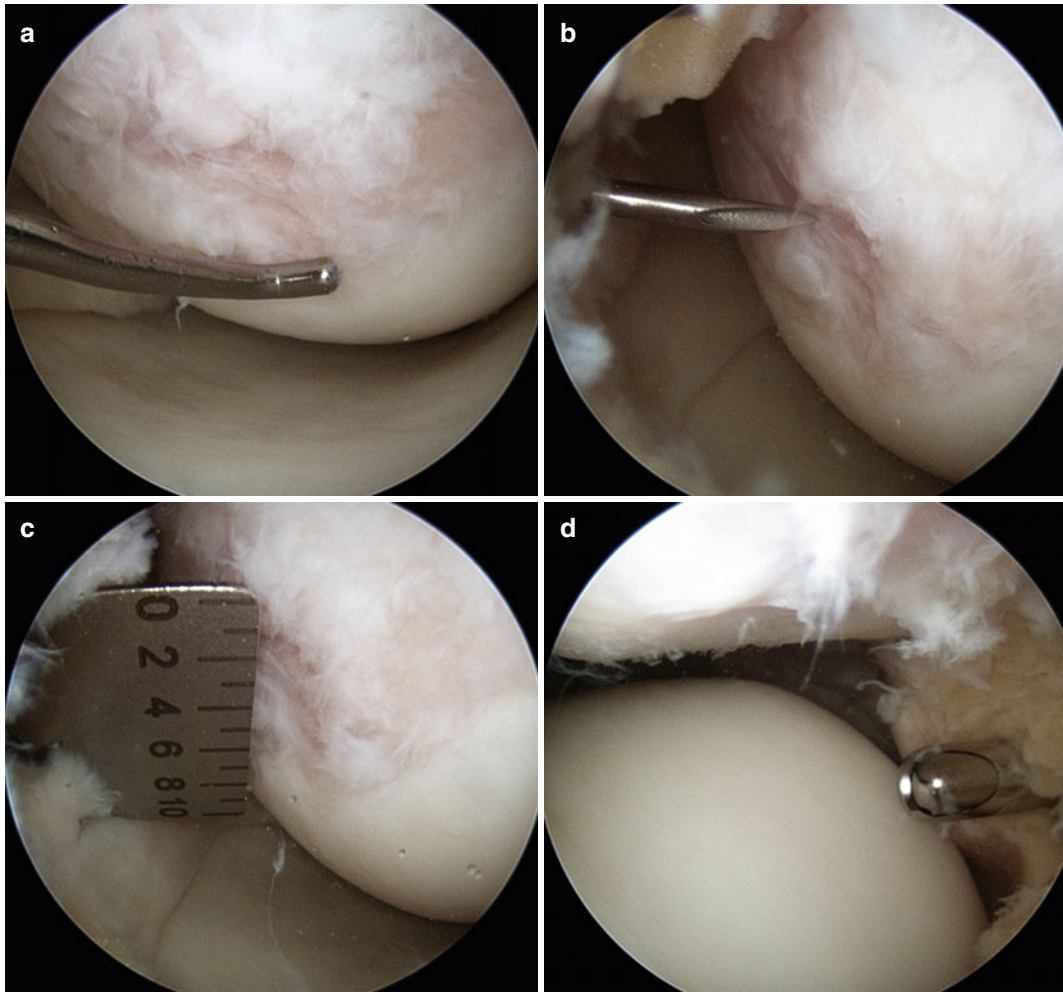

Fig. 15.3 Preparation of the knee. (**a**) Palpating the defect on the medial femoral condyle, (**b**) aligning the working portal by using a needle, (**c**) use of a ruler to measure the dimensions of the defect and to plan the set to open, (**d**) obtaining a good view of the medial trochlea for harvest of the donor

Key Tip Adequate clearance of the anteromedial fat pad is required to enable easy insertion and viewing of the instruments.

15.2.3 Step 2: Sizing of the Defect

An arthroscopic ruler or a sizing rod is used to measure the diameter of the defect for mapping of the required grafts (Fig. 15.4). Alternatively the arthroscopic probe or a measurement needle can be used. For the OATS technique, the choices are 4.75, 6, 8 and 10 mm diameter grafts, and a reusable sizing and tamp instrumentation set is available.

15.2.4 Step 3: Donor Graft Harvest

Once the plan for covering the defect has been made, the appropriate disposable donor and recipient cutting tube set is opened. The DONOR harvester is chosen noting that the INNER diameter of the device is the specified labelled dimension and the OUTER diameter of the RECIPIENT harvester is the chosen required size. In the system the DONOR harvester is consistently coloured BLUE and the RECIPIENT harvester is coloured WHITE.

The screw-in core extruder knob is advanced so that the rounded end of the inner rod protrudes

1–2 mm outside of the leading edge of the harvester (Fig. 15.5), making it easier to insert through the skin. This also prevents inadvertent marking of the articular cartilage by the sharp edge of the harvester. This step is not so important during open surgery.

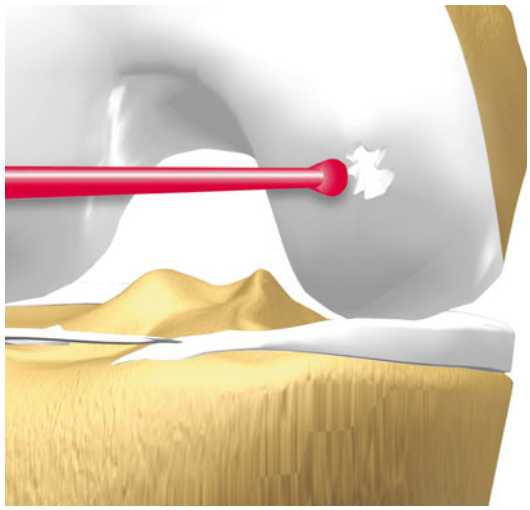

Fig. 15.4 Sizing of the defect using a designed rod (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

The donor harvester is positioned perpendicular to the donor surface (Fig. 15.6), and the screw-in core extruder knob is carefully removed from the back of the donor harvester lowering the sharp edge of the harvester onto the articular cartilage. The harvester is then impacted to 12 mm. A heavy mallet is preferred to minimize strikes and losing position.

Key Tip To ensure harvest is exactly perpendicular, the harvester is viewed from two directions inspecting the first laser line 2 mm along the device. Alterations can be made at this stage ensuring the laser line enters the articular cartilage equally. Repeated checks are required during impaction, and small corrections to the direction can be made up to the next line (5 mm). This is a very exacting stage.

Important Role of the Assistant The surgeon holds the harvester and mallet, while the assistant holds the arthroscope, and an arthroscopic understanding of maintaining a good view is essential. It is best to keep the view tangential along the cartilage surface rather than a more usual view from on high, and the light lead is rotated 180° to

Fig. 15.5 Graft harvester and advancing the extruder knob to allow for easier capsule insertion (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

obtain a different view. The assistant should be familiar with altering position of the arthroscope to help in this key step.

The harvester is removed by applying pressure against the T-handle and sharply rotating 90° clockwise twice (Fig. 15.7). The extruder knob is reinserted, and the core gently pushed distally to see the exact depth harvested and how perpendicular the graft is, by referencing through the windows (Fig. 15.8). The optimal measurement is used to determine the depth of recipient socket preparation.

The donor harvester is laid to one side and covered.

Figure 15.9 a–d shows the steps on a 30-year-old lady illustrating harvest from the lateral trochlea.

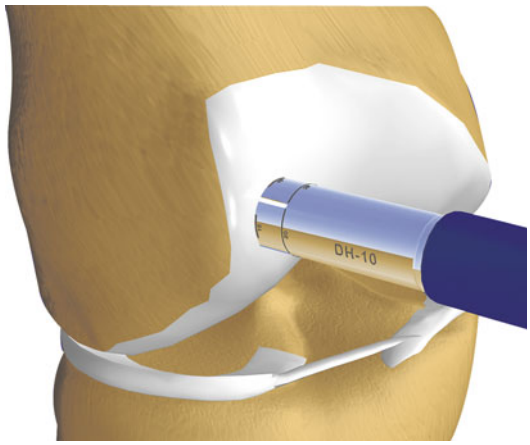

Fig. 15.6 Insertion of the harvester for the donor graft (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

15.2.5 Step 4: Recipient Area Harvest and Preparation

The core extruder knob is inserted into the recipient harvester, so that the central extruder protrudes 1–2 mm to allow easy entry into the knee. The harvester is positioned perpendicular to the defect and the core extruder knob is removed (Fig. 15.10). Once again care is taken by manipulating the arthroscope to ensure perpendicular approach. If the view is inadequate, then additional fat pad tissue needs to be removed with the shaver.

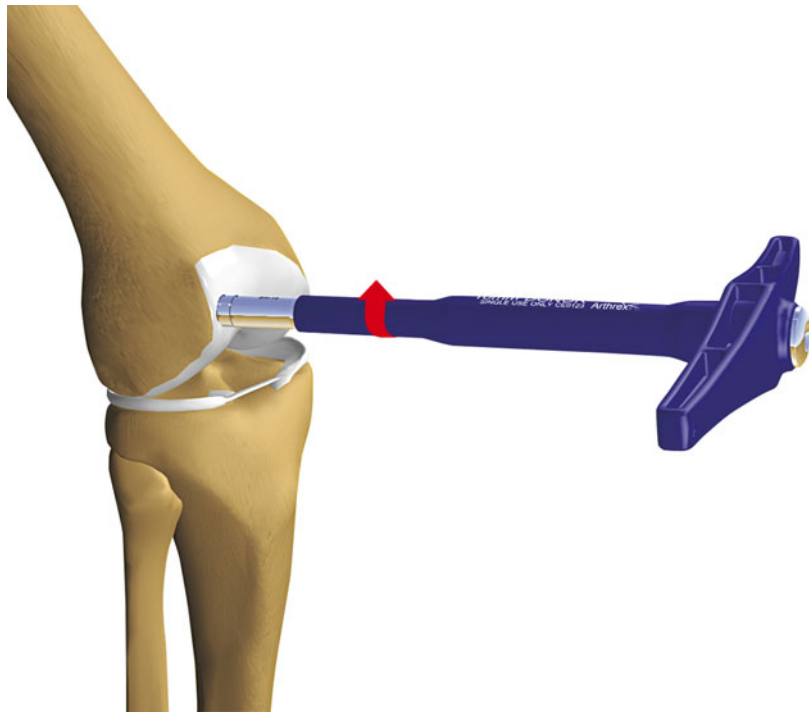

Fig. 15.7 Extraction of the harvester by a sharp rotation of the tube using the T-handle (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

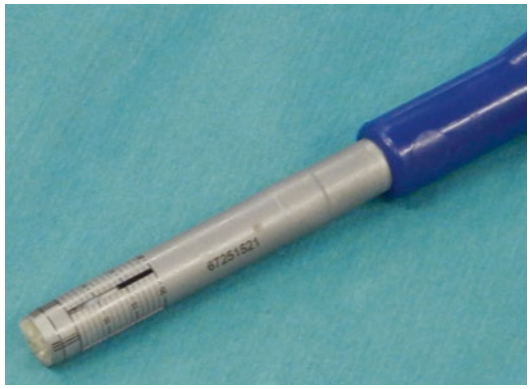

Fig. 15.8 The graft is checked through the windows of the harvesting system to determine any angulation

The recipient harvester is then impacted to the first line, adjusted and then impacted to a depth of 10 mm or 2 mm less than the length of the donor graft measured (Fig. 15.11). The harvester is rotated sharply and removed, creating the bone socket. The retrieved bone is inspected through the window of the harvester to assess the perpendicular cut noting that the surface may not have been even.

A graduated alignment rod from the instrumentation set is inserted to measure the socket depth and to check the angle of the graft. This can be impacted to achieve adequate depth – usually 10 mm. The alignment rod is advanced into the

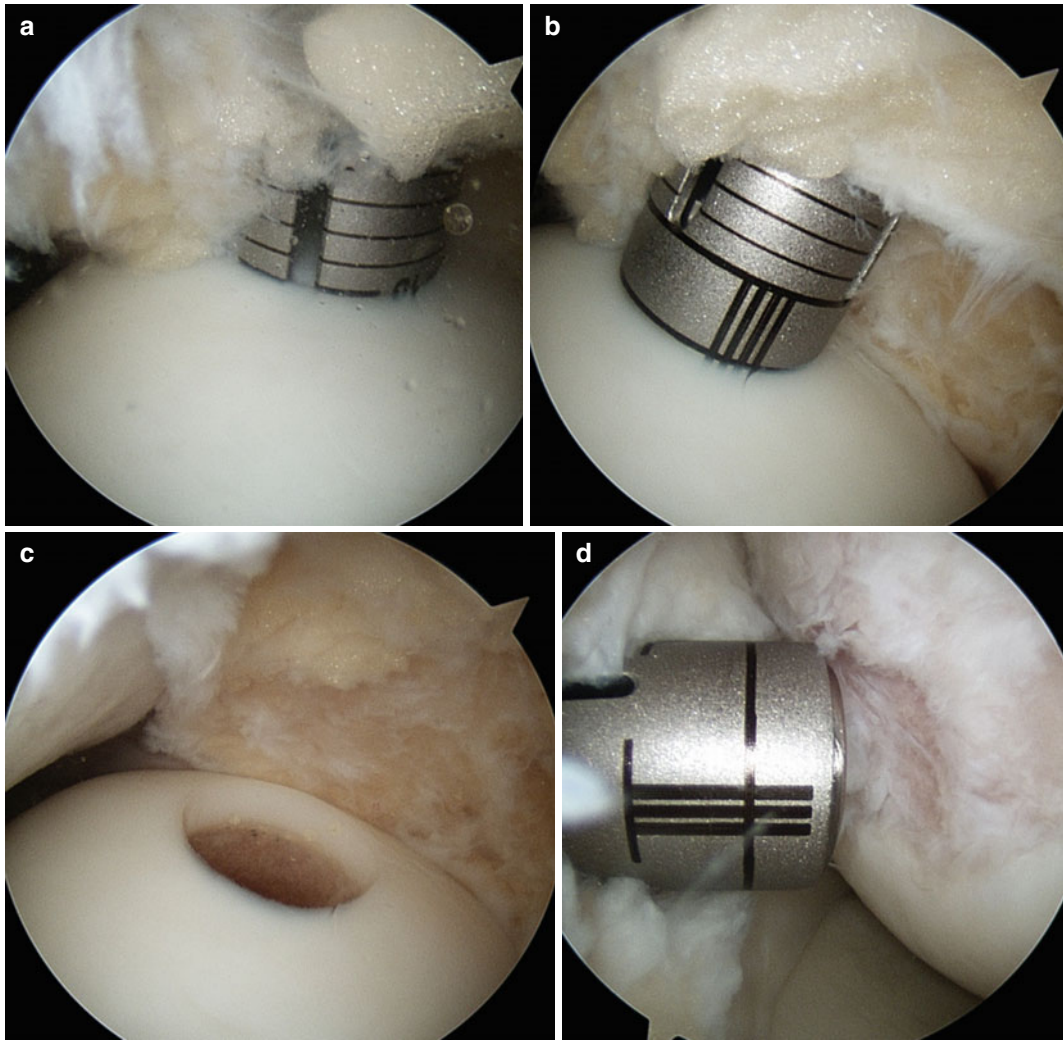

Fig. 15.9 Harvest of the donor site. (**a**, **b**) Insertion of the donor harvester to 10–11 mm depth, (**c**) the empty donor socket with no breakdown of the edges, (**d**) approaching the recipient damaged site with the 8 mm harvester

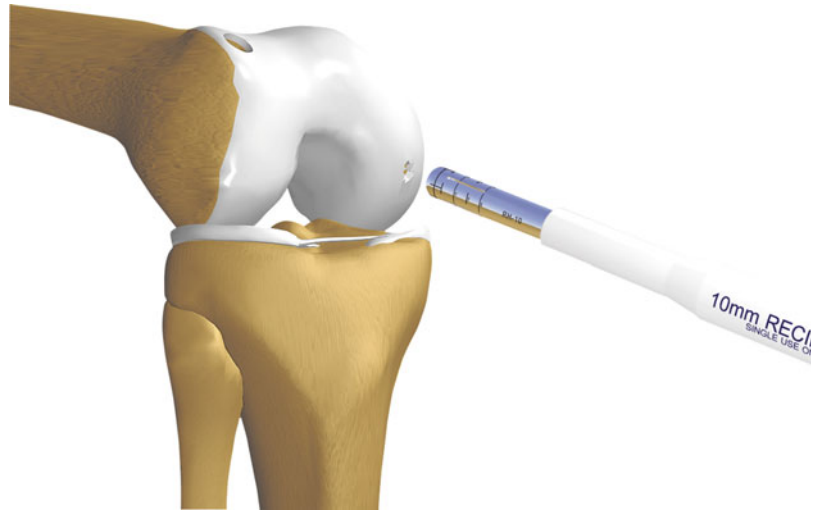

Fig. 15.10 Preparation of the recipient site inserting the recipient harvester perpendicular to the surface (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

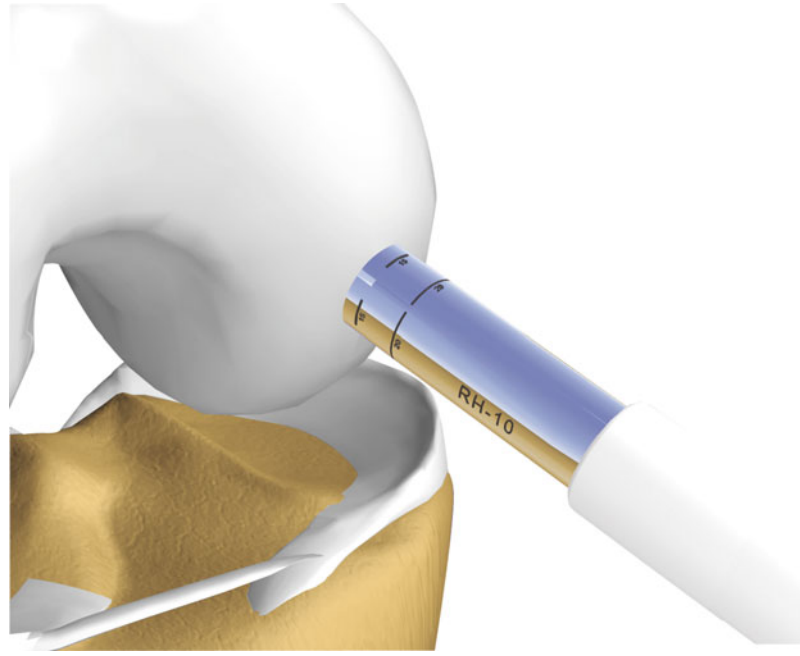

Fig. 15.11 Harvesting the recipient site taking care to be perpendicular (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

socket until the depth, similar to the length of the core, is achieved.

15.2.6 Step 5: Insertion of Donor Graft

The exact depth of the socket is noted, and the donor graft is trimmed to the same exact length by extruding it within the harvester, using the extruder and then trimming with bone cutters. The bevelled edge of the harvester is inserted into the recipient socket and the graft advanced into the socket using the core extruder. Occasionally light tapping with the mallet is required to advance the graft. Alternatively the clear graft delivery tube (Fig. 15.12) can be placed over the end of the donor harvester to allow better visualisation.

When the graft is still 1–2 mm proud, the harvester is removed and a tamp is used for final seating

Fig. 15.12 Alternative method of delivering the graft into the knee allowing the surgeon to see the graft as it advances (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

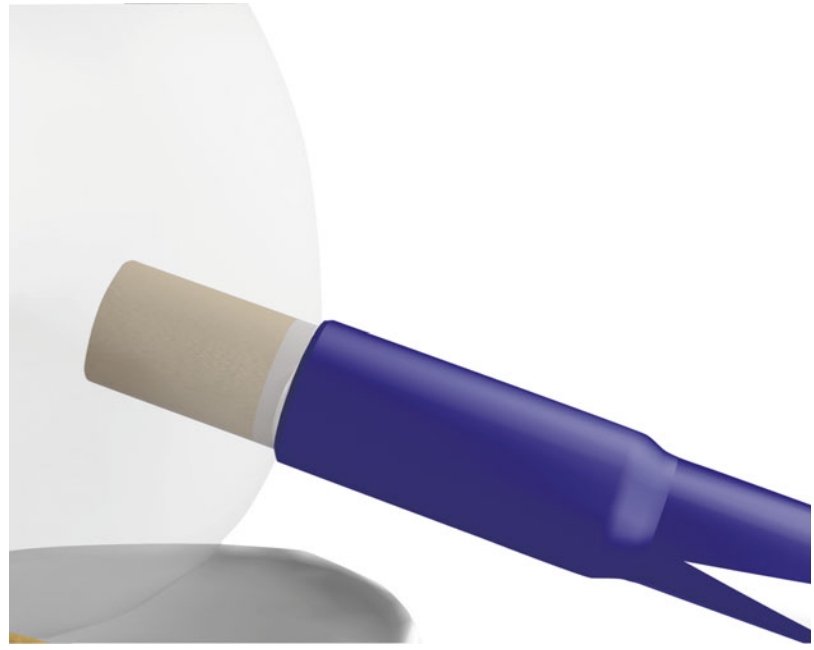

Fig. 15.13 Final seating of the graft using the blunt tamp (The image source is Arthrex (Arthrex GmbH, Erwin-Hielscher-Straße 9, 81249, München))

of the graft (Fig. 15.13), gently tapping it into place, achieving a flush finish. The knee is then cycled and the surface viewed from different angles.

Key Tip It is best to be congruent or 1 mm countersunk in order to preserve hyaline cartilage. More than 2 mm sunk has been shown to lead to graft necrosis in a sheep study [20]. Insertion forces of 400 N (<10 MPa) on 8 mm diameter grafts did not affect cell viability provided the socket is the same depth as the graft, according to a cadaveric study [26]. Forces higher than 15 MPa will damage chondrocytes.

Figure 15.14a–d shows the sequence for a medial femoral condyle defect repaired with a single 8 mm plug.

The capsule defect is closed with a no. 1 absorbable suture to prevent fluid leakage or herniation of the fat pad, and the skin is closed with sutures according to the surgeon's preference.

15.2.7 Alternative Instrumentation Techniques

Mini-Open Surgery The technique can be performed through a small mini-arthrotomy, and this allows much clearer visualisation of the site to be grafted and the site for harvest (Fig. 15.15).

Mosaicplasty In this technique (Smith and Nephew, London UK), emphasis is placed on preparation of the defect with abrasion to stimulate fibrocartilage filling in of the gaps between plugs. Sockets for the grafts are prepared using drills with sizes 2.7, 3.5, 4.5, 6.5 and 8.5 mm in diameter. For the small diameter grafts, the recommended harvest length is double the graft diameter to ensure stability. Grafts are harvested and removed from the harvester before manual insertion into sockets prepared using a dilator.

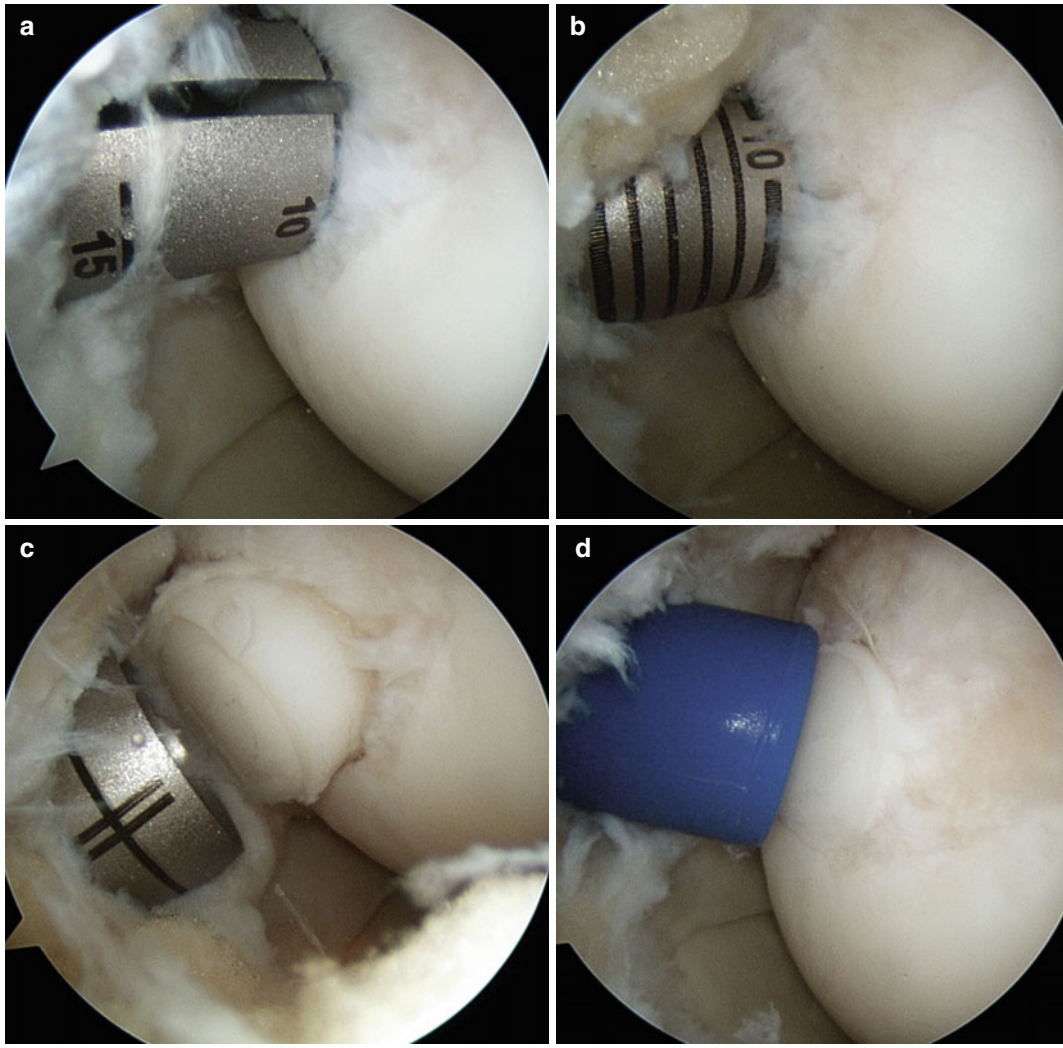

Fig. 15.14 Insertion of the plug (**a**) insertion of the coring harvester ensuring perpendicular axis, (**b**) measurement of the true depth using the calibrated alignment rod, (**c**) insertion of the graft and (**d**) final careful impaction using the tamp

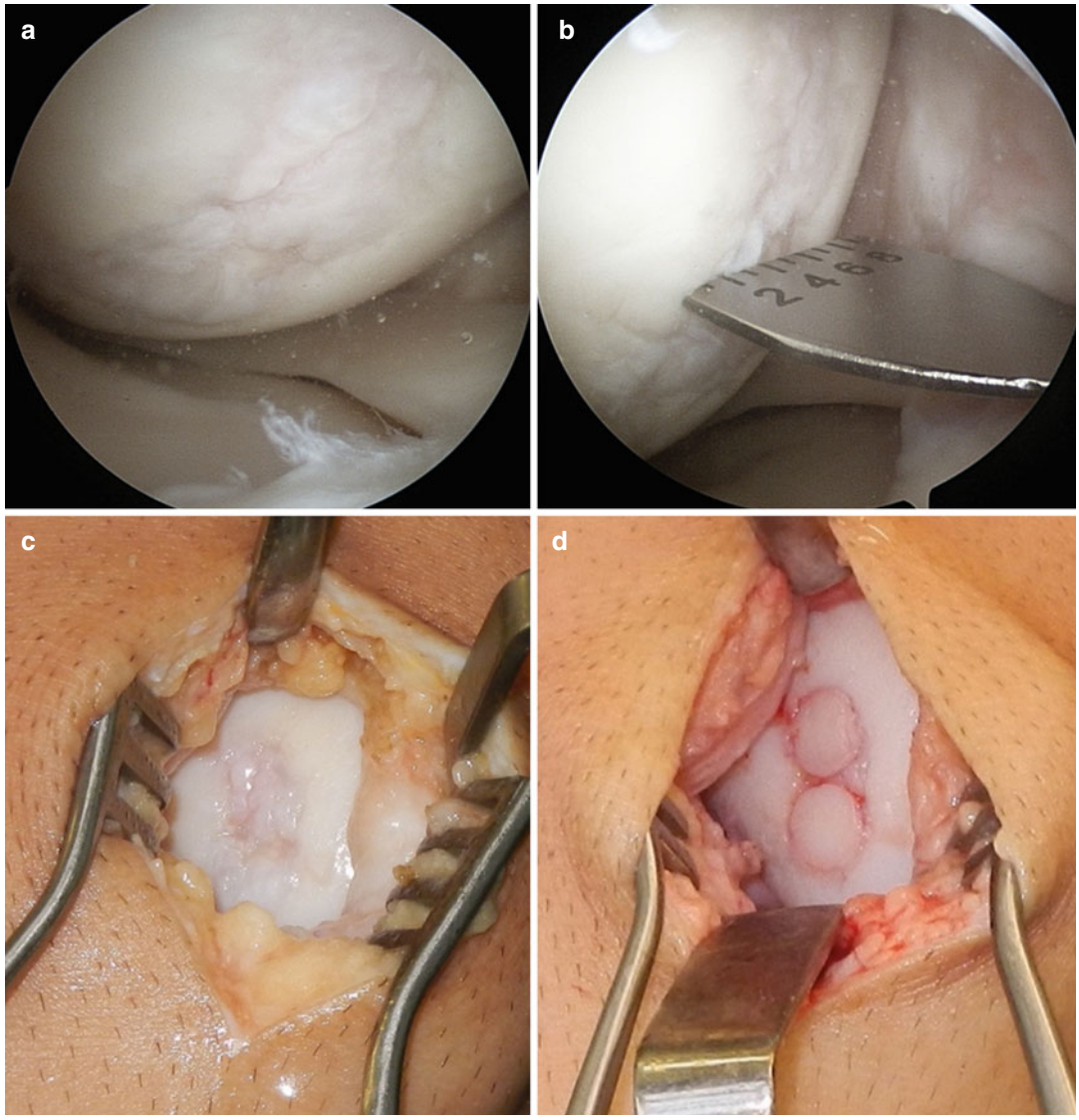

Fig. 15.15 Mini-open surgery (**a**, **b**) assessment and sizing of the chondral defect on the medial femoral condyle, (**c**) exposure of the medial condyle to see the damaged area, (**d**) final result with 2 × 8 mm plugs filling the lesion

Multiple plugs of varying sizes are used to cover as much as possible of the defect.

COR Chondral Osseous Replacement This technique (DePuy Synthes Mitek Sports Medicine Raynham, MA) is very similar to the OATS technique using a COR precision targeting system with clear delivery tubes, potentially allowing easier delivery of the graft to the recipient site. Each plug is harvested and implanted before moving to a second plug.

15.3 Rehabilitation

The procedure is usually performed as a day surgery operation, and there is likely to be slightly more discomfort and swelling compared to arthroscopy for meniscal surgery.

Weight Bearing Weight bearing as tolerated as allowed using crutches for 6 weeks though usually this is graduated over the first few weeks as symptoms of discomfort improve.

Movement of the Knee Joint Early flexion is encouraged immediately following surgery to help with nutrition of the new articular surface. Cycling on a static bike without load aids nutrition of the surface and can commence a week after surgery.

Muscle Exercises Static quadriceps and hamstring exercises commence immediately while working on range of movement.

At 6 Weeks Progression to full weight bearing is allowed if not achieved before. Load and strengthening exercises begin, building up balance and proprioception work depending on swelling in the knee. Full bending is encouraged.

Further Rehabilitation Gradual increase in exercise activity is allowed building up to commencing impact type activities at 3 months. A gradual increase in exercise with pivoting and impact is then allowed expecting maximum improvement by 6 months. Return to contact sporting activities starts around 4–6 months dependent on progress and reaching appropriate goals.

Trochlea Grafts For grafts on the trochlea, an extension splint is worn on walking for the first 2 weeks to protect load on the graft. Full weight bearing is allowed as there is no restriction on femoro-tibial load and at 2 weeks a normal gait pattern can commence. Squatting and open chain exercises are avoided for 6 weeks and are gradually introduced according to progress, functional quadriceps control and resolution of swelling.

15.4 Complications

Donor-site morbidity occurs due to excessive postoperative bleeding and donor-site pain. Aspiration of the knee may be required, and mobilisation should subsequently be slow for the first week to allow bleeding to reabsorb.

Grafts may dislodge if not inserted appropriately and if the bone is too soft. It may then be possible to harvest a longer plug, reinserting this to achieve stability.

Problems may occur from grafts inserted at an angle, and some surgeons have managed this by using a no. 15 blade to trim the prominent edge rather than over recess and impact the plug. This however does not address incongruity of the underlying osteochondral level, and it removes the important lamina splendens.

If the graft is inserted too deeply, then it is usually not possible to regain from this error. Surgeons in conference presentations have demonstrated insertion of a probe next to the plug and using the hook end to extract the plug slightly, but this is not published. An alternative is to fashion a new recipient hole next to the depressed plug, using the instrumentation, and then to elevate the plug before grafting the new socket. If the plug is removed completely, bone graft can be placed in the depth of the hole, but subsequent insertion of the 'used' graft may be unsatisfactory.

In summary many of the complications are technique related, and this emphasises the importance of adherence to the surgical technique.

15.5 Results

The appeal of osteochondral grafting using autologous grafts is that the transplanted cartilage is hyaline, theoretically maintaining the specific microstructure of articular cartilage. There are issues that the new graft may have different rotational orientation to the host surface and may be of different thickness or imperfectly implanted. Gaps between the round graft plugs need to heal and such healing may be insufficient.

Laszlo Hangody, one of the pioneering surgeons, has published widely on his institutions results. In a maximum 15-year follow-up of 789 femoral condyle defects, 31 tibial defects and 147 femoro-patellar defects including 81% with an associated procedure (meniscal, ligamental or bone), good or very good results were reported in

92 % for the femoral condyle, 87 % for the tibia and 74 % for the femoro-patella defects. Eighty-three biopsies were performed with hyaline cartilage found in 83 % of the cases and excellent integration of the cartilage to the surrounding surface [17]. Chow et al. reported results on femoral condyle defects, with 84 % of good and very good results at 4 years of follow-up [6].

In competitive athletes, good to excellent results were found in 91 % of femoral mosaicplasties, 86 % of tibial and 74 % of patellofemoral patients [18]. Interestingly in this group, patellofemoral pain related to graft harvest was observed in only 5 % of cases, indicating the importance of careful rehabilitation. Good results have also been reported in a specific subgroup of soccer players [25]. Sixty-one patients who received mosaicplasty in the knee joint were followed for 9.6 years (range 2–17); 89 % showed good and excellent results; 89 % of the elite players and 62 % of the competitive players returned to the same level of sport at an average time of 4.5 months (range, 3.5–6.1 months). Younger players and those with smaller lesions had better clinical outcomes [25].

In a recent systematic review of comparative trials for autogenous osteochondral transplant outcomes [23], the authors conclude that OCG is superior to microfracture, but the long-term results are not as good as with autologous chondrocyte implantation (ACI). The review notes that when searching for trials with over 25 patients and follow-up greater than 12 months, there are only 9 prospective comparative studies of OCG covering 607 patients, with only 1 comparing results with ACI [3, 4, 9–12, 19, 22, 29]. The authors of the review conclude that patients undergoing microfracture trended towards more reoperations and deterioration around 4-year post-surgery. OCG had better clinical results and a higher return to sport.

In a longer term (10-year) follow-up of an athletic population, the OATS procedure had a higher return to sport when compared with microfracture, and in addition OATS had a higher proportion achieving maintenance of sport at the preinjury level [9].

When comparing with ACI, Horas et al. [19] reported better clinical scores with OCG, but Bentley et al. [4] reported that the repair surface was more normal in the ACI group on arthroscopic evaluation and had better scores at 18-month follow-up. The same group reported on the 10-year follow-up [3], finding better outcome scores and failure rate with the ACI group. Fifty-five percent of OCG group had failed (23 of 42) compared with 17 % of the ACI group (10 of 58). Of note however the mean size of the defects in the ACI group was 4.4 cm^2 and for the OCG group was 4 cm^2 – larger than the currently recommended lesion size for OCG. As further evidence of the current view regarding lesion size, outcome was reported to be better with higher return to sport when the lesion was less than 2 cm^2 [9]. The time to return to play was an average of 6.5 months [9, 11] with better results for sport in the younger patients – defined as age <30.

In a retrospective study looking at predictive factors for outcome in 55 patients at 5.9-year follow-up, Robb et al. [27] reported a Kaplan-Meier analysis of 87.5 % survival at 8 years (95 % CI 72–97 %). The mean Oxford score at follow-up was 16.3 % (95 % CI 10.6–22.1 %). Two of six failures occurred in patients with varus malalignment. Younger patients had improved outcome on linear regression analysis but other factors had no influence. It is important that attention be paid to the other factors around the knee including alignment and stability. Similar findings were found in a study using backward regression analysis to assess factors, which concluded that age, lesion size, localization and associated intraarticular injuries were predictors of the final Lysholm score [7].

MRI evaluation has shown integration of the bone component [11], without loosening at follow-up. There is scant data however on long-term radiographic changes. Finally, the early reoperation rate is reported as low [23].

Conclusion

The conclusion from the published results is that OCG is most suited to lesions less than 2 cm^2. Though a challenging technique, the instrumentation allows for accurate placement of the grafts, but care and training are required for optimization.

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Cartilage Repair: Arthroscopic Microfractures

16

Patrick Orth and Henning Madry

16.1 Introduction

Microfracture is an established and frequently performed arthroscopic marrow stimulation technique, representing a key first-line treatment option for symptomatic, focal, small defects of the articular cartilage [1]. It was first developed by Dr. Richard Steadman about 20 years ago [2], and its evidence-based clinical efficacy has since been underlined [3]. Here, we describe indications, surgical technique and potential pitfalls, possible complications and postoperative results reported in the literature following microfracture treatment.

16.2 Indication

Microfracture [2] is indicated as first-line treatment for symptomatic, small (<4 cm^2), focal chondral defects in adult patients younger than 50 years [1]. Microfracture treatment is also applicable to degenerative focal cartilage lesions with an intact adjacent articular cartilage in middle-aged patients. In infantile and juvenile patients, microfracture is an important and established treatment option even for large, circumscribed chondral defects because of the high endogenous repair capacity of the osteochondral unit in this age group. Unicompartmental osteoarthritis in the elderly is a relative indication for the microfracture treatment and only applicable when other surgical options (e.g. high tibial osteotomy or unicompartmental arthroplasty) are not feasible. Here, the pain caused by osteoarthritis is the major motivation for microfracture treatment and may be relieved for a limited postoperative period of time, possibly postponing partial or total joint arthroplasty.

16.3 Technique

The aim of all marrow stimulation procedures is to establish a communication of a cartilage defect with the bone marrow cavity, either by focal perforation of the cement line with awls (microfracture [2]), drill bits (subchondral drilling [4]) or generalized abrasion to a maximal depth of 1–2 mm of the subchondral bone plate with burrs (abrasion arthroplasty [5]). The guiding principle of these techniques is to allow mesenchymal cells from the underlying cavity to migrate into the defect [1], allowing for the induction of chondrogenesis and fibrocartilaginous repair [6]. As a result, the articular cartilage defect is filled with a

P. Orth, MD • H. Madry, MD (✉)
Center of Experimental Orthopaedics,
Saarland University, Kirrberger Strasse 100,
Building 37-38, Homburg, Saar 66421, Germany

Department of Orthopaedic Surgery,
Saarland University Medical Center,
Kirrberger Strasse 100, Building 37-38,
Homburg, Saar 66421, Germany
e-mail: patrick.orth@uks.eu; henning.madry@uks.eu

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cartilaginous repair tissue [7] that also serves to stabilize the adjacent cartilage and prevent early osteoarthritic degeneration [8–10]. Depending on the intra-articular location of the cartilage defect, one marrow stimulation treatment option might be superior to another with regard to technical feasibility. Of note, arthroscopic microfracture has increasingly replaced subchondral drilling in the clinical situation, mainly due to a better handling and practicability.

16.3.1 Preparation of the Cartilage Defect Border

Once the cartilage defect and the neighbouring as well as the opposing articular cartilage has been identified and inspected, its size is measured using a calibrated arthroscopic probe. With the help of curettes, the borders of the cartilage defect are debrided to reach stable and vertically oriented peripheral margins, including removal of loose cartilage flaps that undermine the adjacent normal articular cartilage. Following these measures, the size of the defect is recorded again [2, 11].

16.3.2 Preparation of the Cartilage Defect Base

The defect is then prepared by removing the entire calcified cartilage layer from the base of the defect [12, 13] (Fig. 16.1). The calcified cartilage has a whitish appearance, in contrast to the yellow colour of the subchondral bone plate 14. Manual instruments such as ring curettes are superior to arthroscopic shavers and burrs, since they allow for a better tactile feedback and a more even defect base preparation [13, 15].

16.3.3 Microfracturing

Microfracture holes are created using arthroscopic awls of different diameters and angulations of their tips at different degrees (e.g. 30°, 45° and 90°) (Fig. 16.2). Multiple perforations of the subchondral bone plate are induced with the sharp tip of the microfracture awl placed in a 90° angle to the subchondral bone plate 11. Care is taken not to penetrate the subarticular spongiosa too deeply or to damage the subchondral bone plate by a deflection of the cutting tip of the instrument [16]. Mechanistically, the impaction of the conical or polyhedral awl tip into the subchondral bone plate induces multiple standardized small bone injuries. To avoid confluence of microfracture holes and collapse of the bone bridges, it is advisable to start the penetration of the subchondral bone plate in the part of the defect which is closest to the portal of the instrument [17] (Fig. 16.3). The penetrations should have a distance of about 3–4 mm [18]. After the entire defect base has been penetrated, the surface is inspected again. All debris is carefully removed. The arthroscopic pump pressure is decreased to about 30 mmHg. Successful microfracture is indicated by the appearance of fat droplets and blood from the microfracture holes. A drain without suction may be used [16].

16.3.4 Rehabilitation

Passive motion of the joint by the physiotherapist without restriction of the range of motion is recommended after removal of the drain and should be accompanied by continuous passive motion (CPM) for at least 6 weeks postoperatively and 6–8 h per day [19, 20]. If the treated cartilage defect is located within the weight-bearing area of the joint surface (e.g. femoral condyle at the knee), a postoperative period of partial weight bearing or non-weight bearing for 6 weeks is mandatory, followed by a stepwise increase of weight bearing. Immediate postoperative joint loading is only possible if the treated defect is located outside the weight-bearing region (e.g. axial weight bearing of the knee in full extension using a knee immobilizer for patellar or trochlear lesions). Swimming and biking may be performed after 6 weeks, jogging after 6 months [21]. Due to the prolonged process of articular cartilage repair, high-impact sports activities should be avoided for a minimum of 12–18 months following microfracture [21].

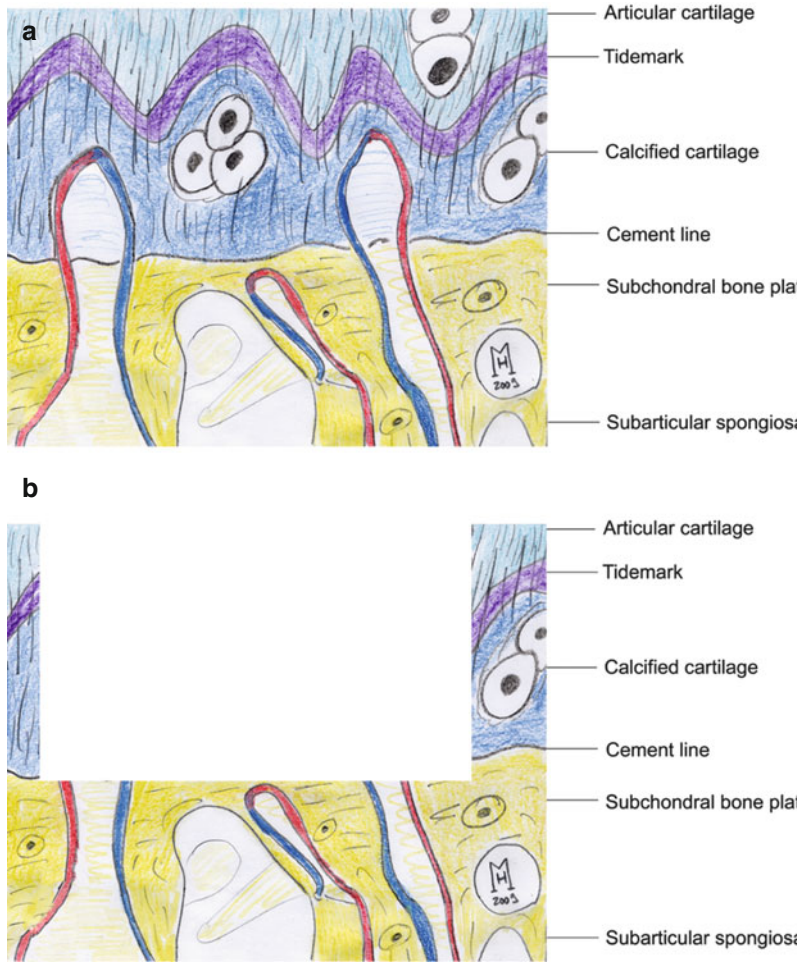


Fig. 16.1 Schematic drawing of the tidemark, the calcified cartilage layer, the cement line and the subchondral bone plate (Modified from [14], with permission) (**a**). Note that blood vessels from the subchondral region may extend into the calcified cartilage through canals in the subchondral bone plate. When the defect is prepared, the entire calcified cartilage layer is removed from the base of the defect and the subchondral bone plate may be identified by its *yellow* colour (**b**). This may lead to an opening of some vascular canals in the subchondral bone plate [13]

16.4 Complications

The major complication of microfracture treatment is a postoperative haemarthrosis caused by excessive bleeding from the subchondral bone marrow cavity [22]. Joint effusion or infection is seldom observed. Insufficient preparation of the defect prior to microfracture (i.e. incomplete removal of the calcified cartilage layer or unstable defect margins) may result in an inferior repair tissue quality. The subchondral bone plate is at risk of collapse or expanded fractures as a result of too narrow distances between the microfracture holes and/or full weight bearing immediately postoperatively.

16.5 Results (Literature Review)

After microfracture surgery, the cartilage defect is filled with a fibrocartilaginous repair tissue (Fig. 16.4) which is structurally and biomechanically inferior to hyaline articular cartilage. Randomized controlled clinical trials with

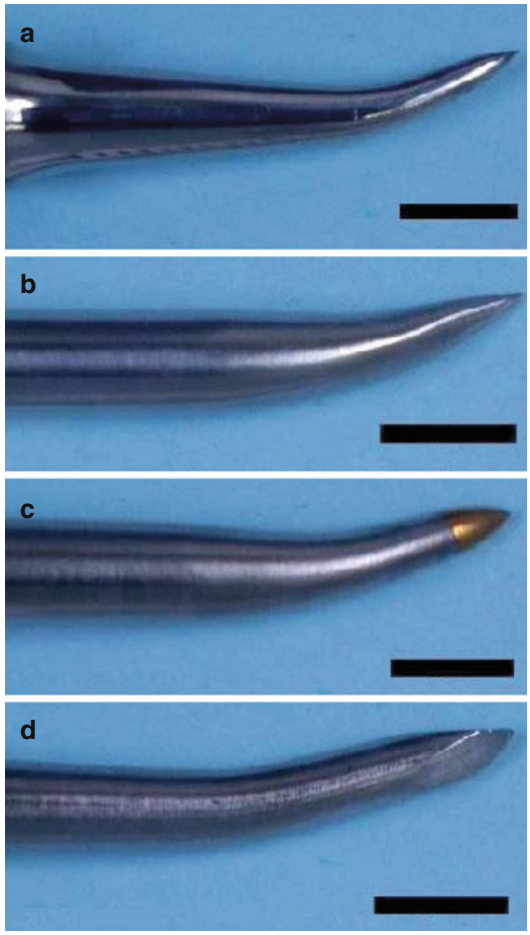


Fig. 16.2 Microfracture holes are created using (arthroscopic) awls of different diameters, angulations and three-dimensional shapes of their cutting tips (e.g. conical (**a**–**c**) or polyhedral (**d**)). Scale bars: 5.0 mm

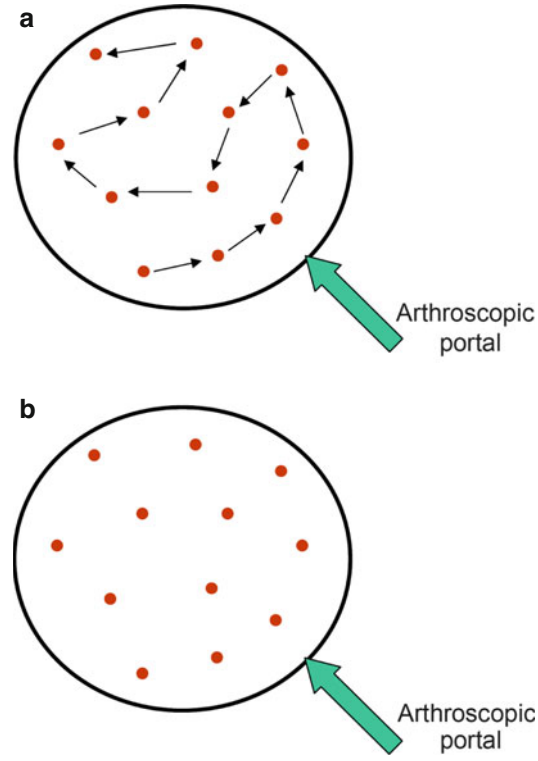
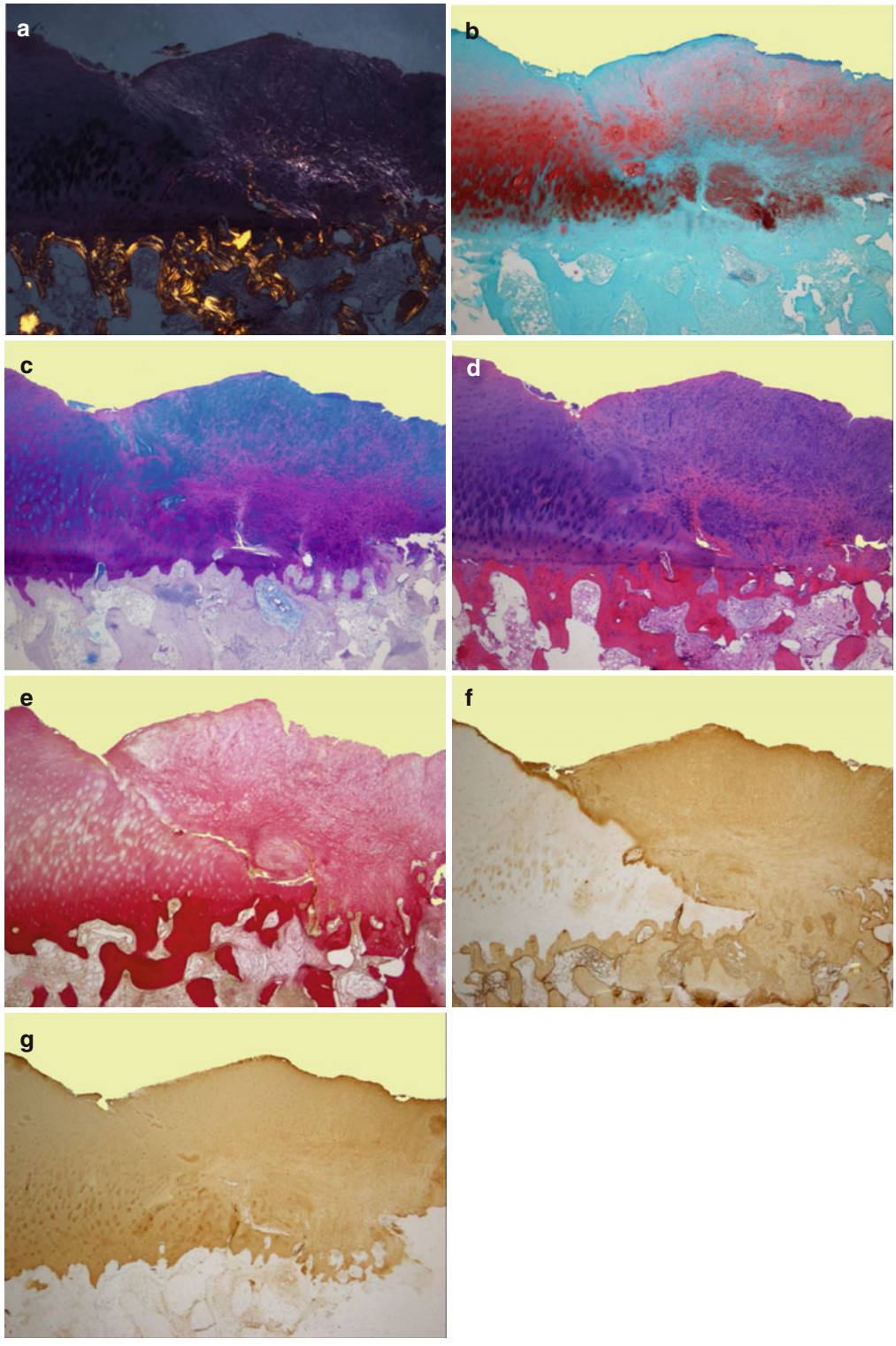


Fig. 16.3 The impaction of the microfracture awl tip into the subchondral bone plate induces multiple standardized small bone injuries. These penetrations should start in the part of the defect which is closest to the portal of the instrument and have a distance of 3–4 mm (**a**). Following microfracture treatment, a homogenous distribution of microfracture holes within the cartilage defect is desirable (**b**)

Fig. 16.4 Analysis of the cartilaginous repair tissue from a 62-year-old patient who underwent marrow stimulation at the age of 54; retrieved during a total knee replacement. Histological pictures showing polarized light microscopy (**a**), safranin O-fast green (**b**), alcian blue (**c**), periodic acid-Schiff (**d**) and van Gieson stain (**e**) as well as anti-type I collagen (**f**) and anti-type II collagen (**g**) immunohistochemistry. The repair tissue can always be identified on the right side of each image and the adjacent cartilage on the left side. Polarized light microscopy indicates an irregular pattern of collagen fibrils in the repair tissue. Note the relatively good integration of the repair tissue with the adjacent cartilage. Also note the relatively similar safranin O, alcian blue, periodic acid-Schiff and van Gieson staining pattern of the repair tissue and the adjacent cartilage. Analysis by type I collagen immunochemistry however reveals a relatively rich content of the repair tissue with this type of collagen, indicative of its fibrocartilaginous nature, in contrast to the adjacent cartilage on the left side. However, the repair tissue also contains similar amounts of type II collagen, the major collagen present in hyaline cartilage. Original magnification: ×40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negative controls (patients without microfracture treatment) have not been performed to date, possibly because translational studies in large animals showed that microfracture treatment of cartilage defects leads to better defect fill compared with untreated defects [7]. Clinical improvement is achieved as early as 6 months postoperatively, with the largest improvement occurring during the first 18–24 months [3, 23]. Regarding the clinical long-term results of the microfracture technique, good to excellent results are reported in 60–80 % of patients [18, 22, 24–26]. The size and number of defects [27], the patient's level of physical activity and age are prognostically important factors [3]. Physically active patients younger than 30–40 years provide better results than older, physically inactive patients [23, 28, 29]. In the clinical situation, defects at the femoral condyle yield better postoperative results than trochlear lesions [23]. Microfracture was inferior for the treatment of full-thickness articular cartilage defects of a mean area >3 cm^2 when compared with autologous chondrocyte implantation (ACI) [30]. For defects with a smaller area (mean size 2.4 cm^2), clinical and radiographic results were similar compared with ACI [31]. Whether an additional insertion of a collagen membrane [7] improves clinical results compared with microfracture alone needs to be subject of long-term randomized controlled studies [32, 33]. In second-look arthroscopies following marrow stimulation procedures [18, 25, 34–42], defects are usually well covered with fibrocartilaginous repair tissue at different follow-up periods [35, 36, 39, 42], although repaired defects only reach average macroscopic grading scores [18, 36, 37, 43]. In good agreement, the repair tissue of patients with failed microfracture was fibrocartilaginous and hypercellular 4–19 months after marrow stimulation [44]. Interestingly, the subchondral bone beneath this repair tissue was incompletely restored [44].

Specific alterations of the subchondral bone that are associated with spontaneous osteochondral repair following an injury and with articular cartilage repair procedures have been also described for microfracture [45]. These chiefly include the upward migration of the subchondral bone plate, the formation of intralesional osteophytes, the appearance of subchondral bone cysts and the impairment of the osseous microarchitecture [45]. At 3 years after microfracture, upward migration of the subchondral bone plate was detected in 52 % of patients [38] and intralesional osteophytes in 27 % of patients [23]. The mechanisms of development of intralesional osteophytes [23, 46] are not fully understood; disturbed subchondral bone remodelling may be involved [45, 47, 48]. Subchondral bone cysts have mainly been described 1–2 years following microfracture treatment [47] and may be caused by an influx of synovial fluid into the subchondral bone compartment [49]. While no systematic studies have yet investigated the generalized impairment of the osseous microarchitecture below the defect after marrow stimulation – as recently quantified in translational animal models [50] – recent anecdotal evidence suggests that such changes may also be of clinical relevance [50]. Of note, alterations of the subchondral bone have also been reported to occur to a similar extent following ACI [45].

In summary, microfracture treatment yields a promising clinical outcome, whereas the repair tissue remains inferior to normal articular cartilage. Further translational and clinical research on this important articular cartilage repair technique is warranted.

Conclusion

Arthroscopic microfracture treatment is a key first-line surgical technique for small symptomatic articular cartilage lesions in a broad range of patients. Its technical performance is feasible in most joint regions, but several crucial operative aspects need to be respected. Microfracture results in a good clinical outcome especially within the first year postoperatively. However, further research to improve the quality and long-term durability of the fibrocartilaginous repair tissue is mandatory.

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Cartilage Repair: Scaffolding

17

Elizaveta Kon, Giuseppe Filardo, Luca Andriolo, Francesco Perdisa, Francesco Tentoni, and Maurilio Marcacci

Regenerative scaffold-based procedures have emerged in the last years as a potential therapeutic option for the treatment of chondral and osteochondral lesions [1]. The rationale of using a scaffold is to have a temporary 3D structure of biodegradable polymers for the growth of living cells. The ideal scaffold should reproduce biological and structural properties of the native tissue as close as possible, in order to allow cell infiltration, attachment, proliferation, and differentiation. Other important properties include biocompatibility and biodegradability at suitable time intervals, to support the initial tissue formation and then to be gradually replaced by the regenerating tissue. The use of scaffolds has been introduced into clinical practice to improve the results obtainable with the first-generation cell-based approach, autologous chondrocyte implantation (ACI), by overcoming its drawbacks and simplifying the procedure [2]. ACI techniques were combined with scaffolds, developing matrix-assisted autologous chondrocyte transplantation (MACT). Cells were harvested and cultured in vitro and then seeded on the three-dimensional biomaterial, which favored the redifferentiation processes, better protection, more homogeneous distribution, and easier handling for surgical implantation [3]. Many scaffolds have reached clinical practice, and studies are now being published with good mid- and long-term results [4–7], but showing also some limits. Whereas traumatic focal lesions of the femoral condyles were shown to have more chance of benefit from this treatment, other indications have more controversial results, with lower or even poor clinical outcome [8–10]. Moreover, this approach suffers from a two-step operation, technical difficulties and regulatory restrictions for cell manipulation, and high costs [11]. Thus, after a decade focused on expanding and improving MACT techniques, in more recent years, both researchers and clinicians have been looking for different solutions to regenerate the articular surface [11, 12].

Nowadays there is an increasing interest in a new treatment approach for regenerative medicine in clinical practice, which involves the implant of various biomaterials for "in situ" cartilage repair exploiting resident bone marrow stem cells differentiation induced by the scaffold properties, thus favoring the self-regenerative potential of the body. Different new biomaterials are recently pro-

E. Kon, MD (✉)
II Orthopaedic and Traumatologic Clinic – Biomechanics and Technology Innovation Laboratory, Rizzoli Orthopaedic Institute, Bologna, Italy

Nano-Biotechnology Laboratory, Rizzoli Orthopaedic Institute, Bologna, Italy
e-mail: e.kon@biomec.ior.it

G. Filardo, MD, PhD • L. Andriolo, MD
F. Perdisa, MD • F. Tentoni, MD • M. Marcacci, MD
II Orthopaedic and Traumatologic Clinic – Biomechanics and Technology Innovation Laboratory, Rizzoli Orthopaedic Institute, Bologna, Italy

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posed to induce "in situ" cartilage regeneration after direct transplantation onto the defect site both in research and in clinical practice.

Most of the available surgical options aimed at reconstructing a functional joint surface focus on the cartilage layer and offer good results if applied to small traumatic lesions on otherwise healthy joints, whereas they lack indication in more compromised knees [13, 14].

For this kind of osteochondral articular defects, different specific scaffolds have been developed, combining distinct but integrated layers, corresponding to the cartilage and bone regions. In fact, the treatment of this kind of defects is biologically challenging, since two different tissues are involved (bone and articular cartilage) with distinctly different intrinsic healing capacity.

The implantation of biomaterials directly into the lesion site aims at restoring a tissue as conform as possible to the native hyaline cartilage, with physiological properties similar to those of the entire osteochondral unit and durable over time, thus providing a valid therapeutic alternative to the orthopedic surgeon.

17.1 Indication

- Grades III–IV chondral or osteochondral defects, symptomatic.
- Etiology: traumatic, degenerative, and osteochondritis dissecans.
- Defect size: depending on the kind of scaffold.
- Age: less than 60 years is recommended (this approach represents an evolution of bone marrow stimulation, and, as for this latter technique, better results have been reported for young patients, despite an established cut-off has not been defined yet).
- Body mass index (BMI): less or equal to 30.
- Absence of medium or advanced osteoarthritis (OA).
- Absence of uncorrected misalignment and ligamentous instability.
- Absence of rheumatic and autoimmune diseases, infections, and allergy to scaffold components.

17.2 Techniques

Currently, among scaffold-based cell-free techniques, only three chondral and four osteochondral regenerative procedures have been reported into clinical application.

17.2.1 Chondral Cell-Free Techniques

The use of a membrane or a matrix to cover a site of microfracturing has been introduced by Benthien and Behrens [15] with the rationale of stabilizing the blood cloth and providing a protective environment [16] for BMSCs coming from the bone marrow to adhere and differentiate, in the end to promote the formation of new cartilage.

17.2.1.1 AMIC® (Autologous Matrix-Induced Chondrogenesis, Geistlich Pharma AG, Switzerland)

Bilayer collagen I/III membrane (ChondroGide®, Geistlich Biomaterials, Switzerland) with a deeper layer allowing cell adhesion to the collagen fibers for proliferation and differentiation and a superficial cell-occlusive nonporous layer aimed at containing the clot into the defect.

The surgical technique involves a standard knee arthroscopy to carefully debride the lesion down to the subchondral bone using a curette, to obtain stable shoulders surrounding the defect. A circular sharp punch of adequate size is used until a smooth, circular surface with healthy cartilage borders is reached. Lesions smaller than 11 mm can be covered with a single punch, whereas larger lesions require more punches of appropriate sizes to be used. The membrane then is cut into the same amount of corresponding size circles after being poured with saline. The matrix positioning is performed through dry arthroscopy: first, several holes are being performed using a 1.1-mm K-wire at 5-mm intervals into the subchondral bone underlying the defect. Then, the membrane circles are placed in the respective sites, with the porous layer facing the subchondral bone, eventually with partial overlapping

between different circles. Finally, fibrin glue (Tissucol, Baxter, Warsaw, Poland) is applied to cover all the implants and stability is tested with complete ROM. Additional fixation devices or sutures can be applied, as preferred.

17.2.1.2 ChondroTissue® (BioTissue AG, Zurich, Switzerland)

Cell-free polyglycolic acid-hyaluronan (PGA-HA) implant immersed with autologous serum.

The surgical technique consists of two steps: microfracturing followed by the implantation of the ChondroTissue implants through an arthroscopic [17] or arthrotomic approach [18]. The damaged cartilage is debrided down to the subchondral bone with a curette and a shaver. Microfracturing is then performed using a Chondropick awl, according to the protocol by Steadman et al. [19]. The implants, after immersion in 2–3 mL-autologous serum prepared from venous blood preoperatively, are cut to fit the size of the defect and fixated using three to four bioresorbable bone fixation nails. The implant margins can be additionally covered with fibrin glue.

17.2.1.3 BST-CarGel® (Piramal, Laval, Quebec, Canada)

BST-CarGel® was developed to stabilize the blood clot in the cartilage lesion by dispersing a soluble and adhesive polymer scaffold containing chitosan throughout uncoagulated whole blood.

The surgical technique for BST-CarGel consists of three steps: (1) preparation of the lesion through careful debridement and bone marrow stimulation (Fig. 17.1a), (2) preparation of the BST-CarGel®/blood mixture, and (3) delivery of the BST-CarGel®/blood mixture to the lesion (Fig. 17.1b) [20]. Depending on the size and location of the lesion, as well as the preference or best judgment of the surgeon, a mini-open or arthroscopic approach can be used.

First of all, the defect is exposed arthroscopically, and protruding synovial tissue is removed. Proper visualization of the defect in a horizontal position is a prerequisite for later polymerization of the biomaterial. Subsequently, the damaged cartilage is debrided with shaver and sharp curette. The calcified layer is removed to allow adequate adhesion of BMSCs. A stable rim of

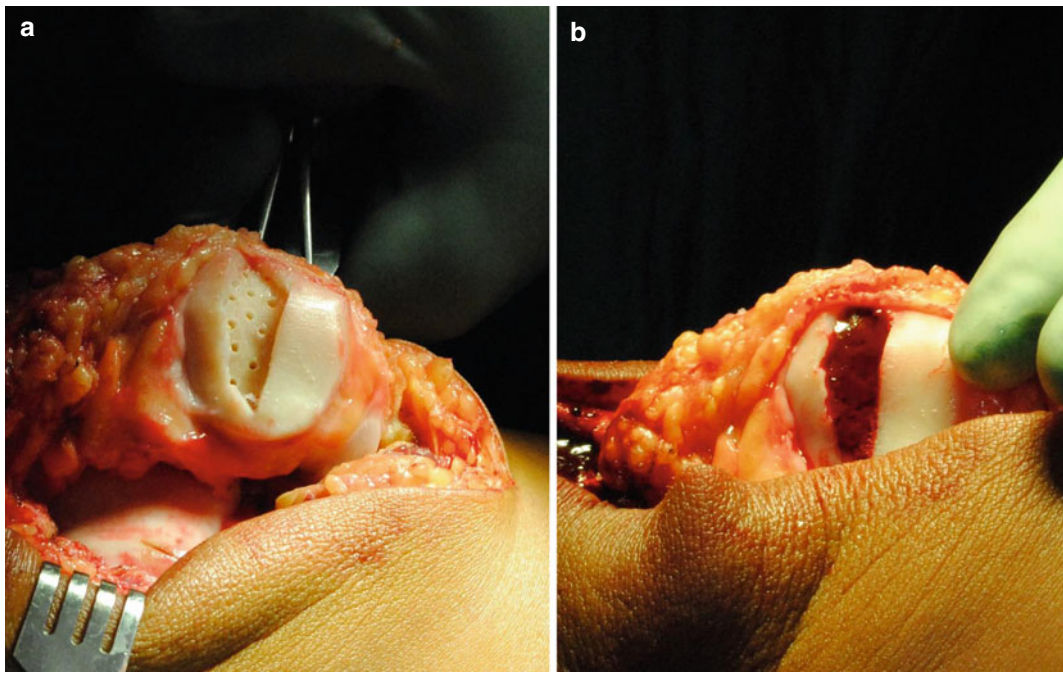

Fig. 17.1 BST-CarGel implantation: after lesion preparation through careful debridement and bone marrow stimulation (**a**), the BST-CarGel/blood mixture is delivered to the lesion (**b**)

healthy surrounding cartilage should be respected with regard to the containment of the defect. The surgeon performs the microfractures with an awl, picking holes of 3–4 mm in depth at a distance of 3–4 mm. If an arthroscopic technique is used [21], it is important that the leg is lifted to arrange the defect in a horizontal position, and the arthroscopy liquid has to be drained. The defect can be further dried by using small swab. Meanwhile, the BST-CarGel® is prepared according to the manufacturer's instructions with 4.5 mL of autologous venous blood at a ratio of 3:1 (blood/BST-CarGel®). Finally, the BST-CarGel® is injected with a syringe in a dropwise manner until the defect is entirely filled. Leakage of the BST-CarGel® must be avoided. After delivery, the BST-CarGel® and blood implant must be clotted in place during the required 15-min waiting period, prior to incision closure. The use of a tourniquet is not standardized, but, as a general rule, when used with BST-CarGel® treatment, the tourniquet has to be released only after the 15-min waiting period.

17.2.2 Osteochondral Cell-Free Techniques

17.2.2.1 Trufit® (Smith & Nephew, Andover, MA)

Biphasic cylindrical porous biopolymer is composed of calcium sulfate and polylactic-polyglycolic acid.

After controversial clinical findings, the scaffold has currently been withdrawn from the global market.

The surgical technique contemplates a mini-arthrotomy in a tourniquet-controlled bloodless surgical field to allow defect exposure. After the bottom of the cartilage defect is debrided and measured, the edges of the defect are trimmed back to stable walls of healthy cartilage. As described by Melton et al. [22], the decision whether to use one plug or multiple plugs is made at this stage, based on the characteristics of the lesion. Then, a single cylindrical hole (or multiple holes for multiple plugs) of 8–12 mm in depth is drilled through a drill sleeve into the defect. The drill hole size will be matched to the size of the defect and the planned implant diameter. A plug prepared to the same depth is introduced into the defect under direct vision. The implant then needs to be "tamped" down with a punch until the surface of the implant is continuous with the surrounding articular cartilage. This tamping is inherent to the technique and in accordance with the device manual. If more than one plug is required, a bridge of 1–2 mm should be left if possible. Finally, the implant is probed to ensure that the plug is stable and the edges are congruent with the surrounding chondral surfaces [22].

17.2.2.2 Maioregen® (Fin-Ceramica S.p.A., Faenza, Italy)

This osteochondral nanostructured biomimetic scaffold has a porous three-dimensional (3D) trilayer composite structure, mimicking the entire osteochondral anatomy. The cartilaginous layer is made of type I collagen. The intermediate layer (tidemark-like) consists of a combination of type I collagen (60%) and hydroxyapatite (HA) (40%), whereas the lower layer is a mineralized blend of type I collagen (30%) and HA (70%), reproducing the subchondral bone layer.

The surgical procedure [23] is performed with pneumatic tourniquet and arthrotomic medial or lateral parapatellar approach is used to expose the lesions. The defect is then prepared as follows: the sclerotic subchondral bone is removed until 8-mm deep site with stable shoulders is created for implant (Fig. 17.2a). The defect is templated with an aluminum foil obtaining the exact size and shape that are needed. The templates are then used to prepare the grafts that are finally implanted by press fit, even though more recently, the use of fibrin glue has been recommended (Fig. 17.2b) [24]. After tourniquet release, the scaffold swells with getting wet and the stability may be checked with cyclic bending and extension of the knee.

17.2.2.3 BioMatrix™ CRD (Arthrex Inc., Naples, FL)

BioMatrixTM CRD is a biphasic scaffold comprised of type I collagen (chondral layer) and porous tricalcium phosphate and polylactic acid (bone layer).

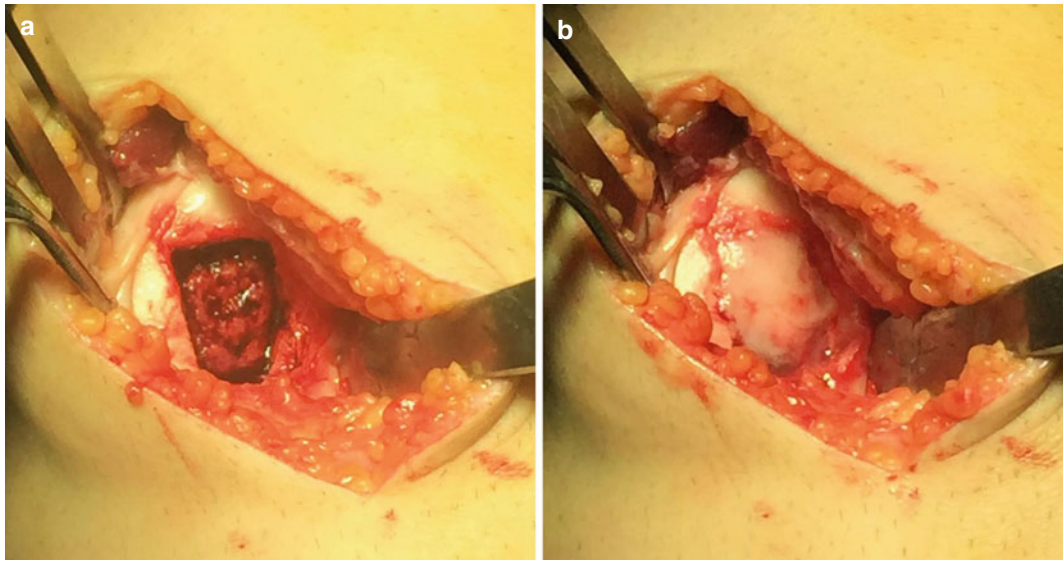

Fig. 17.2 Maioregen scaffold implantation: preparation of the defect, removing the sclerotic subchondral bone, and creating 8-mm deep lodgings with stable shoulders to place the implants (**a**). The grafts are prepared matching the size of the defect and implanted using a press-fit technique with the addition of fibrin glue (**b**)

After preparation of the defect site, using the sizer to evaluate the diameter, the harvester is placed orthogonally to the defect and driven to a depth of 10–15 mm using the mallet. The harvester is then withdrawn, and the tamp rod can be inserted into the implant site, to even potential irregularities on the bottom of the implant site, by gentle tappings with the mallet. After determining the required depth of the implant, the BioMatrix CRD, preloaded in the delivery device, is placed until the desired length is shown on the plunger of the delivery device. Using a scalpel, the exposed portion of the BioMatrix CRD can finally be removed until the plug surface is flush with the surrounding cartilage surface.

17.2.2.4 Agili-C™ (CartiHeal (2009) Ltd., Israel)

Aragonite-based osteochondral scaffold. It is a rigid cell-free implant designed in two layers:

- Bone phase: calcium carbonate in the aragonite crystalline form
- Superficial cartilage phase: modified aragonite and hyaluronic acid

With patient in supine position, a pneumatic tourniquet is placed on the proximal extremity of the lower leg.

A classical arthroscopic or parapatellar arthrotomic (medial or lateral) approach is used to expose lesions.

After accurate sizing of the lesion, the defect is prepared using a specifically designed instrumentation: a specific guidewire is positioned perpendicular to articular surface, and the defect is drilled with an appropriately sized cutter, reaming the debris. The scaffold is then implanted by press fit, with the superficial layer being 1–2 mm deeper than the surrounding cartilage (Fig. 17.3). The implant stability is finally tested with cyclic bending and extension of the knee.

17.3 Complication

Besides classic complications related to the knee surgery (like effusion, stiffness, wound infections), it has been pointed out that osteochondral scaffolds may produce slow or incomplete tissue regeneration, with altered signal at MRI. Despite that, it has been reported that the altered features

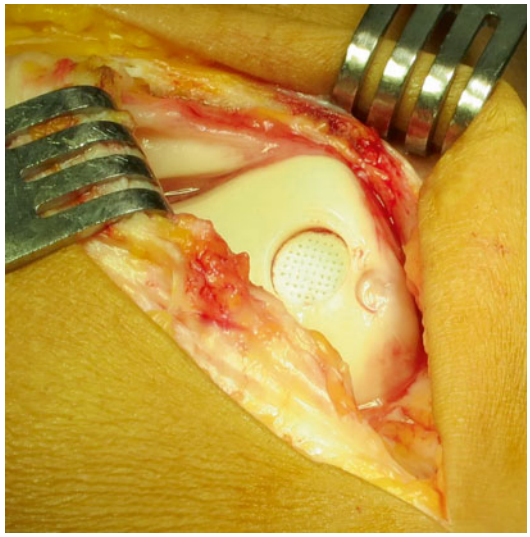

Fig. 17.3 Agili-C scaffold implantation: after the defect is prepared using a specifically designed instrumentation, the scaffold is implanted with press-fit techniques, with the superficial layer being 1–2 mm deeper than the surrounding cartilage

at MRI do not influence the clinical outcomes [25, 26], and these techniques remain indicated when limited alternatives are available.

17.4 Results: Brief Literature Review

17.4.1 AMIC®

The literature reports promise preclinical results: Gille et al. [27] observed multilayered cell growth into the matrix, with an apical sheet with chondrocyte-like cells. The collagen matrix is resorbed within 6–24 weeks of follow-up. Moreover, collagen I/III showed better chondrogenic properties than other matrices. Gille et al. also reported the results of the AMIC® registry on 57 patients at 24 months of follow-up (mean age 37.3 years (17–61) and mean defect size 3.4 cm^2 (1.0–12.0 cm^2)). Significant improvements in all the scores were observed, regardless of patient's age and sex nor the lesion size [28]. A prospective RCT on 30 patients (age 21–50 years, defect size 3.4 cm^2 mean) compared the clinical results after AMIC with those of microfractures alone. The significant score improvement obtained was comparable in both groups at 12 and 24 months postoperatively. Similarly, MRI showed a satisfactory and homogenous defect filling in the majority of patients and no intergroup differences [29].

Currently, paired with these promising results, several ways are tested for improving the AMIC technique: Pascarella et al. showed that seeding ChondroGide with autologous BMC is safe and effective in terms of clinical outcome (modified AMIC®) [30], while Dhollander et al. reported the combination with autologous PRP can offer a clinical improvement in a small group of patients (AMIC® plus) [31]. Finally, the use of the nanofracture technique has been presented as a recent further development to improve the expected outcomes for AMIC (NAMIC®) [32].

17.4.2 BST-CarGel®

After safety and good preliminary results were observed in 33 patients treated at 1 year follow-up [33], a high-level randomized clinical trial was performed. Eighty patients were randomized between the study group ($n=41$) and microfracture treatment alone ($n=39$). At 12 months, BST-CarGel® group showed greater lesion filling and superior repair tissue quality at MRI compared to microfracture alone. Clinical benefit was equivalent between groups and safety as well [34]. These results were later confirmed at 5 years of follow-up [20], with a comparable clinical outcome. MRI evaluation showed significantly better results of BST-CarGel® in terms of lesion filling, with T2 relaxation times closer to those of native cartilage. Moreover, tissue biopsies showed features of the regenerated tissue were consistent with a chondroinduction mechanism of BST-CarGel® in more than half of the treated lesions [35].

17.4.3 ChondroTissue®

Only few clinical reports were published on ChondroTissue®. Patrascu et al. [36] described a case report on a 26-year-old male with a posttraumatic defect of the cartilage of the medial femoral

condyle, showing good clinical results at 2 years' follow-up. Postoperative MRI showed that the repair tissue was hyper- to isointense compared to surrounding cartilage, and biopsy harvested at second look arthroscopy at 18 months revealed hyaline-like cartilage repair tissue. More recently, Becher et al. [18] reported the clinical and radiological results after treatment of five patients affected by retropatellar cartilage defects. After a mean 21 months of follow-up, an improvement of the clinical scores was registered, and 3 T MRI showed good-to-excellent defect filling and complete integration of the implant, with mean MOCART score of 61 points.

17.4.4 Trufit®

Although preclinical studies of Trufit® implantation reported promising findings, latter studies displayed controversial results. Despite some isolated studies showed favorable results after implantation of this scaffold, MRI evaluation performed at 12 months showed an heterogeneous cartilage repair tissue, and assessment of long-term durability is still lacking [22, 37]. Barber et al. [38] evaluated multiple scans of computed tomography (CT) performed between 2 and 63 months after surgery, assessing that the plug showed no signs of maturation, osteoconductivity, or ossification in each of the nine patients evaluated. On the contrary, Bedi et al. [39] evaluated 26 patients, who received Trufit® for filling the harvest site of autologous osteochondral transplantation (OAT) of the knee: despite MRI evaluation at mid-term follow-up showed negative findings, an improvement of the repair tissue was observed at longer follow-up. It was therefore recommended to persevere and wait for satisfactory clinical results. Similar suggestions have been confirmed by Carmont et al. [40], who reported a case of an 18-year-old soccer player with delayed reabsorption and maturation of articular cartilage in the early phases, but a good clinical outcome at 24 months' follow-up. Bekkers et al. [41] evaluated by quantitative MRI the results of 13 patients at 1 year postoperatively, with positive findings both for clinical outcome and cartilage-like signal of the plug's superficial layer.

Conversely, other authors showed poor results. Dhollander et al. reported a 20 % failure rate at 12 months in 15 patients, with biopsies showing fibrous vascularized repair tissue [42]. Moreover, Joshi et al. advice against the use of this graft for the treatment of patellar defects, reporting a 70 % revision rate within the first 24 months of follow-up [43]. Finally, a further study by Hindle et al. showed significantly lower outcomes for patients treated with this plug, with respect with a group of patients who underwent mosaicplasty [44].

17.4.5 Maioregen®

Promising preliminary results have been reported on a pilot study on 28 patients affected by chondral and osteochondral lesions of the knee. A slower recovery was observed in older, less active patients who experienced adverse events or in patellar lesions. However, at 2 years of follow-up, good results were generally reported, regardless of patient's characteristics [45].

The mid-term evaluation of the same group at 5 years' follow-up confirmed a stable clinical outcome and a slow but significant improvement in both mean MOCART score and subchondral bone status at MRI evaluation. Although some signal abnormalities were persisting, they did not affect the clinical outcomes [25]. The same technique showed good results at 12 months postoperatively in 27 patients with symptomatic OCD of the femoral condyles, with further increase at 24 months and no correlation between size and outcome. Also this study reported a controversial MRI appearance of the repair tissue at early follow-up, but no correlation with the clinical scores [46]. Delcogliano et al. [47] applied this technique to 19 patients with large articular defects, with good clinical results at 24 months of follow-up. Berruto et al. [48] confirmed similar positive findings 2 years after the treatment of large osteochondral lesions in a multicenter study on 49 patients. Furthermore, the treatment of a larger series of 79 patients with defects of trochlea or condyles showed satisfactory outcome at 12 and 24 months: better results were reached in

traumatic cases, compared to degenerative ones [49]. Despite this finding, a combined mechanical and biological approach has also been reported to be effective as a salvage procedure in difficult degenerative cases [50, 51]. Filardo et al. [10] treated 33 patients for "complex" osteochondral lesions, reporting a significant clinical improvement at 24 months' follow-up. Interestingly, the clinical results were compared with those of a homogeneous group of patients treated with the implantation of MACT, showing that an osteochondral treatment is more effective in this kind of patients. Finally, this construct showed satisfactory results also for unicompartimental OA in young patients, with the aim to avoid metal resurfacing. Forty-three patients were treated using concurrent procedures together with the scaffold implantation, to address all the comorbidities and restore the correct biomechanics of the knee. This approach led to a significant clinical improvement from pre-op to the 3 years' follow-up, and the best benefits were obtained in patients under 40 years old; thus, the authors propose this surgical approach as a new treatment option for young OA patients [52].

17.4.6 BioMatrix™ CRD

Preclinical studies in the animal model observed a comparable safety and a significantly better improvement with respect to microfractures, both in goat and horse models.

Clinical studies are currently ongoing, to compare the outcome obtained by implanting this plug with those of microfractures, in order to understand not only the healing potential but also possible advantages with respect to traditional techniques [53].

17.4.7 Agili-C®

Preclinical analysis [54] revealed the safety and potential of this scaffold, showing its biodegradability and intrinsic restorative potential. Particularly, the ability to recruit cells from the surrounding tissues allowed a good regeneration of the entire osteochondral unit to be produced, which led to the translation of this scaffold as a one-step implantation without any cell augmentation into the clinical setting.

Only a single case describing the clinical use of this construct has been reported yet: a 47-year-old nonprofessional sportsman affected by a posttraumatic osteochondral lesion around 2 cm^2 on the medial femoral condyle was treated successfully and resumed his pre-injury sport activity after 18 months. The MRI evaluation performed at 24 months of follow-up showed promising findings with the restoration of the articular surface [55]. Multicenter prospective clinical study is ongoing [56].

Conclusion

The aim of an orthopedic surgeon should be to restore the articular surface as similar as possible to original anatomy, thus restoring the osteochondral unit with physiological properties stable over time; the implantation of bioengineered scaffolds directly in the lesion site might allow to achieve these results.

Research in recent years is moving toward "one-step" surgical, and for this reason, the ideal scaffold from both practical and commercial points of view should be product from the shelf and ready to use.

Among these, recently, there have been developed scaffolds with different chondral/osteochondral regenerative potential; however, only six are currently used in the clinic. Despite the promising preliminary results, further comparative studies with high scientific value and longer follow-up times are still needed to testify the effectiveness and reliability of these procedures over time.

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18 ACL Tear: Complete and Partial, Associated to Medial and Lateral Damage

Rainer Siebold and Georgios Karidakis

18.1 Diagnosis of ACL Tear

A clinical evaluation including a careful history and physical examination is the first step to establish a diagnosis after ACL injury. It should begin with a complete history of the symptoms and a full description of the mechanism of injury. In general 50–80% of ACL injuries occur in non-contact situations [1, 6, 9]; thus, patient may describe a pivoting injury pattern on a fixed foot, an abrupt deceleration, or hyperextension [6].

Symptoms depend on the timing of assessment after trauma: in *acute* cases, patients may present with a limp or even inability to weight bear. Patient may also complain of inability to fully extend and/or flex the knee, painful movements, sensation of strain in the joint, and sometimes locking. In *chronic* ACL insufficiency, patients usually are able to walk, but may complain of various degrees of instability from frequently to only in certain situations, such as descending stairs or pivoting sports. The patient may report pain and joint effusion periodically, especially after athletic activities. Patients with chronic ACL tears often sustain secondary injuries to the meniscus or cartilage, which are symptomatic and have to be treaded. History also comprises questions about past injuries to the affected and the contralateral limb.

18.1.1 Physical Examination

The physical examination should include both the injured and contralateral limbs and usually begins with an observation and inspection: the patient may be limping or may be unable to walk without support. Clinical effusion may be apparent visually, especially in acute cases where patients usually develop hemarthrosis, while muscle atrophy could be present in chronic cases. The active range of motion, if feasible, should be recorded along with any limitations to full extension or flexion. The examiner should record any pain produced by palpation, e.g., at the bony landmarks around the knee, the joint line, and should grade the size of joint effusion.

18.1.2 Stability Tests

Abnormal anterior tibial translation of an ACL-deficient knee can be diagnosed clinically by

R. Siebold (✉)
HKF – Center for Hip, Knee, Foot Surgery and Sportstraumatology, ATOS Klinik, Bismarckstr. 9-15, Heidelberg 69115, Germany

Institute for Anatomy and Cell Biology, Ruprecht-Karls-University, Heidelberg, Germany
e-mail: rainer.siebold@atos.de

G. Karidakis
HKF – Center for Hip, Knee, Foot Surgery and Sportstraumatology, ATOS Klinik, Bismarckstr. 9-15, Heidelberg 69115, Germany

Orthopaedic Department, 251 General Air Forces Hospital, Athens, Greece

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using the Lachman and anterior drawer tests, by instruments such as the KT-1000 and KT-2000 knee arthrometer (MEDmetric, San Diego, CA) or by the Rolimeter (Aircast Europa, Neubeuern, Germany).

The ACL is the primary restraint to anterior translation of the tibia and the ligament's greatest contribution occurs at 30° of flexion [8]. In an in vivo study, Beynnon et al. [5] found that the ACL undergoes greater strain in response to an anterior force at 30° than at 90°. When the ACL is sectioned, maximum anterior translation occurs at 30°. After sectioning of the medial collateral ligament (MCL), anterior translation increases only in 90°, suggesting that the Lachman test at 30° carries diagnostic specificity in case of ACL deficiency [14]. Consequently, the Lachman test is the clinical examination of choice for detection of an ACL insufficiency, while the anterior drawer test (performed at 90°) places less strain on the ACL. Unfortunately, in the acutely injured knee, both tests (especially the anterior drawer test) may be of less value as a result of hemarthrosis and patient's pain and resistance. De Haven showed after an acute ACL tear that the Lachman test was positive in 80 % of patients examined without anesthesia but in almost 100 % of patients examined under anesthesia. Concerning the anterior drawer test, it was positive in only 10 % of patients without anesthesia and in 50 % of patients under anesthesia. Both tests had higher diagnostic value in chronic ACL insufficiency [12].

The *Lachman-Noulis test* [25] was originally described by Georgios K. Noulis (1849–1919) in his doctoral thesis *Entorse Du Genou* at the University of Paris in 1875. This test, widely known as "Lachman test" described by Joseph Torg [28], was named for his mentor John Lachman, chairman and professor of orthopedic surgery at Temple University, Philadelphia. Although originally the author recommended holding the knee between full extension and 15° of flexion, it is now common to place the knee in 30° of flexion. The tibia must rest in neutral rotation, because in internal or external rotation, secondary stabilizers will be activated, thereby confounding assessment of the ACL. Another point to mention is that the tibia must not be subluxated posteriorly as in a posterior cruciate ligament (PCL)-deficient knee to avoid a false-positive test. The Lachman test has a high sensitivity and specificity of about 95 % [16], while false-negative results may be found in concomitant bucket-handle meniscal tears with anterior tibial translation [28], although other data indicate that additional injuries do not alter test sensitivity [13].

The test is performed with the patient supine and the knee positioned in 30° of flexion. The examiner stabilizes the anterolateral distal femur with one hand and applies pressure on the posterior aspect of the proximal tibia with the other, in an attempt to produce anterior displacement. Visible anterior translation of the tibia on the femur with "soft" end point represents a positive test result [28]. The results of the test can be described qualitatively and quantitatively, in comparison to the (healthy) contralateral knee: anterior translation of 1–5 mm is defined as grade I laxity, 6–10 mm as grade II laxity, and >10 mm as grade III. The quality of end point is graded as firm, soft, or absent [20]. The Lachman test is illustrated in Fig. 18.1a, b.

The *anterior drawer test*, as mentioned before, has many limitations, mainly because it is performed in 90° of flexion, where the ACL is not the primary restraint for anterior translation. Also, the posterior meniscal horns and the bony contour may interfere with the test. Additional limitation may be the inability to flex in 90° an acutely injured or swollen knee. Although test accuracy is higher in patients with chronic injury, the sensitivity in an alert patient varies and is reported to be from 22 % to 95 %, whereas it improves in anesthetized patients from 50 % to 90 % [13, 15, 16].

The patient lies supine and the knee is flexed to 90° with the tibia in neutral rotation. The examiner must ensure that the tibia is not subluxated posteriorly before performing the test to avoid misdiagnosis in a PCL-deficient knee. It is also important to encourage the patient to fully relax the hamstring muscles to minimize their resistance to anterior translation. The test is performed with the examiner grasping the proximal

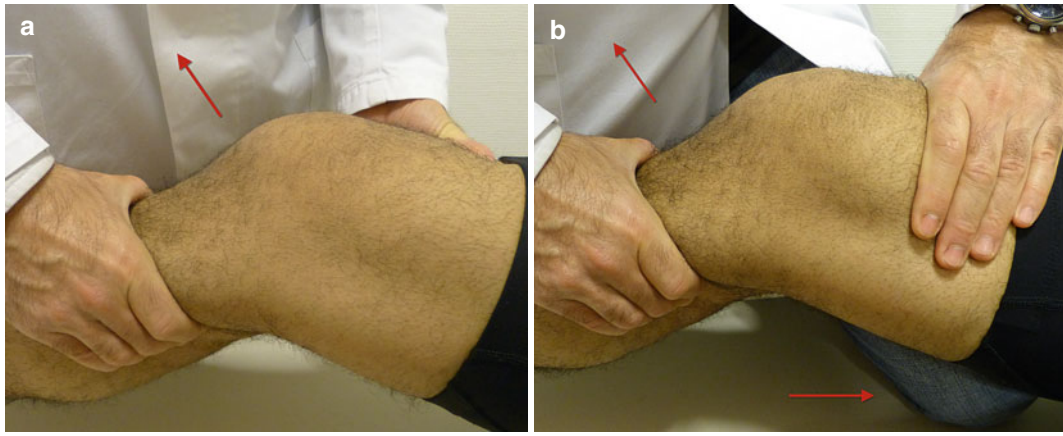

Fig. 18.1 The Lachman-Noulis test (**a**) and the Lachman-Noulis test with leg support (**b**)

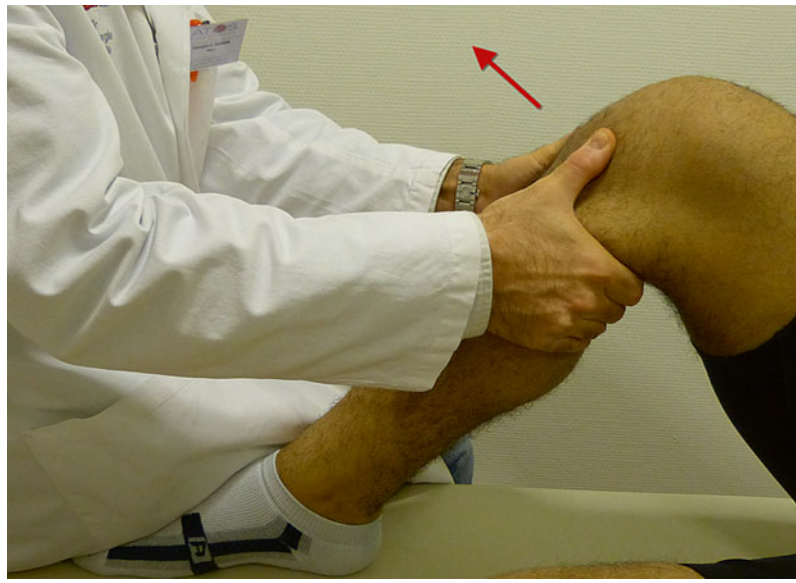

Fig. 18.2 The anterior drawer test

tibia with both hands, placing both thumbs on the anterior joint line. A positive test is indicated by increased anterior translation and a soft end point and graded similar to the Lachman test (Fig. 18.2).

The *pivot shift* is both a clinical phenomenon that results in a sensation of giving way of the knee and a physical sign that can be elicited on examination. The phenomenon is characterized as an anterior subluxation of the lateral tibial plateau in relation to the femoral condyle when the knee approaches extension with reduction produced with knee flexion. Several studies have been performed to determine the diagnostic sensitivity and specificity of the pivot shift test in the diagnosis of ACL injuries. Studies report sensitivity of the pivot shift in ACL injuries from 84 % to 98.4 %, with a specificity of >98 % when the test is performed with the patient under anesthesia, while in the alert patient, values as low as 35 % have been described [13, 16, 21].

The patient lies supine attempting to relax the leg muscles as much as possible. With one hand,

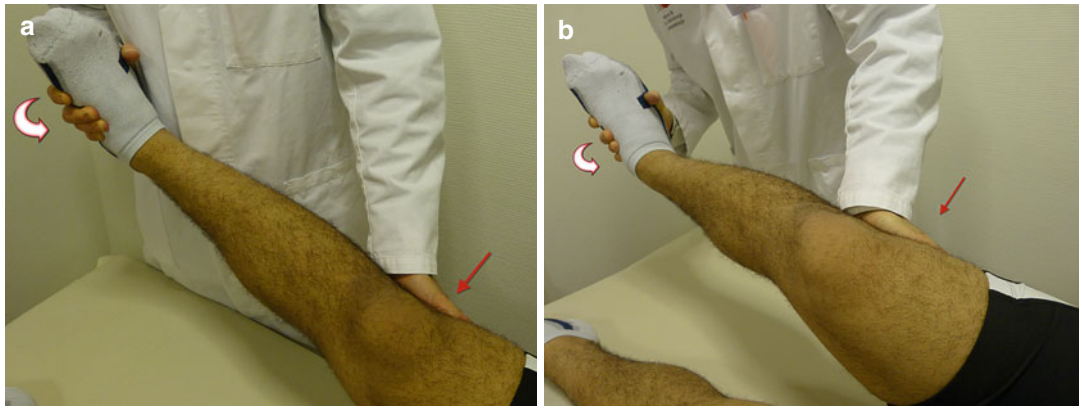

Fig. 18.3 The pivot shift test, starting position (**a**) and ending position (**b**)

the examiner holds the leg in full extension from the foot applying internal rotation to the tibia and, with the other hand on the lateral aspect of the knee, applies valgus stress while flexing it. In an ACL-deficient knee, the lateral tibial plateau will be initially subluxated (in less than 30° of flexion) and will reduce while flexion continues. This is palpable and sometimes also audible (Fig. 18.3a, b). The pivot shift test is graded estimating the relocation event: grade 0 is considered normal, without reduction, grade I represents a smooth glide with slight shift, grade II is assumed when the tibia is reduced with moderate shift, and grade III when the reduction is abrupt with large shift.

Other clinical tests have been described to evaluate rotational instability in ACL-deficient knees. The *flexion rotation drawer test* is built on the Lachman test and notes tibial motion and femoral rotation from 15 to 30° of flexion [29]. It is performed with the leg stabilized between examiner's armpit and hands that apply anterior force to the tibia starting at 15° of flexion. This leads to anterior subluxation, while further knee flexion leads to reduction of the tibia beneath the femur with a noticeable "clunk" and internal rotation of the femur.

The following tests are based on anterolateral motion of the tibia against the femur and are difficult to perform on an acutely injured knee. The *jerk test* begins with the knee in flexion. The examiner holds the leg with one hand on the foot applying internal rotation and the other on the lateral aspect of the knee with the thumb applying forward force to the fibular head and the other fingers valgus stress. This combination subluxes the lateral tibial condyle anteriorly. As the knee is brought into extension, the tibia reduces with a palpable clunk (Fig. 18.4a, b). The *Losee test* [19] is similar to the jerk test. The examiner holds the leg the same way (in flexion and applying valgus stress), but with the tibia initially held in external rotation. Subsequently, as the knee is gradually extended, the tibia is rotated internally and the clunk is again felt as reduction occurs. The *quadriceps active test for the ACL* [11] is performed with the knee held at 30° of flexion. The patient is asked to contract the quadriceps muscle, and this action will pull first the tibia slightly forward before the lower part of the leg begins to extend.

18.2 Exploration

18.2.1 Instrumented Manual Measurement Systems

The tests described above are the most widely, single-plane tests used to evaluate ACL rupture. Although the examiner should grade them quantitatively and qualitatively, this is not always feasible or precise, and the result varies greatly between surgeons because of the inherent variability in the magnitude, direction, and rate of force application.

The need of higher accuracy led to the development of various arthrometers and measurement

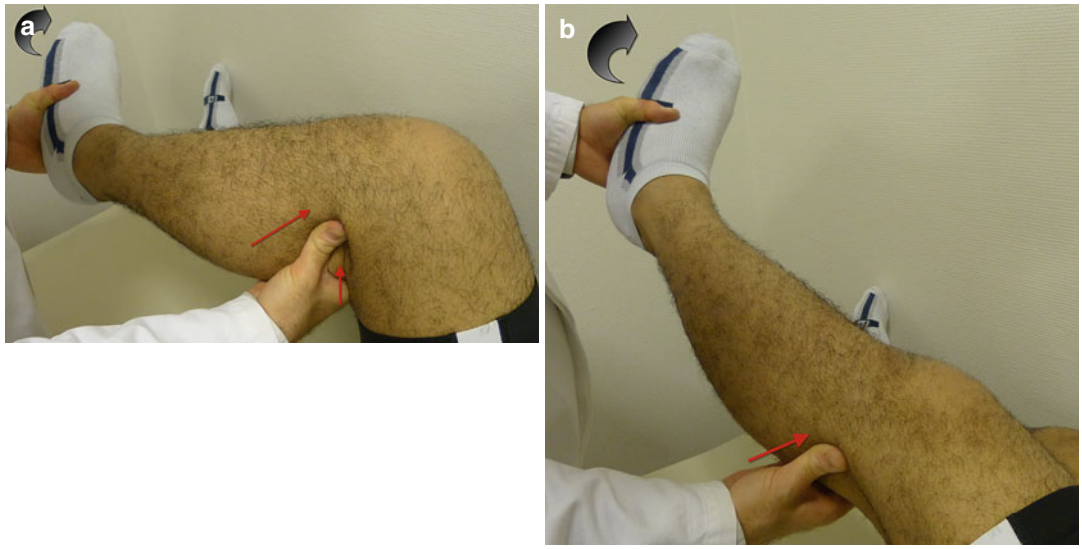

Fig. 18.4 The jerk test, starting position (**a**) and ending position (**b**)

systems. The first device of this type was the KT-1000 (and the newer version KT-2000) Knee Ligament Arthrometer (MEDmetric, San Diego, CA), developed by Dale Daniel and Larry Malcolm [10]. Many other systems are commercially available, e.g., the CA-4000 Electrogoniometer (OSI, Hayward, CA) [18], Genucom Knee Analysis System (FARO Medical Technologies, Montreal, Ontario Canada) [24], Kneelax3 (Monitored Rehab Systems, Haarlem, the Netherlands) [4], Rolimeter (Aircast Europa, Neubeuern, Germany) [3], and Stryker Knee Laxity Tester (Stryker, Kalamazoo, MI) [7].

The *KT-1000* and *KT-2000 arthrometers* are still the most widely used devices to quantify anterior tibial translation. They provide an objective measure of anterior laxity and have been shown to be both accurate and reliable [23]. Patient relaxation, correct positioning, and application of an anterior-directed force are required, as with Lachman and anterior drawer tests [10].

The patient is positioned supine with the thigh support in a position to flex the knees to 30°. Then the heels are placed on footrest to ensure neutral rotation. The device is placed on the knee to be tested (usually first the normal knee), with the arrows of the arthrometer pointing directly at the joint line and the measurement pads secured against the tibial tubercle and patella using the straps provided. Then the device is secured and the zero calibration point should be established. Anterior translation measurements are recorded at 67 N–89 N and 134 N as three different forces are applied through the arthrometer handle indicated by a different audible tone. Finally a manual maximum force is applied to the posterior aspect of the proximal tibia, as in the Lachman test. Results that correlate with ACL insufficiency are a maximum side-to-side difference of >3 mm, a maximum manual translation of >10 mm, or a difference in translation between the first two tests (67 N and 89 N) of >2 mm [2]. KT-1000 use is displayed in Fig. 18.5a, b.

Another popular instrument to measure anterior translation is the *Rolimeter*. The difference to the KT-1000 is that it works completely mechanically. After calibrating the tibial head is manually pulled forward with the examiners hand in 30° of flexion. The amount of maximum anterior translation can be metered at the instrument comparing both knees. Grading is similar to the KT-1000.

18.2.2 Diagnosis of Partial ACL Tears

Patients with a symptomatic partial tear may complain of unspecific symptoms like recurrent pain and swelling. More specifically, patients with a *symptomatic anteromedial (AM) bundle*

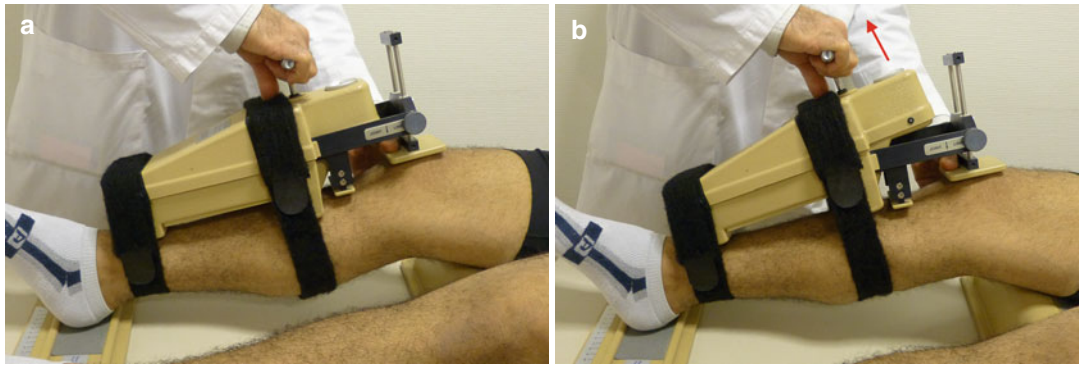

Fig. 18.5 The KT-2000, starting position (**a**) and ending position (**b**)

tear describe an anterior instability during ADL and during sports similar to a complete ACL tear. They usually demonstrate an increased (1+) anterior drawer test and a KT-1000 side-to-side difference of 2–4 mm. The anterior translation in the Lachman-Noulis test is rather small (0–1+) and the pivot shift test is negative or only slightly positive (0–1+) [27].

In contrast patients with a *symptomatic posteromedial (PM) bundle tear* complain of rotatorial instability with pivoting sports rather than significant anterior instability with ADL or sports. Often non-pivoting sports can still be performed without major problems, whereas pivoting sports (e.g., football, soccer) had to be given up due to recurrent symptoms with rotatorial instability. Clinical examination of these patients might demonstrate a positive pivot shift test (1+), whereas the anterior drawer test is only slightly positive (0–1+) and a positive (1+) Lachman-Noulis test. The KT-1000 usually shows a small side-to-side difference of 1–3 mm. Of course the symptomatic is related to the amount of ACL damage [27].

18.2.3 Diagnosis of ACL Tear Associated to Medial and Lateral Damage

The combination of an ACL tear with an injury to the posteromedial and posterolateral structures needs a careful diagnosis. On the *posteromedial side*, the superficial and deep medial collateral ligament (MCL) and the posterior oblique ligament (POL) are of main importance. Two major clinical tests may detect the acute or chronic damage on the medial side: valgus stress test at 0° and at 30° of flexion and the anteromedial drawer test. Pain but no significant gapping during application of the 30° valgus flexion test indicates an intrasubstance grade I tear, increased gapping with end point a grade II tear, and gapping with no definitive end point is indicative of a grade III or complete medial knee injury. On the *posterolateral side*, many structures add to lateral and rotational stability. The major ones are the lateral collateral ligament (LCL), the popliteofibular ligament (PFL), and the popliteus tendon. Another important structure on the lateral side is the tractus iliotibialis. It is impossible to separately test these structures as the stability is a combination of all. Important clinical tests for the lateral side are the external rotation recurvatum test, varus stress test at 0° and 30°, the dial test at 30° and 90°, and reverse pivot shift. In case of an ACL tear with large anterior translation, e.g., a 2+ or 3+ Lachman-Noulis test, 2+ or 3+ pivot shift test or a KT-1000 or Rolimeter of more than 7–10 mm, the examiner must suspect an additional damage to the posteromedial or posterolateral aspect of the knee and should perform the above tests.

18.2.4 Imaging of ACL Rupture

Radiographs of the knee in the anteroposterior and lateral plane are performed routinely to exclude a severe injury with fracture. Secondary bony signs of ACL tear as a tibial avulsion fracture (=Segond fracture) [22] a bony lateral compartment contusion fractures [26, 30] or a tibial avulsion fractures

at the ACL attachment site may be noted [17]. When suspected, additional valgus and varus stress radiographs may give valuable information on the stability of the posteromedial and posterolateral corner. Increased medial knee joint gapping at 20° of flexion indicates a complete or partial rupture of the superficial medial collateral ligament injury, while more than 9 mm gapping indicates a complete medial knee injury.

Computed tomography (CT) is more reliable to detect above bony lesions; however, it has usually no place for primary diagnosis after ACL tear.

Magnetic resonance imaging (MRI) is the gold standard to detect an ACL tear and concomitant injuries. The structure of the ACL can be demonstrated on T1- and T2-weighted MRIs in the sagittal and coronal planes. A clear discrimination of the location of the ACL tear might often be possible, usually in adults on the femoral origin of the ACL. Partial tears are much more difficult to observe and are usually a combined diagnosis of history, clinical examination, and MRI pictures. In the sagittal plane with the knee extended, the AM fibers stretch from the anterior aspect of the tibial ACL insertion to its femoral insertion immediately inferior to the "over-the-top" position (= posterior end of Blumensaat line) on the lateral intercondylar wall. The posterior fibers equal the posterior longitudinal part of the ACL parallel to the AM fibers and stretch from the posterior aspect of the tibial ACL insertion to its femoral insertion immediately inferior to the femoral AM insertion. In most cases two or three planes might be necessary to demonstrate the specific tear. MRI is also the most reliable tool to detect injuries to the posteromedial or posterolateral corner of the knee. On the *posteromedial side*, the superficial and deep MCL and the POL are of main importance to look at. On the posterolateral side, it is the LCL, the PFL, the popliteus tendon, and the tractus iliotibialis.

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19 General Technical Consideration in Arthroscopic Anterior Cruciate Ligament Reconstruction

A. Stoehr, A. Hochrein, and H.O. Mayr

19.1 Inside Out, Outside In

An essential step in successful ACL reconstruction is achieving appropriate tunnels or sockets for graft placement and fixation. Several drilling techniques have been described, all of which have their justification in respect to different operation and fixation strategies [6]. For single-bundle ACL reconstruction, one bone tunnel is needed in the femur and one in the tibia. There are four primary techniques for femoral drilling: inside-out anteromedial portal (AMP) technique, outside-in (OI) technique, outside-in retrograde-drilling (RD) technique, and endoscopic transtibial (TT) technique [15, 18]. Basically two possibilities for tibial drilling exist, also: outside-in technique and outside-in retrograde drilling. Combinations are possible and commonly applied (i.e., outside-in tibial and inside-out femoral drilling). Whether the femoral or tibial tunnel is placed first is up to the surgeon since transtibial femoral drilling is on the decline due to less anatomical tunnel positioning [1, 10]. Primary femoral drilling can facilitate arthroscopy. Fluid loss through tibial tunnel can be controlled with a plug after primary tibial tunnel placement. In general, anatomic tunnel placement is more important than the actual drilling technique [4, 13]. The surgeon must adapt drilling to chosen graft, available instruments, desired fixation method, and individual skills.

19.1.1 Femoral Tunnel Drilling

This section describes the most common femoral drilling techniques with their respective advantages and disadvantages.

19.1.1.1 Anteromedial Portal (AMP) Technique

Using the AMP technique, the femoral tunnel or socket is created through the anteromedial arthroscopic portal independent of the tibial tunnel (Fig. 19.1). Placement within the native ACL footprint on the lateral femoral metaphysis is arthroscopically controlled. Different aiming devices are available, yet proper tunnel placement in the middle of the native ACL footprint is most important. First, a K-wire is placed in the correct position under sight (Fig. 19.2). A drill according to the graft diameter is then introduced into the joint via the anteromedial arthroscopy

A. Stoehr (✉) • A. Hochrein
Department of Knee Surgery and Sports Traumatology, OCM-Clinic Munich, Steiner Str. 6, Munich 81369, Germany
e-mail: ameliestoehr@hotmail.de

H.O. Mayr
Clinic of Orthopedic and Trauma Surgery, University Hospital Freiburg, Hugstetter Straße55, Freiburg 79106, Germany
e-mail: hermann.mayr@uniklinik-freiburg.de

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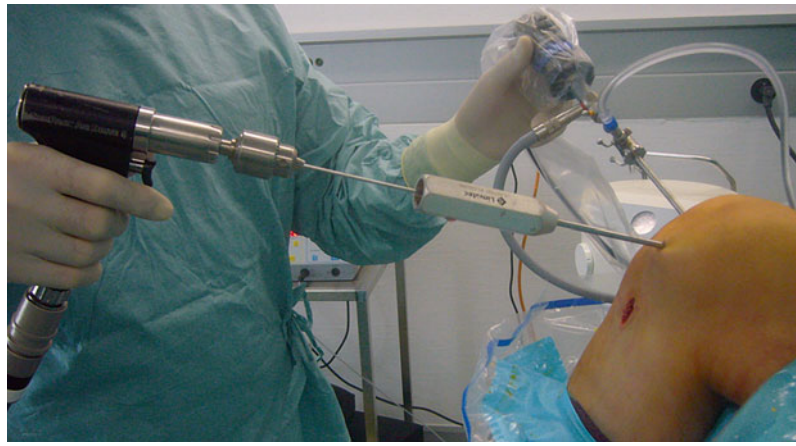

Fig. 19.1 Placing of K-wire using an aiming guide for femoral tunnel drilling in AMP technique on the right knee, view from outside

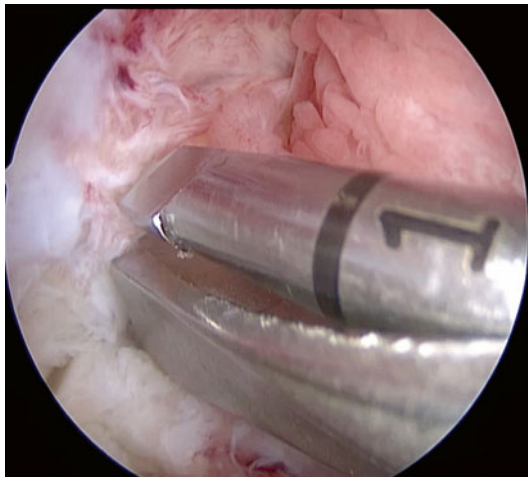

Fig. 19.2 Placing of K-wire for femoral tunnel drilling in AMP technique on the right knee under arthroscopic control

portal. Rigid or flexible drills are available. The created socket length must correspond to the respective fixation technique; the lateral femoral cortex should be spared. This technique is excellent for anatomic single-bundle ACL reconstruction but also ideal for ACL augmentation or anatomic double-bundle ACL reconstruction.

Advantages

- Anatomic placement of femoral tunnel(s) in respect to anteromedial and posterolateral ACL footprints [4]
- Independent placement of femoral and tibial tunnels
- More accurate and horizontal placement of ACL femoral insertion, parallel interference screw placement
- Preservation of ACL remnants allowing augmentation
- Tunnel placement independent of graft type, fixation devices, or tunnel guides
- Increased rotational stability compared to TT technique [3, 19]
- All-inside technique possible [11]
- Advantageous in revision surgery

Disadvantages

- Difficult visualization in deep flexion (>120°).
- Danger of iatrogenic chondral injury if anteromedial portal is not near the intercondylar notch.
- Posterior wall blowout resulting from inadequate drilling angle due to insufficient knee flexion.
- More demanding than TT technique.
- (Accidental) bicortical drilling can limit fixation options due to relatively short anatomic width of lateral femoral metaphysis.

19.1.1.2 Outside-In Technique

Using the OI technique, a drill tunnel is created from extra-articular through the lateral femoral metaphysis into the native femoral ACL footprint

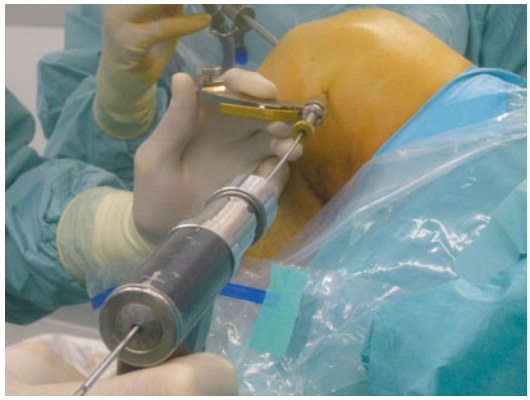

Fig. 19.3 Placing of K-wire for femoral tunnel drilling in OI technique, view from outside

under arthroscopic control. Again, first, a K-wire is placed using special aiming guides (Fig. 19.3). The tunnel is drilled through the lateral cortex via additional skin incision on the lateral thigh [5].

Advantages
- Predictable anatomic tunnel placement [14].
- Less risk of posterior wall blowout.
- Potentially useful for revision surgery.
- More horizontal tunnel trajectory can facilitate bone graft incorporation [16].
- Increased rotational stability compared to TT technique [17].

Disadvantages
- Second skin incision with increased surgical morbidity due to open lateral femoral surgical approach
- Cosmetically unfavorable
- Increased operative time
- Technically demanding (special aiming guides)
- Sometimes persisting pain due to lesion of the iliotibial band

19.1.1.3 Outside-In Retrograde-Drilling Technique

An analog to outside-in technique a special retrodrill (e.g., Flipcutter) is placed into the native femoral ACL footprint using special aiming guides. It is then transfemorally introduced into the joint; the drill bit is manually flipped open when visualized in the intercondylar notch. Subsequently, the socket can be drilled in retrograde direction [2].

Advantages
- Anatomic tunnel placement according to native femoral ACL footprint (compared to TT technique) [14].
- Deep flexion not necessary.
- All-epiphyseal drilling in skeletally immature patients possible.
- Cosmetically favorable small accessory incision.
- More horizontal tunnel trajectory can facilitate bone graft incorporation.

Disadvantages
- Increased operative time.
- Higher cost compared to conventional techniques.
- Steeper angulation between graft and tunnel can increase graft wear at tunnel entrance.
- Divergence between tunnel trajectory and screwing direction (interference screw fixation) [2].

19.1.1.4 Endoscopic Transtibial Technique

Endoscopic transtibial drilling of the femoral tunnel was the standard technique for ACL reconstruction about a decade ago [7]. Since the focus has shifted to anatomic graft placement due to better rotational stability and patient outcome, this technique has been increasingly abandoned [10]. For femoral tunnel placement using TT technique, the tibial tunnel must first be created. A special aiming guide is then introduced into the joint via tibial tunnel and placed on the lateral femoral metaphysis. Ninety degrees of knee flexion is usually necessary. Femoral tunnel placement is limited by tibial tunnel orientation and diameter [8]. Due to nonanatomic placement of the femoral tunnel, transtibial drilling of the femoral tunnel should be avoided nowadays.

Advantages
- Simple and reproducible operation technique

Disadvantages
- Limited placement options for femoral tunnel [1]

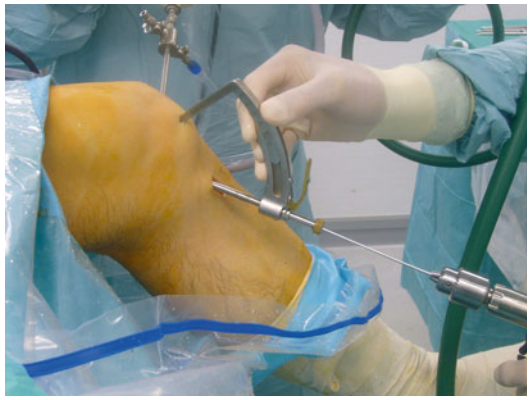

Fig. 19.4 Placing of K-wire using an aiming guide for tibial tunnel drilling in OI technique on the right knee, view from outside

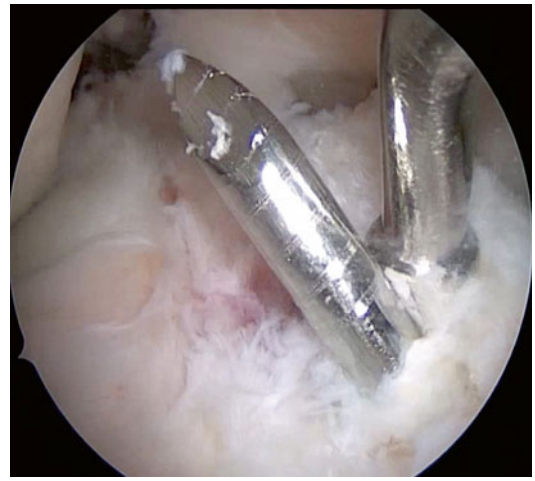

Fig. 19.5 Placing of K-wire for tibial tunnel drilling in OI technique under arthroscopic view

- Often too vertical and anterior graft placement
- Nonanatomic graft placement resulting in altered knee kinematics, persisting motion deficit, and early osteoarthritis
- Less rotational stability
- Divergence between tunnel and interference screw
- Tibial tunnel widening due to altered biomechanic properties and repeated reaming of femoral tunnel [9]

19.1.2 Tibial Tunnel Drilling

Outside-in antegrade and outside-in retrograde drilling is possible on the tibial side. Using hamstring tendon or bone–patellar tendon–bone autografts, the harvest skin incision can be used.

19.1.2.1 Outside-In Technique

A K-wire is placed into the medial proximal tibial metaphysis from a centro-medial approach under utilization of a special aiming device (Fig. 19.4). Positioning within the native tibial ACL footprint on the intercondylar eminentia is ensured arthroscopically (Fig. 19.5). The tunnel is then drilled through the entire tibial metaphysis according to measured graft diameter.

Advantages

- Simple, standardized technique, especially for beginners
- Anatomic placement facilitated by good overall view
- Easy graft insertion into femoral socket via tibial tunnel
- Controlled tibial fixation and various fixation options (i.e., interference screw, staple, and hybrid fixation)
- Possibility of controlled graft (pre-)tensioning after femoral fixation and before tibial fixation
- No additional incisions except using quadriceps tendon autograft
- Accessible for revision surgery

Disadvantages

- Excessive bone loss, especially with larger tunnel diameter.
- Risk for synovial fistulas or cysts due to leakage from the joint into tibial tunnel with possible irritations [20].
- Tunnel widening possible with the use of bioresorbable interference screws.
- Two-stage revision surgery may be necessary in case of tunnel widening or improper placement.

19.1.2.2 Outside-In Retrograde Drilling

Analog to a retrodrill femoral outside-in retrograde-drilling technique retrodrill is introduced into the joint within the margins of the native tibial ACL footprint using special aiming guides. Retrograde drilling of the socket sparing ventral tibial cortex is then performed after manual flipping of the drill. This technique is preferably used for all-inside ACL reconstruction.

Advantages

- Less bone loss (socket preparation) [12]
- Cosmetically more favorable
- All-inside technique possible [11]
- Anatomic placement facilitated by good overall view

Disadvantages

- More difficult graft insertion through extended arthroscopy portal
- Limited fixation options (retro-screw, endobutton)
- Higher cost
- Longer operation time (depending on experience)
- Technically demanding

19.1.3 Conclusion

Each respective technique described above is an accepted ACL reconstruction method and has advantages and disadvantages. The choice of technique depends on the surgeons' experience, available instruments, graft choice, cost, patient age and/or skeletal maturity, habitus, activity level, and cosmetic factors. With all techniques, the goal should be anatomic ACL reconstruction, which seems easier to achieve using AMP, OI, and RD techniques [4]. Better rotational and antero-posterior stability could be shown with AMP compared to TT femoral tunnel drilling [3, 19].

AMP, OI, and RD techniques should be the current "golden standard" for drilling technique in ACL reconstruction.

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20 Arthroscopic Anterior Cruciate Ligament Reconstruction with Bone-Patellar Tendon-Bone

Matteo Denti, Alessandro Quaglia, and Pietro Randelli

20.1 Introduction

Techniques of reconstruction of the anterior cruciate ligament (ACL) of the knee have undergone, in recent years, important changes both in the technical and rehabilitation field, all aimed at a less invasive and better functional recovery for the patient. The appropriate choice of the graft is of focal importance in the success of the procedure, and if only a few years ago the patellar tendon (BPTB) was considered the best choice in ACL reconstruction techniques [1, 2], currently the indications for its use have limited in favour of the hamstring tendons (semitendinosus and gracilis) and to a lesser extent to allografts (especially with regard to the ACL reconstruction revision) [3, 4]. Nevertheless, the patellar tendon still remains today the "golden standard" for the choice of the graft in primary ACL reconstruction particularly in young and active patients.

The advantages it offers concerning the osteointegration are apparent as the interface between the bone and bone that is created in the femoral and tibial tunnels gives better guarantees than the integration between the bone surface of tunnels and soft tissue of the hamstring tendons, thus providing an advantage in the timing of the rehabilitation of the patient.

The potential residual symptoms are pain and discomfort due to the less functional muscle strength and limited range of motion and pain on pressure at the donor site especially when kneeling down [5, 6].

20.2 Indications

Our general indication for using BPTB for ACL reconstruction is in young patients (between 15 and 30 years), who especially practise sports at a high level. We usually prefer not to use this graft in adolescent patients up to 15 years of age, in patients with a low demand for sports and in patients above 30 years. The technique is contraindicated in patients with acute or chronic tendinitis of the patellar tendon. These details must be evaluated case by case, and these limits are obviously related.

20.3 Patient Preparation

The patient is prepared for general anaesthesia or local-regional anaesthesia and positioned on the operating table in the supine position.

M. Denti (✉)
Clinica Luganese, Lugano, Switzerland
e-mail: matteo@denti.ch.it

A. Quaglia
Knee Surgery and Sport Traumatology Unit, Humanitas Research Hospital, Rozzano, Italy

P. Randelli
Orthopaedic Department, University of Milan, Milan, Italy

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The operated limb is supported by a leg holder which allows a range of motion of at least 0–90° of the knee, and a tourniquet is also applied to the root of the thigh.

20.4 Surgical Technique

The first step is a diagnostic arthroscopy in order to make a joint evaluation and the treatment of associated lesions (cartilage, meniscus, etc.). Subsequently, following the classical technique, we perform an anteromedial longitudinal skin incision from 10 to 20 mm proximal to the inferior pole of the patella to the height of the anterior tibial tuberosity. A dissection of the peritenon is performed, and the patellar tendon is incised longitudinally and removed in its middle third for its entire length with a patellar and a tibial bone block.

The length of the patellar bone block is of about 20–25 mm, and the tibial bone block is about 25 mm in relation to the type of fixation to use (Figs. 20.1 and 20.2).

While the surgeon resumes the arthroscopic procedure, an assistant starts the preparation of the graft by accurately measuring the total length of the graft and calibrating the diameter of the bone blocks to the desired size (usually 9 or 10 mm diameter) (Fig. 20.3).

In the meantime, the operator, under arthroscopic control, performs a cleaning of the notch in order to eliminate scar tissue residues.

There are several techniques for the preparation of the femoral tunnels in ACL reconstruction with a BPTB: the transtibial, the "outside-in" and the anteromedial technique [7, 8].

At the tibial side through the anteromedial portal is positioned a drill guide at an angle between 55 and 59° in relation to the length of the graft and the type of setting that you want to run in the tibial anatomical position [9, 10].

The guide is positioned at 20/25° medially to the sagittal plane of the tibia close to the medial collateral ligament. This is followed by the drilling of the tibial tunnel related to the diameter of the tendon graft (usually 9–10 mm) in the "tibial anatomical position" placed in the middle of the tibial anterior cruciate stump (Fig. 20.4a, b).

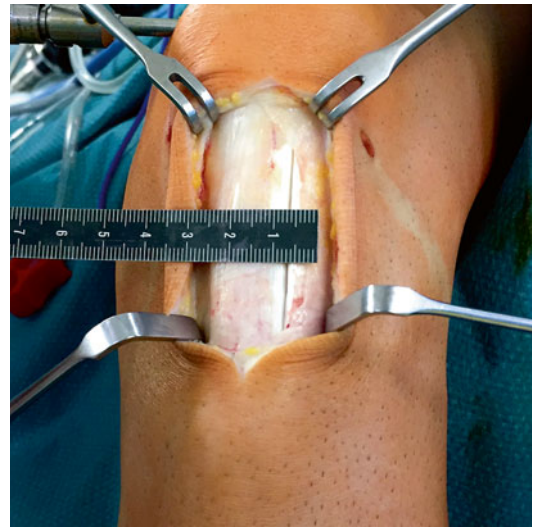

Fig. 20.1 Patellar tendon graft

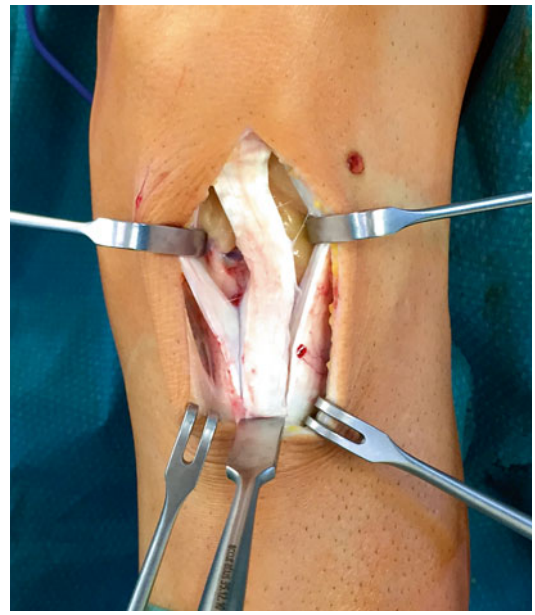

Fig. 20.2 Patellar tendon graft

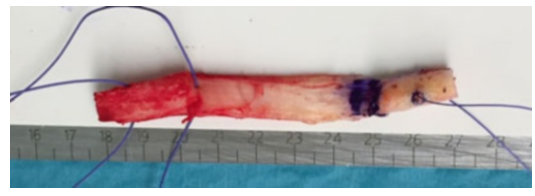

Fig. 20.3 Patellar tendon graft preparation

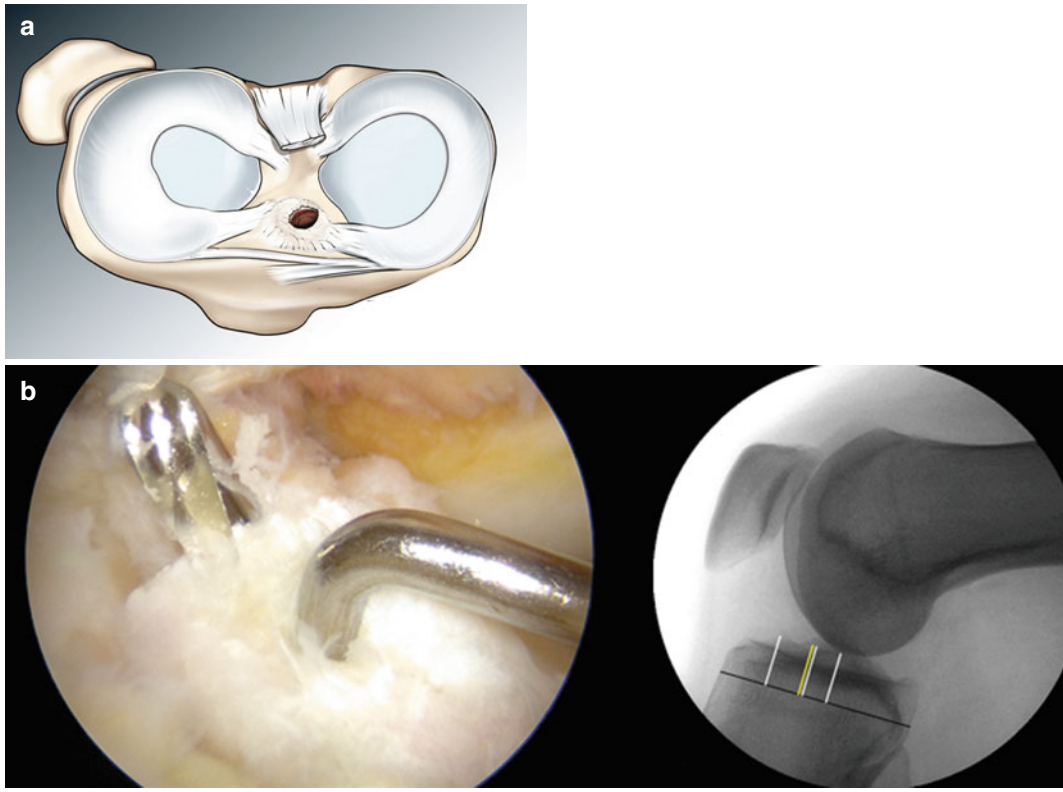

Fig. 20.4 (**a**, **b**) Tibial tunnel position (arthroscopic and fluoroscopic position)

It is important to identify, at the level of the medial aspect of the lateral condyle, the "anatomical point" for the femoral tunnel position.

This "anatomical position" is, following the classical o'clock nomenclature, at 9:30 for the right knee and 14:30 for the left knee where usually the ACL stump is located [10] (Fig. 20.5a, b).

Using the transtibial technique, the femoral tunnel is performed at 90° of flexion through the tibial tunnel with a cannulated drill (9–10 mm size) maintaining the posterior edge of the tunnel at 1–2 mm from the posterior femoral cortex. The length of the tunnel is equal to that of the bone plug in relation to the type of fixation desired.

The anteromedial technique and out-in technique are advantageous for the freedom of positioning of the femoral tunnel. Some authors use the anteromedial technique or the out-in technique as a first choice [3, 7, 8, 11–14]. We always use the anteromedial technique when the transtibial technique does not allow a satisfactory positioning of the graft in the femoral tunnel.

In this case, we proceed through the anteromedial arthroscopic portal to the positioning of the guide wire, keeping the knee flexed approximately 120°. Before performing the tunnel, it is important to check that the drill does not cause iatrogenic injury from contact with the medial femoral condyle. The size of the femoral tunnel will be dictated, as for the transtibial technique, by the size of the bone plug.

The femoral fixation can be performed with systems such as the transverse bioabsorbable cross pin and bioabsorbable or metallic interferential screw or with suspension systems.

In the case of the use of a cross-pin fixation, it is important to verify the correct positioning of the cannulas in the femoral tunnel before the passage of the graft. In the case of the use of interferential bioabsorbable screws, this is introduced into the endoscopic technique from the anteromedial portal with the knee flexed at about 110–120° (Fig. 20.6).

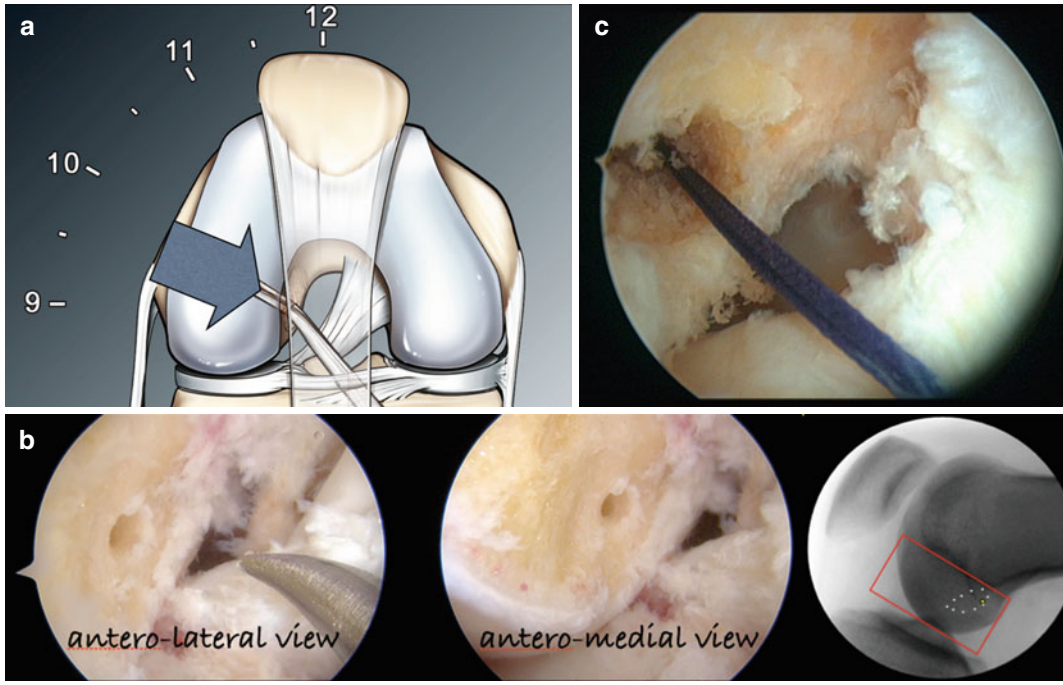

Fig. 20.5 (**a**–**c**) Femoral tunnel position (arthroscopic and fluoroscopic position)

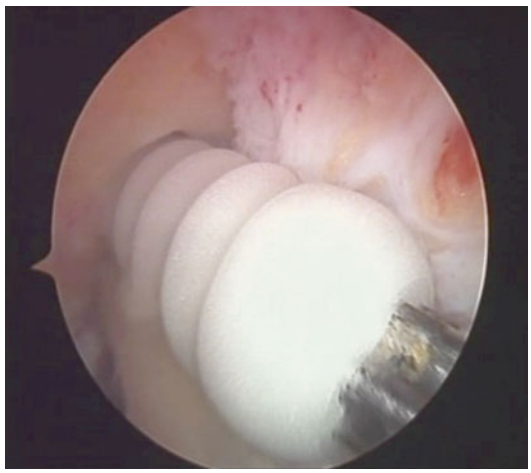

Fig. 20.6 Interferential screw fixation

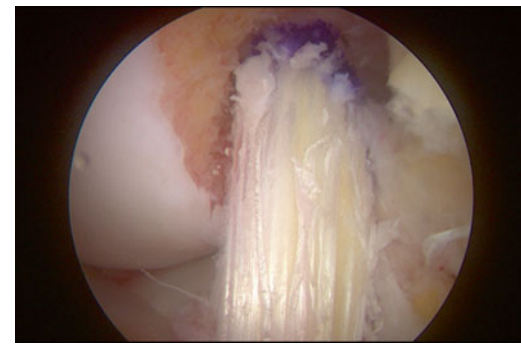

Fig. 20.7 Final position from the anteromedial portal

At the tibial side, the graft is properly tensioned and then secured preferably by a bioabsorbable interferential screw with the knee in flexion between 10 and 20°, although other types of fixing can be considered as well [15].

At the end of the procedure, it is important to perform an arthroscopic evaluation to establish the resilience of the transplant itself and joint stability and to highlight the absence of impingement front knee in full extension (Fig. 20.7).

20.5 Post-Surgery Protocol

Patients start functional rehabilitation, during the first postoperative day with isometric exercises and for the recovery of the range of motion (ROM). The protocol requires 0–90° ROM the

first week and is gradually complete the second week postoperative.

Weightbearing is immediate and is tolerated by the patient and without any brace with the aid of two crutches for about 10 days.

A physiotherapist then follows the patients during the first month two/three times a week. Swimming and exercise bikes are granted after 2 weeks post-surgery.

The rehabilitation continues with exercises and proprioceptive muscle activity gradually becomes more intense. The recovery of one-way ride takes around 3 months for the patient to return to sports-specific gestures and to contact sports after about 6 months after surgery.

ACL reconstruction with BPTB is an established technique in time and allowed us to get, especially with the advent of arthroscopy, bright results and long lasting [15–17].

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Arthroscopic Anterior Cruciate Ligament Reconstruction with Hamstring Tendons

21

Marco Valoroso, Guillaume Demey, Panagiotis G. Ntagiopoulos, and David Dejour

21.1 Introduction

Anterior cruciate ligament (ACL) tears are severe injuries that result in knee instability [1], meniscal lesions [2], and, in the long term, knee osteoarthritis [3]. Patients usually describe subjective symptoms of instability as knee pain and giving way especially during activities involving pivoting or in daily life. The presence of these symptoms is the usual indication for ACL reconstruction [4]. Primary ACL reconstruction is one of the most common orthopedic procedures with generally good-to-excellent (75–95 %) results and patient satisfaction, who eventually return to sports activities [5, 6].

There are many treatment options in the surgeons' armamentarium regarding graft choice, graft fixation, and surgical technique. The standard method of treatment is arthroscopic ACL reconstruction with autogenous graft. Bone-patellar tendon-bone (BPTB) autograft has been traditionally considered the gold standard of treatment. However, the semitendinosus tendon (ST) and gracilis tendon (GT) are increasingly used for ACL reconstruction in an attempt to reduce the donor-site morbidity associated with BPTB harvesting.

The advantages of quadrupled hamstring tendons consist in greater mechanical strength than BPTB [7], with lower donor-site morbidity [8]. Several authors register lower rate of patellofemoral pain and extension loss and a better recovery of quadriceps muscle strength with the use of hamstring tendons [9–11]. Tashiro et al. observed that another advantage of this procedure is the maintenance of hamstring muscle strength [11]. This phenomenon is certainly due to a better rehabilitation protocol and maybe to a postoperative regeneration of the harvested tendons that is described in up to 75 % of the patients. However, they usually do not restore their full cross-sectional area [12].

The major potential disadvantage of hamstring tendons is harvesting inadequate quantity of available tissue. Hematoma of the thigh and temporal dysesthesia at the donor site are commonly observed after tendon harvest. Yet, no graft tissue has shown consistent superiority over other for ACL reconstruction. In 2001 Yunes

M. Valoroso, MD (✉)
Lyon-Ortho-Clinic, University of Insubria – Hospital di Circolo, Viale L. Borri 57, Varese 21100, Italy
e-mail: marco.valoroso@yahoo.it

G. Demey, MD • D. Dejour, MD
Department of Orthopaedics, Lyon-Ortho-Clinic, Clinique de la Sauvegarde, 29 Avenue des Sources, Lyon 69009, France
e-mail: dr.dejour@lyon-ortho-clinic.com

P.G. Ntagiopoulos, MD, PhD
Hip and Knee Unit, Mediterraneo Hospital, 10, Ilias St, Glyfada, Athens, Greece
e-mail: ntagiopoulos@hotmail.com

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et al. showed good results with both BPTB and hamstring tendons. However, they observed higher postoperative activity levels and stability with BPTB [13]. Mohtadi et al. in a Cochrane review recorded no differences between BPTB and hamstring tendons for long-term functional outcome. Nevertheless, they note higher stability but also anterior knee pain with BPTB [14].

21.2 Indication

Our general indication for ACL reconstruction with hamstring tendon is a patient with a symptomatic ACL-deficient knee without gross rotatory instability. Usually, these patients have pivot shift no greater than +1. We also perform this technique in adolescents (BPTB harvesting may interfere with epiphyseal growth), in workers in kneeling position (due to knee pain from BPTB harvesting), and in sportsmen of jumping sports (e.g., basketball) in order to prevent postoperative patellar tendinopathy and to preserve the strength of extensor mechanism required in similar activities. In the past, this procedure was contraindicated in cases of important rotatory instability (gross pivot shift, +2 or +3) and in patients that require high pivoting activities, cases where BPTB was favored. However, recent knowledge resulted in extending the indication of hamstring tendons in these cases as well, with the addition of extra-articular plasty (e.g., modified Lemaire procedure) or an anterolateral ligament reconstruction, thus avoiding the donor-site morbidity of BPTB harvesting [15]. In the case of partial ACL tears, we prefer to preserve and keep the functional remnant of the native ACL and to use a hamstring tendon (finally sized around 7–8 mm) that is much easier to pass in the position of the torn bundle [16].

21.3 Patient Positioning

After the induction of anesthesia, the patient is positioned supine on the operating table with a tourniquet placed high on the thigh and inflated after the limb is exsanguinated. The knee is placed at a flexion of 90° with a footrest and a lateral thigh post.

21.4 Surgical Technique

21.4.1 Hamstrings Harvesting

The hamstring tendons are harvested through a separate 3-cm vertical incision over its tibial insertion or more posteriorly near the anterior border of the medial collateral ligament. In literature, several orientations of skin incision are described in order to minimize the risk of saphenous nerve injury. At present, there is not a standard method that could always prevent this nerve injury. Portland et al. in a retrospective comparative study observed that there is no difference between a horizontal and vertical incision, regarding the scar length, pain at rest, and pain with activity [18]. Nevertheless, Sabat et al. note that oblique incision presents a lower incidence of saphenous nerve injury and a superior clinical outcome. However, they register in the "vertical incision group" a significant reduction of the area of dysesthesia at 6 months of follow-up [19].

The pes anserinus is exposed, and the sartorius fascia is incised accompanying the superior edge of the gracilis and semitendinosus that are harvested with an opened tendon stripper, maintaining its distal insertion or with a closed tendon stripper when the graft is set free. In the author's preferred technique, the graft is left at its tibial insertion attached, and then it is folded to obtain a 13-cm-long double-stranded graft. Its proximal extremity is sutured with absorbable 2.0 Vicryl over its distal still attached extremity. Then the suture is extended to almost the entire graft. At its free edge, another suture is applied to pull the graft [20]. If the graft presents this proper length, the authors preserve the anatomic insertion of the hamstring tendon to improve the vascularization of the graft, to sustain its vitality, and to reduce the stage of avascular necrosis [21] (Fig. 21.1a–c).

In case of a free quadrupled graft ("all-inside technique"), the hamstring tendon (usually the semitendinosus) is stitched into loops by the use

of a traditional strand of no. 2 high-strength suture. Two sutures are placed on both the tibial and the femoral side of the graft. Each stitch should cross every strand, and the suture limbs are wrapped around the bundles in order to create a well-tensioned structure (Fig. 21.2a, b).

21.4.2 Arthroscopical Reconstruction

Knee arthroscopy is performed in a standard fashion with two anterior portals; the anterolateral arthroscopic portal is done close to the patellar tendon, and the anteromedial instrumental

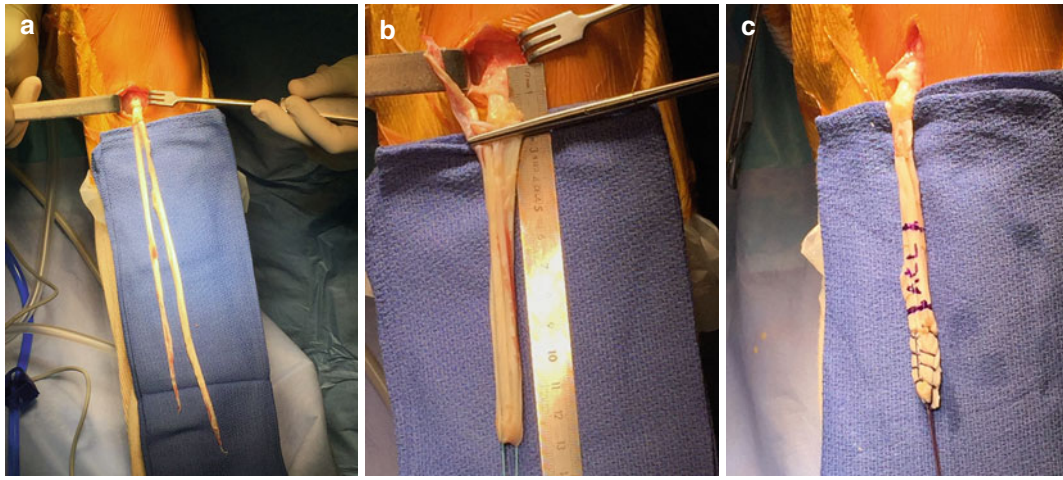

Fig. 21.1 Hamstring tendons graft harvest (**a**) and preparation with preservation of the anatomic insertion (**b**, **c**)

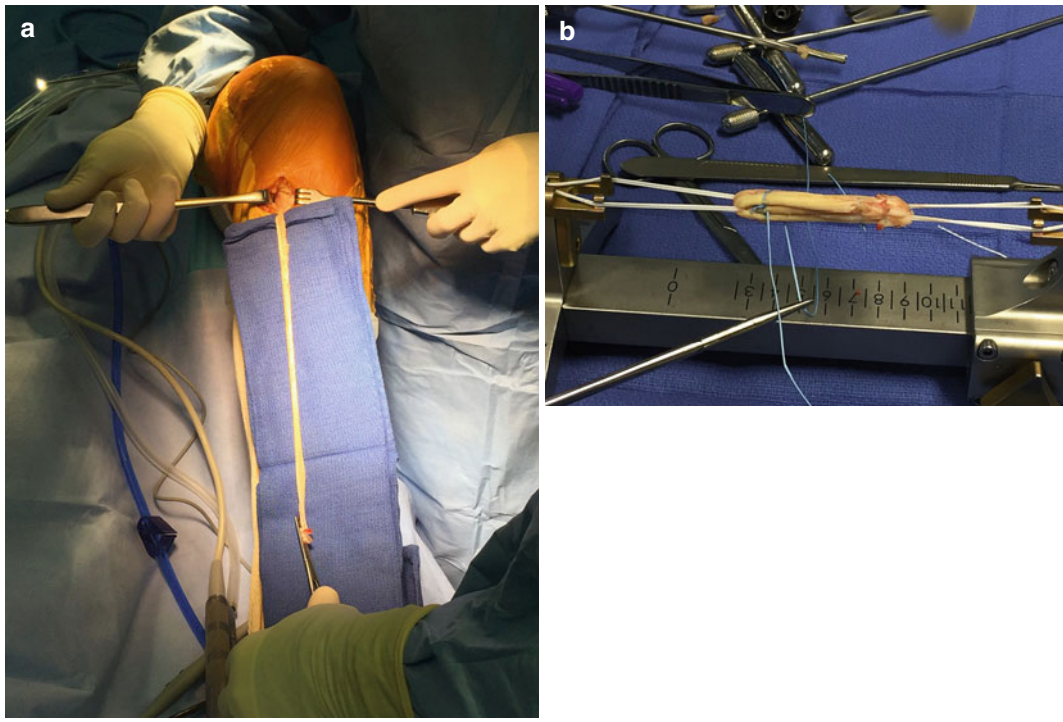

Fig. 21.2 All-inside technique: harvesting (**a**) and preparation (**b**) of a free quadrupled semitendinosus graft

portal is performed at the same level and 15 mm medially to the patellar tendon. After standard knee examination of all compartments, meniscal and cartilage pathology is addressed as required. ACL reconstruction requires excellent visualization of the notch, so the anterior fat pad is debrided to allow better notch visualization but paying attention to preserve the native ACL tibial and femoral insertions, as they serve as anatomic landmarks for tunnel positioning [17]. In ACL reconstruction, the functional result and the patient's satisfaction depend very closely on knee proprioception [22]. Schutte et al. showed that the majority of the mechanoreceptors lie near the tibial ACL insertion [23]. Lee et al. propose that the tibial remnant should be preserved because it improves not only the revascularization of the graft, but also it maintains some proprioceptive function of the ligament [24].

Several procedures to perform ACL reconstruction are described in the literature: the transtibial, the outside-in, the inside-out, and the all-inside technique. In every procedure, the tibial tunnel is performed using a pin guide through a specific drill guide placed in the anteromedial portal and positioned with the use of several landmarks such as the posterior border of the anterior horn of the lateral meniscus, the anterior border of the PCL, and the interspinous area [25]. The drill guide has to be set with an orientation between 55 and 65° regarding the horizontal plane and with a 25° of obliquity in the sagittal plane of the tibia, close to the medial collateral ligament [26–28]. The orthopedic surgeon has to consider not only these angles but also the length of the tunnel. The ideal tunnel length is 4–5 cm. If the tunnel is shorter than 4 cm, it can cause tunnel enlargement, graft loosening, loss of flexion, and intercondylar roof impingement because of its anterior placement [27]. In the transtibial technique, after the tibial tunnel creation, a femoral tunnel guide is inserted through the tibia with the knee at 120° of flexion and placed in the direction of ACL insertion. A tunnel with a depth of 30 mm and a diameter 1 mm less than that of the graft is drilled to preserve approximately 1–2 mm of the femoral posterior wall [29].

In the outside-in, the all-inside and the inside-out technique, anatomic reconstruction of ACL is achieved. As first choice, we use the first two techniques in ACL reconstruction. Several authors observe that the identification of the anatomic position of ACL is mandatory before drilling the femoral tunnel. The center of the ACL femoral insertion site can be located using the residual ACL footprint and the lateral intercondylar and bifurcate ridges [30, 31]. In the literature, several biomechanical studies demonstrate that an anatomic ACL reconstruction graft is more effective to avoid anterior tibial translation and internal tibial rotation [32–34].

In the outside-in technique, the knee has to be flexed at 90° to identify the ACL femoral insertion; thus, excessive knee flexion or an extra assistant is not required. Through the anteromedial portal, a specific femoral drill guide is placed at the site of ACL insertion. The external part of the femoral guide is positioned on the lateral compartment of the knee. A lateral longitudinal skin incision of 2 cm is performed at the point indicated by the femoral guide. The incision is straight to the bone through and parallel to the iliotibial band fibers. The inferior limit of the incision is represented by the proximal insertion of the lateral collateral ligament and posterolateral complex. Finally, the guide pin is placed from outside to inside and femoral drilling follows [35] (Fig. 21.3a, b).

The "all-inside" is an outside-in technique that creates a "bottle-shaped" or double half tunnel (one tibial and one femoral) manually drilled in an outward way using dedicated instrumentation ("retro drill") (Fig. 21.4). A single hamstring (usually the semitendinosus) tendon triplicated or quadruplicated could be used to obtain a length of between 55 and 60 mm (Fig. 21.5). Femoral and tibial sockets are done with retrograde-drilling guide pins. In this procedure the graft fixation is performed with suspensory devices (e.g., button devices).

The "inside-out" technique requires the "anteromedial portal view" because it is essential to visualize the femoral ACL stump [36]. The knee has to be overflexed more than 110° for the placement of the guide pin at the center of the

femoral insertion through the anteromedial portal (Fig. 21.6). When the K-wire is well located at the femoral ACL insertion, the femoral tunnel is drilled with a length that ranges between 30 and 45 mm, being careful not to cause iatrogenic injury from contact with the medial femoral condyle (posterior femoral wall blowout). Finally, a blind tunnel with a diameter according to the size of the graft is performed with a length of 25–30 mm depending on the length of the total tunnel [37]. Femoral fixation can be achieved with several devices, such as bioabsorbable or metallic interference screws or suspensory systems.

After standard cycling to achieve graft tensioning, tibial fixation is performed by bioabsorbable interferential screws while the knee is flexed at 10–20°. However, other types of fixation can be considered as well [38].

After graft fixation, evaluation of the adequate tension of the graft, satisfactory knee stability, full range of motion, and the absence of impingement of the graft in full extension is mandatory.

Robin et al. [39] in a recent systematic review showed the advantages and disadvantages of each technique. The main advantages of the transtibial technique include the following: it requires a single incision, and it is less invasive than outside-in procedure; the graft is in an isometric, or near-isometric, and it results in a stable Lachman test in most patients [40–42]. However, the femoral tunnel depends on the position of the tibial tunnel and it results in vertical, anterior, or posterior graft placement that leads to an excessive femoral external (tibial internal) rotation overloading the graft. [43–45].

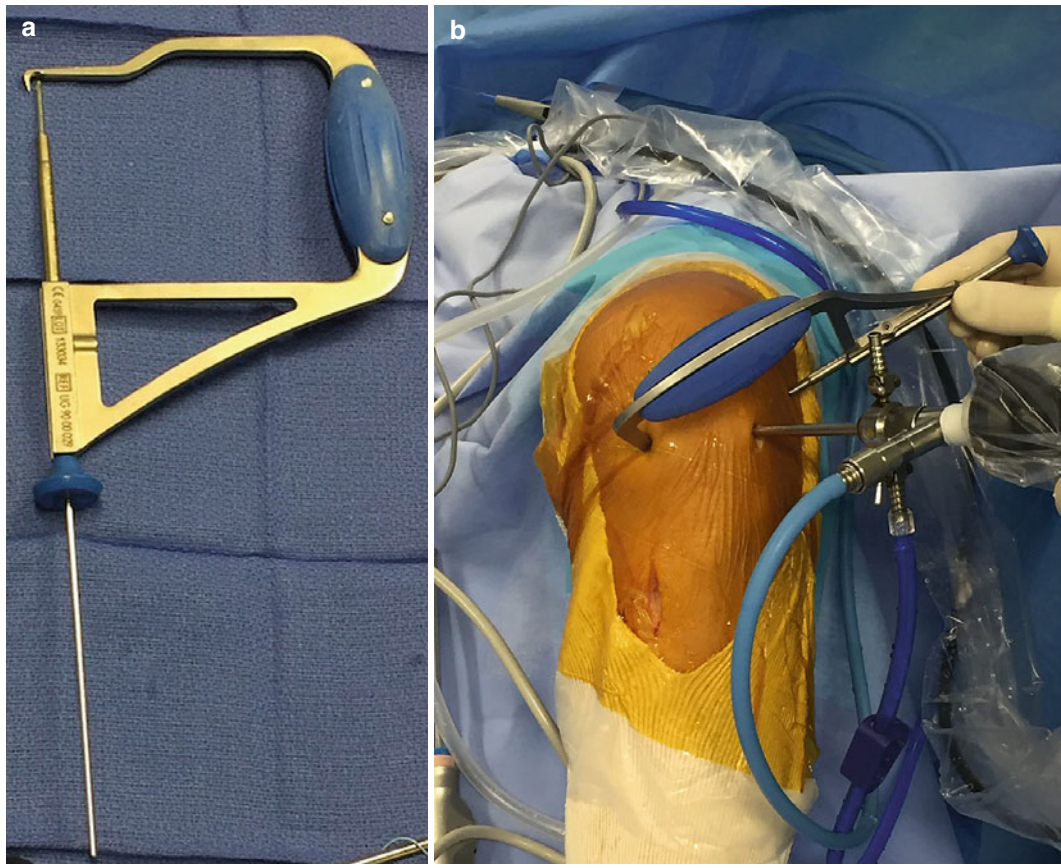

Fig. 21.3 Outside-in technique: femoral drill guide placement (**a**) and orientation (45°) (**b**)

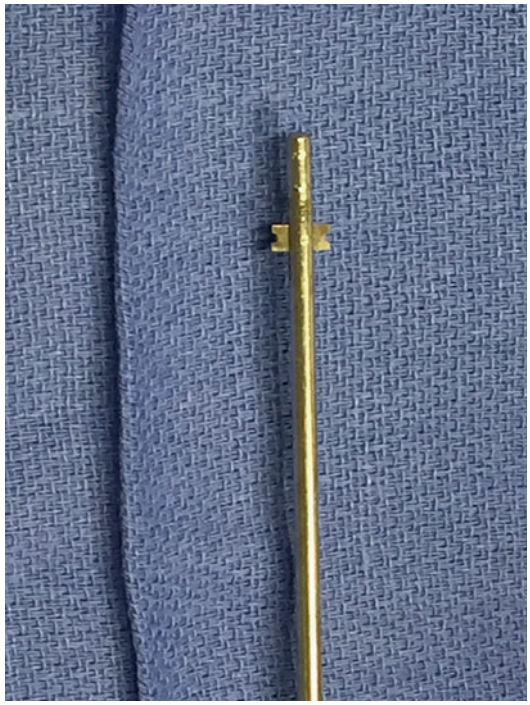

Fig. 21.4 Retro drill instrumentation in the all-inside technique

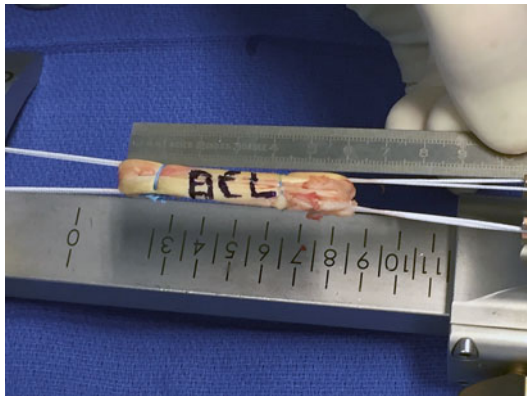

Fig. 21.5 The all-inside technique: the final construct of a free quadrupled semitendinosus prepared on the dedicated graft master

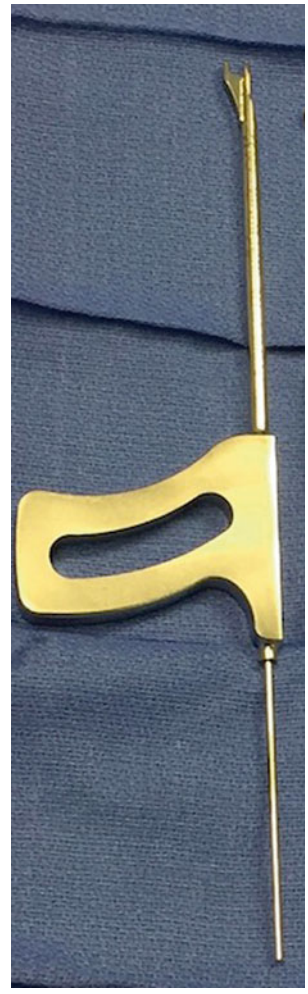

Fig. 21.6 Specific device to drill ACL femoral tunnel in the inside-out technique

The outside-in technique presents many advantages over other procedures, with most important the more predictable anatomic placement of the graft, which achieves better stability both anteroposteriorly and rotatory. Furthermore, it could be used easily in revision ACL reconstruction where a different tunnel orientation is easier to follow in order to avoid previously enlarged and misplaced tunnels. There is also less risk of bone tunnel divergence compared with transtibial procedure [35, 46]. However, a second incision is necessary to perform this technique [35, 41].

In addition to the advantages of the outside-in technique, the "all-inside" offers the possibility to adapt the length of half tunnels to that of the harvested graft, thus decreasing bone loss. This procedure is very useful also for all-epiphyseal technique in skeletally immature patients [47]. Nevertheless, it presents the same disadvantage of the classical outside-in technique [48].

Several authors describe the advantages of inside-out technique such as the anatomic placement of femoral tunnel and the independence of femoral tunnel drilling from the tibial one. They show also a better short-term ROM and faster return to activity compared with transtibial technique [49–51]. The major disadvantages of the anteromedial technique are possible chondral injury due to reduced visibility through the femoral stump in hyperflexion; fixation options may be limited from short sockets. In literature, higher revision rate and increased risk of injury to common peroneal nerve are registered with this procedure [37, 52, 53].

21.5 Rehabilitation Protocol

The rehabilitation program is divided in three phases. In the first one (0–45 days), the patient has to achieve the full extension and a flexion of at least 120°. A partial weight bearing is allowed for the first 3 weeks, after when full weight bearing is allowed. In this phase the isometric strength training of the tight is performed. During the second phase (45 days–3 months), the patient is allowed to start swimming and cycling. Proprioception exercises are also introduced during the same period. In the third phase (3–6 months), running is allowed if there is an objective recovery of the muscle of the thigh (isokinetic tests). Finally, the last step (>6 months) consists of the progressive return to sports.

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22 Anterior Cruciate Ligament Reconstruction with a Single-Bundle Autologous Quadriceps Tendon

Jacques Menetrey, Etienne Cavaignac, and Philippe Tscholl

22.1 Introduction

Anterior cruciate ligament (ACL) tear is frequent, and, in young and sports-active adults, the standardized treatment is to reconstruct surgically the ACL with a tendon [1]. Although the tendon differs biologically and structurally from the cruciate ligament, numerous animal studies have shown that once implanted, the tendon remodels in a structure close to the original cruciate ligament [2]. The autograft of choice for ACL reconstruction remains a matter of debate. Some surgeons consider the bone-patellar tendon-bone (BPTB) as the gold standard for reconstruction in spite of well-documented morbidities [3, 4]. Defenders of hamstring autograft refer to low donor-site morbidity, better strength in extension [5], and a lower incidence of mid- and long-term degenerative joint disease [6, 7]. However, decrease strength in hip extension and terminal knee flexion [8], residual laxity, higher infection rate [9, 10], and variable sizes and lengths of grafts remain a problem [11]. Actually, the quadriceps tendon (QT) is the least used autograft for ACL reconstruction [4]. In 2010, a review on graft choice showed that 2.5 % of all anatomic ACL reconstructions were performed with a QT autograft [12]. Recently, during an international meeting on anatomic ACL reconstruction, Middleton et al. [13] surveyed the practice of 35 surgeons from more than 20 countries. These experts polled averaged over 2,100 ACL reconstructions over their careers, and the use of QT autograft represented 11 % of all ACL reconstructions. However, several studies have shown excellent clinical results and low morbidity with the use of the QT autograft [14, 15], and a recent systematic review has confirmed that the use of QT for ACL reconstruction was safe, reproducible, and versatile [4].

The anatomy of the QT is highly variable with sometimes an unequal contribution of its tendinous components. The usual description of the quadriceps tendon consists of a trilaminar pattern, with the rectus femoris as the major contributor to the superficial layers and the vastus intermedius as a contributor of the deepest layer. In the distal 6 cm of the tendon, the vastus medialis and the vastus lateralis unite to form the middle layer. In an anatomical study, Harris et al. [16] reported an average quadriceps tendon

J. Menetrey, MD, PhD (✉) • E. Cavaignac, MD
P. Tscholl, MD
Unité d'Orthopédie et Traumatologie du Sport,
Swiss Olympic Medical Center,
4, Rue Gabrielle-Perret-Gentil, Genève 4 CH-1211,
Switzerland

Service de chirurgie orthopédique et traumatologie de l'appareil moteur, University Hospital of Geneva,
4, Rue Gabrielle-Perret-Gentil, Genève 4 CH-1211,
Switzerland

Faculty of Medicine, University of Geneva,
4, Rue Gabrielle-Perret-Gentil, Genève 4 CH-1211,
Switzerland
e-mail: jacques.menetrey@hcuge.ch;
etienne.cavaignac@hcuge.ch;
philippe.tscholl@hcuge.ch

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width of 27 mm and an average thickness of 8 mm. Despite the variability in QT morphology, with a careful dissection, the surgeon can harvest a consistent graft of 7–8 cm in length, 6–7 mm in depth, and 9–10 mm in width without violation of the suprapatellar pouch [14]. These anatomical features allow for harvesting of a custom-shaped graft, either rectangular, ribbonlike, triangular, or ovoid. The size and the length can also be determined according to the patient needs. It also allows for the choice of a graft with or without a bone plug. The vascular anatomy of the QT is complex with a better supply of the superficial layers than the deep layers (vastus intermedius) and a relatively hypovascular zone in the region 1–2 cm proximal to the superior pole of the patella [17]. Harris et al. [16] have conducted a histological study comparing the patellar and the quadriceps tendon. They showed that the QT contains 20 % more collagen than the patellar for a same thickness, a higher fibril-interstitium ratio, and a higher fibroblast density. Lee et al. [18] performed biopsies in 37 patients during a second-look arthroscopy, and the analysis of those specimens revealed a bimodal pattern of large- and small-diameter collagen fibrils, which was close to the pattern found in the native ACL. Considering these findings, the QT appears to be a suitable graft for the reconstruction of the ACL.

Biomechanical data are favorable to QT autograft. Staeubli et al. [19] have analyzed one-third of patellar and quadriceps tendons in 16 paired knee specimen. The mean cross-sectional areas were significantly larger in QT autograft in comparison to the PT. When preconditioned, the strain to failure was slightly higher for the PT versus the QT (14.4 % vs 11.2 %), and the PT showed a significantly higher elastic modulus than the QT. Sasaki et al. [20], in another cadaveric study, quantitatively evaluated the knee biomechanics of ACL reconstruction with a QT versus a quadrupled hamstring. They found no statistical differences in between the two grafts in any testing condition. In a recent study, Shani et al. [21] has shown that a 10-mm strip QT had a higher cross-sectional area (91.2 mm2 vs 48.4 mm2), higher ultimate load to failure (2185.9 N vs 1580.6 N), and higher stiffness (466.2 N/mm vs 278.0 N/mm) than the patellar tendon. These values were significantly higher than the native ACL. Given these findings, QT is biomechanically a sound alternative for ACL reconstruction.

Interestingly, in a laboratory experimental study, Adams et al. [22] compared the extension strength deficit after harvesting of 10-mm-wide central free tendon grafts from the quadriceps and patellar tendons. Although the tensile strength of the QT was reduced by 30 % after harvesting, the authors found that harvesting the central third of the QT leaves a stronger extensor mechanism than after harvesting of a patellar tendon graft.

The QT is certainly a suitable alternative for ACL reconstruction. In our individualized and "à la carte" patient care approach, we routinely recommend the use of QT in alpine skiers (prevention of patellar tendinopathy), rugby players, ice-hockey players, in priest, tiler, industrial painter, and all occupations where one has to kneel. It has became, for years now, our first graft choice for primary ACL reconstruction, because QT allows for versatility, customization of the graft size, reduced anterior knee pain, reduced injury of the infrapatellar branch of the saphenous nerve, preservation of ACL agonist, decrease arthrofibrosis when compared to BPTB, better patella mobility, and the implantation of a thicker graft.

22.2 Surgical Technique

The technique presented here uses a free graft made of the middle-third quadriceps tendon harvested on the same side as the injured ACL.

22.2.1 Patient Positioning

The patient is in a supine position. A tourniquet is placed at the base of the thigh. We use a ladder and an external counter-support; this lets us set the leg in different positions, depending on the knee flexion desired (Fig. 22.1).

22.2.2 Graft Harvesting

A vertical, midline 3–4-cm incision is made across the superior edge of the patella. Two-thirds of the incision is proximal to the superior edge of the patella and one-third is distal to it (Fig. 22.2). The skin over the superior edge of the patella is highly elastic, making it possible to expose the entire tendon through a 3–4-cm incision by adjusting the position of the retractors. The two sides of the incision are retracted. The pretendinous velum is then carefully opened in the middle of the quadriceps tendon along the axis of the incision. The entire tendon must be exposed, i.e., from the superior pole of the patella to the muscle bellies of the vastus medialis, vastus lateral, and rectus femoris. The combination of four retractors and skin malleability makes this exposition possible (Fig. 22.3).

22.2.3 Harvesting of a Segment of the Tendon

Harvesting starts at the proximal portion of the quadriceps tendon. The first incision is made with a No. 10 scalpel blade along the axis of the fibers, near the vastus medialis muscle belly. The second incision is made parallel to the first one with an offset tailored to the size of the planned graft. The two incisions are extended distally to the periosteum to define the bone block associated with the graft (Fig. 22.4). At this point, the trickiest part is managing the thickness of the graft to be harvested. The quadriceps tendon is a lamellar structure made up of three layers [23]. Most of the time, we harvest only the two most superficial layers to avoid penetrating the joint. The proximal portion is detached first. The dissection is then extended distally to the superior edge of the patella. The challenge here is to determine and follow the proper cleavage plane without opening the joint capsule (Fig. 22.5).

22.2.4 Harvesting of the Bone Block

The patella's anterior cortex is cut out by following the periosteal incision made previously. Two longitudinal osteotomy cuts are made at a 45° angle toward the midline of the patella (Fig. 22.6). The transverse cut is horizontal. A chisel is used to finish excising the bone block. This results in a 15–20-mm-long, 7–10-mm-wide triangular-shaped bone block (Fig. 22.7).

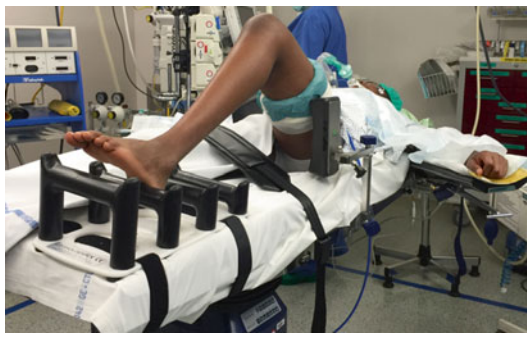

Fig. 22.1 Patient positioning. We use a ladder, which allows for the positioning of the knee in different flexion angle during the operation. This is particularly important for the mini-invasive technique

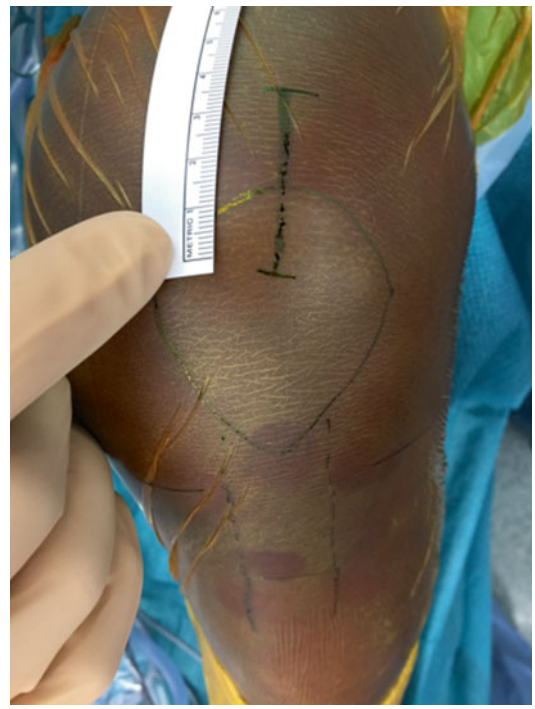

Fig. 22.2 Positioning of the skin incision

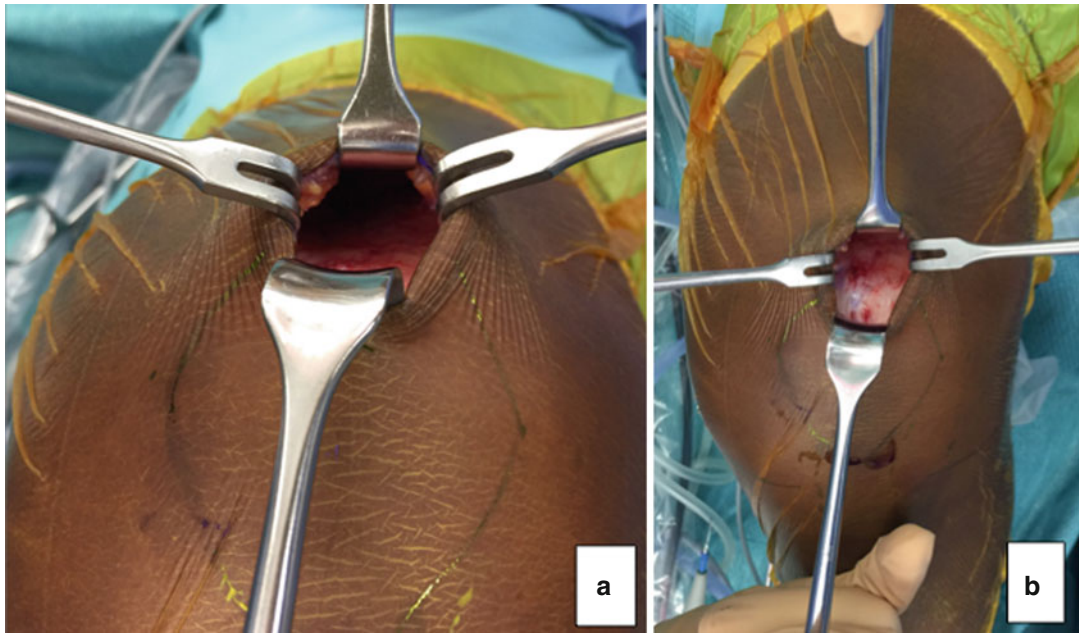

Fig. 22.3 Retractor positioning. (**a**) Proximal tendon view, (**b**) distal tendon view

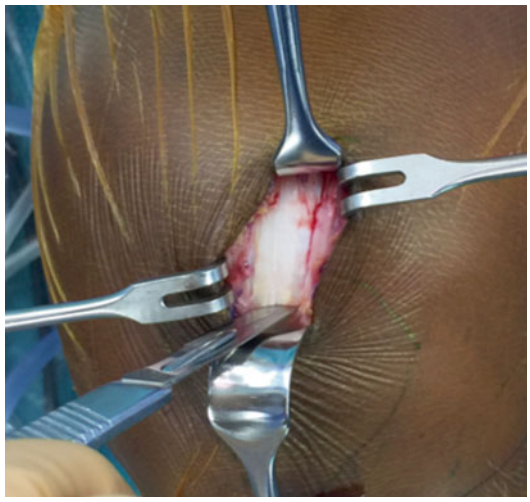

Fig. 22.4 Defining the osteotomy cuts on the periosteum and sharpey fibers of the patella

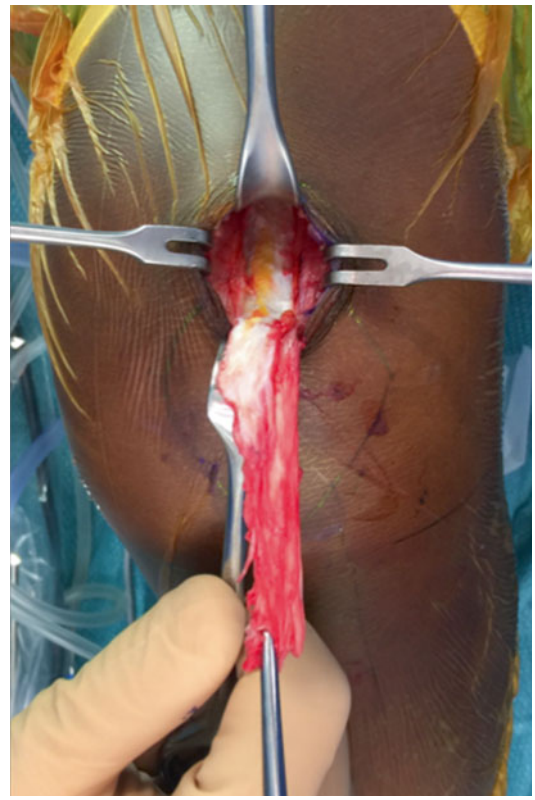

Fig. 22.5 Tendon harvesting without opening of the joint. We see the graft harvested flipped over and the deep layer of the quadriceps tendon kept in place

22.2.5 Management of the Donor Site After Harvesting

The two edges of the remaining quadriceps tendon are carefully and tightly closed together with size 2 absorbable sutures (Fig. 22.8). The patellar defect will be filled at the end of the procedure with bone debris generated during drilling of the

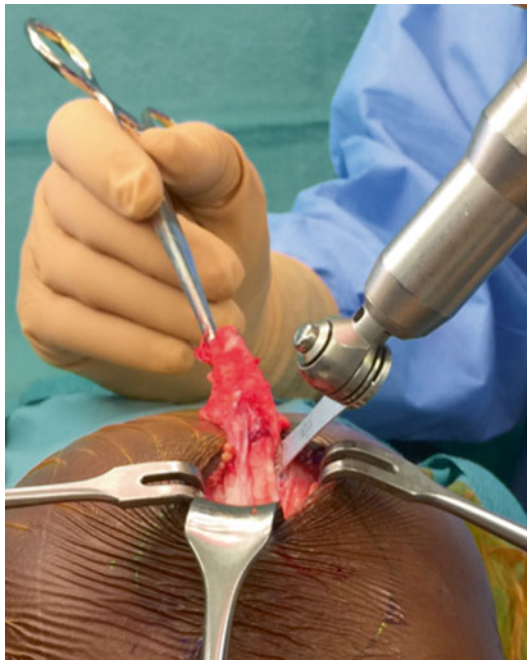

Fig. 22.6 Cutting the bone block with an oscillating saw at a 45° angle. You always have to pay attention to the cartilage underneath, especially in patella of small size

tunnels (Fig. 22.9). Finally, the superficial layers are closed over the donor site. The closure of the donor site is mandatory to permit a rapid and complete healing of the QT.

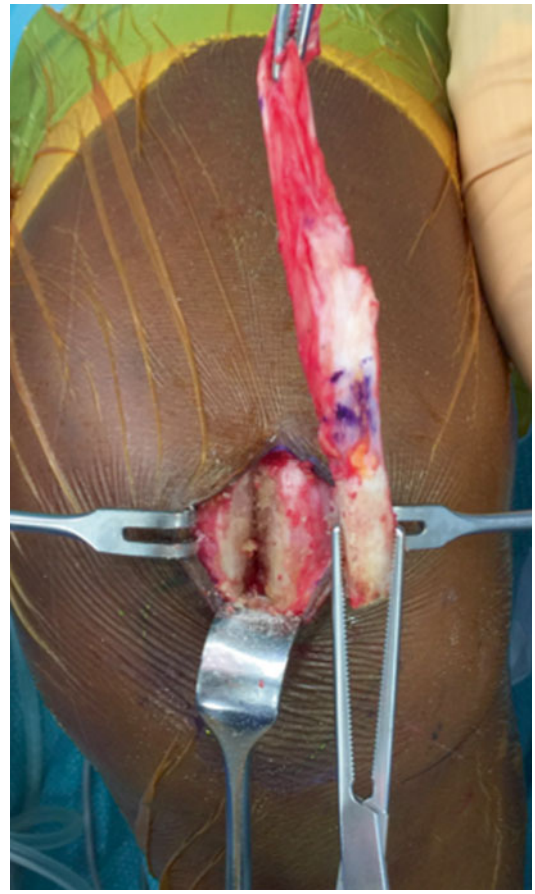

Fig. 22.7 Graft and its donor site

22.2.6 Preparation of the Graft Before Implantation

The tendinous portion of the graft is weaved together over 30 mm using two size 0 absorbable sutures. This leaves four traction sutures in the proximal portion. Two holes are drilled with a 2-mm drill bit at the junction of each third of the bone block to create a passage for traction sutures (size 5 nonabsorbable suture). The bone block is then trimmed down with a rongeur so it can be easily inserted into the chosen diameter hole (Fig. 22.10).

22.2.7 Defining Landmarks on the Graft

The resulting graft will be 8–9 cm long. We use a sterile skin marker to mark the edge of the bone block and the edge of the weaved tendon (Fig. 22.11). These landmarks will be used during the arthroscopy procedure to properly position the graft into the tunnels. The graft is then stored on the back table while the arthroscopy is being performed.

22.2.8 Arthroscopic Procedure

- Notch preparation

  The scope is introduced through the anterolateral portal and the instruments through the anteromedial portal. This procedure uses standard portals on either side of the patellar tendon. The first step is a complete arthroscopic assessment of the joint to determine if the cartilage, meniscus, and ligaments are damaged. Any meniscus or cartilage damage

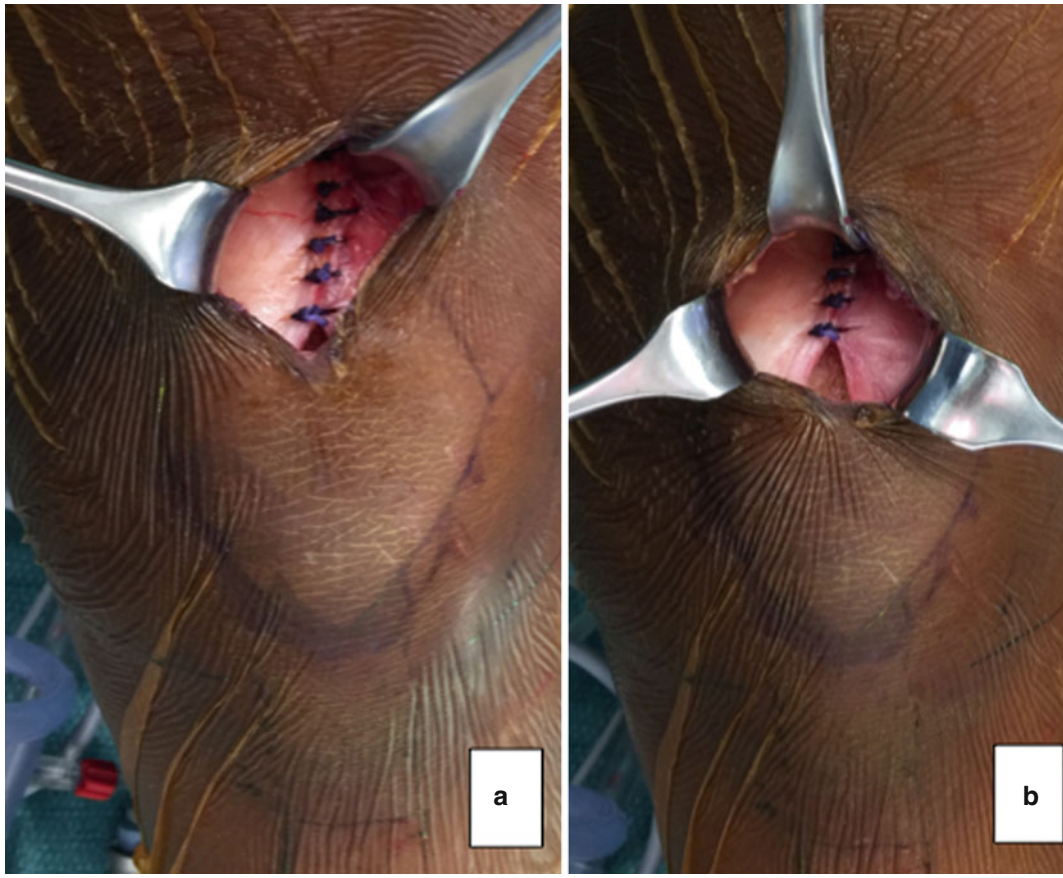

Fig. 22.8 Meticulous and tight closure of the donor site within the tendon. (**a**) Proximal view, (**b**) distal view. This closure is important to restore the shape and organization of the donor site as well as to favor tendinous healing

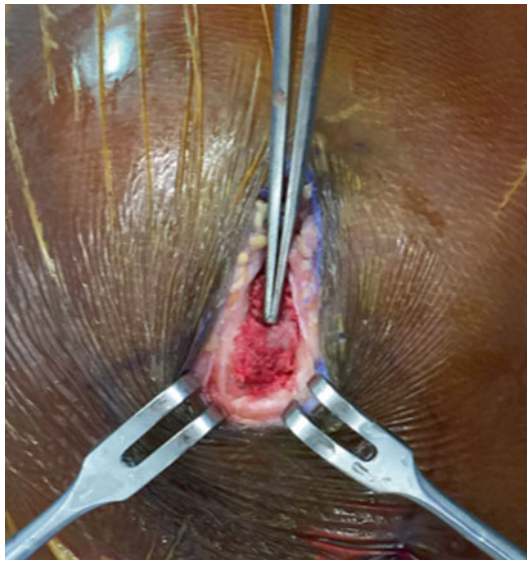

Fig. 22.9 Bone grafting of the donor site at the end of the operation

will be addressed before the ACL is reconstructed. The notch is always prepared starting with the ACL's femoral attachment. If one of the bundles (generally the posterolateral bundle) is still present, its attachment is preserved and only the other bundle's attachment is debrided. The posterior edge of the condyle and the distal junction with joint cartilage serve as landmarks. On the tibial site, as much of the native ACL as possible is preserved to facilitate ligamentization. Debridement is performed with a shaver (Fig. 22.12). A notchplasty is never performed.

- Drilling of femoral tunnel

We use an outside-in method. The aimer identifies the area that the tunnel will occupy on the axial side of the lateral condyle. The aimer's size depends on the graft diameter (Fig. 22.13). It is curved and available in left

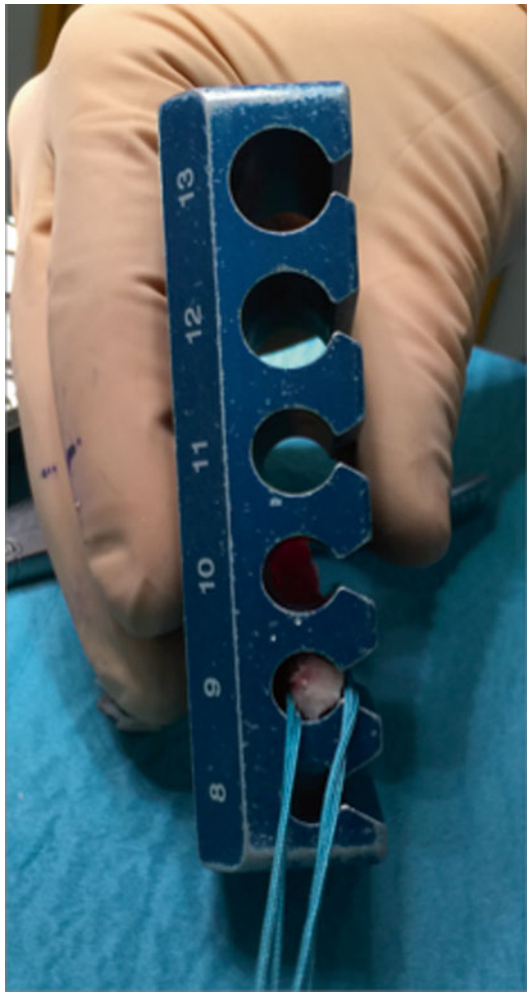

Fig. 22.10 Sizing of the graft

Fig. 22.11 The free graft is prepared on the back table before implantation

and right versions to match the condyle's axial surface. The portals are reversed to insert the guide pin. The scope is introduced through the anteromedial portal to view the axial side of the lateral condyle. The aimer is introduced through the anterolateral portal. It is positioned according to the ACL remnants or stumps and the tunnel is drilled (Fig. 22.14). The assistant performs the extra-articular step consisting of placing the aiming sleeve that will be used to guide the K-wire. The assistant makes a stab incision through the skin and fascia lata to place the sleeve against the bone. A surgical drill is used to advance the K-wire until it emerges inside the joint (Fig. 22.15). Once the position is correct, the guide is removed and the K-wire left in place. The portals are reversed and a curette used to prevent the K-wire from advancing when the tunnel is drilled. We drill the entire tunnel of the same diameter as the graft all at once. A cup is used to collect as much of the bone debris as possible to use as

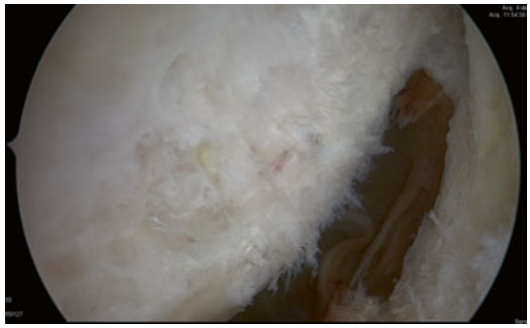

Fig. 22.12 Axial surface of lateral condyle in a right knee showing the native ACL footprint from the anteromedial portal

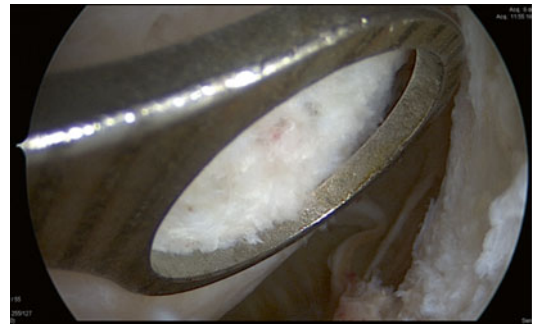

Fig. 22.14 Positioning of the femoral aimer on the axial surface of the lateral condyle under direct arthroscopic control

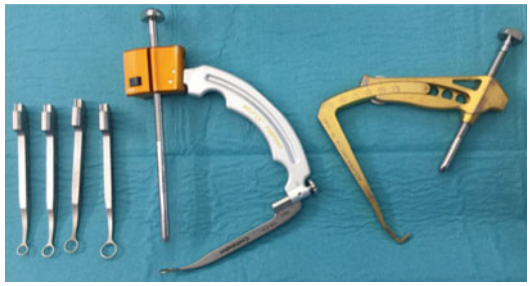

Fig. 22.13 On the *left*, various sizes of femoral out-in aimers are available to match the graft diameter. On the *right*, a point-to-point type tibial aimer

Fig. 22.15 The K-wire emerges in the middle of the aimer

graft material on the patella donor site. We use progressively larger dilators to compact the tunnel and remove all bony debris from the tunnel, as any debris could affect graft passage. The scope is introduced into the femoral tunnel to verify its integrity (Fig. 22.16).

- Drilling of tibial tunnel

  The tibial tunnel is also prepared outside in. Although various orientations can be used (Fig. 22.13), we generally set the tunnel at 50°. The intra-articular portion of the aimer is introduced through the anteromedial portal. The aimer is positioned using the native ACL stump, the PCL, and anterior horns of the menisci as landmarks. The assistant then positions the sleeve, makes a skin incision down to bone, and advances the guide K-wire using a surgical drill. Since as much as possible of the native ACL is preserved, the K-wire will emerge in the ACL's original footprint (Fig. 22.17). Once the K-wire has been drilled in place and its position verified, the aimer is removed. A curette is placed on the K-wire to prevent it from moving during drilling (Fig. 22.17). The tunnel is drilled all at once to match the graft diameter; the bone removed from the tunnel is collected to use for grafting of the donor site. Progressively larger dilators are used to clean out and compact the edges of the tunnel.
- Graft placement

  A passing suture is introduced in the extra-articular opening of the femoral tunnel. The suture is retrieved inside the joint and then brought outside the joint through the tibial tunnel. The traction sutures on the tendon portion of the graft are passed through a loop of the passing suture. The graft is then introduced in a retrograde manner from the tibial tunnel to the femoral tunnel. The graft's passage is monitored using the scope. The landmarks placed on the

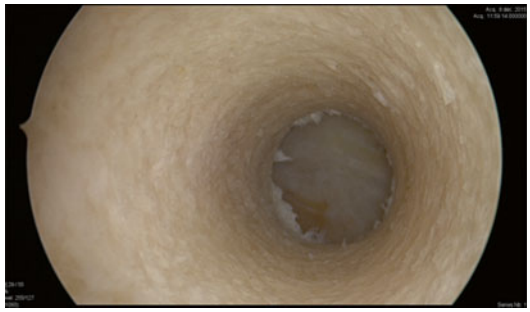

Fig. 22.16 Lateral arthroscopic control of the femoral tunnel

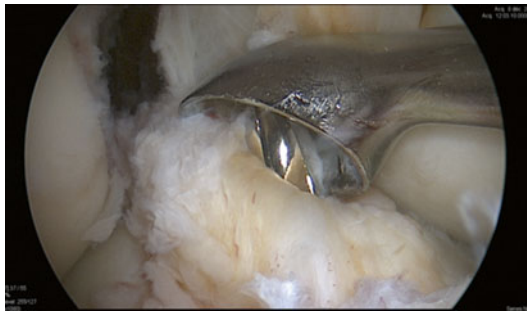

Fig. 22.17 The K-wires emerges through the preserved native ACL footprint on the tibia

graft are used to determine if its placement is correct. Most importantly, the bone block must be close to, but not protrude inside, the joint.

- Graft fixation

  We use interference screws to secure the graft to the femur and tibia from outside in.

  The femoral fixation is always performed first. The portals are reversed and the scope placed in the anteromedial portal. A screw guide K-wire is introduced into the tunnel. We try to place it posterior to the graft in the tunnel (Fig. 22.18). The screw is inserted under arthroscopic control, making sure that it is as close as possible to the joint without protruding into it. Neither a tap nor a dilator is used. The graft is held firmly by the assistant, who places the screw, and by the surgeon who holds the traction sutures in the distal portion of the graft. It is important to make sure the graft does not get pushed inside the joint. We select the screw diameter based on the filling of the tunnel by the graft and the bone quality of the patients. Generally, we use a screw of the same size or 1 mm less than the tunnel. Once the femoral side is secured, the graft undergoes cyclic loading. For the tibial fixation, the screw guide K-wire is placed anterior to the graft in the tibial tunnel; we use a Kocher forceps to lock the K-wire in this position (Fig. 22.19). The graft is fixed at 10–15° of knee flexion, with about 10° of external rotation and with the assistant inducing a posterior drawer. The surgeon keeps the graft under tension, taps the tunnel until contact is felt with the bone plug/block, and then inserts the selected screw (Fig. 22.20). The screw is advanced until it is flushed with the joint. We select the screw diameter based upon the bone quality of the patient. Generally, we use a screw of the same size or 1 mm less than the tunnel.

Fig. 22.18 Placement of the screw guide K-wire posterior to the graft into the tunnel. The position of the K-wire is constantly controlled during the introduction of the interference screw

- Closure

  The tourniquet is released before closing and hemostasis confirmed. The portal and tunnel incisions are closed with nonabsorbable suture. The graft site requires particular attention. As already mentioned, tendon edges are approximated with No. 2 absorbable suture in a simple interrupted pattern. This closure is performed meticulously; multiple fixation points are needed to prevent dehiscence of the QT and to favor its healing. The bone donor site is filled with bone collected during tunnel drilling (Fig. 22.9). The parapatellar periosteum is then closed; subcutaneous and dermal tissues are closed as usual.

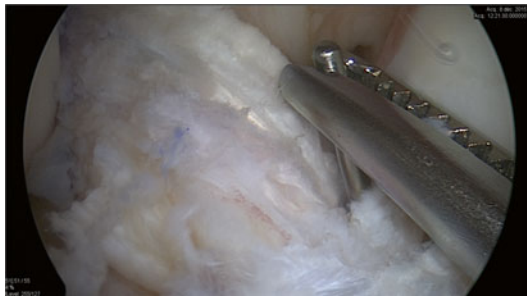

Fig. 22.19 Placement of the screw guide K-wire into the tibial tunnel, which is secured with a Kocher forceps to prevent migration during the introduction of the interference screw

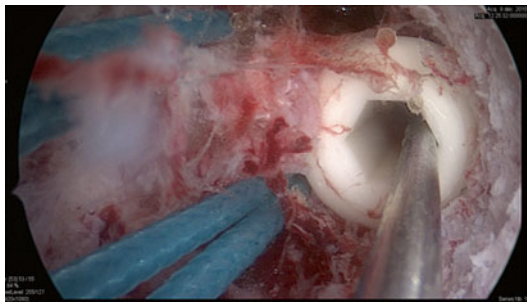

Fig. 22.20 Arthroscopic verification of the screw position in tibial tunnel. The bone plug is on the left and the screw is placed as close as possible to the joint line

22.2.9 Postoperative Course

Lateral and A/P postoperative radiographs are taken when the patient emerges from the recovery room. Anticoagulants are used for 10 days to 4 weeks. Partial weight bearing (15–30 kg) is allowed for the first 3 weeks and then full weight bearing afterward. The sutures are removed on postoperative day 12. The patient is given a physiotherapy protocol to follow. Patients are reviewed at 45 days, 90 days, 6 months, and 1 year postoperatively.

22.2.10 Versatility

We have presented our method for ACL reconstruction using a middle-third quadriceps tendon graft with bone blocks. Using this type of graft does not limit the surgical technique options [24, 25]. It is also possible to perform minimally invasive graft harvesting (in our experience, an incision of 2–2.5 cm long is feasible) [26], to drill the tunnels inside out [27], and to use different fixation devices [28, 29]. A double-bundle reconstruction technique is also feasible [30].

22.3 Postoperative Results

Several authors have published outcome studies using QT in primary ACL reconstruction with a current follow-up up to 2–3 years (Table 22.1). Early results are nevertheless promising with 81–94 % good to excellent results [31–33]. Mean postoperative Lysholm score at 12–36-month follow-up is found between 88.5 and 94 [31, 33–37], which is in line with the reported results using BPTB or hamstrings (HT) graft [38]. Looking at studies comparing QT and BPTB for primary ACL reconstruction, no significant differences can be found in terms of residual laxity (KT-1000) or functional outcome scores (IKDC, Tegner) [35–37, 39]. However, strength deficits in countermovement jumps, and leg-press exercises were found to be smaller after QT than after BPTB at 6-month follow-up [40]. The improved recovery in terms of strength and functional power might be due to the significant reduction of anterior knee pain observed in patients with QT when compared to BPTB autograft (5–19 % vs. 27–44 %) [32, 39]. In the largest comparative study (93 QT vs 101 BPTB), 85 % of the patients with QT and 50 % in the group of BPTB graft rated their knees as normal in terms of donor-site morbidity, 2 years postoperatively [35]. As far as we know, only one clinical study compared postoperative results between QT ($n = 23$) and HT grafts ($n = 21$) with a 3-year follow-up [41]. No differences were observed in functional outcome (single-leg hop, Tegner and Lysholm Score). Surprisingly, 12 knees (52.1 % of the QT) showed a KT-2000 side-to-side difference of more than 3 mm compared to 2 knees (9.6 %) in the HT group. This is in contrast with other QT outcome studies which reported a mean

Table 22.1 Published results (laxity, functional outcome and complication) for primary ACL Reconstruction using QT

Study	Year	Mean follow-up	No. of knees included	Surgical technique	Side-to-side laxity (post-op)	Functional outcome	Anterior knee pain	Complications (QT)
Akoto	2012	12 months	30 BQT	Bone block femoral, sb press fit	KT-1000: 1.6 mm	obj IKDC in 96.7 % near normal subj IKDC in 86.1 % near normal single one-leg hop 91.9 at follow-up	–	–
Kim	2009	12 months	21 BQT	Bone block femoral, db interference screw	KT-2000: 1.65 mm	Lysholm pre- to post-op: 74.6–94.2	–	–
Han	2008	39.7 months 42.1 months	72 BQT 72 BPTB	Bone block femoral, sb interference screw	KT-1000 ≥3 mm: 33.3 % (QT), vs. 27.8 % (BPTB)	Lysholm pre- to post-op: 70.7–91.5 (QT) vs. 71.2–92.8 (BPTB) Quadriceps peak torque (180°/s, ly): 82 ± 11 (BQT) vs. 76 ± 22 % (BPTB)	BQT 8.3 % BPTB 39 %	One patellar fracture One flexion deficit (40°) treated by manipulation
Schul	2013	24–32 months	55 QT	No bone block, sb, cross-pins	Rolimeter: 1.8 mm	Subj IKDC post-op 80.4 Lysholm post-op 89 Single-leg hop test: mean 89 %	Pain when 11 %	One joint mobilization under anesthesia
Geib	2009	55.6 months 64 months	157 BQT 41 QT 30 BPTB	sb, interference screw	KT-1000: 0.51 mm (QT) vs. 1.05 mm (BQT) KT-1000 ≥3 mm: 10.9 % (QT/BQT) vs. 33.4 % (BPTB)	Single-leg hop >90 % side-to side: 87.8 % (BQT) vs. 85.2 % (QT)	QT 4.6 % BPTB 26.7 %	Four re-ruptures

(continued)

Table 22.1 (continued)

Study	Year	Mean follow-up	No. of knees included	Surgical technique	Side-to-side laxity (post-op)	Functional outcome	Anterior knee pain	Complications (QT)
Chen	2006	62 months	34 BQT	Bone block femoral, sb interference screw	KT-1000: 1.74 mm KT-1000 ≥3 mm: 18 %	Lysholm pre- to post-op: 61.4 to 93 IKDC (near) normal in 91 % Quadriceps peak torque ≥90: in 56 % Hamstring peak torque ≥90 %: in 50 %	9 %	–
Gorschewsky	2007	29 months	193 BQT	Bone block femoral, sb cross-pins ($N=100$) interference screw ($N=93$)	KT-1000: 0.71 mm (pin), 0.69 mm (screw)	Lysholm post-op: 94 (screw) vs 89 (pin) (very) good results in 90 %	24 % (pins) 15 % (screws)	Two traumatic re-ruptures (screw)
Gorschewsky	2007	24 months	93 BQT 101 BPTB	Bone block femoral, sb interference screw	IKDCD normal in: 57 % BQT vs. 97 % BPTB KT-1000: no difference	IKDC normal: 11 % (BQT) vs. 66 % (BPTB) IKDC nearly normal: 72 % (BQT) vs 31 % (BPTB) Lysholm post-op: 94 (BQT) vs. 95 (BPTB)	15 % (BQT) 50 % (BPTB)	Two traumatic re-ruptures (2.2 %)
Kim	2009	25.8 months 26.2 months	21 BQT 27 BPTB	Bone block tibial, sb interference screw	KT-2000: 2.8 mm (BQT) vs. 2.7 mm (BPTB) KT-2000 ≥3 mm: 42.9 % (BQT) vs. 33.3 % (BPTB)	(Fully) satisfied: 90.5 % (BQT), 92.6 % (BPTB) Normal hop test 81.5 % (BQT) vs. 81 % (BPTB)	Donor-site pain: 9 % (BQT) vs. 44 % (BPTB) Kneeling pain: 19 % (BQT) vs. 48 % (BPTB)	86 % unsatisfied with don or-site scar

Kim	2009	24 months	59 BQT	Bone block tibial, sb ($N=28$), db ($N=31$), interference screw	KT-2000: 2.6 mm (sb) vs. 1.8 mm (db) KT-2000 ≥3 mm: 35.7 % (sb) vs. 22.6 % (db)	Lysholm pre- to post-op: 75.8–91.8 (sb) vs. 72.8–94.5 (db)	–	–
Barlé	2010	12.4 months	106 BQT	Bone block femoral, sb, press fit/ transosseous sutures	KT-1000: 1.36 mm KT-1000 ≥3 mm: 17 %	Lysholm pre- to post-op: 62.1–88.5 IKDC (nearly) normal in 86 % Single-leg hop test in 77 % ≥90 %	–	One traumatic re-rupture
Lund	2014	12–24 months	26 BQT 25 BPTB	Bone block femoral, sb, interference screw	KT-1000: 1.1 mm (BQT) vs. 0.8 mm (BPTB)	Sub] IKDC: 75 ± 13 (QTB) vs. 76 ± 16 (PBTB) KOOS: 76 ± 16 (BQT) vs. 75 ± 13 (BPTB)	Pain when kneeling: 7 % (BQT) vs. 34 % (BPTB)	One superficial surgical site infection
Lee	2004	41 months	67 BQT	Bone block femoral, sb interference screw	KT-2000: 2.1 mm KT-2000 ≥3 mm: 25 %	Lysholm pre- to post-op: 71–90. Extension peak torque (180°/s) 82 % at 1 year	12 % Pain when kneeling: 6 %	Four re-ruptures (one traumatic) with revision surgery 1 patellar fracture
Sofu	2013	37.6 months	23 BQT 21 HT	Bone block femoral, sb interference screw	KT-2000: 5.7 mm (BQT) vs. 3.7 mm (HT) KT-2000 ≥ 3 mm: 52.1 % (BQT) vs. 9.6 % (HT)	Single-leg hop test >90 % in: 43.5 % (QT) vs. 76.2 % (HT)	–	–

side-to-side difference of 1.1–2.8 mm [28, 32, 39], with an incidence of 9–25 % side-to-side difference higher than 3 mm [31, 32, 34, 37]. This incidence is similar to the ones reported in the literature after primary ACL reconstruction with BPTB and lower than the ones with HT graft [38].

22.4 Complications

Reported incidence of complications in the literature is scarce. There are two studies coming from the same group reporting upon one patellar fracture each [32, 36]. Both occurred 5 months postoperatively after a direct fall on the knee. A second complication reported by this group is about one case of postoperative knee stiffness [36]. There is no further information about the occurrence of surgical site infection or re-rupture in literature. Whereas anterior knee pain is reduced by up to a sixfold compared to BPTB graft [36], one-fourth of patients seems to be unsatisfied with the donor-site scar above the patella [4, 25, 42], requiring in some cases cosmetic surgery with a higher incidence in female patients [37].

22.5 Tips and Tricks of ACL Reconstruction with Quadriceps Tendon Autograft

Usually, a graft of 8 mm can be obtained with no more than the middle third – and in some cases only the centro-medial quadrant – and with the two superficial layers only. We always tend to use the more medial portion of the tendon, since the lateral portion is slightly thinner [43]. If a longer graft is required, it will, in this case, be harvested on the longer lateral side [44]. Indications to full thickness graft, which can reach up to 12–13 mm in diameter, are rare and reserved to selected cases of PCL or double-bundle ACL reconstructions [19, 30, 45, 46]. If possible, it is essential to leave the deepest tendinous layer untouched and to avoid the opening of the suprapatellar articular pouch. Indeed, any leakages may lead to loss of water pressure during arthroscopy and may potentially increase the risk of scar tissue formation between the QT and the suprapatellar fat pad.

We prefer to use a longitudinal incision, rarely longer than 3–4 cm, which is sufficient for the standard 15–20-mm bone block and the 60-mm tendinous graft. It is only marginally larger than the reported incision for the minimal invasive harvesting technique reported by Fink et al. and others using a horizontal approach of 2–3 cm length [26, 47]. The longitudinal incision can easily be enlarged if necessary, especially if the suprapatellar articular pouch is accidentally incised. Furthermore the three-layered architecture of the quadriceps tendon is better visualized proximally, which is an additional advantage of the slightly longer longitudinal incision. However, we have also developed a mini-invasive approach with a longitudinal incision no longer than 2–2.5 cm that we reserve to woman.

Whereas most studies fix the bone block into the femur with interference screws [15, 33], or press-fit technique [28, 31], we prefer tibial bone-to-bone fixation to counteract tunnel widening and the lower bone density of the tibial epiphysis. Whether the bone block is prepared in rectangular, triangular, or round shape plays only a marginal role; however it should be at least 15 mm long. Harvesting the QT without a bone block is also feasible and can be used as graft for ACL reconstruction, especially in specific indications where patellar bone loss should be prevented. Double-bundle ACL reconstruction is technically possible, but challenging. It can be prepared as two separate bundles [48] or with a single bone block – hence as a y-shaped graft, making tibial fixation easier [30, 45, 46].

Major limitations for QT harvesting are not known. We even use the QT graft after failed primary BPTB ACL reconstruction without having experienced patellar fracture. The influence of QT harvesting on patellofemoral kinematic has not been studied yet; however it has been suggested as the first choice graft in patients with patella infera, retropatellar chondropathy, patellar tendinopathy [49], or medial femoro-tibial instability.

Conclusion

The quadriceps tendon is a suitable graft for anterior cruciate ligament reconstruction. Its

versatility, especially in graft sizing, and its biomechanical and histological properties allow for proper individualized treatments. Clinical outcomes are also good, with the advantages of increased primary bone-to-bone fixation strength associated to less tunnel widening and less postoperative laxity as found in BPTB, without the disadvantage of increased incidence of anterior knee pain. Complication rate is low, with minimal risk of patellar fracture reported in literature. Given these findings, the quadriceps tendon autograft can be considered as one of the autograft of choice for primary ACL reconstruction in patients with high functional demands.

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ACL Reconstruction, Single-Bundle Allograft

23

Jakob Van Oldenrijk, Peter A.J. De Leeuw, and Gino M.M.J. Kerkhoffs

23.1 Introduction

Anterior cruciate ligament (ACL) injuries are one of the most common injuries in athletic young adult patients, and the number of ACL reconstructions continues to rise. There was an estimated 16.9 % increase of the number of anterior cruciate ligament reconstructions from 2004 to 2009 in the United States [24]. It is estimated that about 20 % of the approximately 100,000 ACL reconstructions performed each year in the United States use allograft tissue [31]. Furthermore, there is a significant increase in the number of pediatric and adolescent patients undergoing ACL reconstruction. From 2007 to 2011, there were a 27.5 % increase in the 10–14-year age group and a 15.7 % increase in the 15–19-year age group in the United States [39]. In pediatric patients some Australian authors consider using allografts from living donors, being the parents, as a viable option [13]. In Europe allografts are mostly used for complex multiligament reconstructions, revision cases, or (collateral) augmentation of a primary ACL.

The main advantages of allografts in ACL reconstructions are avoiding donor-site morbidity, less extensive tissue dissection, and decreased surgical time. Allografts are especially useful in revision cases, when autograft options have been exploited during the index surgery. Despite these potential benefits, the use of allografts in ACL reconstruction poses a surgeon with specific challenges. Successful outcomes after ACL allograft surgery not only depend on the surgical technique but also are highly affected by graft procurement, processing, and sterilization techniques as well. In this chapter the surgical challenges of allograft ACL reconstruction are explained in an illustrative case example followed by a discussion of risks and benefits of allograft applications in ACL reconstruction.

Case

A 33-year-old male suffered from a high-energy trauma following a motorbike accident in 2009, resulting in bilateral multiligament knee injuries with associated fractures of the femur and patella on both sides. In the acute phase, the patient was stabilized with external fixators, followed by

J. Van Oldenrijk
John Radcliffe Trauma Service, Oxford University Hospitals NHS Trust, Oxford, UK

P.A.J. De Leeuw
John Radcliffe Trauma Service, Oxford University Hospitals NHS Trust, Oxford, UK

G.M.M.J. Kerkhoffs (✉)
Department of Orthopedic Surgery, Academic Medical Center, University of Amsterdam, Amsterdam, The Netherlands

Academic Center of Evidence based Sports medicine (ACES), Amsterdam, The Netherlands

Amsterdam Collaboration for Health and Safety in Sports (ACHSS), Amsterdam, The Netherlands
e-mail: G.M.Kerkhoffs@amc.uva.nl

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open reduction and internal fixation of the femoral and patellar fractures. No early ligament reconstructions were performed because at that point in time, it seemed questionable if the patient would survive any extra surgery due to concomitant internal health issues. A removal of the metalwork took place in 2012. At that point in time, the patient had recovered from all internal health problems, and his main problem was the difficulty to walk without braces due to knee instability, despite extensive rehabilitation. We planned to reconstruct the unstable knees in two sessions, thereby enabling him to walk again without braces. To reduce the risk of additional scarring in this already severely traumatized knee, we started with an ACL and PCL reconstruction using nonirradiated bone-patellar tendon-bone and Achilles tendon allografts for the right knee in 2013. The patient again recovered well. During the final stage in his rehabilitation earlier this year, the patient demonstrated mild persistent ACL instability on the contralateral side.

Physical examination of the left knee revealed a mild effusion, normal leg alignment without divergences to the ipsilateral hip and ankle. Functional examination of the left knee revealed a flexion-extension of 120-0-0. Lachman and Pivot shift tests were positive. The rotatory component was mild and the AP component was 3+. There was no joint line tenderness and meniscal tests were negative. The extension apparatus was intact with mild pain over the patellofemoral joint. The patient had prior incisions over the patella, extended to both the quadriceps and patella tendon, and there was a wound of the initial trauma on the medial distal femur extending distally over the pes anserinus, with the typical posttraumatic indentations, thereby hampering the enthusiasm to use any of the autograft options for this knee.

An MRI scan of the left knee was made for the preoperative planning. It revealed a rupture of the ACL, a malunion of the patella with mild osteoarthritis of the patellofemoral joint and no meniscal tear (Fig. 23.1). The malunion did not hinder the patient and we decided not to intervene. In close correspondence with the patient, he was planned for a reconstruction of the ACL. And as pointed out above, due to a lack of available good-quality autograft options in this polytrauma patient, we decided to use a bone-patellar tendon-bone allograft.

23.1.1 Surgical Technique

Preoperatively the correct knee was marked. The patient was positioned in the supine position with a tourniquet applied around the ipsilateral upper leg pressured at 250 mmHg. A support was placed against the tourniquet and a second one at the end of the operation table in such a manner that the knee can stand on its one in 80–110° of flexion (Fig. 23.2).

A time-out procedure was performed followed by 1 g of intravenously administered flucloxacillin. Examination under general anesthesia confirmed ACL insufficiency. The nonirradiated fresh-frozen bone-patellar tendon-bone allograft was thawed at room temperature in a mixture of saline, gentamicin, and flucloxacillin. The graft was subsequently prepared; the bone blocks were reshaped and reduced with the use of a small oscillating saw, its thickness measured; and in both the blocks, two holes (2 mm) were drilled (Fig. 23.3).

Through standard medial and lateral knee arthroscopic portals, the knee joint was inspected (Fig. 23.4), the patellofemoral joint revealed a Grade II chondropathy, and both the medial and lateral compartments were intact.

The ACL remnant was unstable and partly fused with the PCL (Fig. 23.5a). A minimal notchplasty was performed with the use of a 4.5 mm bonecutter shaver and an arthroscopic coagulant device (Fig. 23.5b). The correct tibial tunnel position was determined with the aiming device (Fig. 23.5c) and set to 47°, and the inferomedial skin incision was made followed by a Kirchner wire under arthroscopic control. Since both bone blocks from the allograft were reduced to a circumferential diameter of 10 mm, a cannulated equally sized drill was used to create the tibial tunnel (Fig. 23.5d). Remaining debris

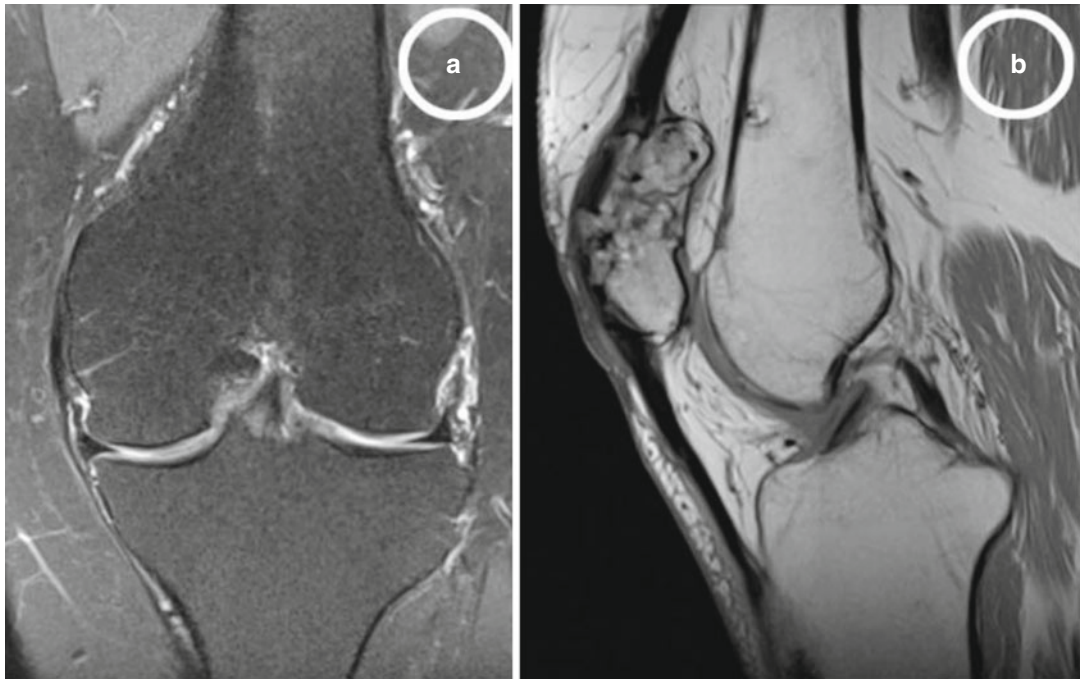

Fig. 23.1 MRI of the left knee in the coronal and sagittal plane. (**a**) Coronal T2-weighted MRI image indicating intact medial and lateral meniscoid tissue and the suggestion of an ACL rupture. (**b**) Sagittal T1-weighted MRI image showing a malunion of the patella and irregularity of the patellofemoral cartilage and an ACL rupture

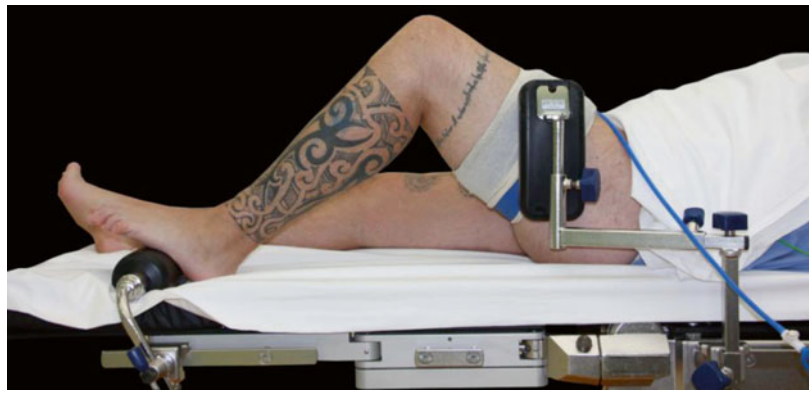

Fig 23.2 Patient positioning: the patient is positioned in the supine position with a tourniquet around the ipsilateral upper leg, the leg supported at the level of the tourniquet, and foot to allow for a free-standing leg in various flexion angles of the knee

was meticulously removed from the knee to prevent cyclops formation.

A transtibial approach was used to determine the femoral tunnel position using the straight femoral aimer (Figs. 23.5e and 23.6); a Kirschner wire was drilled inside out followed by the cannulated 4.5 mm Endobutton drill. Subsequently, both the Kirschner wire and the drill were removed to measure the length of the femoral tunnel (60 mm), and the Kirschner wire was repositioned.

A 30 mm Endobutton (Smith and Nephew, London UK) was fixed to one of the bone blocks through the former drilled holes. Through the holes of the other bone block, two Novosyn 2 sutures were placed (Fig. 23.3). Since the femoral

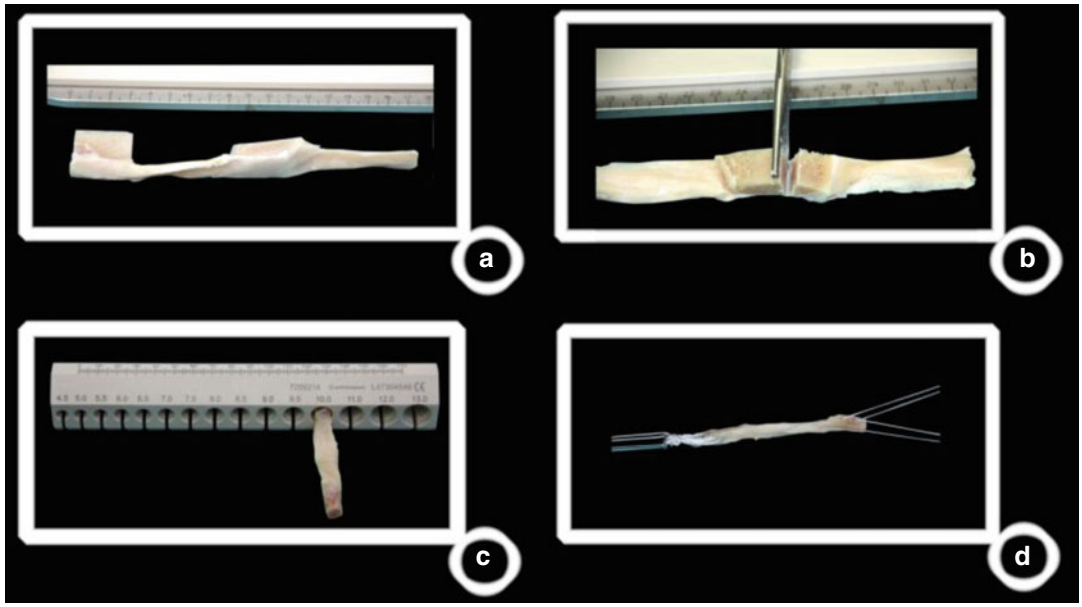

Fig. 23.3 Graft preparation: the bone patellar bone allograft preparation. (**a**) The total length of the bone patellar bone allograft is measured. (**b**) The bone blocks are reshaped and cut in the preferred size. (**c**) Measurement of the circumference of the prepared graft; this determines the size of the tunnels during ACL surgery. (**d**) Fully prepared bone patellar bone allograft; one of the bone blocks is connected to the Endobutton, while the other is connected to strong sutures

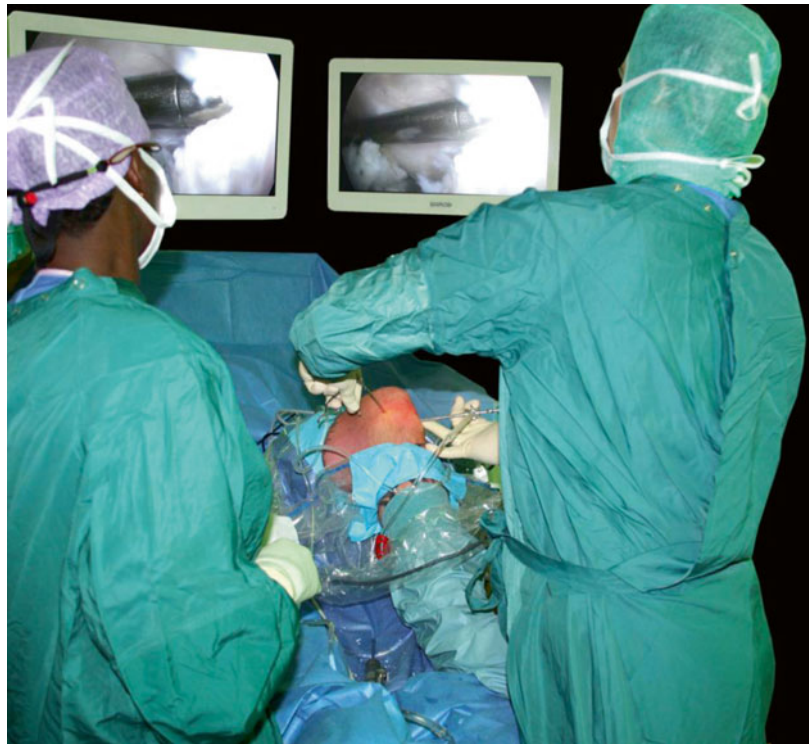

Fig. 23.4 Intraoperative image showing the comfortable position of the surgeon in relation to the knee in ACL reconstruction. The arthroscope is situated in the lateral portal and the grasper in the medial portal

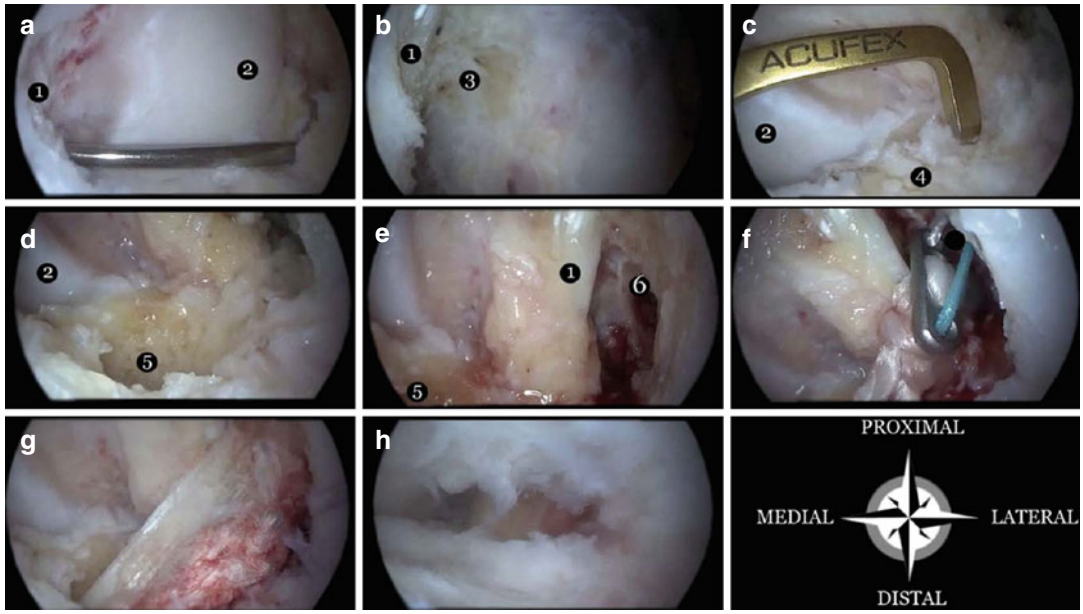

Fig. 23.5 Arthroscopic overview of ACL reconstruction with a bone patellar bone allograft. *1* PCL, *2* lateral femoral condyle, *3* resident's ridge, *4* tibia plateau, *5* tibial tunnel, *6* femoral tunnel. (**a**) The 4.0 mm 30° angled arthroscope was in the lateral portal and a probe was inserted through the medial portal. The remnant of the ACL was merged with the PCL and the lateral part of the medial femoral condyle was empty. (**b**) Arthroscopic overview after the notchplasty had been performed, the resident's ridge could be identified. (**c**) With the use of the tibial tunnel aimer, the correct position was determined; the aimer was set to 47°. (**d**) Overview after finalizing the tibial tunnel. (**e**) Arthroscopic image indicating the level of both the tibial and femoral tunnel. (**f**) The allograft was pulled into the femoral tunnel with the Endobutton for fixation at the femoral side. (**g**) Arthroscopic image after the graft was fixed at the femoral and tibial level, satisfying intra-articular position of the graft with the knee in full flexion. (**h**) Identical to G, however with the knee in full extension indicating there is no impingement

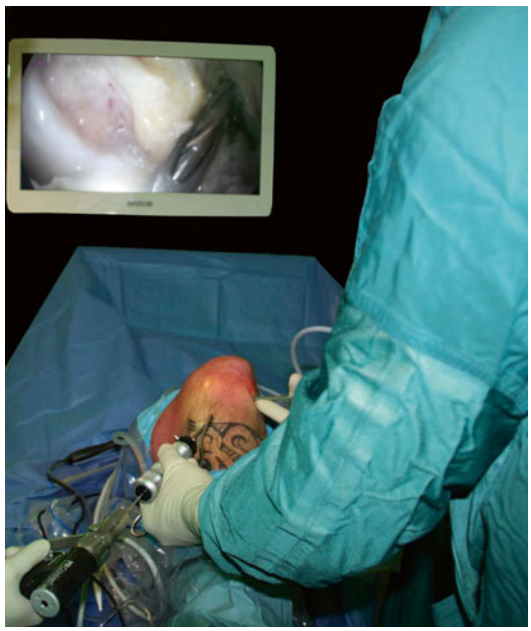

Fig. 23.6 Intraoperative image demonstrating femoral tunnel positioning through a transtibial surgical approach using the straight femoral aimer

tunnel was 60 mm and the chosen Endobutton 30 mm, a 10 mm-diameter femoral tunnel was created to a depth of 40 mm. The prepared bone patellar bone allograft was then pulled in (Fig. 23.5f) and the Endobutton flipped. The position was confirmed arthroscopically. The knee was repetitively flexed and extended while the graft was kept tensioned. Subsequently tibial fixation was performed with a Biosure HA interference screw (Smith and Nephew, London UK) with the knee in 15° of flexion (Fig. 23.7).

Arthroscopically the knee was inspected for impingement of the graft in flexion and extension (Fig. 23.5g, h).

An intra-articular drain was placed in the knee for the first 4 h, wounds were sutured, and a compression bandage from the foot to above the level of the tourniquet was applied. The patient was instructed to fully weight bear using two elbow crutches for a duration of 2 weeks, followed by a routine ACL rehabilitation protocol, without the use of a brace.

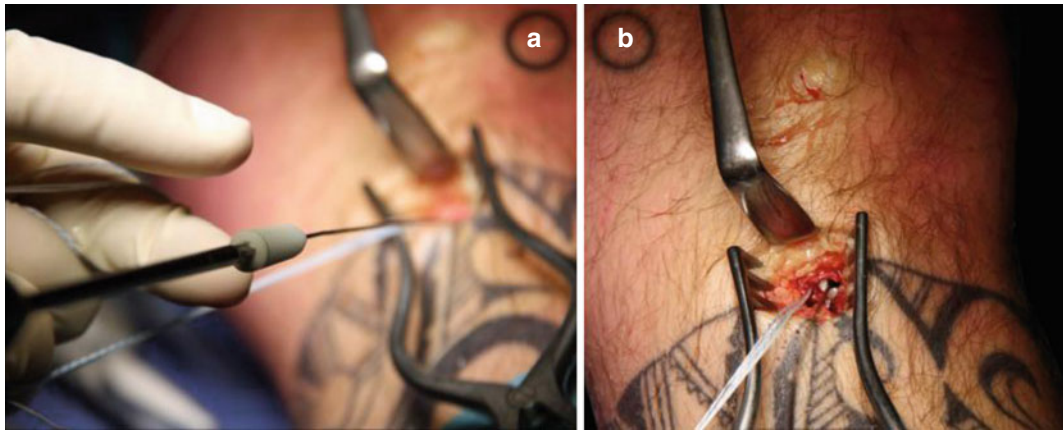

Fig. 23.7 Interference screw: with the knee in 20° of flexion, the tibial part of the allograft is fixed with an interference screw. (**a**) A nitinol wire is inserted in the tibial tunnel and the cannulated interference screw is positioned while the graft is continuously tensioned by hand. (**b**) The interference screw is fully screwed in the tibial tunnel

23.2 Allografts Versus Autografts

In today's literature, there are numerous systematic reviews available comparing allograft with autograft primary ACL reconstructions [2, 11, 18, 22, 23, 28, 33, 37, 41]. Current evidence however is discordant, some systematic reviews demonstrating higher failure rates with allograft use, while others fail to demonstrate any difference. Considering the conflicting evidence between systematic review, Mascarenhas et al. performed a systematic review of overlapping systematic reviews by including eight systematic reviews published between 2007 and 2008 [28]. They found that current best available evidence did not demonstrate any difference in rerupture rates and clinical functional outcomes. However, when reviewing lower-quality studies, allografts did appear to have a higher rerupture rate and worse hop test performance. Moreover, they found that the surgical technique, allograft sterilization process, and other graft characteristics were inconsistently described, despite their strong confounding effect on outcome. Although Krych et al. demonstrated inferior functional result and higher revision rates with the use of allografts, these differences were not significant when irradiated allografts were excluded from the analysis [23].

The outcome of allograft ACL reconstruction surgery highly depends on surgical technique as well as the processing, sterilization, and storage techniques of the allograft. In general allograft ACL reconstruction follows the same principles as autograft techniques. Grafts can be fixed either cortical or apertural (in the tunnel), both at the femoral and tibial side. The allografts heal in the same manner as autografts: an inflammation, revascularization, and remodeling phase, although allografts provoke a prolonged inflammation response, and a slower incorporation after implantation as compared to autografts [1]. The tunnels for the orientation and fixation of the ACL graft need to be such that the "new" ACL is as anatomical positioned as possible. Surgical techniques available for the tunnel preparation can generally be summarized as transtibial and anatomical. When the transtibial approach is used, one should be cautious that the femoral tunnel is not too vertical. Vertical femoral tunnel positions are related to a significantly increased postoperative laxity and rerupture rate.

23.3 All Monobundle Allografts Equal or Some More Equal Than Others?

When considering the use of allografts for ACL reconstruction, a surgeon must be aware of the procurement, sterilization, and preservation techniques employed by the local tissue bank. The European Directorate for the Quality of Medicines & HealthCare (EDQM) published the guide to the quality and safety of tissues and cells for human application, which provides a comprehensive guideline describing donor selection, tissue procurement, testing, preservation, storage, and sterilization criteria [21]. Although national guidelines and regulations may vary, most European tissue banks adhere to the basic principles described in the EDQM guide.

The use of allografts is costly and supply by tissue banks is often limited. Selecting the most suitable donors is therefore essential. Although bone-patellar tendon-bone (BPTB) allografts from male donors have a higher bone mineral density (BMD) than those from female donors, no correlation was found between age and BMD in BPTB allografts [20]. Moreover, donor age and donor sex did not have a significant effect on functional outcome nor were the biomechanical properties reduced in older donors [14].

To reduce the risk of disease transmission, donors must be carefully selected through an extensive medical history and behavioral risk assessment. Bone banks have significantly improved their selection criteria in the last three decades, thereby reducing viral transmission to a minimum. An investigation into musculoskeletal allograft adverse events by the World Health Organization revealed nine cases of HIV transmission. Except for a single case involving an untested donor in 1996, all other cases occurred between 1984 and 1986 [16].

Completely inactivating any possible pathogens by terminal sterilization would greatly reduce the viability of the allograft and is therefore not appropriate in ACL allograft surgery. Therefore, the procurement and processing of donor tissue must be performed under sterile circumstances. Processing involves the removal of all redundant tissue, such as fat and blood vessels, taking samples for risk analysis and extensive rinsing. Antibiotic decontamination is preferred over chemical decontamination to preserve tissue viability.

While ethylene oxide has been used in the past as sterilization method, it has currently been abandoned. It has been suggested that ethylene oxide sterilization may cause toxic by-products, which may cause an inflammatory response and toxic cell necrosis thereby reducing graft incorporation and potentially causing bone tunnel enlargement [17, 19]. Gamma irradiation is commonly applied as a sterilization method in varying dosage levels, ranging between 17 and 35 kGy or 1,7–3, and 5 Mrad [21]. Gamma irradiating has a dose-dependent effect on the structural properties of ACL allografts, reduced initial tensile strength, and a slower maturation or ligamentization process. Fideler demonstrated a 15 % reduction of biomechanical strength after 2.0 Mrad irradiation, 10–24 % after 3.0 Mrad irradiation, and a further 19–46 % reduction after 4.0 Mrad irradiation [9]. Inactivating viruses may however require doses up to 4.0 or 5.0 Mrad, which emphasizes the importance of meticulous donor selection [10, 32, 34, 40].

To find a balance between maintaining allograft structural integrity and sterilization, many tissue banks apply low-dose irradiation protocols between 1.0 and 2.0 Mrad [32, 34]. A systematic review of 21 studies by Park et al. compared 1,038 primary ACL reconstructions using nonirradiated allografts with 415 low-dose, less than 2.5 Mrad, irradiated allograft ACL reconstructions [32]. Nonirradiated allografts had higher functional scores, less residual laxity, and lower revision rates compared to low-dose irradiated allografts. However, Yanke et al. demonstrated that although very low-dose irradiation, between 1.0 and 1.2 Mrad, reduced stiffness by 20 %, it did not affect maximum load, maximum stress, elongation, or strain at maximum stress [40]. Similarly, in a rabbit model, Bhatia et al.

confirmed that low-dose irradiation did not alter biomechanical properties at 8 weeks. However, incorporation and maturation of irradiated grafts were slower as compared to nonirradiated allografts [1].

Preservation methods need to result in a graft with high strength, high stiffness, persistent restraint after cyclic loading, and early incorporation, thereby withstanding the forces in the early postoperative rehab period. Musculoskeletal allografts are preserved by either fresh freezing, freeze drying, or cryopreservation. Fresh-frozen allografts are deep freezed up to −80 °C, while freeze-dried allografts are additionally dried, thereby removing 3–5 % of the moisture [32]. Freeze-dried allografts may be stored at room temperature, while fresh-frozen allografts need to be kept under refrigerated conditions. Freeze drying is the easiest performed technique to preserve soft tissues. It does not affect graft strength and reduces graft antigenicity [27]. Cryopreservation is a technique, in which the allograft is stepwise freezed up to −196 °C, thereby preserving between 45 % and 80 % of cell viability [21, 32]. Park et al. did not find a difference in functional outcome and revision rate between fresh frozen, freeze drying, or cryopreservation [32].

For single-bundle ACL reconstructions, we use primarily nonirradiated fresh-frozen bone-patella tendon-bone allografts, although the tissue bank may provide a wide variety of other tendon options. Specific requests may be granted through an extensive international collaborative network of tissue banks.

23.4 Other Applications of Allografts in ACL Surgery

23.4.1 Revision ACL Reconstructions

Allografts are often used in revision ACL reconstruction to avoid additional scarring. Furthermore, autograft options are often exploited during the index procedure. Results from the Danish registry for knee ligament reconstructions demonstrated that allografts were used in 21 % of revision ACL cases [26]. However, the use of allografts in ACL revision surgery resulted in a higher revision risk compared to autografts (RR, 2.05; 95 % CI, 1.5–2.4). Current evidence on revision ACL surgery using allografts primarily consists of small-case series.

In a retrospective study, Mayr et al. compared 15 ACL revisions using nonirradiated allografts with 14 ACL revisions using autografts and found no functional differences at 2–5-year follow-up [30]. Tunnel widening was not statistically significantly different. Lateral osteoarthritis was however more prevalent in the allograft group (14.3 %) compared to the autograft group (7.7 %). Re-revision rate was not assessed.

Incorporation of allografts takes longer than allografts especially in revision cases due to some persistent pivot. Chougule et al. described the 6 (3–9)-year follow-up in 19 patients who underwent revision ACL reconstruction using quadrupled semitendinosus allografts [3]. Five percent was revised for early graft failure or instability, while an additional 15 % was reoperated for meniscus injuries and ongoing pain.

Reverte et al. described a series of 19 patients undergoing revision ACL surgery using tibial or hamstring tendon allografts and found a laxity of more than 5 mm or a Lachmann or pivot shift test of more than grade 1 in 21 % of patients at 12-month follow-up [35]. Similarly, Fox et al. found a high risk of persistent pivot in a series of 32 patients who underwent revision ACL reconstruction using nonirradiated fresh-frozen patellar tendon allografts [12]. After a 2–11-year follow-up period, one patient required another revision and 25 % demonstrated a 1+ pivot. Overall functional improvements were comparable to those of revision ACL surgery mentioned in the literature. Despite the high incidence of persistent pivot, 87 % of patients indicated to be completely or mostly satisfied with the outcome of the procedure.

Adding a lateral iliotibial band tenodesis decreases the force on the ACL graft by 43 % and reduces persistent pivot rate due to the pulley effect on the lateral collateral ligament during extension [6, 15]. This adds additional protection during the graft's incorporation and maturation

period and may therefore be a particular suitable addition in allograft ACL revision surgery. Trojani et al. demonstrated a negative pivot shift after revision ACL reconstructions in 80 % of patients when combined with an iliotibial band tenodesis, compared to 63 % of patients without [38]. Ferretti et al. combined a revision anterior cruciate ligament reconstruction using a doubled semitendinosus and gracilis tendon autograft combined with the Coker-Arnold modification of the MacIntosh lateral iliotibial band procedure [7, 8]. Out of a total group of 30 patients, one patient was revised after 5-year follow-up. Pivot shift was positive in two patients, and two patients had a side-to-side anterior tibial translation of more than 5 mm on laxity tests, thereby demonstrating a failure rate of approximately 10 %.

Mascarenhas et al. described the technique of combining a BPTB allograft with a iliotibial tenodesis similar to the technique described by Lemaire and Christel [4, 25, 29]. The iliotibial band strip is first passed from distal to proximal beneath the LCL and subsequently passed through a femoral bone tunnel followed by again passing beneath the LCL and finally through a tibial bone tunnel proximal to distal. Instead of passing the strip beneath the LCL for the second time, the strip can also be fixed at the isometric point proximal to the LCL, which requires a smaller strip and a smaller incision [5]. While an extra-articular reconstruction may provide additional stability during the incorporation period of the ACL allograft, there is a risk of early osteoarthritis when the tenodesis is overtightened. It is therefore important to fix the tenodesis in a neutral position instead of external rotation. Furthermore, the additional incision required for an extra-articular reconstruction may not be a viable option in previously severely traumatized knees, such as in the case presented.

23.4.2 Multiligament Reconstructions

In multiligament reconstructions, allografts can be particularly useful for either collateral reconstructions or augmentations. In combined ACL or PCL and collateral reconstructions, multiple different techniques using allografts have been described [36]. Most involve the use of autografts for reconstruction of the cruciates and allografts for collateral augmentation or reconstructions. Since incorporation time is prolonged with the use of allografts, protected weight bearing in a hinged brace is recommended postoperatively to prevent lengthening or loosening of the graft and allow early motion thereby reducing the risk of arthrofibrosis [36].

Conclusion

Using allografts can be an excellent option for ACL reconstructions in selected patients. Especially in severely injured knees or revision cases, the use of allografts can limit additional soft tissue damage, reduce surgical time, and offer reconstruction options in cases where autologous options were previously exhausted. Current evidence however suggests higher failure rates when compared to using autografts. Using the right type of allograft reduces the risk of failure. Knowledge of graft selection is therefore essential, since procurement, sterilization, and preservation techniques greatly affect the success of the procedure.

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ACL Reconstruction in Immature Athletes

24

Romain Seil, Julien Coquay, Alexander Hoffmann, and Franck Chotel

24.1 Introduction

There is a lack of current international guidelines with respect to the treatment of ACL-injured children, leaving the treating physicians with a therapeutic dilemma. Therefore, the subject is highly controversial [3, 12, 19, 49, 51, 52, 53, 58, 59, 76]. Nonoperative treatment has shown to be successful in some patients, but the reasons for this are poorly understood [51, 72]. Furthermore, a strong association between the delay of surgery and the occurrence of meniscus and cartilage lesions strongly suggests that a nonoperative treatment may be detrimental to the intra-articular soft tissues [14, 24, 35, 44, 45]. Surgery is difficult and highly specialized, due to the specific anatomy of children's knees and its serious complication potential [2, 3, 15, 25, 30, 64–66, 71]. Surgical results are good [6, 8, 10, 31, 32], but due to remaining growth and knee maturation, they seem to be less predictable than in adults. Furthermore, there are not enough high-quality outcome studies after surgical treatment [49]. Finally, little is known about the long-term consequences of ACL reconstruction in this specific population.

The prevalence of ACL tears in children amounts less than 5 % of all ACL injuries [57, 63, 68]. In a nonathletic adult population, the incidence of ACL injuries is approaching the 1‰ rate [22, 23, 60]. However, in a population of young athletes, we found an incidence approaching the 1 % rate (nonpublished data). Due to improved clinical and diagnostic skills, together with a growing popularity of high-risk and organized sports in children and adolescents, and maybe also decreasing motor skills in this young population [54], their number seems therefore to be on the rise. They do rarely occur before the age of nine, and three out of four are sports injuries [10].

R. Seil, MD, PhD (✉)
Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg-Clinique d'Eich, 76, rue d'Eich, Luxembourg 1460, Luxembourg
e-mail: seil.romain@chl.lu

Sports Medicine Research Laboratory, Luxembourg Institute for Health, 76, rue d'Eich, Luxembourg 1460, Luxembourg

J. Coquay, MD • A. Hoffmann, MD
Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg-Clinique d'Eich, 76, rue d'Eich, Luxembourg 1460, Luxembourg

F. Chotel, MD, PhD
Department of Pediatric Orthopaedic Surgery, Lyon University Hospital for Mother and Children, Université Claude Bernard Lyon I, 59 Boulevard Pinel, Bron 69677, France

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24.2 Indication

24.2.1 Acute Setting

In an acute setting, ACL tears are often associated to the presence of a hemarthrosis. Associated meniscus lesions, often causing mechanical extension deficits, or cartilage injuries should be ruled out because they determine the course of further treatment. Standard radiographs (including AP, strict lateral, and skyline views) as well as MRI are mandatory in this setting. The interpretation of the latter may however be difficult because MRI identification of the ACL is more difficult in comparison to adults [38]. It could be shown that the sensitivity of MRI in children under 12 years amounted to only 62 %, with a specificity of 90 %. In the age group from 12 to 16 years, sensitivity and specificity increased to 78 % and 96 %, respectively [29]. Secondary MRI features like subchondral bone bruise may be less frequently seen as well due to the inherent increased laxity of pediatric knees.

In the absence of an indication for acute surgery (dislocated bucket handle meniscus tear, large osteochondral flake fracture), the priority of treatment at this stage is to regain free range of motion and a pain-free, unswollen knee. In the presence of an indication for acute surgery, ACL reconstruction may be considered provided that (1) there is minor swelling and synovitis, (2) the surgical environment is experienced with this type of surgery, and (3) the parents are fully aware of the complication potential and the need for a close clinical follow-up until the end of the growth period (Fig. 24.1). Treating only the meniscus or the cartilage and leaving the ACL untreated in the long-term cannot be recommended.

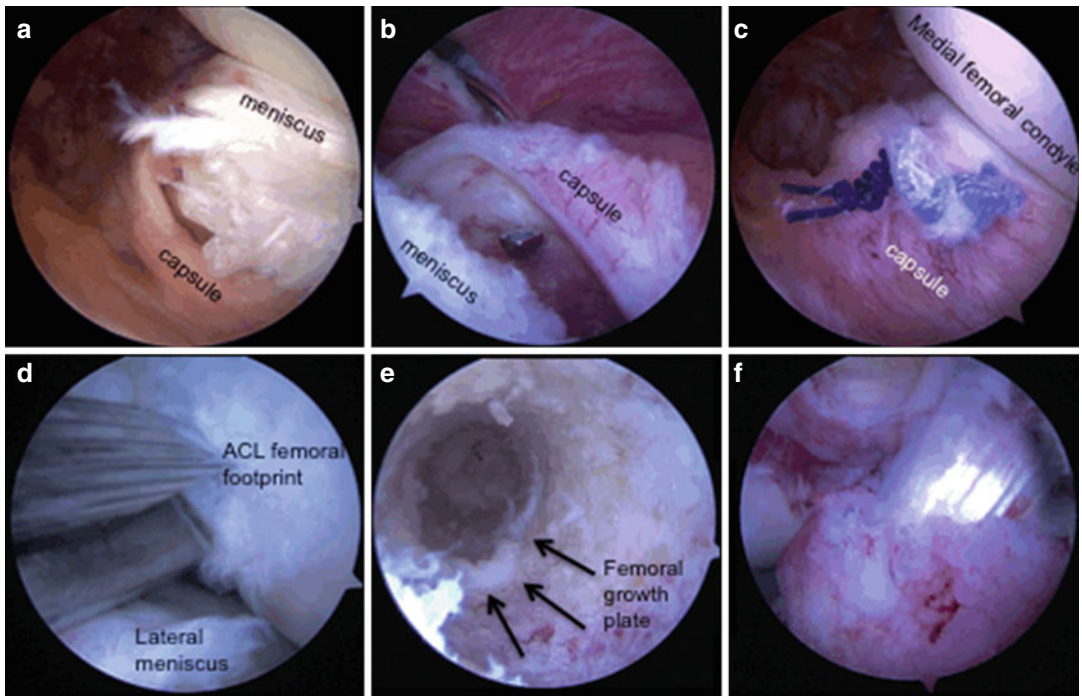

Fig. 24.1 Acute ACL reconstruction in the left knee of a 14-year-old boy who presented with a dislocated bucket handle tear of the medial meniscus in a knee with wide open physes. Arthroscopy through a posteromedial approach revealed a total capsular detachment of the posterior horn of the meniscus after reposition of the bucket handle (**a**). A meniscal suture was performed through a posteromedial approach (**b**, **c**): after repair. Pediatric ACL reconstruction was performed with a quadruple hamstring graft and extracortical fixation. Femoral drilling occurred through the anteromedial portal (**d**). A femoral tunnel view revealed the femoral growth plate (**e**)

24.2.2 Chronic ACL Deficiency

After the acute period, timing and indication for surgery is becoming more complex and should take into consideration the child's individual needs and maturation process. The former should not be confounded with the parents' ambition for their child's future athletic career. Remaining functional instability with recurrent giving way episodes is an indication for surgery. However, such symptoms are rarely spontaneously described by children, although they do sometimes report them if they are questioned specifically. Finally, ACL surgery should be indicated in the presence of a secondary meniscus tear. A dislocated bucket handle tear can be the primary sign of a previously undiagnosed ACL injury. This should be kept in mind by the surgeon if a skeletally immature patient is referred for a dislocated bucket handle tear.

Although significant evidence has been brought to the orthopedic literature over the last decade, showing that pediatric ACL reconstructions are safe procedures and provide good results, surgery cannot yet be recommended on a systematic basis. There are three reasons for this: (A) Surgery is difficult and highly specialized, due to the specific anatomy of children's knees and its serious complication potential [2, 15, 25, 30, 64, 65, 71]. (B) Due to the nonanatomic graft placement, the remaining knee growth, and maturation, surgical results are less predictable than in adults. It is known that children have very lax knees with many of them presenting high-grade pivot shifts even under physiologic conditions. Our own clinical experience (unpublished data) has shown that many of the ACL-injured and ACL-operated children remain hyperlax in the operated and nonoperated knee after the end of their growth period (Fig. 24.2). It is well known that the outcome of ACL surgery in adult patients with knee hyperlaxity is inferior to normolax patients, and it may be assumed that this applies for children as well. Currently, it is impossible to predict which degree of knee stiffness a child reaches at the end of its growth period and in how far this may influence the future outcome. Future studies will need to address this question specifically. (C) A good outcome has been reported from several studies, after nonoperative treatment of pediatric ACL injuries in some patients with an acceptable amount of subsequent meniscus and cartilage lesions. There are hardly any prospective studies on ACL-injured children. Moksnes [47, 48] reported on a group of children less than 12 years of age in whom a nonoperative treatment was proposed at initial presentation. 65 % returned to their pre-injury level of sports, and 9.5 % had suffered a

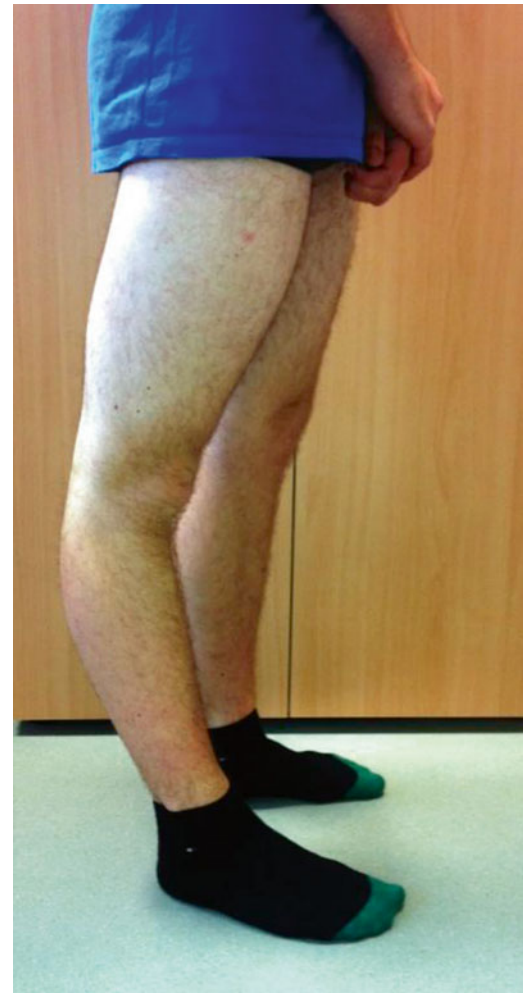

Fig. 24.2 Recurvatum knees in a 17-year-old boy who was operated with a transphyseal ACL reconstruction at the age of 12. The boy had a positive pivot shift both in the operated and the healthy knee. The proportion of hyperlax knees remaining at the end of growth is high in our pediatric ACL population

secondary meniscus injury. In an MRI follow-up study of this population, 32 % of the initial population of 41 children required ACL reconstruction, and the incidence of new meniscus injuries was 19.5 % over a follow-up period of approximately 4 years [50, 51]. Similarly Streich [72] followed initially nonoperated Tanner I and II children (median, 13 years) prospectively; 42 % of these children did not need surgery, but 58 % had to undergo ACL reconstruction because of persistent instability. Moksnes [47, 48] used functional tests to evaluate the child's ability to cope with the ACL tear. Two conditions seem to be mandatory for this outcome: A very close and individualized follow-up of this pediatric population and their parents as well as a frequent change from level I to level II sports. Future studies will need to address if the fact to create an environment of systematic and regular functional testing combined to close follow-up will be as successful as the surgical treatment in this patient population. For some families, it may however be a limited option to adhere to this concept because of the potential need for later surgery, subsequent meniscus or cartilage injury, and a less active lifestyle for their child.

On the other hand, many reports have shown that nonoperative treatment often leads to secondary cartilage and meniscus lesions. Initial meniscus lesions have been described in 36–100 % of the midsubstance ACL tears in children [4, 7, 39]; secondary meniscus lesions were seen in 75 % of the cases within the first year after the ACL tear [7]. Several authors have observed the development of an early osteoarthritis within this patient group over the years [1, 26, 45]. Millet [44] as well as Henry [24] found that a delay in surgical treatment was associated with a higher incidence of medial meniscal tears. Similarly, Lawrence [35] found an association between the delay in treatment (over 12 weeks) and an increase in the severity of medial meniscal tears and higher-grade lateral and patellotrochlear chondral injuries in children less than 14 years of age. Unlike the previous authors, Woods [75] stated in a case control study including 13 adolescents with open physes, in whom the ACL reconstruction had been delayed until closing of the physes, that the rate of intra-articular knee disorders was not significantly higher than in the healthy group. Yet, there was a trend toward a larger number of medial meniscus lesions in those patients with a chronic ACL insufficiency (>6 months), although the statistical power was not high enough to give statistically significant results. The investigators concluded that an absolute restriction of the activity level was necessary in order to reduce the risk for intra-articular lesions [75].

In conclusion, the natural history of ACL tears in children has not been completely elucidated yet. The current evidence seems to indicate that nonoperative treatment may be the right treatment for some patients, but the future will show if we will be able to preselect these children early after injury or before the occurrence of secondary lesions. The following treatment algorithm was thus proposed: In isolated ACL ruptures, a conservative treatment with tight follow-up should be preferred to an early reconstruction. A structured rehabilitation program over a 3–6 months period is suggested, whereas normal physical activity is allowed. In pivoting sports, a special brace should be worn. The indication for surgical ACL reconstruction is given either in case of secondary meniscus lesions, with repeated giving way episodes or after completion of knee growth (13.5 years in girls; 15.5 years in boys) [47].

24.2.3 Knee Growth, Maturation, and Preoperative Planning

The knee growth and maturation chart (Fig. 24.3) [20] is based on the growth speed of the growth plates at the knee and the skeletal age and allows to differentiate between three different periods of ligamentous ACL injuries in children and adolescents: (A) the prepubertal phase with a high remaining growth potential of the distal femoral and the proximal tibial physis. This phase ends at the age of 13 in girls and 15 in boys. During this phase, pediatric surgical techniques are mandatory. (B) The pubertal phase, during which physeal growth potential decreases. It lasts for approximately 1 year (13–14 in girls and 15–16 in

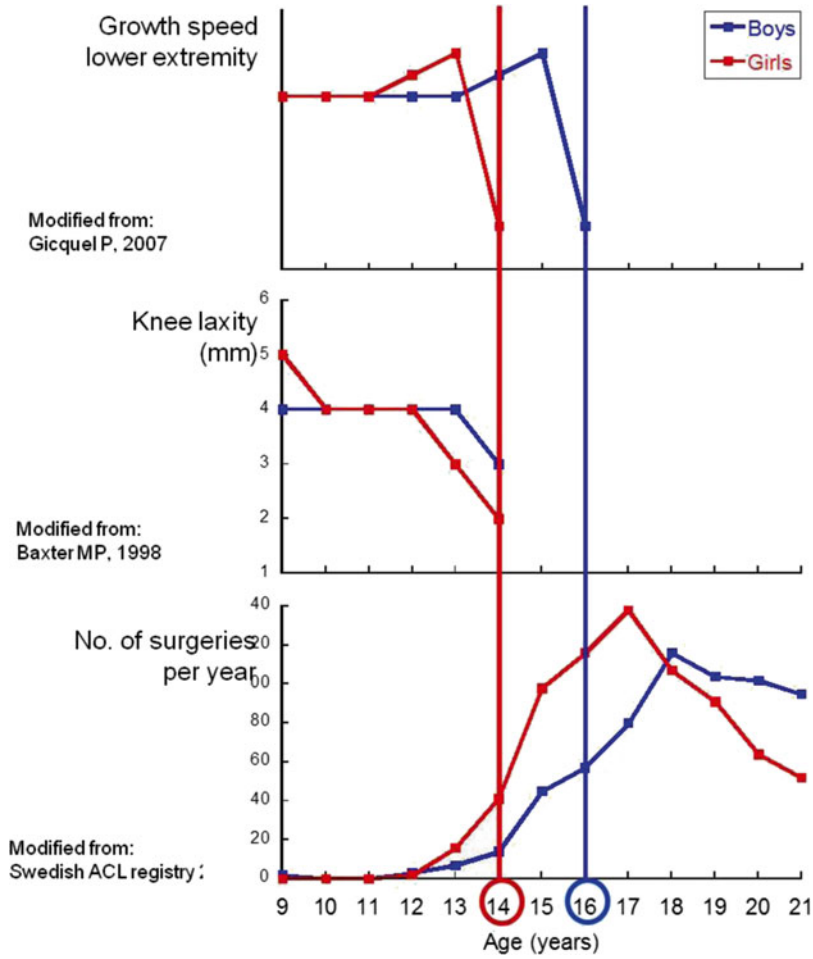

Fig. 24.3 Superposition of three tables illustrating growth velocity of the physes around the knee in relation to skeletal age (*top*). This diagram allows a quick preoperative categorization of the patients. During growth (rapid acceleration phase), the growth plates around the knee have a high growth velocity of about 2 cm/year. The use of pediatric ACL reconstruction techniques is mandatory in this phase. From age 13 in girls and 15 in boys, growth velocity rapidly decreases (gradual deceleration phase) until growth stop of the lower limb at the age of 14 in girls and 16 in boys. From this moment on, adult techniques can be used. The middle graph shows the decrease of physiologic knee laxity as reported by Baxter (Modified from: Baxter [77]). Laxity decrease corresponds to the final phase of knee growth. The lower graph represents the numbers of ACL surgeries performed in Sweden in 2010. It confirms the clinical experience that the frequency of ACL injuries increases after the end of knee growth and once they have stiffened

boys). Pediatric surgical techniques are still mandatory at this stage, because growth plate injuries still can cause significant growth abnormalities. (C) The adult phase, starting at 14 in girls and 16 in boys. At this moment, growth plate closure has occurred at the distal femur and the proximal tibia and adult procedures can be used.

It has been shown that defining the degree of maturation by relying on the Tanner stages alone is insufficient and sometimes lacks of reliability [70, 73]. Moreover, skeletal age should rather be used than chronological age. Some authors modulate the reconstruction technique according to the patient's maturity: They recommend extraphyseal reconstruction for very young patients, transphyseal reconstruction for older patients, and partial transphyseal procedures in between [16, 27, 43, 46]. The background for this strategy

is based on the theoretical age-related risk of growth arrest. These authors claim that the extent of the deformity after a potential growth arrest is inversely proportional to the patient's age. However, a recent survey [10] noted that growth changes occurred mainly in adolescents during the last year before knee physeal closure. The capacity of the growth plate to break small epiphyso-metaphyseal bone bridges spontaneously is important in young children, but it slows down with the maturation process [76]. In others words, the amount of potential growth deformity is minor in older children, but the risk of growth arrest could be much higher. For this reason, there is a place for a delayed reconstruction in adolescents close to skeletal maturity [13].

A systematic preoperative planning is mandatory in these young individuals [77]. The standard radiological diagnostics should include AP, lateral, and patellofemoral views, as well as an AP view in 45° of knee flexion (Fig. 24.4). A systematic determination of the skeletal age and the remaining growth potential is recommended by using X-rays of the left hand and the tables by Greulich and Pyle. Furthermore, a long leg standing radiograph should be obtained in order to document the alignment and possible preoperative leg length discrepancies. A novel 3-D MRI tool, the Module for Adolescent ACL Reconstructive Surgery (MAARS), has been described recently [28]. It may be helpful in the future for surgical planning.

24.3 Techniques

24.3.1 Surgical Techniques

Many surgical techniques have been described in order to perform the best possible ACL replacement in children and at the same time to reduce the surgically induced complication potential to a minimum. On the contrary to an adult knee, an anatomic graft placement is difficult to obtain in children with the currently available techniques [40]. This is due to the presence of the growth plates, especially on the femoral side. According to the localization of the tibial and femoral tunnels, the surgical techniques can be divided into three categories (Fig. 24.5): (A) transphyseal procedures, where the tunnels are drilled through the growth plates; (B) epiphyseal techniques,

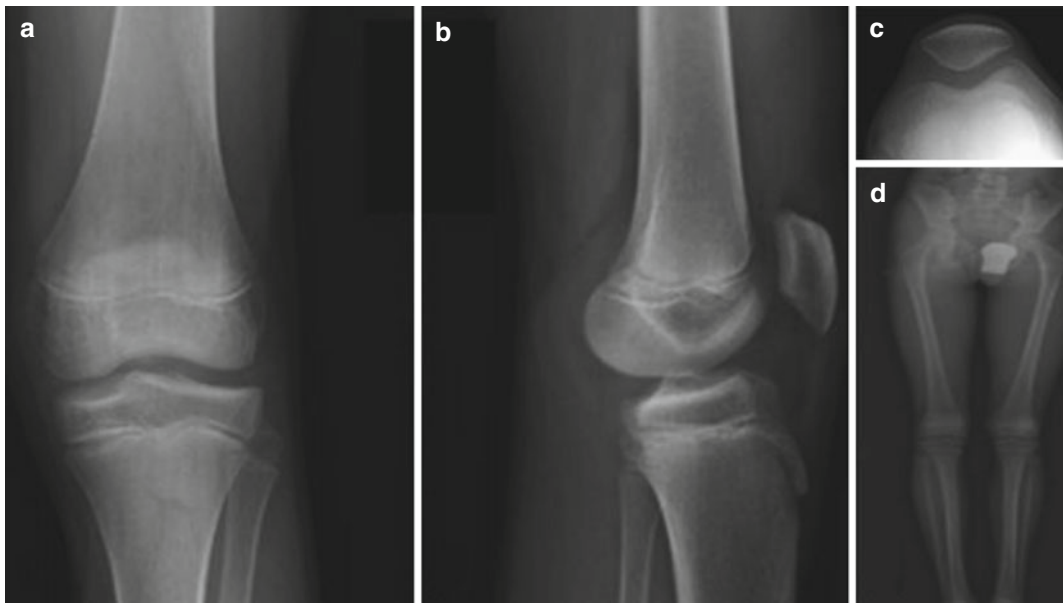

Fig. 24.4 Standard radiographs for the preoperative planning of an ACL reconstruction in children: AP (**a**) and lateral (**b**) views, patellofemoral view (**c**), full leg view (**d**)

where the tunnels are located in the tibial and femoral epiphysis, not injuring the growth plate; and (C) extraepiphyseal techniques, where the graft is placed around the growth plate. Finally, different types of graft placements can be used on the tibial and the femoral side. Every surgical technique bears its own, specific complication potential. General surgical guidelines have been established to make the surgical procedure as safe as possible with respect to continuity of normal growth (Table 24.1).

The different available graft types in adults may also be used with some modifications in children. Hamstring grafts are probably the most popular. In some rare cases, they can be too thin and may be reinforced with other tendon material, i.e., by a quadriceps strip. It is important not to harm the periosteal attachment of the hamstrings. As opposed to the adult harvesting technique, it is recommended to leave the tibial attachment site intact and cut the hamstrings proximal to their bony insertion site. This avoids an injury and potential growth arrest of the tibial tuberosity apophysis which may cause a later development of a recurvatum knee. Quadriceps and patellar tendon grafts can be used as well, in which case they should be harvested without a bone block. If a bone block is part of the technique, care should be taken not to place it through the growth plate in order to avoid an early growth plate fusion. The iliotibial band may be used as a graft material as well, especially if an extraepiphyseal, extra-articular technique is performed [43]. Care should be taken to inform the patient on potential cosmetic (large incision) and harvesting site problems (pain). In Europe, there is limited experience with allografts in immature children. A new approach is the use of living donor hamstring tendon allografts. This allows for a more predictable graft size and for preservation of the child's own tendons for potential use in later life. First reports of parents donating their

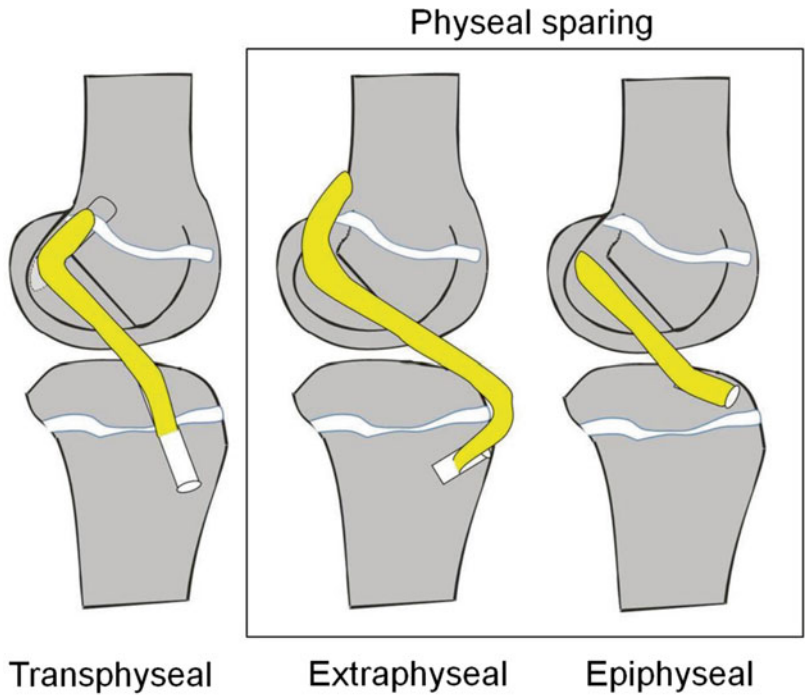

Fig. 24.5 Schematic representation of different techniques for intra-articular ACL reconstruction in children. *Left*: transphyseal technique. The soft-tissue graft passes through the tibial and femoral physis. *Center*: growth plate preserving technique. The tendon graft is conducted around the tibial and the femoral physis. *Right*: growth plate preserving technique with epiphyseal tunnels. A large number of variations to these techniques have been described

Table 24.1 Fifteen surgical-experimental principles for safe pediatric ACL reconstruction

1	Growth plate cartilage does generally not regenerate after a drill injury
2	Leaving a transphyseal drill hole empty results in the formation of a bone bridge
3	Small bone bridges may resolve spontaneously
4	The formation of a bone bridge may be prevented by the transphyseal placement of a tendon graft
5	Permanent transphyseal hardware placement can result in a growth abnormality
6	A central growth plate lesion may result in a symmetric shortening, whereas a peripheral growth plate lesion may result in an axial deformity
7	The critical size for a growth abnormality due to a central growth plate lesion is 7–9 % of the size of the growth plate
8	The critical size for a growth abnormality due to a peripheral growth plate lesion is 3–5 % of the circumference of the growth plate
9	The size of the growth plate injury increases with drilling obliquity
10	The risk of a growth deformity is inversely proportional to the remaining growth potential
11	The force of the growth plate is associated with body weight
12	An excessive graft tension may lead to a tenoepiphysiodesis
13	During femoral tunnel drilling, iatrogenic injury to perichondral structures should be avoided
14	Epiphyseal and transphyseal ACL reconstructions may induce rotational deformities at the distal femur
15	Graft incorporation is faster in immature specimen as compared to adults

From Seil et al. [62]

hamstring tendons to their children have recently been published and showed good results, both for the outcome of the child's and parent's knees [21]. The permanent use of synthetic graft material is prohibited as it may cause significant growth arrest as well as the need for complex, three-dimensional corrective surgeries for malalignment or leg length discrepancies. Newly developed ACL repair techniques [34] must be critically evaluated before pediatric use in order to avoid large growth plate injuries and the need for extended revision surgery in case of failures.

Some authors differentiate their specific pediatric ACL reconstruction technique according to the amount of knee growth remaining [17]. In order to minimize the risk of growth disturbance, Kocher [32, 33] advocated a physeal-sparing combined intra-articular and extra-articular reconstruction with an autogenous iliotibial band in prepubescent (Tanner stage 1 or 2) children with a large amount of growth remaining. In pubescent adolescents with growth remaining (Tanner stage 3), they recommend a transphyseal hamstring graft technique with extracortical fixation [33]. This technique is similar to the one used by one of the authors of the present article (RS) on a routine basis, both in prepubescent children and adolescents [74] (Fig. 24.6). This arthroscopic single-bundle technique differs only minimally from the adult technique. Graft diameter generally varies between 6 and 8 mm. In prepubescent children under the age of ten, the femoral tunnel is drilled in a transtibial fashion. This allows for a more perpendicular positioning of the femoral tunnel in relation to the distal femoral physis in order to keep the drill injury as small as possible. After the age of ten and with still significant knee growth remaining, we drill the femoral tunnel through the anteromedial portal in deep knee flexion. This causes a larger drill injury but allows for a more anatomic femoral graft placement. An injury of the perichondral structures should be avoided [65]. This can be done by using a femoral drill guide with a 5 or even a 7 mm offset, to prevent a blowout of the posterior cortex of the femur (Fig. 24.7). On the tibial side, care must be taken to position the tunnel entrance more medially as it is done in adults in order to protect the apophysis of the tibial tuberosity and avoid subsequent development of a recurvatum knee [67].

Chotel [9, 24] uses an arthroscopically assisted transphyseal technique on the tibial side and an intraepiphyseal technique on the femoral side. The quadriceps tendon is harvested with a trapezoidal bone block from the patella. A femoral pin is inserted under fluoroscopic guidance in order to be parallel and at the same time at a safe distance from the physis. After validating the

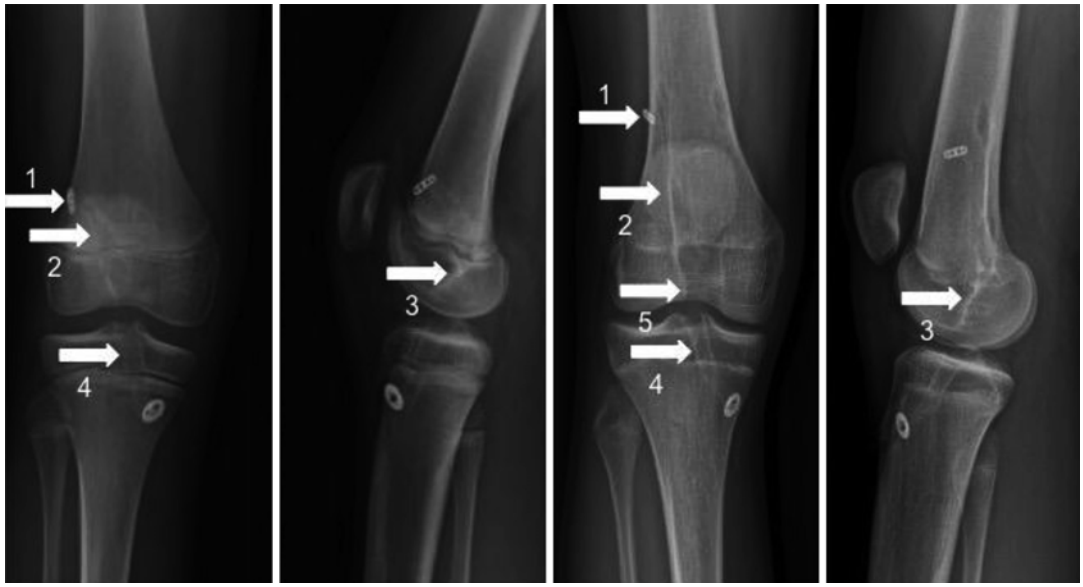

Fig. 24.6 Postoperative AP and lateral radiographs of an ACL-reconstructed knee of an 11-year-old boy. ACL reconstruction was performed with a quadruple hamstring graft and extracortical button fixation. *Left*: postoperative image; *right*: 5 years after reconstruction and 20 cm of longitudinal growth. The clinical outcome was excellent: the patient returned to pivoting sports; Lachman and pivot shift tests were negative. The images illustrate anatomic changes after ACL reconstruction: *1* upward migration of the femoral tunnel, *2* verticalization of the femoral tunnel, *3* verticalization of Blumensaat's line, *4* relative thinning of the tibial tunnel, *5* narrowing of the intercondylar notch

femoral pin placement, an outside-in technique is used for femoral tunnel drilling. The graft is introduced from outside-in and from the femur to the tibia. The bone block is impacted press fit in the femoral tunnel. Double tibial fixation is achieved by an extracortical staple and a biodegradable screw in the tunnel which is placed distal to the tibial physis.

An example of a nonanatomic, extraphyseal technique is the so-called Clocheville technique [6, 61] using the mid-third of the patella tendon without bone blocks. Instead of bone plugs, a periosteal flap is harvested at the patellar and the tibial insertion sites. The femoral tunnel is positioned proximally to the growth plate. On the tibial side, the graft is fastened at the epiphysis in a 1 cm deep bone trough. This procedure is technically more demanding than the arthroscopic single-tunnel technique. It has been used for many years, especially in very young, prepubertal children.

Rehabilitation is similar for all the techniques, although more carefully handled than in adults. There is no universally accepted rehabilitation protocol. Children are allowed to bear weight on the operated leg in an extension brace over a period of 6 weeks; motion must be started early on to avoid arthrofibrosis [56]; sports activities can be resumed after 6 months at the earliest; return to pivoting sports should be recommended only after 9–12 months.

24.4 Growth Plate Injury and Complication Potential

The risks related to different techniques of pediatric ACL reconstruction are increasingly recognized, and scientific research in the field is growing. In the last decade, it has been shown that a technically correct pediatric ACL reconstruction has little risk in creating growth abnormalities [18]. Nevertheless, they do occur [11, 30, 34, 35, 42, 62], and the understanding of the pathophysiologic changes of an iatrogenic injury to the growing cartilaginous structures in the

Fig. 24.7 Schematic representation of the tibial and femoral tunnels after a transphyseal ACL reconstruction in a 10-year-old girl. The surface area of injury to the growth plate could be reduced because of a stronger verticalization of the tibial tunnel. This was not the case on the femoral side. The *red point* marks the femoral insertion of the ACL. Its distance from the ossification groove of Ranvier is only 3 mm. A 2 mm safety margin between the posterior wall of the tunnel and the groove is therefore recommended

knee is still incomplete. Growth disturbances can be described from different perspectives, depending on their pathophysiological explanation, their anatomic location, and their clinical relevance. An attempt to classify these different aspects and the respective treatment options is presented in Table 24.2.

From a pathophysiological point of view, reported growth disturbances after ACL reconstruction were classified into three categories [24]. The process of growth **a**rrest (A) is caused by a localized growth plate injury which generates the formation of a transphyseal bone bridge. Spontaneous breakage of the bone bridge may occur in very young children whose growth plate can create large distraction forces [5, 13]. Bone bridge formation can be prevented with a soft-tissue graft at the height of the injured growth plate [71]. A transphyseal bone block, i.e., with a quadriceps or a bone-patellar tendon-bone graft, or a transphyseal hardware placement can cause a sudden growth arrest as well. A growth disturbance evolves throughout the remaining growth process. The amount of deformity is proportional to the timing of surgery, the localization, and the size of the initial growth plate injury. A growth arrest can lead to axial deformities if it is located at the periphery of the physis or to symmetrical leg length discrepancies if it is located in the center of the growth plate. On the distal femur, peripheral growth plate injuries can be caused either by a tunnel with a too large diameter or a posterior blowout with an injury of the perichondral structures of the growth plate (Ranvier zone and perichondral ring of Lacroix) if a transphyseal technique is employed. If an epiphyseal tunnel is drilled (which should always be performed under fluoroscopy), the femoral tunnel is located distally to the growth plate. If a growth plate injury occurs with this technique, it will be much larger in comparison to the transphyseal technique, and asymmetric growth may be much more severe in comparison to an arrest which is caused by transphyseal drilling. Finally, if the surgeon chooses an extraepiphyseal technique (over the top technique), caution must be paid to avoid an excessive rasping of the over the top position for a better graft adherence. This surgical maneuver may injure the perichondral structures and lead to axial malalignment as well. Due to its posterolateral position, a growth arrest at the femoral tunnel will lead to a deformity in valgus and flexion. In such cases, anticipating the remaining growth allows to predict the amount of deformity. On the tibial side, peripheral injuries may be caused by damaging the tibial tuberosity apophysis, either during harvesting

Table 24.2 Classification criteria and treatment options of growth disturbances after ACL reconstruction

	Clinical presentation	Treatment option
Subtype	*Pathophysiological classification* [11]	
A	Growth arrest	Early diagnosis: consider Langenskiöld procedure
		Late diagnosis: osteotomy
B	Acceleration of growth	Observation; eventually temporary epiphysiodesis
C	Growth deceleration	Consider ACL revision to release graft tension
Localization	*Anatomical classification*	
Medial proximal tibia	Varus deformity	Uniplanar deformity correction if clinically relevant
Anterior tibial tuberosity	Recurvatum deformity	Uniplanar deformity correction if clinically relevant
Distal, posterolateral femur	Valgus deformity	Uniplanar deformity correction if clinically relevant
Distal femur and proximal tibia	Severe three-dimensional deformity	Complex, multiplanar deformity correction
Subtype	*Clinical classification*	
Clinical, symptomatic	≥5° deformity at end of growth	Deformity correction after end of knee growth
Clinical, asymptomatic	3–5° deformity at end of growth	Observation
Subclinical, asymptomatic	<3° deformity	Observation

of the hamstring tendons or through a too anterior positioning of the tibial tunnel entrance. In this case, the growth arrest will cause a recurvatum of the proximal tibia. A too proximal and medial position of the tibial tunnel may lead to a varus deformity.

Yoo et al. reported MRI analysis of transphyseal ACL reconstruction in adolescents with open physis. Focal physeal disruptions developed in 5 of 43 adolescent patients without any clinical consequences [76]. The authors concluded that transphyseal techniques are not harmless and should not be used in young children. Unlike this conclusion, others believe that those focal bone bridges will break easier in younger children [13] and that these young children bear a lower risk of epiphysiodesis in comparison to adolescents. Hence, risks and consequences cannot be assimilated: in fact, adolescents are at a higher risk of epiphysiodesis but with low clinical consequences in terms of growth disturbances, while young children are at a lower risk of epiphysiodesis but with sometimes dramatic clinical consequences if the physeal bridge persists and continues to develop until the end of growth.

- The second type of growth abnormality is an overgrowth process (type B: **b**oost). It may be caused by a local hypervascularization which stimulates the physeal growth process. This phenomenon occurs mainly in very young children. The growth disturbance is temporary, and it usually becomes apparent in a limited period of 2 years following surgery. It is usually symmetric and may lead to a moderate leg length discrepancy. In the study by McIntosh et al., 15 out of 16 patients had a leg length discrepancy of less than 10 mm, and one patient had the operated limb 15 mm longer than the healthy limb [41]. In Nakhostine's series, the youngest patient (12-year-old boy) had a leg length discrepancy of 15 mm [55]. The clinical impact of such a complication is usually low compared to a full growth arrest. Nevertheless, the need of a percutaneous epiphysiodesis has been reported because of a

provisional leg discrepancy around two cm in an 8-year-old child at the time of ACL reconstruction [11]. Sometimes, a tibial valgus deformity can also occur, due to asymmetrical overgrowth. This is similar to the valgus deformities observed after metaphyseal pediatric proximal tibial fractures (so-called posttraumatic genu valgum). After an initial progressive increase of the deformity, a spontaneous correction has been documented, and a close follow-up with nonoperative treatment of the deformity is recommended [11].

- The 3rd type of growth disturbance (type C: decelerate) may be caused by a so-called "tenoepiphysiodesis" effect [15]. In this case, an excessive graft tension across the physis causes a deceleration of the remaining growth and a secondary growth abnormality. The exact amount of graft tension being able to cause such an abnormality in humans has not been defined yet. Experimental animal studies have shown that it should not exceed 80 N. Similarly, the use of a nonbiological, synthetic graft would cause the same effect. The mechanism behind this growth abnormality is called the Hueter-Volkmann principle, according to early experimental studies of the nineteenth century, which showed that an excessive pressure on the growth plate reduced longitudinal growth and vice versa.

The threshold from which a deformity may become symptomatic is difficult to define. It depends on the anatomic localization as well as the plane (frontal vs. sagittal) and the amount of the deformity. In a previous study [64], it has been shown that axial deformities of 3° or less may be related to a measurement error. Although they would probably remain asymptomatic, malalignments from 3° upward may become visible, whereas deformities of 5° or more may be considered clinically relevant and potentially detrimental in terms of compartment overload and long-term osteoarthritis development.

As a consequence of these possible growth abnormalities, children must undergo a much stricter postoperative follow-up as adults. Not performing this follow-up on a systematic basis may lead to an underestimation of growth abnormalities [53]. Clinical and radiological controls should therefore be mandatory until the end of the growth period. In case of a permanent growth abnormality, immediate surgical revision can be recommended if the cause of the complication has been clearly identified (i.e., transphyseal hardware or bone block placement). In such cases with a remaining growth potential, epiphyseal stapling or a Langenskiöld procedure may be considered. If surgical revision is not considered immediately, a correction osteotomy may be mandatory at the end of the growth period [34, [35, 62, 69]. In such cases, the complexity of the corrective procedure is strongly related to the complexity of the deformity where uniplanar single-bone deformities are easier to correct than multiplanar malalignment concerning both the femur and tibia. Fortunately, these complications are extremely rare, especially if the surgical technique has been properly performed. Nevertheless, the children and their parents must be informed preoperatively that they may occur even in experienced hands.

24.5 Results and Clinical Outcomes

Providing a complete overview of clinical results after pediatric ACL surgery would be beyond the scope of this article. Therefore, this chapter will be restricted to two recent essential reviews. The first analyzed the quality of published studies, and the second analyzed the clinical results and complications.

Moksnes [49] recalls that caution is necessary when interpreting study results on the treatment of pediatric ACL injuries. The main reasons for this are the widespread methodological deficiencies of many of those studies. Currently, no randomized controlled trials and only two prospective cohort studies can be found in the literature [49]. This indicates a potential bias in these publications as mostly operated patients which may represent a negative selection of all ACL-injured skeletally immature patients were

considered. The authors evaluated 31 studies analyzing the outcome of the treatment of ACL injuries in skeletally immature individuals. The methodological quality of published studies was evaluated by the Coleman Methodology Score, which can range from 0 to 100 (maximum). Only four studies were found with a score of 60 or more (maximum 64). The authors concluded that the current treatment evidence of ACL injuries in children is low.

In a recent meta-analysis of case series (level of evidence IV) of ACL-reconstructed patients, Frosch et al. reported on a total of 55 articles with 935 patients (median age 13 years). After a median follow-up of 40 months (range 14–89 months), leg length discrepancies or axial malalignment was found in 1.8 % of the cases. Excellent or good function (International Knee Documentation Committee grade A or B) was achieved in 84.2 % of all knees, and Lysholm scores averaged 96.3. Close to 5 % of recurrent tears were reported. In comparison with physeal-sparing techniques, transphyseal reconstructions were associated with a significantly lower risk of leg length differences or axial malalignment. However, a higher risk of recurrent tears was noted for the latter (4.2 % vs. 1.4 %). The authors concluded that randomized controlled trials are needed to clarify important issues in managing ACL injuries in children and adolescents.

Conclusion

The knowledge of pediatric ACL injuries and their treatment has made significant progress over the last three decades. In the 1980s and 1990s, most surgeons were confronted with a negative selection of children with chronic ACL injuries and secondary soft-tissue damage. Therefore, specific pediatric surgical techniques were successfully developed and proved to be safe if performed in a technically correct way. Nowadays they are used on a larger scale, but due to the pediatric specificities, surgery remains a challenge. Surgery-related complications still occur, although at an acceptably low frequency (<2 %). The last decade showed that nonoperative treatment may be suitable for 30–50 % of patients, whereas others may develop rapidly secondary soft-tissue injuries. Today, pediatric ACL injuries are increasingly recognized, and physicians are confronted with many different situations at different stages of knee growth and maturation. Thus, future progress has to be made to select the right treatment at the right moment for the right patient.

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Revision Anterior Cruciate Ligament Reconstruction

25

Etienne Cavaignac, Philippe Tscholl, Marco Valoroso, and Jacques Menetrey

25.1 Introduction

Anterior cruciate ligament (ACL) injuries are fairly common in athletes [1], with a documented incidence of 36.9–60.9 per 100,000 persons/year [2, 3].

ACL reconstruction satisfactorily restores stability and function in 75–97 % of cases [4, 5]. Injuries to secondary restraints, ligamentocapsular structures, articular cartilage and meniscus impact the overall success or failure of ACL reconstruction procedures [1]. Surgical technique, postoperative rehabilitation and patient expectations also play a significant role in the outcome of ACL reconstruction [6]. As the number of primary ACL reconstruction procedures continues to grow, the number of graft failures has increased accordingly. The re-rupture rate for a single-bundle reconstruction was 4 % in randomised controlled trials [7, 8]. A systematic review of nine studies comparing patellar tendon versus hamstring grafts found an overall re-rupture rate of 3.6 % [9].

Revision ACL (R-ACL) surgery is a complex procedure that requires a rigorous and meticulous approach [10]. R-ACL surgery requires distinct arthroscopic knowledge and skills, especially since its failure rate is three to four times as for primary ACL reconstruction [11]. In this chapter, we will review the epidemiology and causes of ACL graft rupture and describe the pre-operative assessment and surgical technique. We will also review the outcome of this procedure from various published studies.

E. Cavaignac, MD (✉)
Unité d'Orthopédie et Traumatologie du Sport, Service de chirurgie orthopédique et traumatologie de l'appareil moteur, Swiss Olympic Medical Center, University Hospital of Geneva, Genève, Switzerland
e-mail: etienne.cavaignac@hcuge.ch

P. Tscholl, MD • J. Menetrey, MD, PhD
Unité d'Orthopédie et Traumatologie du Sport, Service de chirurgie orthopédique et traumatologie de l'appareil moteur, Swiss Olympic Medical Center, University Hospital of Geneva, Genève, Switzerland
e-mail: philippe.tscholl@hcuge.ch; jacques.menetrey@hcuge.ch

Faculty of Medicine, University of Geneva, 4, Rue Gabrielle-Perret-Gentil, Genève 4 CH-1211, Switzerland

M. Valoroso, MD
Lyon-Ortho-Clinic, 29 Avenue des Sources, Lyon 69009, France
e-mail: marco.valoroso@yahoo.it

25.2 Epidemiology and Aetiology

25.2.1 Definitions

There is no universally accepted definition of a failed ACL reconstruction. Johnson et al. defined a clinical failure of ACL reconstruction as recurrent instability or knee pain and stiffness with 10–120° decrease in range of motion [12].

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Dissatisfaction expressed by the patient postoperatively can be due to three problems: recurrent objective instability (graft failure), postoperative complications (infection, loss of motion, patella fracture) and comorbidities related to concomitant pathological abnormalities (lower extremity malalignment, extensor mechanism dysfunction, donor-site pain, meniscus loss, arthritis). But failure of the ACL graft does not necessarily entail a revision procedure.

Noyes et al. [13] listed their indications for R-ACL: (1) complete graft tear with >6 mm of anterior tibial displacement relative to the healthy knee and (2) positive pivot shift test graded +2 or +3 compared to the healthy knee, with or without knee pain or inflammation or functional limitations for daily life and/or sports activities. Alford et al. reported that a greater than 3-mm difference in anteroposterior knee laxity compared to the healthy knee or an absolute laxity value of more than 10 mm measured with an arthrometer (KT 1000, Medmetric, San Diego, CA, USA) had a 99% sensitivity for detecting ACL graft rerupture [14].

The indications used by the Noyes and Alford group suggest that R-ACL surgery is mainly indicated in cases of graft failure.

25.2.2 Aetiology of Graft Failure

The causes of graft failure vary widely and can be multifactorial. The University of Pittsburgh has separated these causes into four categories: technical errors (including diagnostic error), trauma, poor graft incorporation and healing (biological failure) and rehabilitation problems [15] (Fig. 25.1).

The time elapsed between the reconstruction procedure and the failure provides information as to the cause. Early failures (<3 months) are generally related to poor fixation (biological failure) or to infection [16–19]. Graft failures between 3 months and 1 year postoperative are due to a technical error, overly aggressive rehabilitation, early return to sports or an undetected secondary restraint injury [12]. Later failures are generally due to a new injury event.

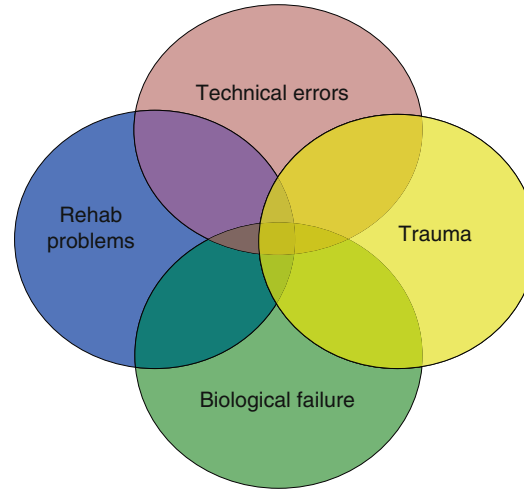

Fig. 25.1 The University of Pittsburgh classification for ACL rupture [15]

Figure 25.2 shows the causes of graft failure documented in published studies. It is important to note that in many cases, more than one cause of failure is found.

25.2.2.1 Technical Errors

This is the most frequent cause of graft failure [12, 20–23].

In some cases, the failure can be attributed to the graft being damaged and weakened when it was harvested [6]. But the most common technical error is related to tunnel placement [24]. If the tunnels are not positioned anatomically, the graft is subjected to non-physiological loading and varies in length depending on the knee position (Table 25.1).

The ideal placement of the femoral tunnel in single-bundle reconstruction is as posterior as possible without damaging the posterior cortex [6]. The most common error on the femur side is the tunnel being too anterior [6]. If the tunnel is too close to the knee's rotational axis (generally too vertical), the graft will not be able to properly control the knee's rotational stability [25, 26].

On the tibial side, the ACL footprint is said to be located anterior to the intercondylar eminence and never extends to the lateral portion of the tibial epiphysis. The most common error is overly posterior placement of the tibial tunnel. The

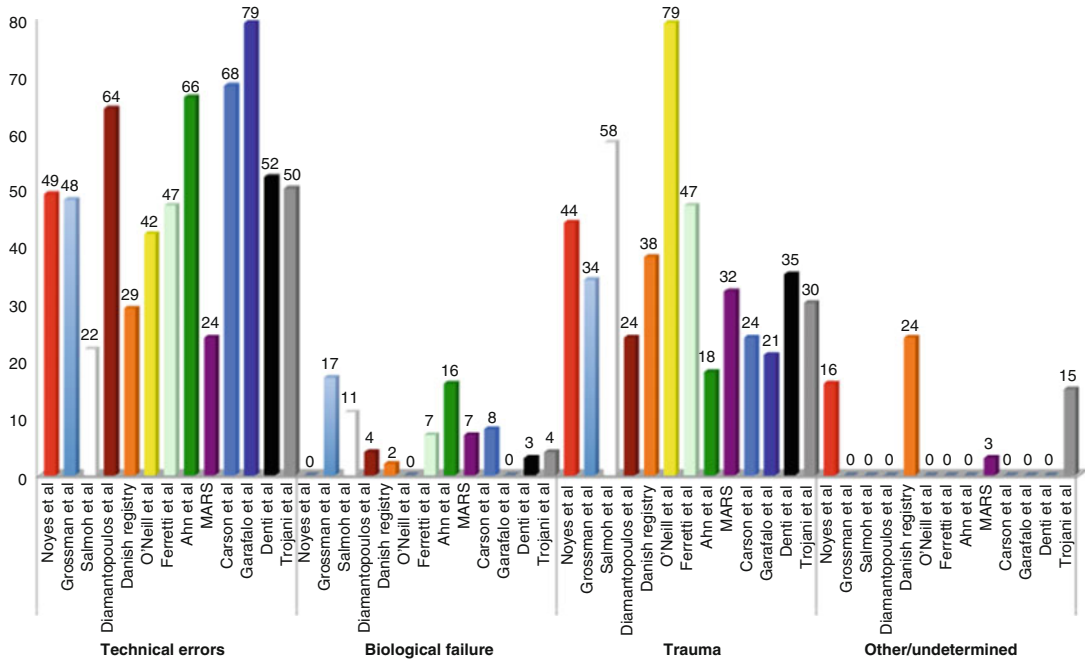

Fig. 25.2 Published causes of graft failure (%)

Table 25.1 Common mistakes in tunnel placement and their consequences

Tunnel	Position	Consequences for the graft
Femur	Anterior	↑ Tension in flexion/stiffness in extension
	Posterior	↑ Tension in extension/laxity in flexion
	Central (vertical)	Lack of rotational stability
Tibia	Anterior	↑ Tension in flexion/ impingement against the notch in extension
	Posterior	↑ Tension in extension/ impingement with PCL
	Medial	Impingement against the medial femoral condyle and/or PCL
	Lateral	Impingement against the lateral femoral condyle

tunnel must be parallel and posterior to the Blumensaat line when the knee is extended (Fig. 25.3) [6, 27–31]. Placing the tunnel less than 23 mm away from the anterior edge of the plateau will lead to notch impingement and inadequate extension [28, 30]. In cases of recurvatum or vertical intercondylar roof, the tibial tunnel must be located slightly posterior [32]. Nevertheless, if the tibial tunnel is too posterior, the patient will experience flexion instability, and the graft can impinge the Posterior Cruciate Ligament (PCL) [1]. Incorrect placement in the coronal plane can lead to tibial cartilage damage or impingement with the intercondylar notch [18, 22, 28–30]. And finally, an overly vertical tunnel will reduce rotational stability control [33].

Graft fixation is a key factor. The primary fixation must be strong enough to allow graft integration [34]. During the early postoperative period, the graft fixation sites have a lower load to failure than the graft itself [35, 36]. Interference screws appear to provide greater stability than staples, suture fixation around a post or soft-tissue washer with screw fixation [19, 34]. But interference screws lose their effectiveness in cases of incorrect bone plug sizing, osteopenic bone, divergence or convergence between the screw and tunnel, along with transection of the graft [19, 34, 37–40].

The optimal graft tension during its fixation and its exact position during fixation remain

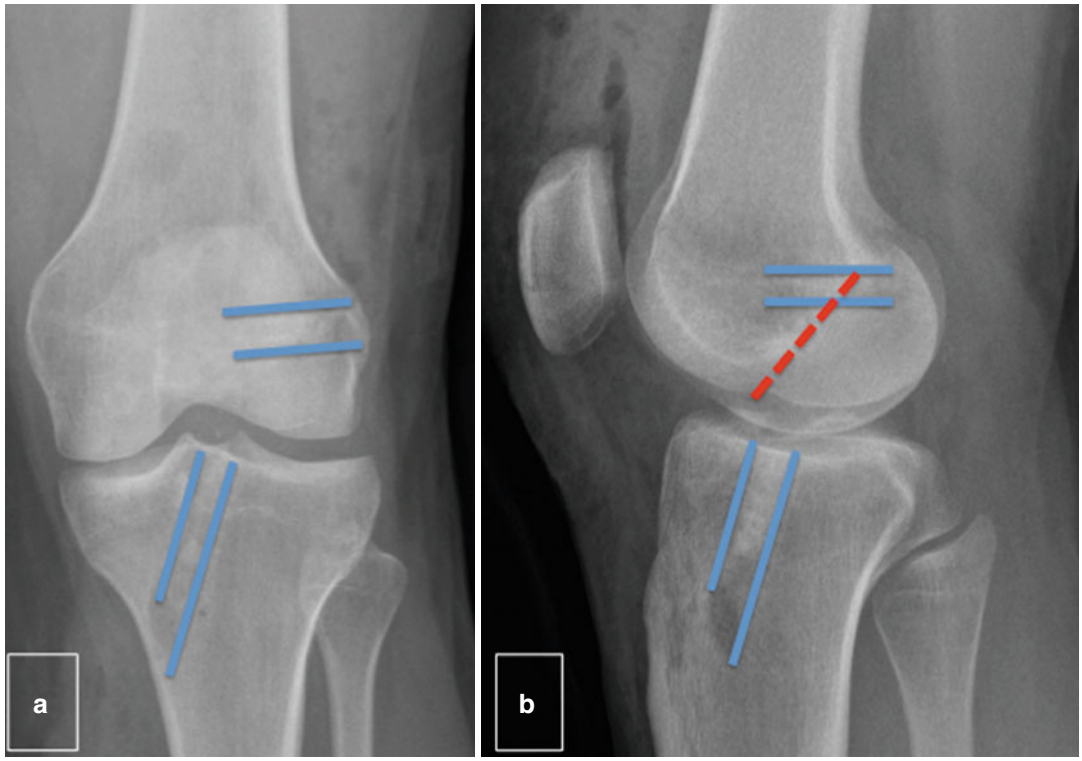

Fig. 25.3 (**a**): A/P and (**b**): lateral view of a well-performed ACL reconstruction. Tunnels are in *blue*. Blumensaat's line is in *red*

controversial [37–42]. Between 20 and 40 N of tension is necessary for physiologic and kinematic laxity [41, 43]. Applying 80–90 N tension on a graft reduces the tibia's anterior translation [44].

Diagnostic error, in which an injury to a secondary or tertiary restraint was missed, should be added to the technical errors category. Not repairing these secondary and tertiary restraints results in excessive loads being placed on the graft. Posterolateral corner injuries are missed in 15–20 % of cases [45]. The MCL, posterior segment of the medial meniscus and the posterior and medial portions of the joint capsule are important secondary restraints that need to be evaluated [6]. Pre-operative examination with the patient under anaesthesia is essential for the diagnosis of these injuries [46]. Other conditions can lead to excessive loads being placed on the graft; sequelae of meniscectomy and osteoarthritis must also be addressed at the time of the reconstruction [47, 48]. Finally, excessive varus will cause the graft to stretch out; a high tibial osteotomy must be considered in these cases [47].

The most common error reported in various studies on this topic is incorrect tunnel placement, followed by undetected secondary restraint injuries and lastly inadequate primary graft fixation [13, 49–56].

25.2.2.2 Trauma

The context of ACL graft re-rupture is not quite the same as that of the initial ACL injury. In most cases (58 %), the graft fails during elongation [57] without discernible stumps, while the native ACL typically fails at its proximal attachment [58].

Later in the postoperative period, a new injury event similar to the first injury event can lead to graft failure [58]. In patients who return to a similar activity level after the ACL reconstruction procedure, the re-rupture rate is 5–10 % [20]. At least 43 % of re-ruptures have been found to be related to an acute traumatic event [32, 59–62].

Resuming sports activities before proper leg's neuromuscular abilities have been completely restored reduces the patient's ability to adapt to loading conditions and increases the risk of a new injury [6].

25.2.2.3 Biological Failure

Biological failure is suspected in patients who present with recurrent instability with no recollection of trauma and no obvious technical error [63]. The graft is integrated after undergoing necrosis, followed by revascularisation, cellular repopulation, collagen deposition and finally matrix remodelling [6]. Excessive tension on the graft, overly aggressive rehabilitation or an immune reaction can lead to inadequate graft revascularisation [16, 18, 19]. Infection has been identified in less than 1 % of cases [56, 64, 65].

25.2.2.4 Rehabilitation Problems

Failure of graft fixation can be observed if the graft was damaged before being fully incorporated [34]. During the first postoperative year, the strength and resistance of the graft are only 30 % and 50 %, respectively, of the original ACL. Excessive loads during this period lead to plastic deformation and to graft lengthening [66].

The rehabilitation programme must be adjusted based on this observation. It must not be overly aggressive, but must still prevent stiffness and joint contracture from developing.

25.3 Pre-operative Evaluation

25.3.1 Clinical Exam

Careful anamnesis of the patient is essential when the ACL graft has failed. This will help the surgeon determine whether the patient falls into category of recurrent instability, postoperative complications or pre-existing comorbidities of ACL graft failure. Not all of these situations require revision surgery.

Before further research into the cause, the patient's desired activity level and expectations must be determined. The results of R-ACL are not as good as those of primary ACL reconstruction [67–72]. The primary goal of ACL revision is to reconstruct the failed or inadequate ACL graft, so as to stabilise the knee and prevent potential meniscus and cartilage damage, while improving the patient's satisfaction and activity level. The patient must be fully informed of the ins and outs and the potential risk of R-ACL. In some cases, lifestyle and activity changes may be warranted if other knee structures are injured.

The medical history taking starts by getting a detailed description of the initial injury event and the symptoms experienced by the patient after the primary reconstruction procedure. This information is essential for identifying any injuries to secondary restraints that may have been missed during the primary procedure.

All the aspects surrounding the first surgical procedure must be analysed extensively, including the surgical report. This provides information on the type of graft used, fixation methods (type of hardware used and plan for removal), damage to associated structures (meniscus, cartilage) and their treatment, along with any other procedures performed at the same time (e.g. lateral tenodesis). The postoperative rehabilitation programme must also be reviewed, in part to identify any deficits during this phase. Any intra- and postoperative complications must be analysed, along with how these complications were treated. And last but not least, the new injury event and mechanism must be analysed.

The clinical examination is carried out by a careful, bilateral, comparative physical examination that involves both static and dynamic conditions. The dynamic assessment consists of evaluating the patient while walking. Patients with ACL insufficiency may exhibit abnormal rotational or varus/valgus thrusts with ambulation [1]. The static analysis involves looking at limb alignment. The active and passive range of motion are measured to identify any abnormal or limited motion (e.g. recurvatum).

The knee is inspected to look at the existing incisions (potential neuroma), painful areas, knee effusion and crepitation. Particular attention must be paid to the extensor mechanism to detect any anterior knee pain, pain at the graft-harvest site or patellar tendinitis.

The peripheral structures (secondary and tertiary restraints) must be meticulously examined.

Emphasis is placed on the posterolateral drawer and external rotation recurvatum test to detect any posterolateral rotatory instability [73]. Posterolateral instability is present when there is at least 10° of increased tibial external rotation compared to the normal knee at 30° flexion (positive dial test and external rotation thigh foot angle test) and variable degrees of varus instability depending on the injured anatomic structures [74]. Any antero-medial instability must also be identified. The menisci must also be examined. Anteroposterior laxity must be evaluated through the Lachman test and anterior drawer, along with determining if a pivot shift is present.

The clinical examination must be repeated in the immediate pre-operative phase because anaesthesia improves the sensitivity of the various tests used to detect instability [46].

In addition, muscle testing is absolutely essential for evaluating the neuromuscular capacity of the injured leg. In addition to measuring the quadriceps circumference (which in itself does not provide much information), consultation with a sports medicine physician and isokinetic testing may be indicated.

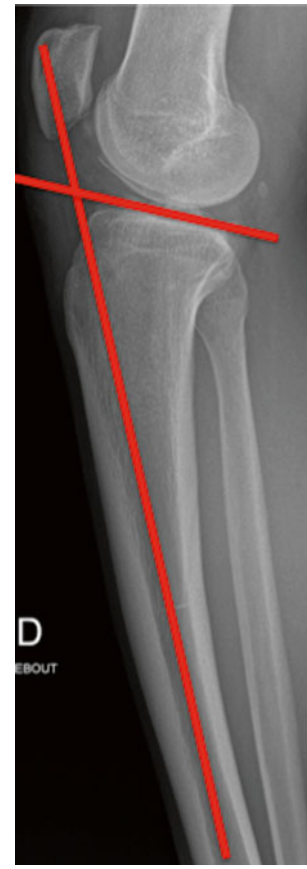

Fig. 25.4 Lateral view of the tibia. Tibial slope = 25°

25.3.2 Paraclinical Examination

Residual laxity must be measured objectively. This is an essential information for the R-ACL decision-making process [14, 75]. We still prefer to use the KT-1000 arthrometer for this test (Medmetric, San Diego, CA, USA). Noyes et al. [13] believe that the threshold for the revision indication is a 6-mm side-to-side difference, while Alford et al. use a leg-specific threshold of 10-mm anterior laxity and 3-mm side-to-side difference [14]. Other groups, including ours, use also a threshold of 3-mm side-to-side difference [53, 76, 77].

Standards X-rays are systematically performed and analysed extensively. Anteroposterior (A/P) and lateral views of the extended knee are used to look at three major elements: (1) the presence of hardware that will interfere with the revision procedure, (2) tunnel position and (3) tunnel expansion. An A/P view with the knee in 30° flexion will improve detection of degenerative changes. Long-leg radiographs are needed to determine the leg's alignment and determine if a tibial osteotomy is required along with the ACL revision. A lateral view of the entire tibia is needed to measure the tibial slope and to discuss a proximal tibial anterior closing wedge osteotomy if necessary (Fig. 25.4) [78, 79].

CT scan with 2D views (Fig. 25.5) and 3D (Fig. 25.6) reconstruction completes the assessment as they provide a better view of the tunnel placement, widening and osteolysis. Hoser et al. [80] showed that CT scans were more accurate than standard radiographs for evaluating the bone tunnels. In particular, 3D reconstructions provide a better view of the tunnel position relative to bone landmarks and make them easier to be identified intraoperatively [81].

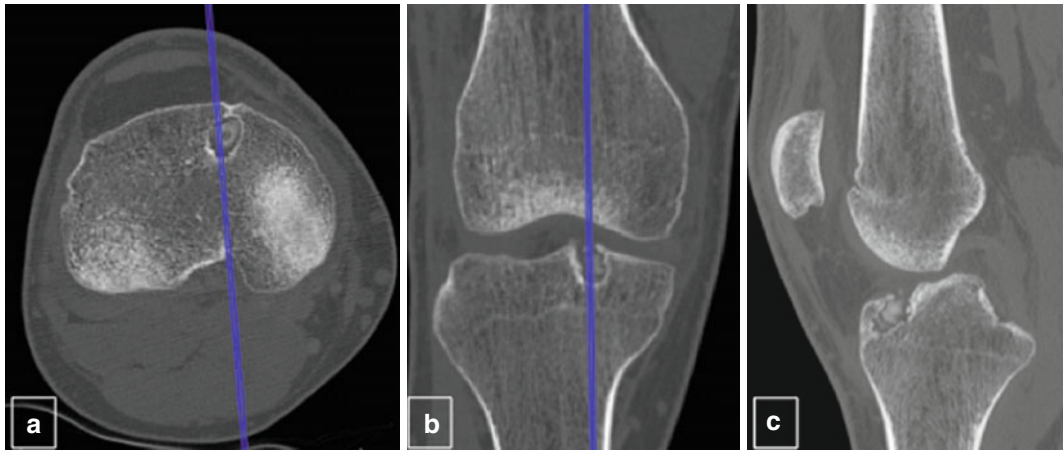

Fig. 25.5 CT scan with axial (**a**), frontal (**b**) and sagittal (**c**) view. In this case, the tibial tunnel is too anterior

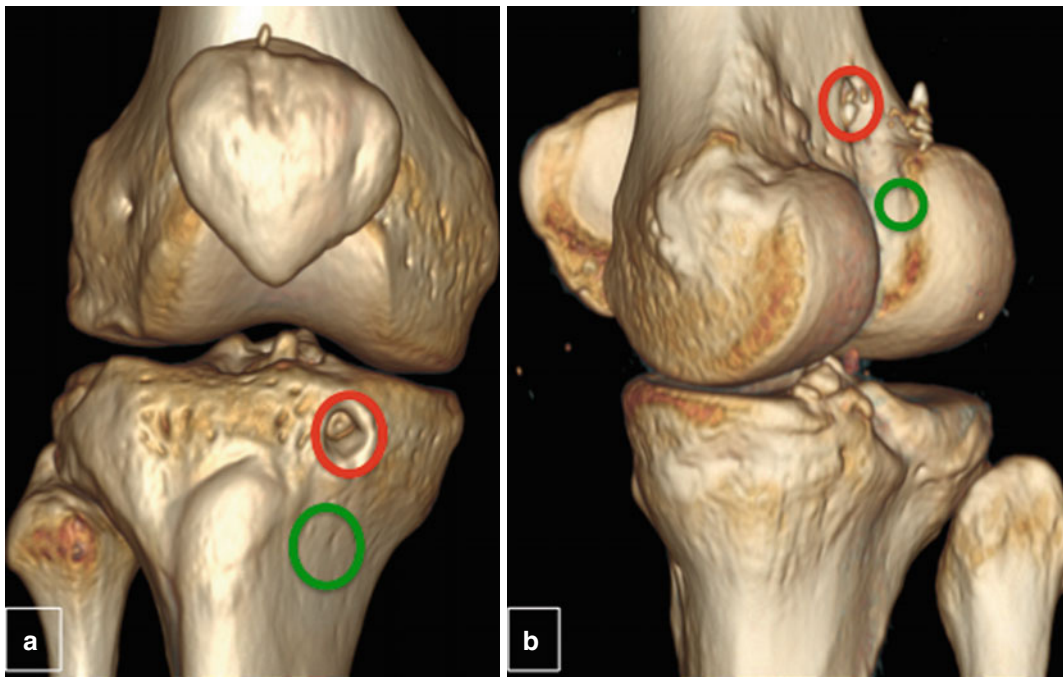

Fig. 25.6 3D CT reconstruction. (**a**) The tibial tunnel is too anterior and superior (*red*). (**b**) The femoral tunnel is too proximal (*red*). In *green*, desired positions

MRI is also a component of the standard imaging assessment (Fig. 25.7). It provides information about the condition of the graft, meniscus and cartilage tissues in the injured knee. Sequelae of damage to the secondary restraints may also be visible on MRI. MRI will show whether the tunnels have widened [82, 83]; however, CT scans are better suited to quantify the tunnels [80, 84].

Laboratory tests are indicated if there is clinical evidence of infection or inflammation.

Nevertheless, the surgeon must realise that the pre-operative clinical and paraclinical assessments are not absolute. Harter et al. showed a poor correlation between the clinical findings and how the patient feels. Matava et al. [85] have stated that more objective criteria are needed to

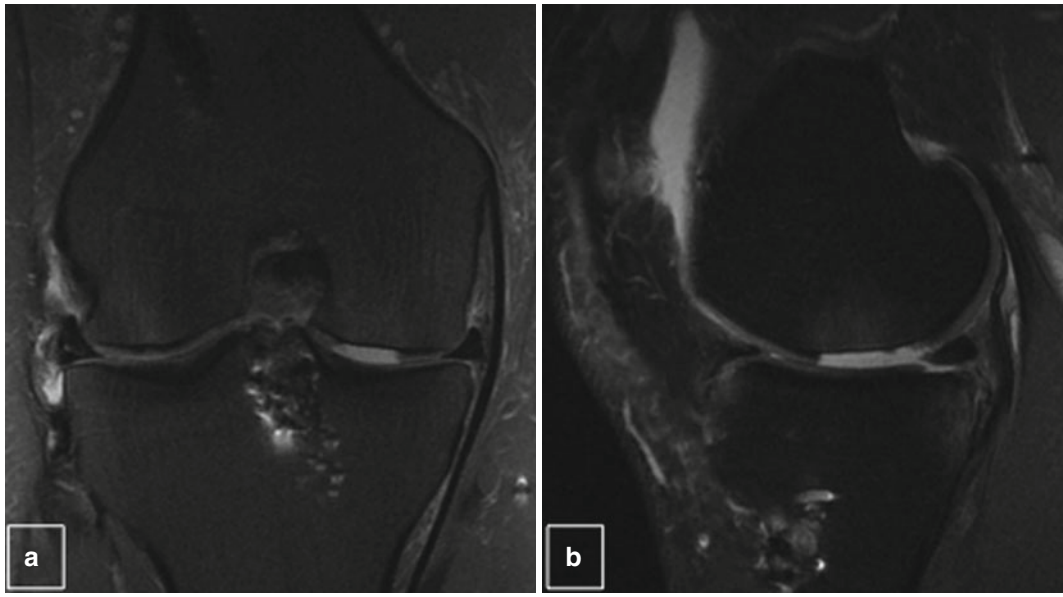

Fig. 25.7 (**a**) Frontal and (**b**) sagittal MRI view showing a cartilage lesion of the medial condyle

accurately determine the causes of primary ACL graft failure, as well as the ideal femoral and tibial tunnel placement in patients undergoing revision ACL reconstruction. In this review, we described the assessments that we believe are the most relevant to properly analyse why an ACL graft has failed and for the planning of the revision procedure (Table 25.2).

25.4 Surgical Procedure

Revision surgery is contraindicated or should be indicated cautiously after inadequate rehabilitation including insufficient neuromuscular control, loss of range of motion, uncorrected severe malalignment, diffuse osteoarthritis and inflammatory or septic arthritis.

Options for graft fixation include ignoring previous fixation devices, removing them and finally removing and reusing the same fixation technique.

Draping the contralateral knee for graft harvesting or the ipsilateral iliac crest for osseous bone plug harvesting should be envisaged according to the options needed during surgery.

Surgical steps are summarised in Fig. 25.8.

25.4.1 Arthroscopic Evaluation and Tunnel Management

First of all, the synovial state is analysed. In cases of severe undetermined synovitis, we recommend not performing R-ACL surgery due to increased risk of arthrofibrosis and hampered rehabilitation. Intra-articular assessment is then continued of a careful analysis of the primary graft to determine (1) whether a total or partial graft tear is present, (2) the previous tunnel placement, (3) and whether a conflict with pre-existing tunnels may be expected (Fig. 25.9).

The decision upon the removal of fixation device is taken according to the tunnel localisation and types of fixation previously used. In case of largely misplaced tunnels with no conflict with any new tunnels, interference screws should not be removed. It may indeed lead to considerable bone loss, hence weakening of the bone stock, and consequently, it might result in subsequent failure of the fixation [86]. In cases of anatomical tunnels with no widening, those tunnels can be reused and maybe slightly overdrilled by 1 mm. The biggest challenge is represented by close to anatomical tunnels with large widening, which may potentially result in compromised graft

Table 25.2 Comprehensive University of Geneva check list for diagnosis and pre-operative evaluation of R-ACL

		TEST: interpretation	Implication
Clinical	History	Failure categories:	Indication for revision?
		Instability	
		Postop complication	
		Pre-existing comorbidities	
		Patient's expectations	Indication for revision?
		Initial injury event	Search for associated damage
		Surgical report: hardware and fixation method used	Hardware to be removed
			Condition of cartilage and meniscus
		Rehabilitation period	Reason for graft failure
		Postop complications	Treatment of complications
	Physical examination Bilateral and comparative	Gait analysis (decoaptation ext.)	Long-leg standing views
		Limb alignment	Long-leg standing views ± osteotomy
		Joint range of motion	Indication for revision?
		Existing incision(s)	Associated procedure?
			Aetiology diagnosis: complications or failure
		Extensor mechanism	Differential diagnosis: anterior knee pain
		Peripheral structures	Addition procedure to R-ACL Re-tensioning/reconstruction
		Meniscus assessment	Meniscectomy Meniscus replacement
		Anteroposterior laxity Rotational laxity	Positive diagnosis
		Muscle assessment ± Isokinetic testing	Pre-op rehabilitation
		Exam under anaesthesia	Improves sensitivity of tests
Paraclinical	Knee laxity measurements	KT-1000 threshold >3 mm/healthy side >10 mm (absolute value)	Objective diagnosis of graft failure
	X-rays	A/P and lateral with knee extended	Hardware Tunnel position Tunnel expansion
		A/P with knee flexed	Degeneration? Associated procedures (e.g. HTO)
		Long-leg standing views	Realignment osteotomy
		Lateral view of entire tibia (tibial slope)	Proximal tibial anterior closing wedge osteotomy
	CT scan	2D: tunnel position Tunnel expansion Hardware radiolucent	Single vs two stage Plan for removal Graft type
		3D: tunnel position	Revision of initial tunnels?
	MRI	Cartilage condition Meniscus condition Ligament structures	Cartilage procedures Meniscus procedures Re-tensioning/reconstruction
	Laboratory tests	CBC, SR, CRP, pathology Culture of joint fluid (based on clinical observations)	Infection or inflammation Adjuvant treatment (antibiotics)

fixation. In this situation, the fixation devices need to be removed either with the appropriate screwdriver or by overdrilling of a soft biodegradable screw. However, overdrilling might lead to intra-articular debris. We therefore do not recommend the use of a drill unless it is not

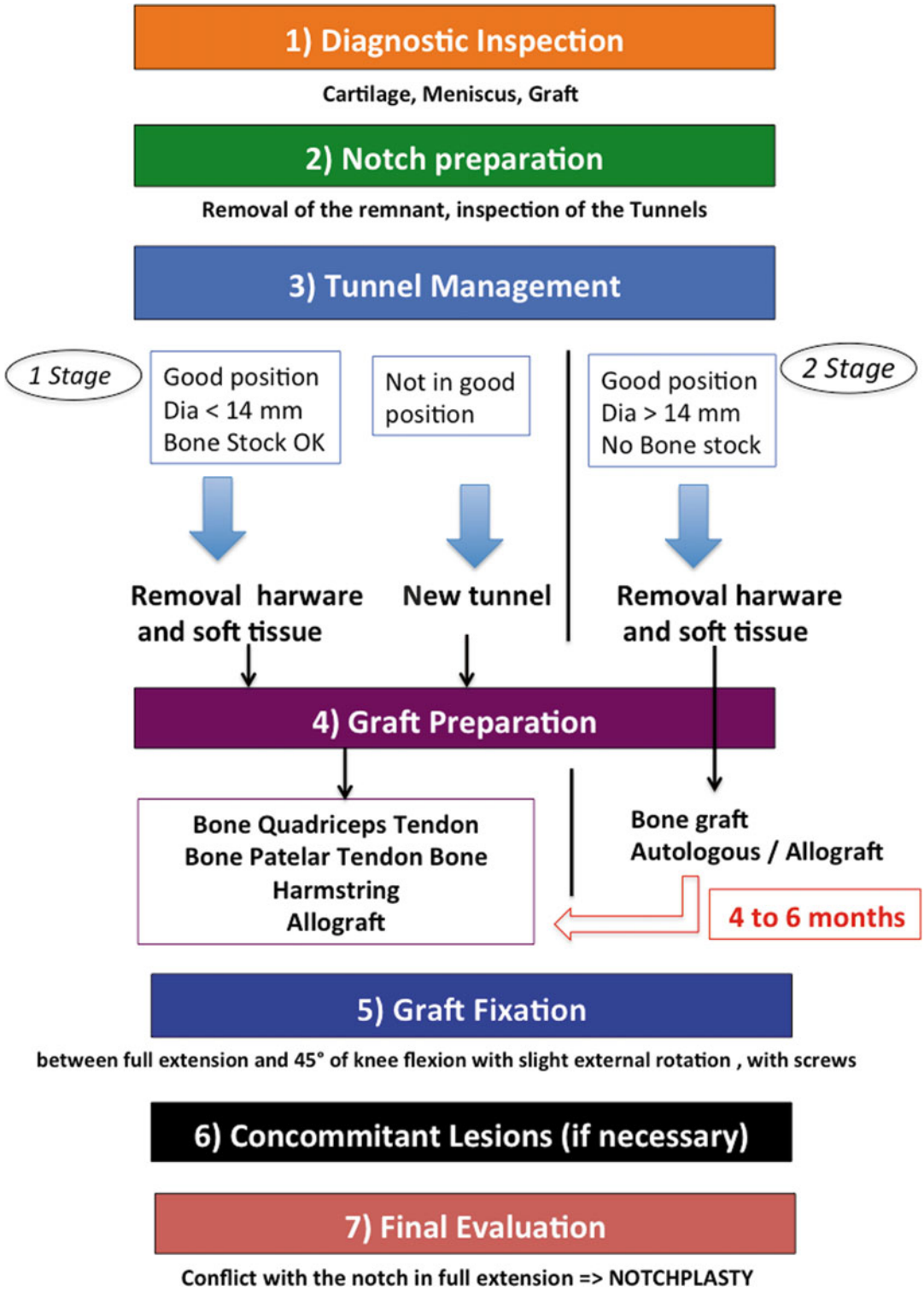

Fig. 25.8 Surgical steps for R-ACL

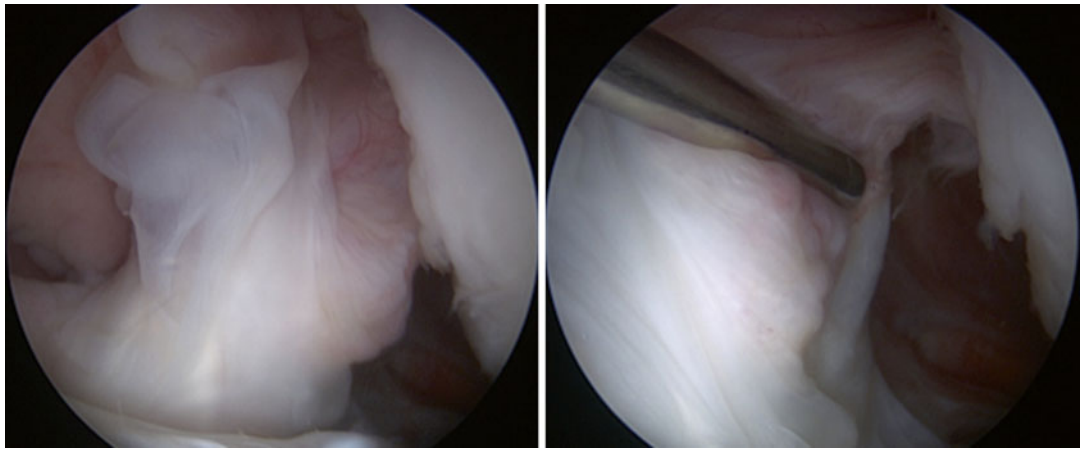

Fig. 25.9 Arthroscopic views showing an insufficient graft

possible otherwise. Removal of interference screws may be factitious and it should be well planned. It is a little easier, when the tunnel drilling technique of primary ACL reconstruction (trans-tibial, antero-medial or outside in) is known and the same approach is chosen for the hardware removal. In some cases, especially when outside-in drilling was used, an extra-articular approach with placement of a guide wire in the centre of the pre-existing tunnel might be useful. After extraction of the fixation device, the tunnels should be debrided off of any granulating soft tissue and remaining parts of the biodegradable interference screw by direct visualisation with the arthroscope. The often sclerosed walls of the tunnel should be roughened. The extent of bone loss is then analysed and the effective tunnel size estimated. Only when anatomic tunnel placement with a sufficient bone stock for adequate graft fixation is ascertained, the graft can be chosen and harvested. Otherwise, the procedure can be staged, and the first operation consists then of hardware removal, tunnel grafting and joint cleaning.

25.4.2 Graft Selection

There is no gold-standard graft either for primary or revision ACL reconstruction. Whereas bone-patellar tendon-bone (BPTB) is used in up to 81 % of top athletes for primary reconstruction, allografts have been used in 43–50 % in top and recreational athletes [87, 88]. Although allografts avoid donor-site morbidity, and their versatility in length, graft thickness and bone-block size are certainly advantageous to any autologous graft; it is hardly ever used in Europe as well as in our centre. First of all, there is a (low) disease transmission risk that patients are not willing to accept. On the other hand, there are biologic reasons such as slower incorporation in the osseous tunnel and irradiation processing weakening microarchitecture of the allograft leading to the higher failure rates reported in literature [89–92]. Costs and availability are other not negligible facts [93].

Our preferred autologous graft in R-ACL is the quadriceps tendon with a bone block (BQT), unless used at primary ACL revision surgery. Even if BPTB has been used at primary reconstruction, we have not encountered patellar fracture when using BQT. This graft has several advantages: (1) Having high load to failure, enabling bone-to-bone integration in one tunnel, which has been found to be superior to tendon-graft-to-bone integration [94]; (2) Its high versatility regarding length and thickness and the possibility to provide a tendinous graft up to 10–12 mm in diameter [95, 96]; (3) The BQT has been shown suitable for primary and revision

surgery with low-donor-site morbidity [95, 96]. The graft of second choice may be either a BPTB or more rarely a quadrupled hamstring graft (qHT), according to the patient's primary graft and demands. The downside of BPTB graft is its high-donor-site morbidity, the increased risk of contralateral ACL rupture and its low versatility in terms of thickness and length [93, 97, 98]. A major advantage is its bone-block fixation in the femoral and tibial tunnel leading to less tunnel widening and faster graft integration [88, 94, 99–101]. As in BQT, the size of the bone blocks can be anticipated and adjusted to the osseous defect to fill the bone loss estimated during diagnostic arthroscopy even using a press-fit technique, enabling single-stage ACL revision surgery [56].

Re-harvesting BPTB or qHT is risky, is associated with increased failure rates and is therefore not recommended. The regeneration capacity of the remaining quadriceps tendon after harvesting has not yet been highlighted in the literature and can currently not be recommended for re-harvesting. However, results of quadriceps tendon without bone block in primary ACL reconstruction have shown reliable results [102], and therefore re-harvesting the quadriceps tendon might be an additional source of graft harvesting in future ACL revision surgery. Iliotibial band autograft [103], contralateral tendon harvesting [104] or double-bundle technique [105] could be performed at ACL revision surgery.

25.4.3 Tunnel Management and Placement in One-Stage Surgery (Fig. 25.10)

The advantages of one-stage ACL revision surgery are the lesser time for rehabilitation, earlier return to sports and the more favourable cost benefit for the patient. It therefore should be preferred if it is feasible. One-staged surgery can be performed only in patients with largely malpositioned or anatomically placed tunnels without large bone loss once the fixation device is removed. One-staged surgery is however contraindicated in patients with restricted range of motion due to delayed or insufficient rehabilitation, graft impingement or malposition. In this case, a first stage is necessary to perform an arthroscopic debridement and/or an arthrolysis. There is another situation where one-stage surgery should be well evaluated; it is in the presence of important concomitant articular injuries (infection, multiple intra-articular debris) and/or axial deviations requiring correcting osteotomies [106].

Only in knees with primary anatomical tunnels that can be overdrilled, bone quality and stock remain near normal. In largely malpositioned tunnels, where fixation material is left in place, the fixation strength is probably not diminished. In slightly confluent tunnels, biomechanical studies have shown good fixation strengths when the graft is fixed with larger interference screws or bone grafting in press-fit technique [89]. Whether graft integration and ligamentisation is thereby influenced is still unknown.

The most problematic tunnel is the tibial tunnel, which is usually only slightly malpositioned. If the tibial tunnel is placed too anteriorly, a one-stage procedure can be performed by using either a bone plug or a larger interference screw placed anteriorly. An additional extra-articular fixation should be performed in case of doubtful fixation strengths. Sutures from the graft can be tied over a button or through transosseous holes made at the tibial tunnel emergence.

Now, if the tibial tunnel is placed too posteriorly, it is difficult to perform a proper placement of the new tunnel, and a weak bone fixation strength can be expected. In such cases, we recommend to perform a two-stage surgery, which has shown good results in terms of postoperative laxity and objective outcome [107].

Not only in primary, but especially in R-ACL surgery, the trans-tibial femoral tunnel technique shows significant disadvantages. Drilling through a (low) antero-medial portal or using the outside-in (alternatively the retrodrill) technique gives the surgeon a higher variability to direct their femoral tunnel [108]. This implies a meticulous pre-operative planning of the tunnels using 3D

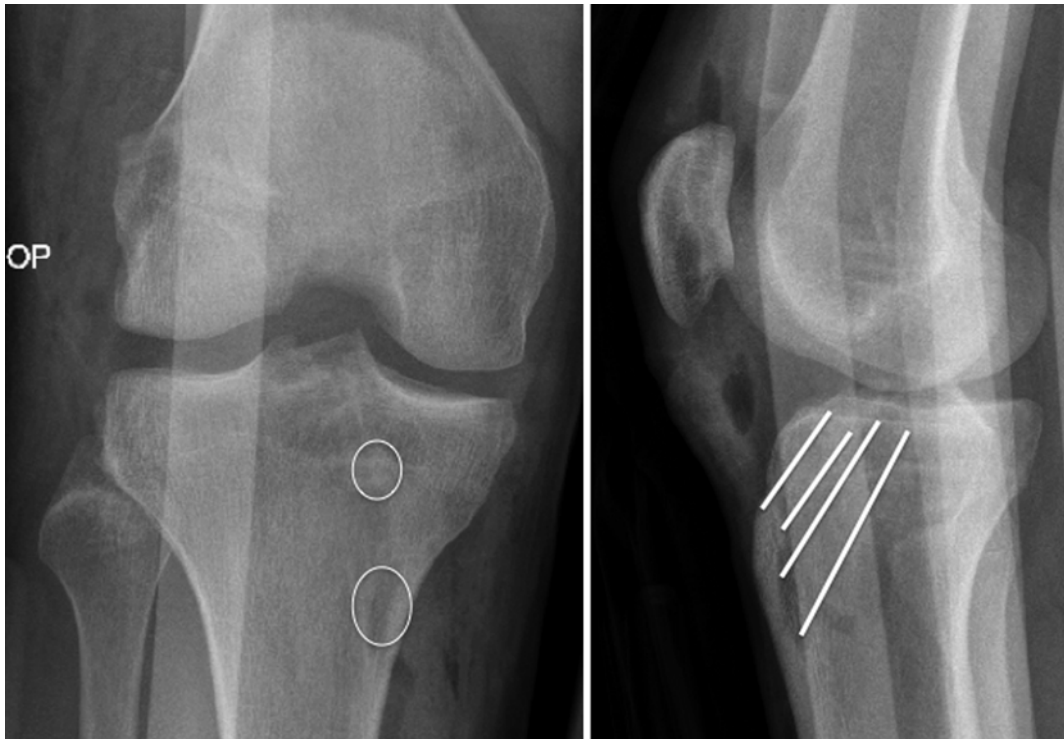

Fig. 25.10 One stage procedure. Both femur and tibia tunnels are too anterior, it was possible to drill new tunnel in the good position

CT. One may advocate navigated reconstruction [109], which in our experience is not absolutely necessary.

If the posterolateral portion of the lateral femoral condyle is insufficient for the positioning of an anatomical femoral tunnel, a nonanatomical tunnel in an over-the-top position with extra-articular fixation needs to be pondered. This technique of ACL revision surgery associated to an additional extra-articular reinforcement showed good functional outcomes, with however a trend of increased residual laxity [110, 111].

25.4.4 Tunnel Management in Two-Stage Surgery

In case of anatomical tunnels with major bone loss, a two-staged revision surgery with autologous bone grafting of tunnels is recommended. In large defects, we combine autologous bone grafting with allograft (Tutoplast). The cut-off value of tunnel widening necessitating grafting published in literature is set at 16–17 mm [112]. In our experience, we perform two-staged surgery with bone grafting already in anatomical bone tunnels larger than 13–14 mm (Fig. 25.11).

There are several techniques described in literature for filling the bone loss in ACL revision surgery using either autologous (iliac bone crest or medial tibial metaphysis) of allografts [113]. For the tibial tunnel, either bone chips or bone plugs can be introduced in press-fit technique using OATS tube harvester, for example [113]. Bone chips for the femoral tunnel should be used with caution, since they might be washed out of the tunnel and become loose bodies in the knee joint. A postoperative conventional radiograph is necessary in such situations. Before performing bone filling, the granulation tissue and all particles from biodegradable screws should be removed.

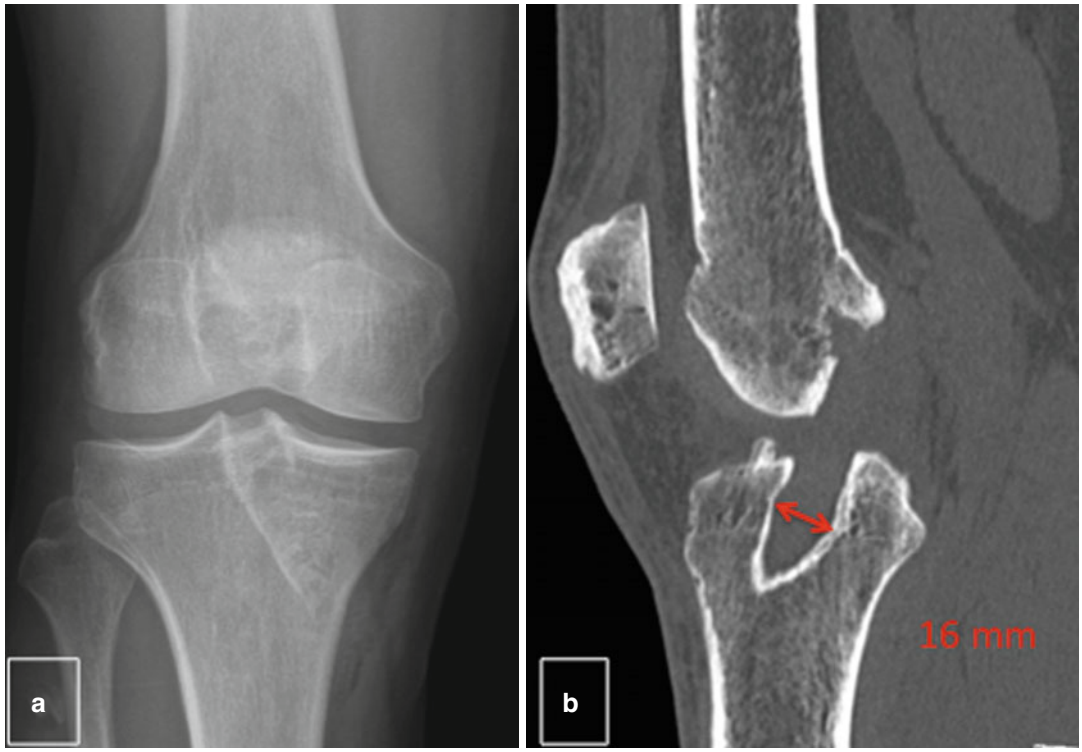

Fig. 25.11 (**a**) X-ray and (**b**) CT showing a tunnel widening of the tibia >14 mm

Ideally, 4–6 months after bone grafting, the bone plug or the chips have undergone osseous integration, and the tunnels can be freely placed, with usually the assurance of a good quality of fixation (Fig. 25.12).

25.4.5 Graft Tensioning and Fixation

The ideal graft tensioning remains a matter of debate; however undertensioned graft – most probably rather due to poor initial fixation strength than insufficient tensioning during surgery – will lead to immediate laxity and failure, whereas overconstrained graft can lead to poor graft revascularisation, which will lead to failed ligamentisation [40]. The safest position for graft tensioning has been described between full extension and 45° of knee flexion with slight external rotation [93]. Graft tensioning and fixation in higher flexion tend to overconstrain the knee.

Interference screws are the standard fixation device for tendinous grafts and with bone blocks. Whether biodegradable or metallic screws should be used is still a matter of debate. Biodegradable screws are thought to disappear with time; however they are not unfrequently still seen at 3 years postoperatively on MR imaging or at surgery [114]. In terms of functional results, residual laxity and failures, no difference was found comparing biodegradable or metallic screws; however, a higher incidence of persisting knee effusion, tunnel widening and screw breakage were observed in the biodegradable screw group [93, 115, 116].

25.4.6 Concomitant Injuries

Concomitant ligamentous injuries have been reported to be present in up to 10–15 % of the failed ACL reconstructions, which might have been missed at primary ACL reconstruction. This additional instability leads to increased load to

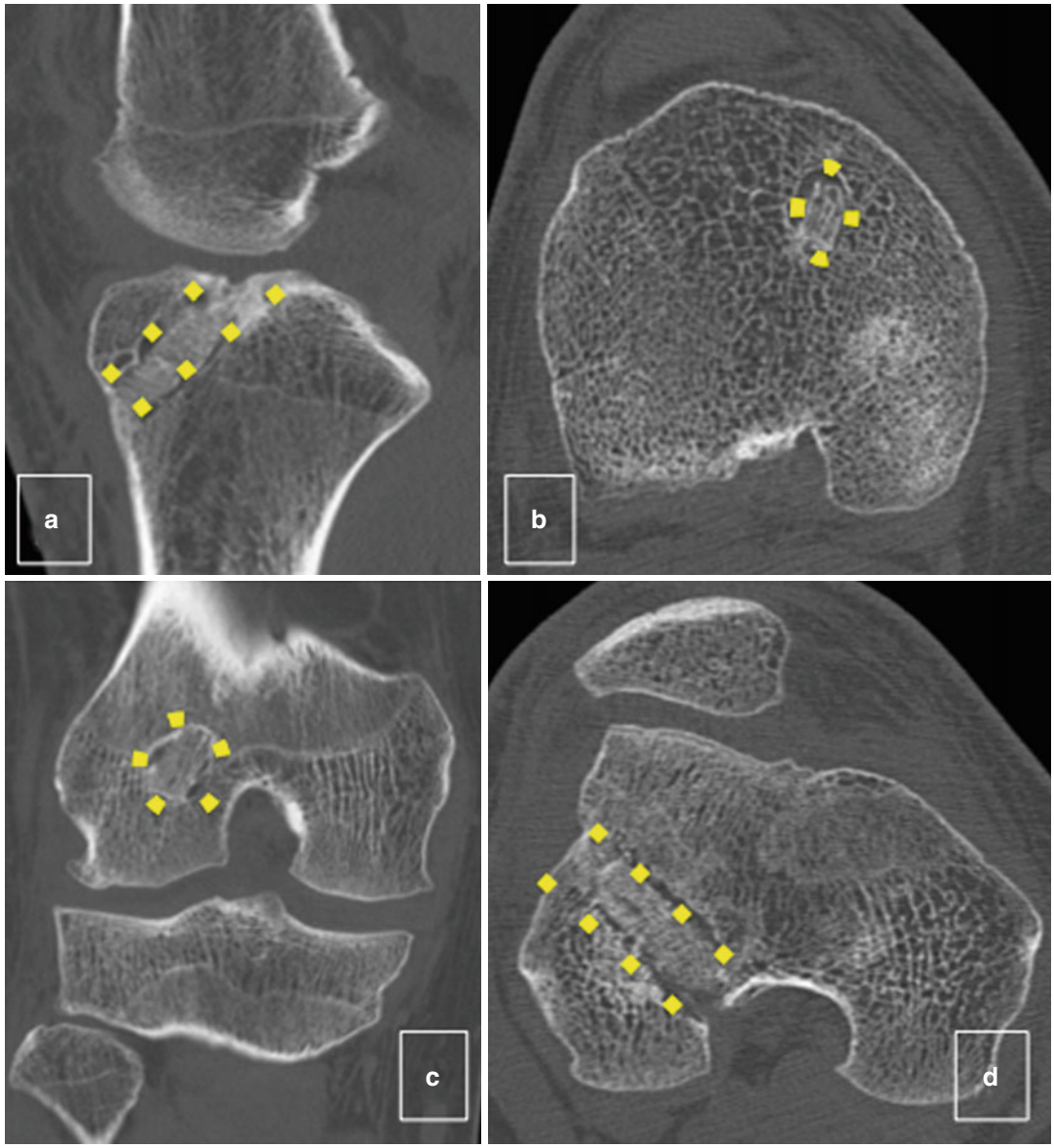

Fig. 25.12 CT scan 4 months after the first of two-stage procedure. Graft is incorporated in the tunnel; (**a**, **b**) Tibia, (**c**, **d**) femur

the graft and hence potential failure [66]. The most often associated ligamentous injury is a posterolateral insufficiency, which should be addressed during ACL revision surgery. In our experience, we often used the re-tensioning technique described by Werner Muller [117].

In extreme cases of varus deformity and lateral thrust associated or not to medial compartment osteoarthritis, a high tibial osteotomy (HTO) needs to be considered [118]. Several tips and tricks may help in performing this demanding surgery, but those are beyond the scope of this chapter. One important point to emphasise: Increasing the posterior tibial slope should be avoided implicitly, since it might increase the rate of failure and ACL re-rupture.

Whether an anterolateral ligament (ALL) reconstruction should be performed for every

ACL revision surgery is highly debated. We perform ALL reconstruction with a pediculate inferior slip of the iliotibial tract only in patients with high-grade positive pivot shift, to improve anterolateral rotational control [70].

Meniscal and cartilaginous treatment will be discussed elsewhere. However, if two-staged surgery needs to be performed due to large bone loss, we perform cartilaginous and meniscal repair at the same time as bone grafting procedure. The knee will be then stabilised with a hinged knee brace until the ACL revision surgery will be performed.

25.5 Postoperative Results of ACL Revision Surgery

The failure rate was noted as three to four times higher in a R-ACL population compared to prospective series of primary ACL reconstruction [11].

Revision anterior cruciate ligament (ACL) reconstruction is believed to have an inferior outcome compared with primary ACL reconstruction.

Wright et al. [11] realised a systematic review to answer the question of clinical outcomes in R-ACL. Twenty-one studies were included representing 863 R-ACL with minimum 2 years follow-up. They concluded that R-ACL reconstruction resulted in a worse outcome compared with primary ACL reconstruction [11]. Patient-reported outcome scores were inferior to results of primary ACL reconstruction. Objective failure occurred in 13.7 % ± 2.7 % of patients. The mean Lysholm score was 82.1 ± 3.3, the mean International Knee Documentation Committee (IKDC) subjective score was 74.8 ± 4.4 and the mean Cincinnati score was 81. For comparison, in a systematic review including nine studies of primary ACL reconstruction, Spindler et al. [9] found a mean Lysholm score of 85, and the mean Cincinnati score was 90. The mean IKDC subjective score in this MOON (Multicenter Orthopaedic Outcomes Network) primary ACL reconstruction cohort was 84. Gifstad et al. [67] compared results after R-ACL with primary ACL reconstructions: KOOS and Lysholm scores were significantly inferior in R-ACL group compared with the primary group. Patients in the R-ACL group showed a greater laxity measured with the pivot shift test, larger reduction in the Tegner activity score, and reduced muscle strength in the injured knee. However, no difference in anterior-posterior translation was found. A case control study of 55 patients who underwent R-ACL showed that clinical results using the IKDC score were inferior to primary ACL, but stability results using KT-2000 arthrometer were not different to results of primary ACL [49].

Subjective outcome scores for IKDC and Lysholm score are significantly lower after multiple ACL reconstruction, which might be due to the increased incidence of cartilaginous and meniscal injuries or concomitant ligamentous instability as reported in the literature [76, 107, 119, 120].

The Danish ACL reconstruction registry showed less increase in activity levels in revision surgery than in primary ACL reconstruction [121]. Denti et al. [106] reported that 78 % of the patients who underwent R-ACL were returning to perform the same sport at the same level as before their initial knee injury compared to only 58 % who returned to the same sport at the same level after the primary reconstruction. In their opinion, this might be due to the remaining knee instability after primary reconstruction.

Trojani et al. [55] found that anterior femoral tunnel malposition, as the cause for failure of primary surgery, is a predictor for good clinical outcome of revision surgery provided that the tunnel was positioned anatomically at R-ACL. Furthermore, patients with preserved menisci had better IKDC values and pivot knee stability results.

Studies to date are limited by their weak design, small numbers, heterogeneous populations and lack of concurrent control groups [1].

Conclusions

Revision ACL surgery is a challenging procedure that necessitates consideration of many factors. Good outcomes in revision surgery can be three times lower than that of primary ACL reconstruction. Correct identification of

the cause of failure and anatomic positioning of tunnels are the keys for success in a patient with realistic expectations.

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PCL Tear: Complete, Partial, and Associated with Medial or Lateral Damage

26

Chase S. Dean, Robert F. LaPrade, and Lars Engebretsen

26.1 Introduction

Posterior cruciate ligament (PCL) tears have been documented to occur in between 1.5 % [48] and 38 % [13] of all structural knee injuries in the outpatient and trauma settings, respectively. PCL tears most commonly result from sports trauma or motor vehicle collisions [2, 13, 74]. One level I trauma center reported 57 % of their PCL tears resulted from motor vehicle collisions [13]. A European study of 19,530 sports injuries over a 10-year period showed that skiing had the highest risk of PCL injury, followed by soccer and handball [48]. Regardless of whether the PCL injury was isolated or combined, reports indicate that PCL injuries more commonly occur in males, who account for 73–97 % of all PCL injuries [2, 13, 71].

Although isolated PCL tears do occur, it is considerably more common for PCL tears to occur in conjunction with other knee injuries, particularly ligamentous injuries [13]. Reports on isolated PCL injury range from 3.5 % [13] to 18 % [71] of all PCL injuries. PCL tears have been shown to occur concomitantly with medial collateral ligament (MCL), anterior cruciate ligament (ACL), and posterolateral corner (PLC) injures in up to 31 %, 46 %, and 62 % of cases, respectively [13].

PCL tears can take the form of midsubstance disruptions, bony avulsions, or insertional disruptions and range from isolated partial tears to complete tears with associated multiligament injuries. As injury severity varies, so does the patient's presentation. Patients with isolated PCL injuries may present with minimal symptoms with a history of a minor fall months ago or may present after a high-velocity trauma with an acute hemarthrosis and a grossly unstable knee [12].

The purpose of this chapter is to provide up-to-date information regarding complete and partial PCL tears, both isolated and combined with medial and lateral ligament damage. This chapter will discuss how to diagnose PCL injury, clinically and radiologically, and how to properly classify PCL tears.

26.2 Diagnosis: Clinical

When diagnosing PCL injuries, it is essential to differentiate an isolated PCL tear from a multiligament injury because the treatment and prognosis are dramatically different [29, 59, 68, 76].

C.S. Dean, MD
Steadman Philippon Research Institute, Vail, CO, USA

R.F. LaPrade, MD, PhD
The Steadman Clinic, Vail, CO, USA

Steadman Philippon Research Institute, Vail, CO, USA

L. Engebretsen, MD, PhD (✉)
Department of Orthopaedic Surgery, Oslo University Hospital, Oslo, Norway
e-mail: lars.engebretsen@medisin.uio.no

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A thorough patient history and comprehensive physical examination are vital to diagnose and characterize PCL injuries.

26.2.1 History

The history should include the time of onset, mechanism of injury, and initial and current symptoms [12]. Patients with isolated PCL injuries are sometimes unable to recall a specific moment or mechanism of injury and often report vague feelings of unsteadiness or discomfort. This is in contrast to ACL or MCL injuries, where patients typically recall a specific incident and describe feeling a "pop" or "tear" indicative of ligamentous injury [36, 50]. In an acute PCL tear, the patient may present with a mild to moderate effusion, stiffness, pain while kneeling, pain with deep knee flexion, and moderate pain in the posterior knee [50, 52]. The patient may complain of instability during sudden changes in direction, but this is more common with combined ligamentous injury. In a subacute or chronic PCL tear, the patient may complain of pain with deceleration and descending inclines, pain with running at full stride, and vague anterior knee pain. As the time from the initial injury progresses, pain tends to increase and localize to the patellofemoral and medial knee compartments [50]. Patellofemoral pain in chronic PCL injuries is thought to be due to increased surface contact of the patella with the trochlea as a result of posterior subluxation of the tibia on the femur [70]. Multiligament injuries involving the PCL are rarely asymptomatic and typically present with initial swelling of the knee and instability [12]. When the history involves high-energy trauma, a multiligament knee injury should be on the surgeon's differential.

26.2.2 Mechanism of Injury

PCL injuries characteristically result from a posteriorly directed force on the proximal anterior tibia. In motor vehicle collisions, this is referred to as a "dashboard injury." PCL tears involving a high-energy mechanism of injury commonly result in simultaneous multiple ligament injuries in the knee. Sports-related PCL tears can occur when an athlete falls to the ground with the foot plantarflexed and the knee flexed, causing the tibia to receive the initial impact with the force directed posteriorly from the ground to the proximal tibia [50]. Additionally, hyperflexion of the knee commonly produces isolated PCL injuries in the athlete [16]. The PCL can also be torn from hyperextension of the knee and forceful valgus or varus stress combined with leg rotation [50].

26.3 Physical Examination

After collecting the relevant history, a physical examination should be performed. Regardless of high- or low-velocity trauma, or whether the injury is acute or chronic, a thorough and systematic physical examination is paramount to direct further work-up and an eventual arrival at the correct diagnosis. A proper physical examination should always precede imaging studies. However, testing for a PCL tear in the acute setting can be challenging. The clinical evaluation can be adversely effected by the presence of an effusion, skin abrasions, concomitant injuries, and/or pain. In such cases, advanced imaging or rescheduling the clinical examination within the next 2 weeks should be considered [50].

26.3.1 Inspection

Inspection should start with a general overall assessment, followed by a more focused one. Throughout the physical examination, always inspect the uninjured knee to use as a comparison. First, major deformity, gross malalignment, open wounds, and active bleeding should be ruled out [11]. The patient's alignment and gait should be noted. Subtle varus alignment and varus recurvatum thrust during gait increase suspicion of concomitant posterolateral corner injury [12, 44]. Evaluate for a joint effusion, hematomas, ecchymosis, and prior surgical scars. The skin should be inspected for signs

that may indicate the mechanism of injury, including the direction and magnitude of the applied force. Pay close attention to the anterior portion of the proximal tibia for any sign of trauma that may indicate a history of posteriorly directed force that could be the result from impact with a dashboard in a motor vehicle accident or fall onto the tibia with a flexed knee and plantarflexed foot [11].

Additionally, the medial and lateral knee should be closely inspected for signs of associated injuries. Medially, look for skin furrowing or the "dimple sign" which indicates an irreducible posterolateral knee dislocation with medial tissue entrapment; typically, the medial femoral condyle has buttonholed through the medial joint capsule, and the free end of the medial collateral ligament has invaginated into the joint [24, 61, 69].

26.3.2 Neurovascular Evaluation

Neurovascular assessment of the lower limb is critical. Note any active hemorrhage or expanding hematoma. Look for ischemia and palpate for temperature. The dorsalis pedis, posterior tibial, and popliteal arteries should be palpated and the capillary refill examined [11, 58]. If the suspicion of vascular injury is high, a Doppler ultrasound should be utilized to check for pulses, and the ankle-brachial index assessed. If there is any doubt, a CT angiogram should be obtained.

As mentioned previously, associated ligament injuries are common with PCL tears, particularly a concurrent PLC injury. Evaluation of neurological structures is important because 12–29 % of patients with acute PLC injuries also have peroneal nerve injuries [4, 43, 78]. Numbness in the first dorsal web space and weakness to dorsiflexion, foot eversion, and great toe extension should be evaluated [12]. While injury to the tibial nerve is less common, a comprehensive neurological exam should be performed. The tibial nerve can be evaluated by assessing for numbness on the plantar surface of the foot and weakness to plantarflexion and great toe flexion [11].

26.3.3 Palpation

Methodical palpation of the skin, soft tissues, and bones is essential to distinguish between normal and distorted anatomy. For a complete knee examination, the patient should be evaluated in the sitting position with legs hanging over the edge of the table, the "figure four" position, and the prone and supine positions. Induration and gaps in soft tissue should be noted. Positioning the patient in a "figure four" position is helpful to palpate the lateral knee structures, particularly the fibular collateral ligament [58]. Tenderness at the inferior pole of the patella or proximal anterior tibia may indicate a "dashboard" mechanism of injury [11]. Examine the suprapatellar region for a potential effusion which may suggest soft tissue injury or recent patellar dislocation [58]. Passive and active range of motion should be assessed bilaterally. As mentioned previously, the examination of acute injuries may be limited by pain, swelling, and associated injuries and should be taken into consideration. Flexion and extension of the knee may help localize areas of tenderness. Inability to fully extend the knee may indicate meniscal injury or damage to the extensor mechanism. Increased hyperextension may indicate a PCL injury combined with a PLC or posteromedial corner (PMC) injury. To fully assess the PCL, knee flexion of at least 90° is required [11, 19]. An inability to reach 90° of flexion will require an examination at a later date or an examination under anesthesia. If 90° of flexion cannot be achieved, ice and antiinflammatory medication may reduce swelling and thereby increase range of motion. Alternatively, the examination can be repeated after a period of physical therapy; once it is determined, there are no critical meniscal or concurrent injuries, to help restore motion [11].

26.4 Special Tests

Numerous special tests of the knee have been described. Some have been validated to be more sensitive and specific than others. Furthermore, bear in mind that there is always a degree of

operator dependence. The following paragraphs describe the most relevant tests in regard to PCL tears and associate medial and lateral injuries.

26.4.1 Anteroposterior Translation

26.4.1.1 Step-Off

To examine the tibial step-off, the patient is placed in a supine position on an examination table with knees flexed to 90°, hips flexed to 45°, and feet placed flat on the table. The anterior tibial plateau is palpated, and the anteroposterior (AP) relationship to the medial femoral condyle is assessed. Normally, the anterior border of the tibial plateau sits about 1 cm anterior to the medial femoral condyle and is easily palpable by running a thumb or index finger down the medial femoral condyle toward the tibia. Classification of PCL injuries using this method is based off of the degree of posterior subluxation of the tibial plateau relative to the femoral condyle. A grade I injury occurs when the tibial plateau is still anterior to the femoral condyle. A grade II injury occurs when the anterior border of the tibial plateau is flush with the femoral condyle. A grade III injury occurs when the anterior tibial plateau rests >10 mm posterior to the medial femoral condyle, and a high concern for other ligamentous injury should be suspected [44, 50, 77].

26.4.1.2 Sag Sign

To assess for a "sag sign," the knees should remain flexed to 90°, the hips are flexed to 45°, and the feet are placed flat on the table. Alternatively, to maximize the assistance of gravity, this test can be performed with the hips flexed to 90° with the examiner lifting the patient's heels up so the knees are flexed to 90° [50]. The knees are observed in the sagittal plane on each side, evaluating the relationship between the tibial tubercle, the patella tendon, and the inferior pole of the patella. If the PCL is torn, the tibial tubercle may be translated posteriorly relative to the distal pole of the patella, especially when compared to the uninjured knee. This appears as an abnormal contour or posterior sag and is referred to as the "sag sign" [11, 36, 46].

26.4.1.3 Quadriceps Active Tests

The quadriceps active test is performed with the patient supine on the examination table, one knee is flexed to 90°, and the examiner holds the patients foot flat on the table while the patient flexes their quadriceps by attempting to extend the leg. If a PCL injury is present, the posteriorly subluxed tibia will be drawn anteriorly. The test is considered positive if the tibia moves anteriorly >2 mm, indicating a potential PCL tear [10, 36, 56].

26.4.1.4 Posterior Drawer

The posterior drawer test is performed in a supine position with the knee flexed to 90°, the hip flexed to 45°, and the foot placed flat on the table. This has been validated with a biomechanical study that reported posterior tibial translation with a sectioned PCL was greatest at 90° [19]. To properly assess the degree of posterior translation, it is essential that the patient relax the quadriceps and hamstring muscles. With the foot in neutral rotation, the examiner sits on the patient's foot to prevent slippage. Both hands are used to grab the proximal tibia with palms facing each other; the thumbs are placed on the tibial tubercle and the other fingers around the back of the knee (Fig. 26.1). A posterior force is then applied to the proximal tibia, and the resultant posterior tibial translation is noted and compared with the contralateral knee [26, 36]. In order to avoid performing the posterolateral drawer test, it is critical that the force be applied straight posteriorly. Grading can be done using the previously described criteria for step-off or by using the International Knee Documentation Committee (IKDC) grading for joint translation. The IKDC grading is as follows: normal, 0–2 mm; nearly normal, 3–5 mm; abnormal, 6–10 mm; and severely abnormal, >10 mm. One study reported that the posterior drawer test was highly sensitive (90%) and specific (99%) [64]. However, a recent meta-analysis found the sensitivity of the posterior drawer test to be heterogeneous among reports, and only one study recorded specificity (Table 26.1) [34]. A major limitation to the posterior drawer test is that it provides only a subjective assessment of the degree in posterior tibial

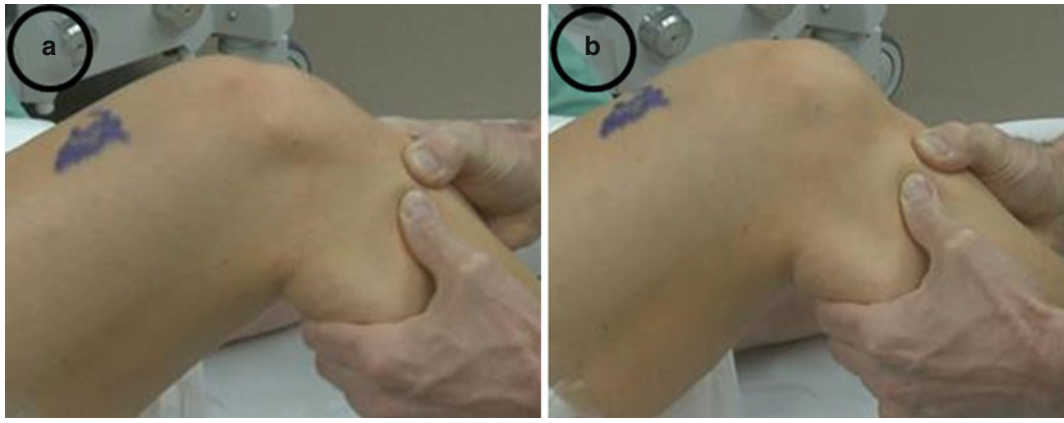

Fig. 26.1 Posterior drawer test of a right knee performed on operating table while the patient is under anesthesia. (**a**) Starting position without posterior force and (**b**) ending position with application of posterior force

Table 26.1 Sensitivity and specificity of different physical examination techniques for isolated posterior cruciate ligament injuries

Technique	Sensitivity	Specificity
Posterior drawer	0.22–1.00	0.98
Posterior sag	0.46–1.00	1.00
Quadriceps active	0.53–0.98	0.96–1.00
Supplemental tests		
External rotation recurvatum test	0.22–0.39	0.98
Reverse pivot shift test	0.19–0.26	0.95
Varus and valgus at 0°	0.28–0.94	1.00
Varus at 30°	0.00–0.17	No data
Valgus at 30°	0.20–0.78	No data
Dial test	No data	No data

Adapted from Kopkow et al. [34]

translation, and the amount of translation assessed varies greatly among clinicians [36].

26.4.2 Supine Internal Rotation (IR) Test

Moulton et al. [55] recently reported on a new test that uses IR between 60 and 120° of knee flexion to evaluate PCL injuries. During examination under anesthesia, IR torque is applied to the patient's foot at 60°, 75°, 90°, 105°, and 120° of knee flexion and assessed by measuring (in mm) the amount of displacement of the tibial tubercle from neutral rotation to maximal internal rotation. Side-to-side comparison is necessary to account for physiologic laxity, which often varies between patients. The supine IR test demonstrated a sensitivity of 95.5 %, a specificity of 97.1 %, a positive predictive value of 72.4 %, and a negative predictive value of 99.6 % for the diagnosis of grade III PCL injuries [55].

26.4.3 Special Tests for Associated Medial or Lateral Injuries

As stated previously, PCL tears are often associated with an MCL or PLC injury. As a result, supplemental physical examination of the medial and lateral sides of the knee must be performed.

26.4.3.1 Valgus and Varus Stress Tests

Valgus and varus stress tests should be performed to assess for medial and lateral ligamentous injury, respectively. With the patient positioned supine, one hand is placed directly over the joint line to assess for any medial or lateral gapping. The other hand is placed on the foot or ankle and used to apply a valgus or varus force (Fig. 26.2). Each knee should be examined at full extension and 20–30° of flexion [36]. As with all special tests, the uninjured leg should be examined first and then compared to the injured leg.

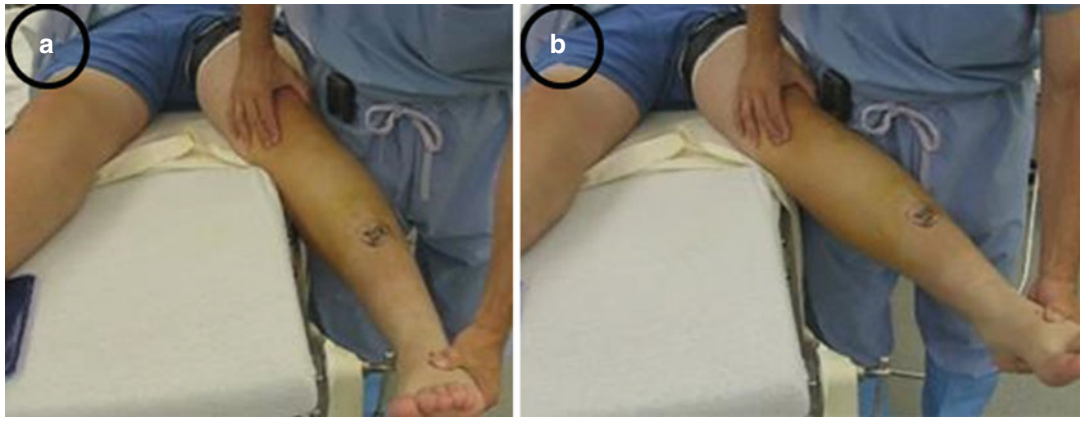

Fig. 26.2 Images showing valgus stress test of left leg performed at 20–30° of flexion (**a**) before valgus stress is applied and (**b**) with a valgus force being applied

26.4.3.2 Posterolateral and Posteromedial Drawer Tests

The posterolateral and posteromedial drawer tests can be used to assess PLC injury, with and without PCL injury. The crucial component to correct interpretation of these tests is determining the degree of rotation to translation. The posterolateral drawer test is performed with the patient in the same position as the posterior drawer test, except the foot is externally rotated 15°. In a knee with an intact PCL and injured PLC, when a posterior tibial translation force is applied, the lateral tibial plateau will externally rotate to a greater degree than the medial tibial plateau as it pivots around the PCL [27]. In the same knee, when a posteromedial drawer test is performed by internally rotating the tibia approximately 15° and applying a posterior force, the PCL fibers become taut due to the internal rotation, and there is little or no motion. However, when the posterolateral drawer test is performed in a knee with injury to the PLC and PCL, the tibia does not have an intact PCL to rotate around, and so the lateral and medial tibial plateau both sublux posteriorly in a relatively equidistant manner [27]. When the PLC- and PCL-deficient knee is internally rotated and a posterior force applied, significant posterior subluxation of the tibia on the femur is still seen and occurs equally on the medial and lateral tibia. Furthermore, a posteromedial drawer test on a PCL-deficient knee with an intact PLC will demonstrate greater internal rotation of the medial tibial plateau compared to the lateral tibial plateau [11, 27]. A comparison to the contralateral uninjured knee should always be performed because there is some normal laxity seen in patients with physiologic genu recurvatum [9].

26.4.3.3 External Rotation Recurvatum Test

Another test to assess for concomitant PLC injury is the external rotation recurvatum test. While the posterolateral and posteromedial drawer tests assess for instability between the tibia and femur during flexion, the external rotation recurvatum test examines instability during extension [27]. With the patient lying supine, the legs in full extension and muscles relaxed, the examiner gently lifts both legs up by the great toe. A positive test will show increased recurvatum compared to the uninjured knee as well as varus angulation and external rotation of the tibia. The degree of recurvatum should be measured and compared bilaterally by assessing the difference in heel height [27]. Additionally, this test can be performed one leg at a time by lifting each leg with one hand and using the other hand to hold the distal thigh against the table (Fig. 26.3). The distance of the heel from the table is measured and then compared bilaterally [41]. Of note, a positive test can also be seen in combined PLC and ACL injuries, and therefore the clinician

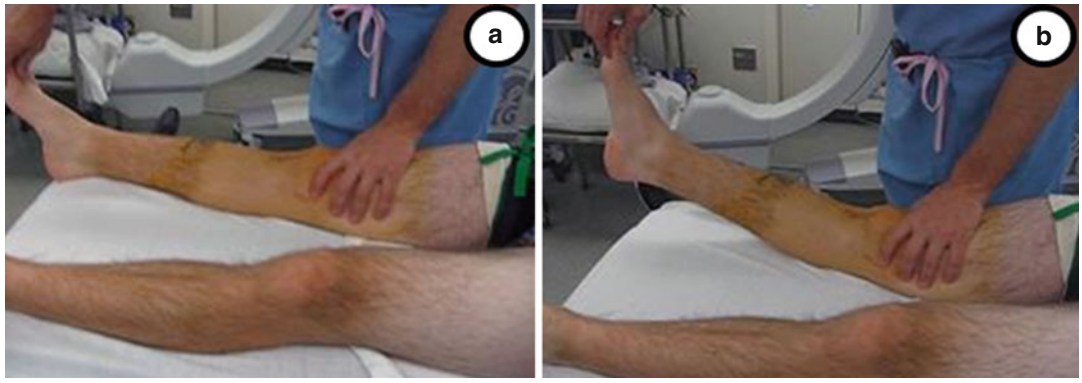

Fig. 26.3 Photograph of external rotation recurvatum test performed on a right knee (**a**) initial position in extension and (**b**) after the leg has been lifted, exhibiting a positive test

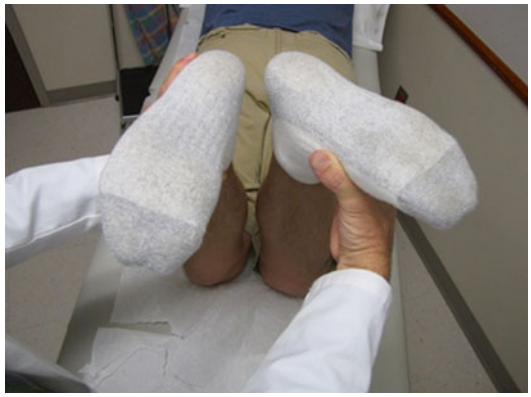

Fig. 26.4 Photograph of dial test performed on patient in prone position with knees flexed to approximately 90° showing a positive test on the right leg

should consider this when evaluating concurrent injuries when evaluating for a positive test. Furthermore, it is important to realize that this exam was reported to be positive in <10 % of PLC injuries [41].

26.4.3.4 Dial Test

The dial examines the degree of external rotation of the tibia on the femur. The dial test is most known for assessment of PLC injury, but medial side injuries can also result in a positive test. The test is performed with the knees flexed to 30° and 90°. With the patient in the prone position, the tibia is externally rotated while keeping the heels together (Fig. 26.4). Any difference in degree of external rotation is then observed. At 30° of knee flexion, biomechanical studies have reported that complete sectioning of the PLC leads to an increase of 15° of external rotation [19, 77]. With the knee flexed to 90°, sectioning of the PLC only results in approximately 5° of additional external rotation. However, sectioning of the PCL and PLC at 90° of flexion results in 15° of additional external rotation [19, 77]. Taking this into account, the dial test can be used to differentiate between isolated PLC injury and combined PLC and PCL injury. However, a biomechanical study has shown that a positive dial test at 90° can also indicate an isolated or combined medial knee injury [17]. Thus, like all other tests, the dial test should always be used in conjunction with a multitude of physical examination maneuvers. Performing the dial test in the supine position can help differentiate between medial and posterolateral sided injuries by observing the axis of tibial rotation and location of joint line gapping [17]. To perform this test in a supine position, one leg is tested at a time with one hand controlling external rotation and the other stabilizing the femur.

26.4.3.5 Reverse Pivot Shift Test

Another way to evaluate possible concomitant PLC injury is to examine the reverse pivot shift test. To perform this test, the patient is supine and the examiner uses one hand to hold the ankle or foot and flexes the knee to 80–90° and externally rotates the tibia. The other hand is used to apply a valgus stress while palpating the joint line. With a

positive test, the tibia will be posteriorly subluxed in this position. The knee is then extended while maintaining valgus stress and external rotation. If subluxed, the tibia will reduce as a result of the iliotibial band function changing from knee flexor to knee extender with extension [42]. The reverse pivot shift has been reported to have a positive predictive value of 68 % and a negative predictive value of 89 % [42].

26.5 Exploration: Radiological, Instrumented

If PCL injury is suspected after a complete history and physical examination has been performed, further tests are indicated. The following section will cover the tests that can be used to evaluate for PCL tears and associated medial and lateral injuries including radiographic techniques, MRI, instrumented exploration, and arthroscopic evaluation.

26.5.1 Radiography

Radiographic evaluation is indicated in patients with suspected acute PCL injury. A radiographic series should consist of AP, lateral, Rosenberg, and long-leg alignment views. Plain radiographs of the knee are inspected for any posterior tibial subluxation, avulsion fractures, joint space gapping, and associated knee injuries [36, 44, 53]. PCL avulsion fractures may be seen on lateral views and appear as a focal discontinuity of the posterior aspect of the tibia (Fig. 26.5) [79]. Fibular head avulsion fractures associated with avulsion of the biceps tendon, popliteofibular ligament, and fibular collateral ligament can be associated with PCL injury [25, 54]. Additional injuries associated with PCL tears include avulsion fractures of Gerdy's tubercle with the iliotibial band and avulsion of the medial capsular structures, also known as the medial Segond sign [54]. Radiographs may also demonstrate a bone avulsion of the meniscotibial ligament portion of the mid-third lateral capsular ligament (anterolateral ligament) at the tibial insertion, known as a

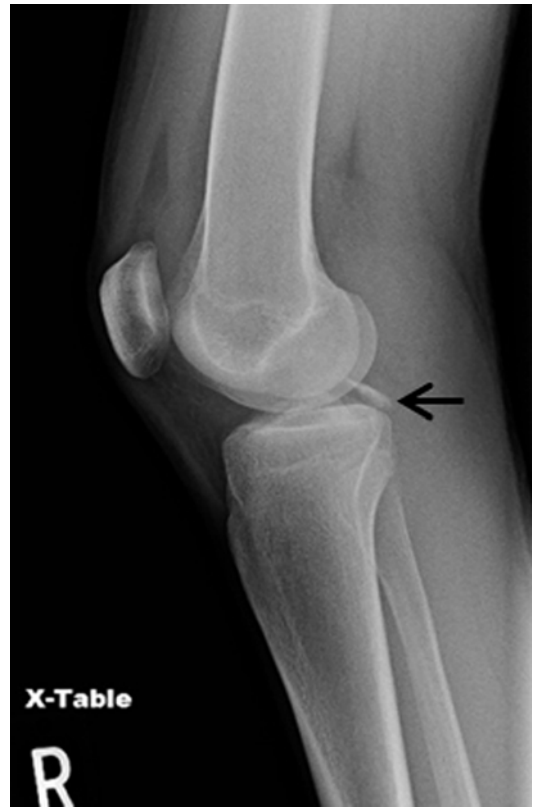

Fig. 26.5 Lateral radiograph of a right knee with a tibial avulsion fracture of the PCL, indicated with the *arrow*

Segond fracture [39]. However, Segond fractures are most commonly associated with ACL injuries [8, 22]. In cases of chronic multiligament instability with suspected malalignment, long-leg standing images should be obtained to determine the mechanical axis and to help plan for corrective osteotomies if necessary [3].

26.5.2 Stress Radiography

26.5.2.1 Posterior Stress Radiographs

Posterior stress radiographs are helpful in aiding the diagnosis of PCL injury and can be used to distinguish between partial, complete, and concomitant multiligament injuries. Through the use of a standardized posterior force, posterior stress radiographs have repeatedly been shown to reliably reproduce an objective assessment of posterior tibial translation [28, 31, 50, 72]. Furthermore,

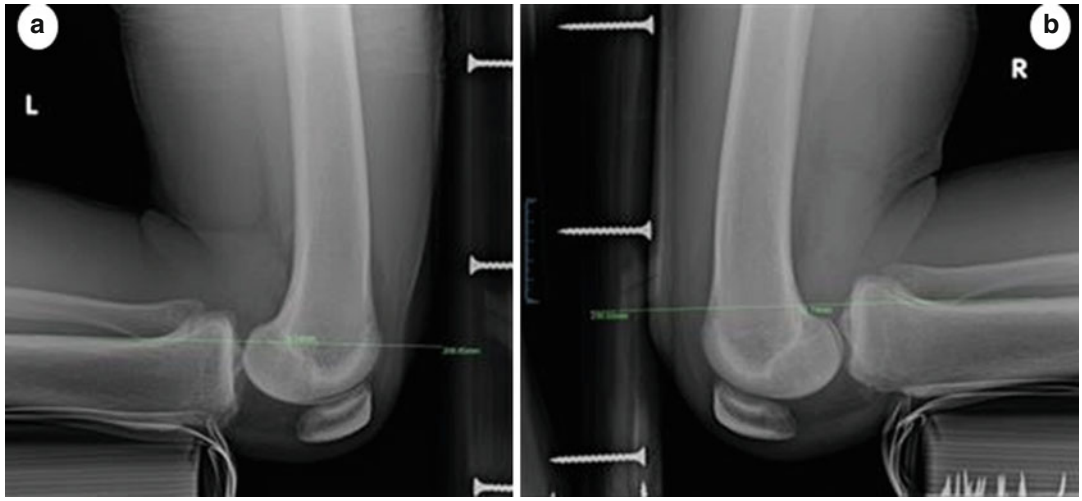

Fig. 26.6 Single-leg kneeling posterior stress radiographs of the same patient demonstrating a substantial side-to-side difference in posterior tibial translation. (**a**) Posterior stress radiograph of the left leg with no measured posterior translation. (**b**) Posterior stress radiograph of the right leg with posterior translation measured at 12.7 mm, indicating a high likelihood of a combined PCL-PLC injury. Radiographic measurements are made by tracing a line along the posterior cortex of the tibia starting at a point 15 cm distal to the joint line and then measuring the perpendicular distance to the most posterior aspect of Blumensaat's line [28, 45]

these are extremely helpful to follow patients over time. A study by Hewett et al. [23] found posterior stress radiography for the diagnosis of PCL tears to be superior to both the posterior drawer test and KT-1000 arthrometer measurements. Multiple techniques have been used to produce posterior stress radiographs, including single-leg kneeling [28, 45], active hamstring contraction [6], gravity assistance [73], and the Telos device (Austin and Associates) [72].

The following techniques all use lateral radiographs to assess degree of posterior tibial translation and compared with the uninjured side. The active hamstring contraction method is performed in the lateral decubitus position with the knee flexed to 90° and held in place by a stand or by a hand of the examiner while the patient contracts their hamstring [11, 50]. Performance of gravity assisted radiographs is performed with neutral rotation and 90° of hip and knee flexion, with the feet resting on a table or being held by the examiner [73]. To perform the kneeling technique, the patient kneels on a bench, flexing the knee to 90° with the bench supporting the lower leg only up to the tibial tubercle, allowing the femoral condyle and patella to remain unsupported (Fig. 26.6) [28, 45]. The Telos device is used with the patient in the lateral decubitus position, the knee flexed to 90°, and fixed to a stand. With the patient relaxed, the Telos device provides a 150 N posteriorly directed force on the anterior tibia 10 cm distal to the joint line [31, 72].

The Telos device and single-leg kneeling methods have proved to be the most reliable techniques for diagnosing PCL tears through the measurement of posterior translation [28, 31, 65]. While both techniques are clinically acceptable, the single-leg kneeling technique is more cost-effective and less time consuming [28, 31]. Reports have documented that partial PCL tears result in <8 mm of posterior translation, complete PCL tears result in 8–12 mm of posterior translation, and complete PCL tears with combined ligamentous injury (most often PLC injury) result in >12 mm of translation [51, 66, 67].

26.5.2.2 Varus and Valgus Stress Radiographs

Similar to posterior stress radiographs, varus and valgus stress radiographs accurately provide a reproducible objective method to assess ligamentous injury. Varus and valgus stress radiographs are helpful to quantify associated injury by

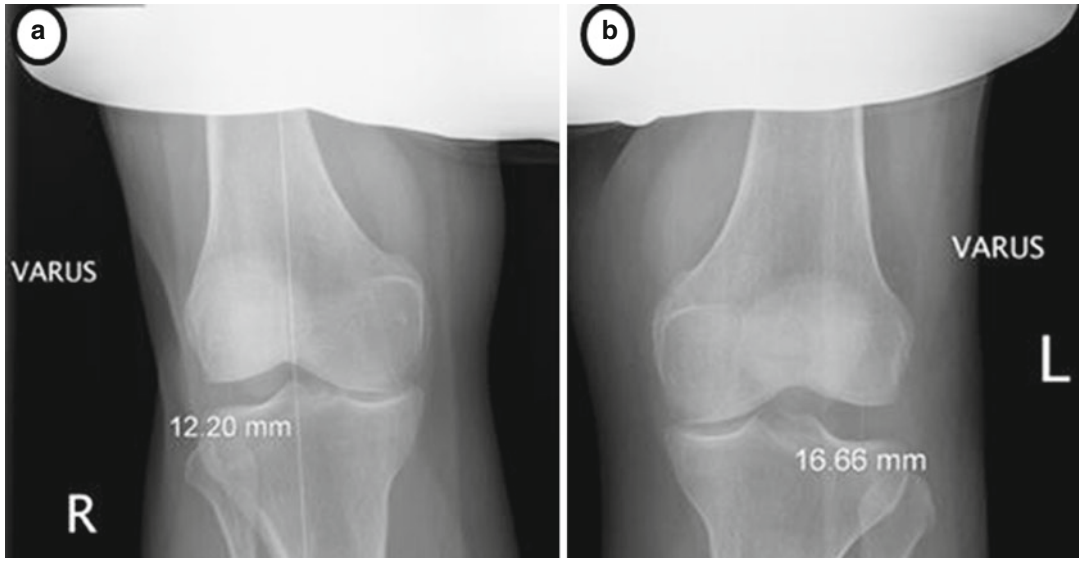

Fig. 26.7 Varus stress radiographs demonstrating a side-to-side lateral gap difference of 4.4 mm, indicating a high likelihood of a grade III PLC injury. (**a**) This image shows the right knee with a lateral gap measurement of 12.2 mm, and (**b**) this image shows the left knee with a lateral gap measurement of 16.6 mm

measuring the amount of lateral and medial compartment gapping compared to the contralateral side. A biomechanical study by Laprade et al. [38] showed that valgus stress radiographs resulting in medial gapping >3.2 mm at 20° of flexion compared to the contralateral knee were indicative of a grade III MCL injury. When sectioning the PCL in addition to the medial structures, medial gapping increased by an additional 3.7 mm and 2.5 mm at 0° and 20° of flexion, respectively [38]. A separate biomechanical study by LaPrade et al. [40] reported that varus stress radiographs resulting in lateral gapping >2.7 mm compared to the contralateral knee indicated a complete FCL tear and gapping >4 mm was highly indicative of a grade III PLC injury (Fig. 26.7). Furthermore, lateral gapping of approximately 7.8 mm compared to the intact state was reported to occur with grade III PLC injuries combined with PCL and ACL tears, verifying the importance of the cruciate ligaments as secondary stabilizers to varus force [40].

26.5.3 Computed Tomography

Computed tomography (CT) scanning has a useful but limited role in the diagnosis of PCL injuries. Indications for CT include avulsions, tibial plateau fractures, other associated fractures, and revision surgeries to visualize the previously placed tunnels [11, 18, 44].

26.5.4 Ultrasonography

Although limited in number and scope, several reports have documented to potential utility of ultrasonography (US) for the diagnosis of PCL injuries [7, 32]. Potential advantages of US include the relative inexpensiveness, the noninvasive nature of the study, and the ability to be performed in a timely manner. A report by Cho et al. [7] indicates that US may be helpful to diagnose PCL injury when prior studies are inconclusive and before performing expensive MRI or invasive arthroscopy. Using a posterior approach, an acutely torn PCL thickens to >10 mm, loses its sharply defined posterior border, and has a heterogeneously hypoechoic appearance in contrast to the normal homogenous hypoechoic appearance [7]. However, US may be only able to identify the posterior portion of the PCL because the anterior portion is too deep to be detected [7]. Further studies needed are needed to validate the utility of ultrasonography.

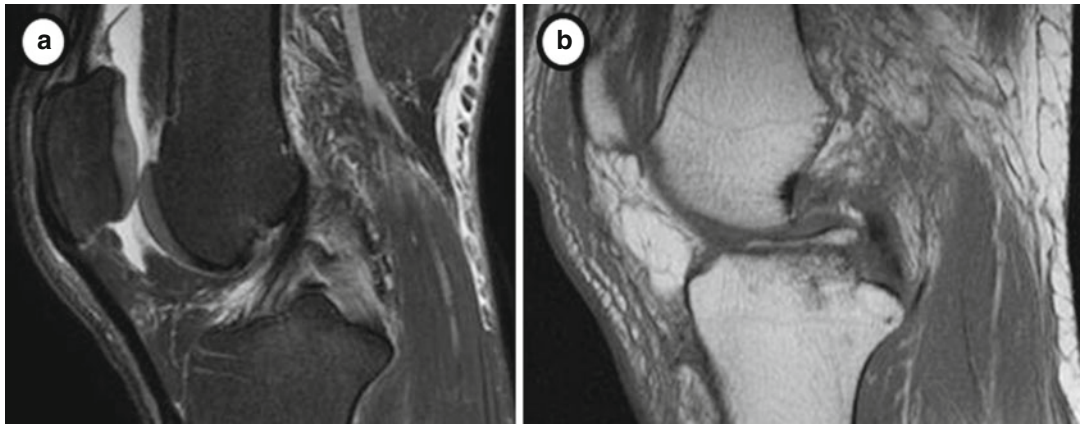

Fig. 26.8 Magnetic resonance images demonstrating PCL tears. (**a**) Sagittal T2-weighted image demonstrating a complete PCL tear at the femoral attachment, with discontinuous fibers seen near the tibial attachment. (**b**) Sagittal T1-weighted image demonstrating a midsubstance partial PCL tear

26.5.5 Magnetic Resonance Imaging

Reports on MRI use for the detection of PCL injuries have repeatedly demonstrated excellent accuracy for acute injuries, documenting a sensitivity of 100 % and specificity ranging from 97 % to 100 % [15, 20, 21, 35, 60]. Complete PCL evaluation with MRI requires axial, coronal, and sagittal views [11]. Additionally, MRI can provide clues to the mechanism of injury, such as bone bruises on the anterior proximal tibia [54]. The normal appearance of the PCL on MRI can vary in shape but consistently appears as a continuous band of low signal intensity in all pulse sequences with a maximum AP diameter of 6 mm on sagittal T2 images [20, 63]. On the contrary, a torn PCL will have an AP diameter of >7 mm on sagittal T2 images.

The appearance of PCL tears on MRI varies by type of tear and can be classified into midsubstance, partial, complete, or avulsion tears. Midsubstance tears are identified by edema and hemorrhage within the ligament. Complete PCL tears exhibit a loss of tendon continuity and may show an increased signal at the edges of the tear (Fig. 26.8a). Partial tears show segmental interruption at one of edges of the ligament and occasionally a circumferential ring of hemorrhage can be seen (Fig. 26.8b) [11]. PCL avulsions typically occur at the tibial insertion and the ligament and bony fragment appear retracted [11, 18].

Additionally, MRI is considered the gold standard imaging modality to detect multiligamentous knee injury [11]. MRI can readily detect bone bruises, which have been reported to commonly occur in PCL tears, specifically to the medial and lateral compartments [47]. Mair et al. [47] reported that bone bruises to the medial compartment occur significantly more often with concomitant PCL-PLC injuries, and lateral compartment bone bruises were highly associated with combined PCL-MCL injuries. Inspection of the medial compartment is critical, with particular attention to the integrity of the deep and superficial MCL, the posterior oblique ligament (POL), and the medial meniscus. Inspection of the lateral compartment is no less important and should focus on the FCL, popliteus tendon, popliteofibular ligament, ITB, biceps femoris attachment to the fibular head, and lateral meniscus. In multiligament knee injuries, meniscal pathology should not be overlooked because the high-energy mechanism that is typically involved in these injuries has been reported to frequently result in meniscal injury, including meniscal root avulsions [33].

While MRI of acute PCL tears is highly accurate and reliable, MRI detection of chronic ligament tears may not be as useful due to scar tissue

that can give the appearance of an intact ligament, although it is physiologically incompetent [11, 36, 75]. However, complete absence of PCL fibers typically indicates a chronic PCL injury [54]. In chronic PCL tears, stress radiographs are a more reliable modality to assess the structural integrity [28, 31, 65]. The static nature of MRIs creates another limitation, resulting in the inability to assess function and limits of motion [11]. Therefore, an MRI should be supplemented with a clinical history and thorough physical examination.

26.5.6 Arthrometers: KT-1000

The KT-1000 arthrometer (MEDMetric Corp., San Diego, CA) can be used to measure anteroposterior tibiofemoral translation. Posterior translation is calculated by adding the posterior sag with the posterior displacement. First, the posterior tibial sag is measured by having the patient contract their quadriceps to bring the tibia anteriorly to the "quadriceps neutral" point and then having the patient relax and measuring posterior tibial sag. Second, posterior displacement is measured by applying 20 lb of posteriorly directed force to the anterior tibia and measuring the displacement [5, 10]. Hewett et al. [23] reported that the KT-1000 substantially underestimated the amount of posterior displacement and was inferior to posterior stress radiographs. While the KT-1000 has proven reliable and accurate for measuring ACL laxity [49], it has failed to do the same for the PCL [23].

26.5.7 Examination Under Anesthesia

Prior to beginning the operation, examination should be performed while the patient is under the influence of anesthesia. Anesthesia allows for complete muscle relaxation, which is not always achievable during a clinical examination. Bilateral examination of the knee should be performed and compared to the clinical examination. Particular emphasis should be placed on the special tests such as the posterior drawer test because a significant difference may be noticed with and without muscle contraction. Examination under anesthesia (EUA) can be particularly useful when the patient's clinical examination was limited to <90° of flexion, thereby preventing a complete assessment of PCL integrity [11]. The surgeon must be prepared for the possibility that EUA can occasionally reveal occult injuries that were previously undetected, such as posterolateral or posteromedial injury and can thereby affect the surgical planning [14].

26.5.8 Arthroscopic Evaluation

Arthroscopy allows for a unique opportunity to further evaluate the status of the knee. Arthroscopic inspection and assessment of the PCL should be part of any meniscal or ligamentous knee reconstruction [11]. First, generally assess the state of the knee. Hemarthrosis indicates an acute knee injury, while hemosiderin deposition and a scared and thickened synovium are typical of chronic injuries [11]. General inspection of the menisci and articular surfaces should follow. The patellofemoral articulation should not be overlooked because PCL tears can alter the biomechanics by increasing contact pressure and result in articular cartilage lesions. Significant scar tissue may be present in chronic PCL tears, particularly in the intercondylar notch. This tissue should be debrided to fully visualize the individual PCL bundles [11].

To ensure complete evaluation of the PCL, Fanelli et al. [14] outlined a technique that divides the PCL into three zones. Using an anterolateral parapatellar portal, zone 1 extends from the femoral insertion of the PCL to where that ligament disappears behind the ACL. Zones 2 and 3 are best visualized using a posterior medial portal. Zone 2 is composed of the portion of the PCL that lies behind the ACL. Zone 3 is the tibial insertion. While possible to visualize zone 2 and 3 through the intercondylar notch with the use of a 70° arthroscope, a 30° arthroscope viewed through the posteromedial portal provides superior views [14].

Evaluation should cover direct and indirect signs of PCL tears. Directs signs are those that involve the PCL itself, including midsubstance tears, partial, complete, and avulsion fractures. Indirect signs are the result of altered biomechanics due to PCL insufficiency. One such finding is the sloppy ACL sign; this is where the ACL appears sloppy or loose as a result of posterior tibial translation [14]. It is important not to misinterpret apparent ACL slack as an ACL tear. To differentiate between an ACL tear and a sloppy ACL sign, the tibia must be translated anteriorly to its normal position. This should result in a taut ACL if the ACL is intact.

A posteromedial drive-through sign has been reported to 91.7 % positive predictive value for grade III PCL tears [57]. This sign is assessed by using an anterolateral portal to view the posteromedial compartment by passing through the intercondylar notch between the medial femoral condyle and the PCL. A positive test is when the arthroscope passes easily without the need for valgus stress or increased knee flexion, which is normally required with an intact PCL due to the limited space between the PCL and medial femoral condyle.

In addition to the PCL, the knee should be fully assessed for concurrent injury. PLC injury can be evaluated with a posterolateral drive-through sign, performed by passing the arthroscope between the lateral femoral condyle and tibial plateau. In a PLC-deficient knee, the scope easily passes as a result of increased lateral gapping [37]. Meniscal inspection is critical as injury to the menisci has been documented to frequently occur with multiligament injury, particularly meniscal root damage [33]. Failure to repair a meniscal root tear has been shown to be equivalent to a complete meniscectomy [1, 30].

26.6 Rating: Classification

Classification of PCL tears is helpful to determine to proper management and to predict the prognosis. PCL tears can be classified by severity, time since injury, type of tear, and the presence of associated injuries. Severity is determined by the amount of posterior tibial translation and is classified as grade I, II, or III, where grade I and II are partial tears and grade III represents a complete tear. As mentioned previously, this is done assessing the tibiofemoral step-off. A grade I injury is when the tibial plateau is still anterior to the femoral condyle. A grade II (partial tear) injury occurs when the anterior border of the tibial plateau is flush with the femoral condyle. A grade III (complete tear) injury occurs when the anterior tibial plateau rests >10 mm posterior to the medial femoral condyle, and a high concern for other ligamentous injury should be suspected [12, 44, 50, 77].

Classification of time since surgery is important for predicting outcomes and surgical planning, if it is indicated. The cutoff between acute and chronic injuries is defined as 3 weeks since the initial injury. Pericapsular stretching is seen at a higher incidence in chronic PCL tears [12]. Identification of the type of PCL tear can affect the management as well as prognosis. Tear types can be classified as midsubstance, insertional, or avulsion and further categorized as partial or complete. A PCL partial tear is defined as one that has functional fibers within the ligament that resist posterior tibial translation. A complete tear has no functional fibers within the ligament that resist posterior tibial translation [62]. PCL avulsion fractures almost always occur at the tibial insertion [18].

Determining whether a PCL tear is isolate or part of a more complex multiligament injury has significant implications on management. Multiligament injuries involving the PCL are best managed surgically [68, 76]. On the contrary, isolated PCL tears have shown good outcomes with conservative management [29, 59, 68].

26.7 Summary

PCL tears most commonly result from motor vehicle collisions or sports-related trauma. The most common mechanism of injury is a posteriorly directed blow to the anterior proximal tibia, often from a dashboard in automobile collisions, or due to impact from the ground when falling

with a flexed knee in sports. Multiligament knee injuries involving the PCL are much more common than isolated PCL tears. The work-up must always begin with a complete history and physical examination. The posterior drawer test and tibiofemoral step-off are particularly useful. Following the history and physical examination, radiographs and MRI are often used to assist in the diagnosis. Stress radiographs have been shown to be particularly helpful with initial diagnosis and follow-up because of reliable reproducibility and objective assessment of posterior translation. Posterior stress radiographs using the kneeling technique and Telos device have proven superior to other methods. Moreover, examination under anesthesia and arthroscopic evaluation are also critical part of the work-up of PCL injuries. Additionally, classification of PCL tears is helpful to determine the management and to predict patient outcomes.

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27 Posterior Cruciate Ligament-Deficient Knee: Indications for Reconstruction

Matteo Denti, Pietro Simone Randelli, Luca Mangini, and Davide Cucchi

27.1 Principles

The purpose of PCL reconstruction is to restore normal knee stability, in order to prevent the development of osteoarthritic changes in the joint [118]. Although PCL has a greater likelihood of spontaneous healing than the anterior cruciate ligament in the subacute or acute stages, residual laxity or PCL rupture associated with other injuries may necessitate surgical intervention [62, 76, 77]. The principles of PCL reconstruction are to identify and treat all pathology, accurately place tunnels to produce anatomic graft insertion sites and utilise strong graft material, mechanical graft tensioning, secure graft fixation and an appropriate post-operative rehabilitation program [26–30, 33, 34].

M. Denti
Orthopaedic and Traumatology Department, Clinica Luganese, Lugano, Switzerland

P.S. Randelli (✉) • D. Cucchi
Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Via Mangiagalli 31, Milan 20133, Italy

IRCCS Policlinico San Donato, Via Morandi 30, Milan, San Donato Milanese 20097, Italy
e-mail: pietro.randelli@unimi.it; matteo@denti.ch.it

L. Mangini
Facoltà di Medicina e Chirurgia, Università degli Studi di Milano, via Festa del Perdono 7, Milan 20122, Italy

27.2 Indications

The indications for a PCL reconstruction vary depending upon whether the injury is isolated or combined and whether the injury is acute or chronic [44, 124]. The cut-off between acute and chronic injuries is defined at 3 weeks since the initial injury. Isolated PCL tears have shown good outcomes with conservative management [58, 105, 119].

27.2.1 Acute PCL Tears

Acute isolated injuries with grade I tibiofemoral step-off and injuries with grade II step-off with firm end (type IIA) are amenable of conservative treatment. On the contrary, injuries with grade II step-off with soft end (type IIB) and with grade III step-off are better addressed by surgical treatment (Chap. 19) [30, 83, 86, 130]. Acute multiligament injuries involving the PCL, injuries of the PCL in conjunction with a knee dislocation or anteroposterior laxity >12 mm and complete PCL tears combined with repairable meniscal body or root tears are a possible indication for PCL reconstruction [4, 89, 110, 114, 115, 119, 126].

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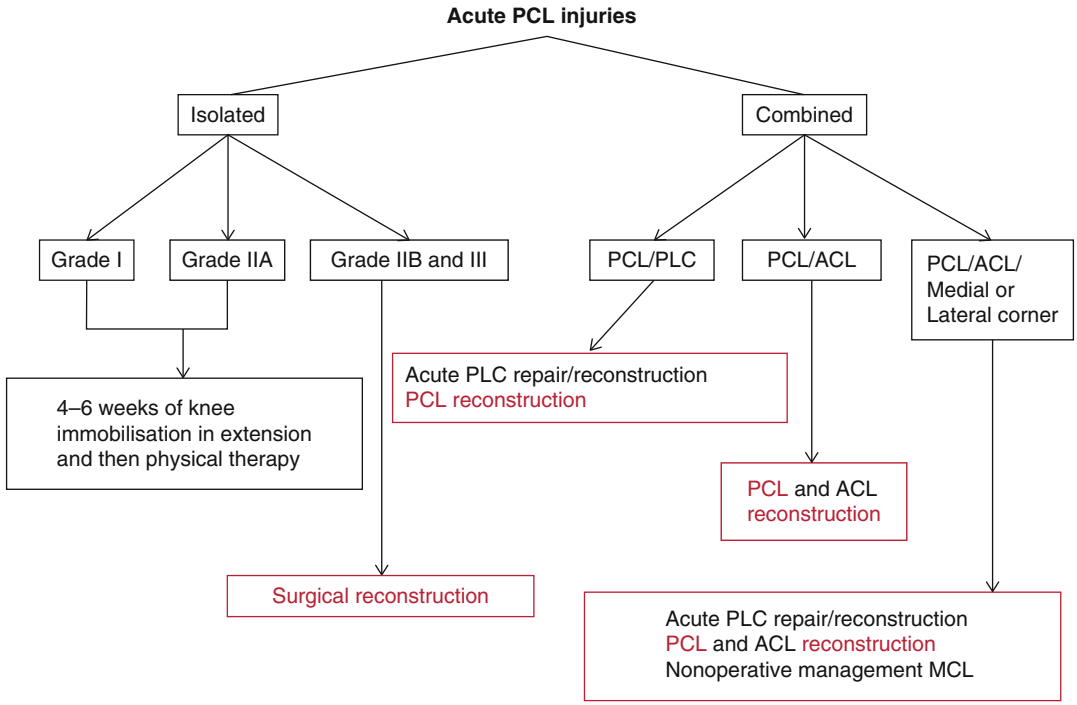

Fig. 27.1 Algorithm for the evaluation and treatment of acute posterior cruciate ligament tears (Modified from [30])

27.2.2 Chronic PCL Tears

Chronic PCL tears combined with grade IIB or III step-off, functional limitations, instability or pain directly related to the PCL injury, anteroposterior laxity >8 mm and the absence of contraindications to a ligament reconstruction are amenable for surgical repair [97].

To identify all associated pathologies, including ligament injuries, meniscal tears, chondral defects or degeneration and limb malalignment, is of capital importance for a correct surgical planning. Patients with chronic PCL or PLC (posterolateral corner) insufficiency may progressively develop medial compartment narrowing and genu varum. Limb malalignment must be corrected through osteotomy, performed in conjunction with ligament reconstructions either concurrently or in a staged fashion. Biplanar osteotomy can optimally control simultaneous correction of coronal malalignment and increase in posterior tibial slope for chronic PCL deficiency and should therefore be preferred [30, 73, 111].

Figures 27.1 and 27.2 provide a simple clinical algorithm for the evaluation and treatment of acute and chronic PCL tears.

27.3 Conservative Treatment

The PCL has intrinsic healing ability after injury, although this healing may occur in a lax or attenuated position [58, 105, 119, 120, 125]. Nonoperative treatment based on splinting and rehabilitation only can be used to address isolated acute grade I and IIA PCL injuries. The knee should be splinted in extension with a pad to counteract gravity pulling the tibia posteriorly for the first 4–6 weeks or protected in a brace that applies a constant or dynamic anterior force to counteract the posterior sag of the tibia [58, 59, 74, 87].

Full extension reduces the tibia, prevents posterior sag and diminishes the effects of gravity and hamstring muscle contraction on tibial translation. Moreover, in this position the anterolateral

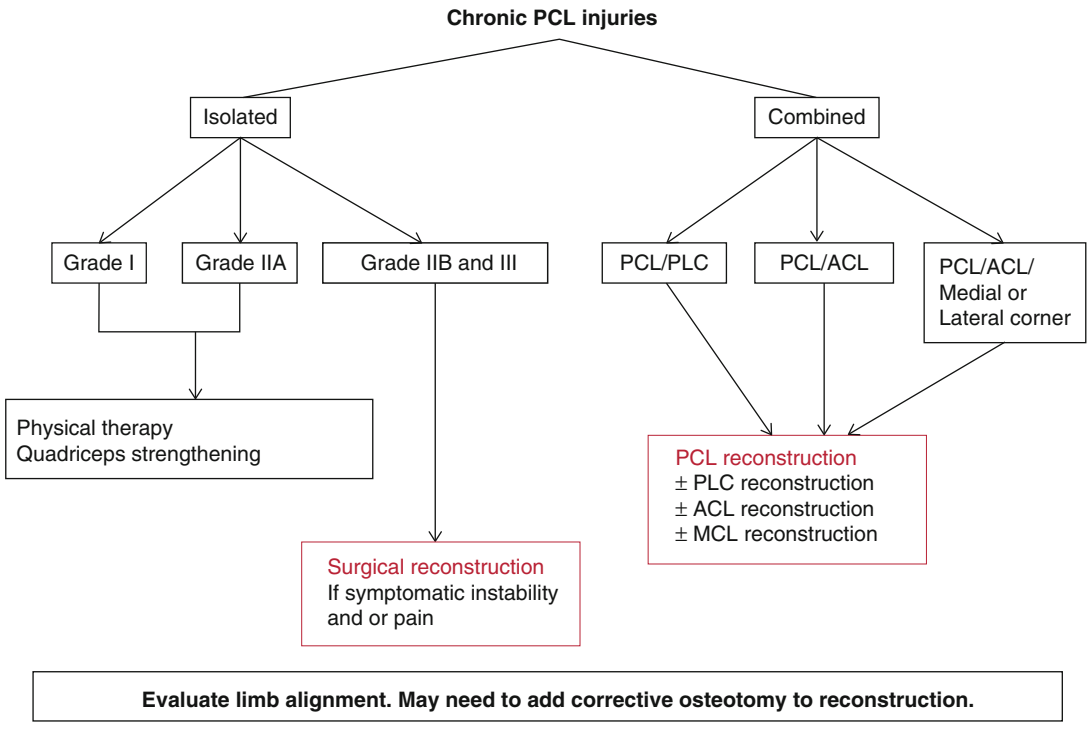

Fig. 27.2 Algorithm for the evaluation and treatment of chronic posterior cruciate ligament tears (Modified from [30])

component of the PCL is slack, allowing healing to occur in a more favourable position from the biomechanical point of view. During this period, quadriceps muscle-strengthening exercises are encouraged, whereas the use of the hamstring muscles is prohibited to minimise posterior tibial load. The patient is then started on progressive weightbearing, with active, assisted range of motion (ROM) exercises and quadriceps strengthening.

Goals of rehabilitation are allow PCL healing, minimise effusion, restore full ROM, strength and function allow return to previous activities. Rehabilitation principles are cooling and compression with elevation to reduce the effusion; exercises to restore full knee extension, flexion and strength; and stationary bicycle or stairclimbing machine to increase endurance. Functional activities and sport-specific training should precede the return to play [118].

In a similar fashion, chronic grade I and IIA PCL injuries can be treated nonoperatively with a physical therapy protocol, which consists in active, assisted ROM exercises and quadriceps strengthening.

27.4 Timing

Compromise of vascular structures, compartment syndrome or the presence of an open or irreducible joint can necessitate an urgent surgical intervention consisting of revascularisation, surgical reduction or compartment release. In high-energy PCL injuries which do not involve the aforementioned complications and in low-energy PCL injuries, to delay ligament reconstruction for a few weeks in an attempt to decrease swelling of the soft tissue envelope is preferred by most surgeons. Better outcomes have been associated to definitive ligament repairs and/or reconstructions performed within 2–3 weeks from the time of injury, while pericapsular stretching is seen at a higher incidence in chronic PCL tears [29, 35, 48, 77, 78, 129].

27.5 Procedures

27.5.1 Graft Choice

The grafts commonly used to reconstruct the PCL can be classified as indicated in Fig. 27.3. Each type of graft has advantages and disadvantages and can have a significant impact on the clinical management and outcomes.

27.5.1.1 Autografts

When compared to allografts, all autograft tissues exhibit faster incorporation with adjacent tissues and have no risk of immune-mediated tissue rejection or infectious disease transmission. Additionally, autograft tissues are not exposed to sterilisation or other processes, which could negatively impact on both the biomechanical and biological properties of the graft.

Donor-site morbidity represents a distinct disadvantage associated with autograft harvest [77].

Several autograft tissue options are available (Fig. 27.4) for harvest either in the ipsilateral or contralateral extremity, including bone–patellar tendon–bone (BPTB), hamstring (semitendinosus and/or gracilis) and quadriceps tendon–patellar bone (QTB). Each graft has its own strengths and weaknesses with regard to biomechanical properties, ease of harvest, morbidity, biology of healing and fixation [77]. Hamstring tendon appears to be the preferred among autografts, being used in 72 % of patients, followed by BPTB in 16 % and QTB in 12 % [53].

BPTB

In BPTB the patellar block is approximately 8 × 20 mm, the tibial block is 10 × 30 mm, and the main length of the tendon is 40–60 mm [18, 20].

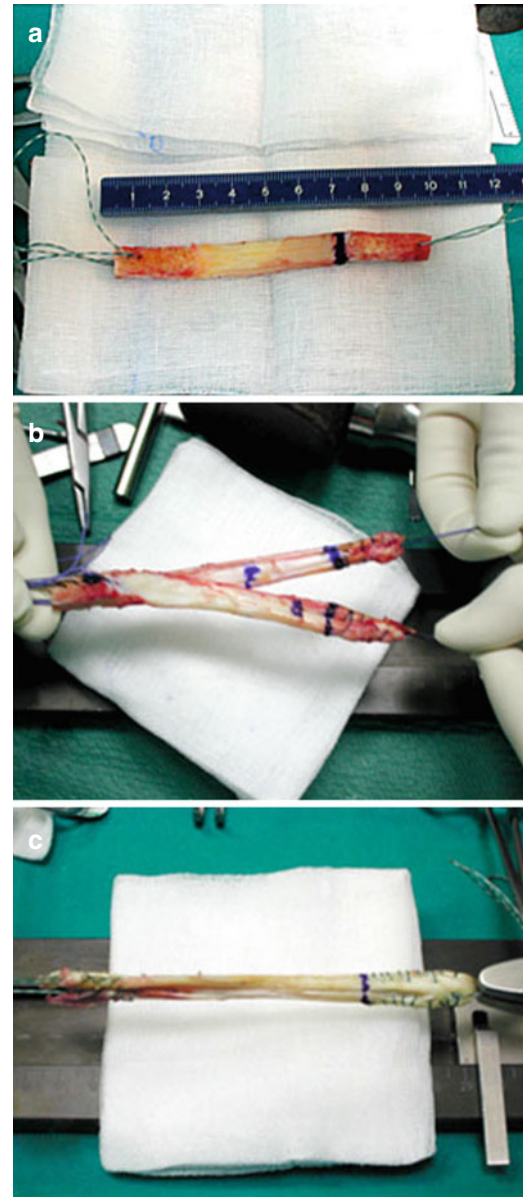

Fig. 27.4 Autografts available for PCL reconstruction, after preparation: BPTB (**a**), QTB (**b**), hamstrings (**c**)

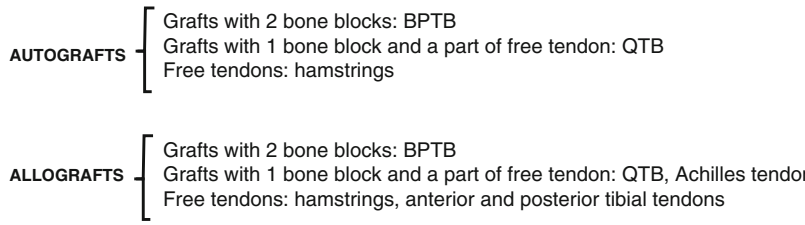

Fig. 27.3 Types of PCL grafts available

BPTB allows stable and simple fixation, and the bone-bone healing promotes quick integration. Possible disadvantages are the arousal of anterior knee pain and worsening of patellofemoral osteoarthritis, patellar fractures, bone block fractures in case of difficult passage of the graft through the tibial tunnel or during fixation of the inlay and herniation of the infra-patellar fat pad through the tendon scar. In rare cases the patellar tendon can be too short to adequately reconstruct the PCL (especially with trans-tibial technique). For this reason the use of BPTB is to be avoided in patients with too short patellar tendon and after patellar fractures.

Moreover, the small section of the tendon might not permit to perform a double-bundle repair [51, 77].

QTB

QTB presents a tendon portion approximately 8–10 cm long, a bone block of 2.5–3 cm and a large cross-sectional area (12×8 mm) [16, 39]. QTB is a versatile graft: its bone block can be fixed either in the femoral or in the tibial tunnel, and its free tendon portion can be splinted to perform a femoral double-bundle surgical technique. QTB is therefore suitable for trans-tibial and tibial inlay techniques and for revision surgeries [51, 100, 140].

QTB is less popular than other graft options for the more demanding surgical technique, the possible arousal of anterior knee pain and worsening of patellofemoral osteoarthritis and the theoretical concern of weakening the quadriceps and the extensor mechanism in its harvesting [22, 136].

Hamstrings

Hamstrings are versatile graft: their harvest is low demanding, quick and does not damage the patellofemoral complex, and it's possible to perform all surgical techniques with easy passage of the graft through every type of bone tunnel. Disadvantages of the hamstrings are possible tendon rupture during harvest, hematoma of the soft tissues (more frequent if harvesting is performed "aggressively") and some difficulty in the tendon preparation. Worsening of the medial instability is a concern when using hamstrings; for this reason autograft hamstrings are contraindicated in sports, in which the medial structures are under tension (e.g. dancing) and in patients with a medial collateral ligament tear [51, 77].

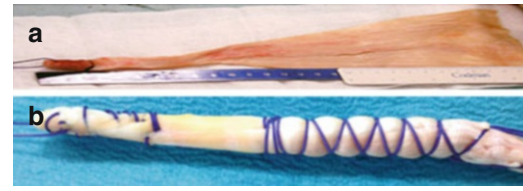

Fig. 27.5 Achilles tendon allograft before (**a**) and after preparation (**b**)

Good short- and long-term results have been reported for PCL reconstruction with QTB [16, 140], hamstring [14, 15, 52, 81, 116, 139, 144, 146] and BPTB autografts [63, 81, 116], with no significant difference found in direct comparisons of QTB with hamstrings or BPTB with hamstring grafts [16, 63, 81].

27.5.1.2 Allografts

Overall advantages of allografts compared to autografts are the broader choice of size and shape options, the elimination of any donor-site morbidity and any additional risk-associated tissue harvest and the reduction of total operative and tourniquet time. Distinct disadvantages are a small risk of infectious disease transmission, slower incorporation of graft tissue, potential for immunologic rejection and increased costs [3, 5–7, 38, 44, 46, 47, 49, 54–56, 77, 94, 99, 117, 123, 133].

The Achilles tendon is currently the most frequently used allograft, due to the presence of a bone block and thanks to its large size and wide sectional area (12×8 mm) which permit to easily splint it to perform a double-bundle repair (Fig. 27.5) [131]. Double-stranded anterior and posterior tibial tendons are also commonly used allografts. Other allograft options include BPTB, hamstrings, and QTB [77].

Artificial ligaments were also proposed for PCL repair [13, 17, 23, 36, 41, 82, 98, 127].

27.5.2 Surgical Techniques

Various techniques have been described to reconstruct the PCL. The main differences among

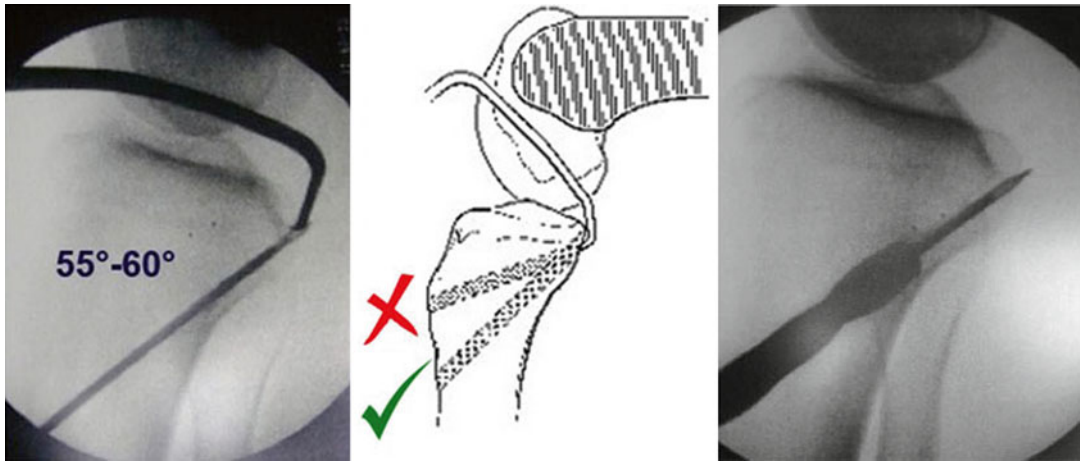

Fig. 27.6 Correct positioning of tibial guide and reamer in the trans-tibial technique

them are the tunnel placement technique (trans-tibial and tibial inlay for the tibial one; outside-in, inside-out and all-inside techniques for the femoral one), the number of femoral tunnels drilled (single-bundle and double-bundle) and the surgical approach (open or arthroscopic).

27.5.2.1 Setting, Portals and Diagnostic

The patient is placed supine. General or epidural anaesthesia may be used. Examination under anaesthesia is useful to confirm and classify ligamentous injuries (Chap. 19). Depending on surgeon's preferences, a leg holder may support the ipsilateral or the contralateral leg, and a lateral post can be used to control the surgical extremity; the use of a tourniquet may facilitate visualisation. Fluoroscopic imaging is recommended, although not routinely used by some authors. A 70° arthroscope may improve visualisation and should be available [30].

The arthroscopic instruments are inserted with the inflow through the superolateral patellar portal. Instrumentation and visualisation are positioned through inferomedial and inferolateral patellar portals and can be interchanged as necessary. Additional portals are established as necessary.

If blood clots or loose bodies are present, irrigation and debridement are performed. Routine diagnostic arthroscopy is first performed addressing meniscal and chondral pathology as encountered. Capsular or meniscal lesions are treated according to surgeon's preferred technique. The PCL tear is then documented and the insertion sites are debrided [28].

27.5.2.2 Tibial Graft-Positioning Techniques

Trans-tibial Technique

Any adhesions in the posterior aspect of the knee must be removed and the capsule elevated from the posterior tibial ridge with curved over-the-top PCL. This will allow accurate placement of the PCL drill guide and correct placement of the tibial tunnel. The arm of the PCL guide is inserted through the inferior medial patellar portal, and the tip of the guide is positioned at the inferior lateral aspect of the PCL anatomic insertion site. Many PCL guides have a graded intra-articular arm which enables the surgeon to accurately determine the distance from the joint surface, which must be 15–20 mm from the articular surface. The bullet portion of the guide is placed 1–2 cm below the tibial tubercle (7 cm below the joint line), after having retracted the pes anserinus tendons. The angle between this guide and the transverse plane of the tibial plateau must be 55–60° (at least 45°, Fig. 27.6); a more proximal positioning of the guide (which decreases the aforementioned angle and produces a horizontal tunnel) may cause difficulties in introducing the graft and increase the risk of injury to the neurovascular structures. Furthermore, a sharp angle between the intra-osseous and intra-articular

portion of the graft may cause abrasion, attenuation and eventually failure of the graft at this "killer turn" [10, 11, 92].

Once the position of the bullet portion of the guide is decided, a blunt spade-tipped guide wire is drilled from anterior to posterior, and the appropriately sized standard cannulated reamer is used to create the tibial tunnel.

It is recommended, especially for less experienced surgeons, to use an image intensifier and maintain the instruments under constant visual control, to ensure the correct position of the guide wire and of the tunnel.

Tibial Inlay

All-arthroscopic tibial inlay technique combines the advantages of both the trans-tibial and open inlay techniques while obviating the disadvantages of each technique.

The tibial socket is created prior to the femoral tunnels at the PCL insertion site, using a guide pin and a retrograde drilling system (Fig. 27.7); the target for insertion of the guide pin is within the footprint and 7 mm distal to the proximal pole of the tibial footprint. Guide pin placement and reaming should be performed with assistance of fluoroscopy and under direct arthroscopic visualisation. Care must be taken to avoid plunging into the posterior structures of the knee. A graft with a bone block is then inserted arthroscopically from the anteromedial portal (which may need to be extended 1–2 cm to ease the passage of the graft). Arthroscopic passage of the bone block and tibial socket docking can be technically challenging.

After proof of the adequate press fit, the graft is secured with suspensory fixation [79, 135].

27.5.2.3 Femoral Graft-Positioning Techniques

Single-Bundle

The synovial membrane at the PCL femoral insertion must be removed in order to properly view the femoral PCL footprint. During this manoeuvre, care must be taken in preserving the meniscofemoral ligaments of Humphrey and Wrisberg, which act as PCL agonists.

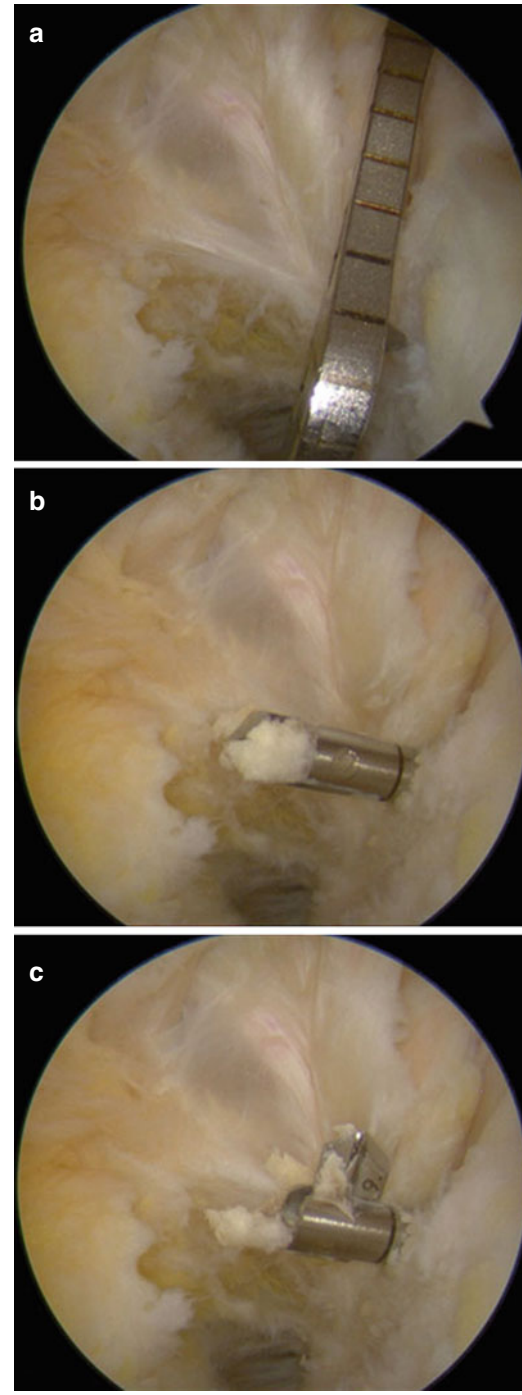

Fig. 27.7 Arthroscopic tibial inlay, creation of the tibial socket: the tip of the guide is positioned at the PCL insertion site (**a**); a retrograde drilling system is inserted (**b**) and activated (**c**)

Nonanatomic "isometric" reconstruction (entry point approximately 11 mm from articular surface, more proximal than anatomical entry

point) has been reported to result in initial joint overconstraint and increased laxity over time [40, 44, 90, 91, 106, 108, 110, 128, 137]. Therefore, recent efforts have focused on an anatomic single-bundle reconstruction using arthroscopic and radiographic reference points [4, 61].

The authors prefer an eccentric position of the femoral tunnel. The intercondylar roof and the articular cartilage profile of the femoral condyle are used as anatomical landmarks, to place the entry point of the femoral tunnel at 11 o'clock position (right knee) and 8 mm distant from the articular cartilage. Eccentric placement of the tunnel allows reduction of tensile forces in hyperextension and similar force distribution to native PCL [47, 84, 90, 102].

The "outside-in" technique is performed by creating an incision on the medial side of the knee with dissection through the vastus medialis oblique (VMO) muscle. A tunnel is then drilled from the medial cortex of the femur to the intercondylar notch using an arthroscopically placed PCL femoral footprint guide. The guide arm is introduced trough the anteromedial portal and the tip of the guide is positioned 8 mm from the anterior medial femoral cartilage at 11 o'clock position (right knee). A 2–3 cm bone margin is considered safe to avoid phenomena of bone necrosis of the medial femoral condyle (Fig. 27.8).

The "inside-out" technique is performed by creating an accessory inferolateral portal. Through this portal, a guide pin is inserted into the femoral footprint and then over-reamed through the femoral cortex, with the knee flexed to approximately 100° (90–120°). This position must not be changed during reaming. This technique causes less iatrogenic damage to the VMO and shows lower risk of subchondral bone fractures in comparison to outside-in technique.

The "all-inside" technique is performed using a guide pin and a retrograde drilling system to create the femoral tunnel with minimal damage to the medial cortex. The choice of the guide wire position is similar to the outside-in technique. The retrograde blade is then activated, and a femoral socket to a depth of 25 mm is drilled in a retrograde fashion (Fig. 27.9).

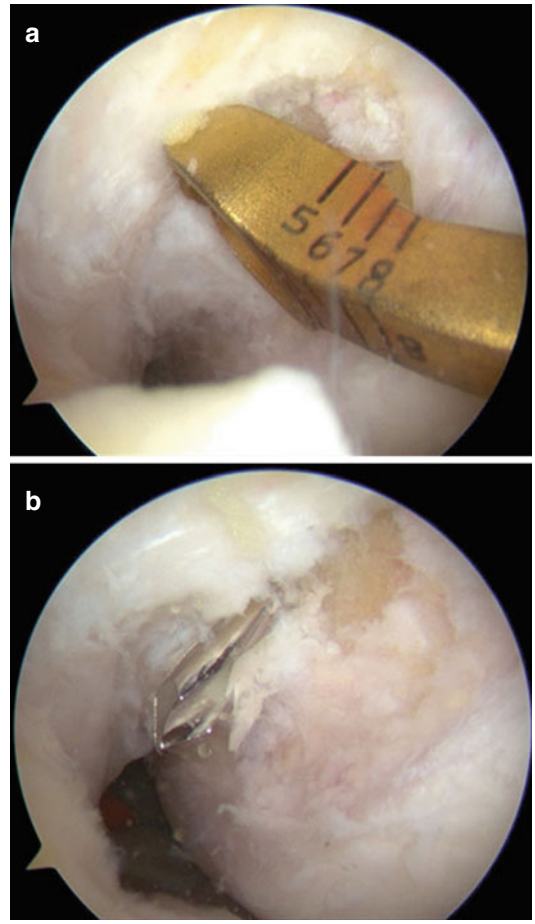

Fig. 27.8 Creation of the femoral tunnel, outside-in technique: the tip of the guide is positioned in the intercondylar notch at the PCL insertion site (**a**); a guide pin is placed and afterwards an appropriately sized cannulated reamer is used to create the tunnel (**b**)

In all three techniques, care must be taken in avoiding the "second killer turn" (otherwise called the "critical corner" [43]). Excessive entry angle of the femoral tunnel is believed to cause graft lengthening and eventually failure [8, 24, 43, 69, 113].

Double-Bundle

Anterolateral and posteromedial bundles of the PCL act in codominant manner, a peculiar aspect which cannot be restored by a single-bundle PCL reconstruction [1, 65, 103, 137]. Anatomic double-bundle PCL reconstruction should there-

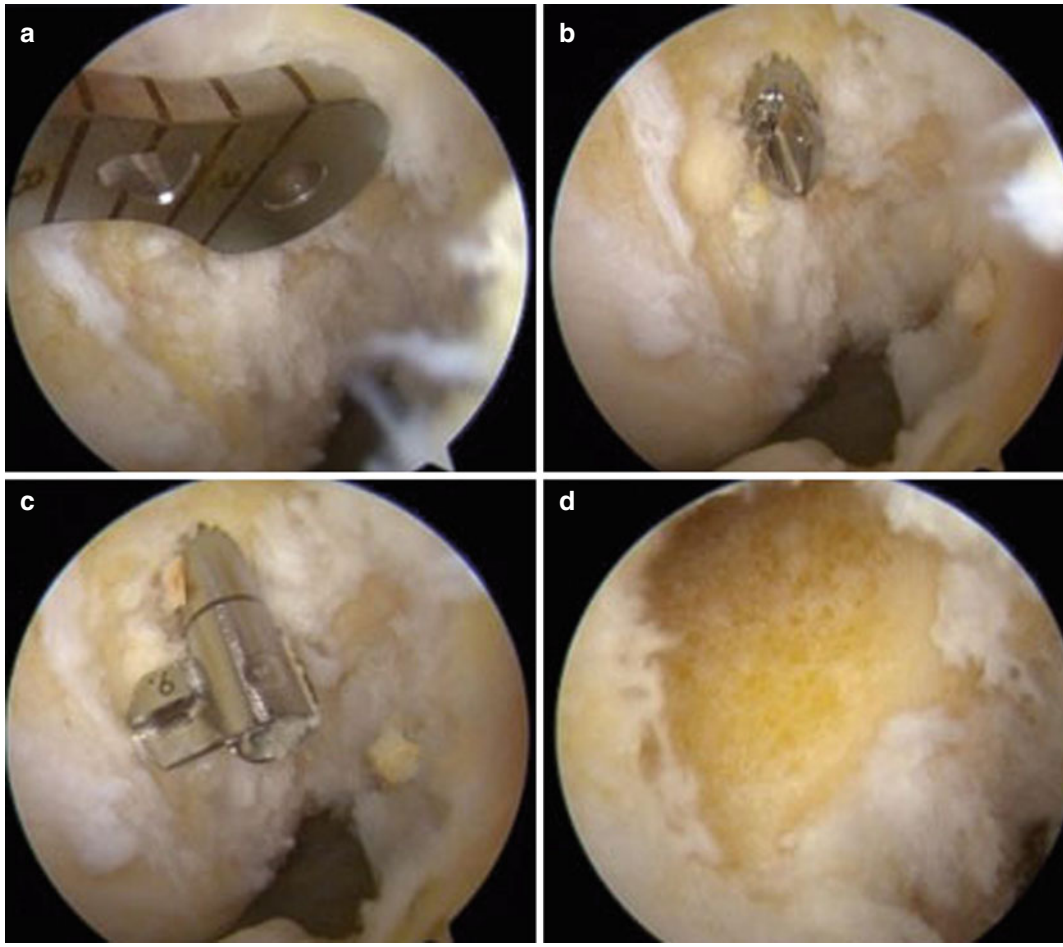

Fig. 27.9 Creation of the femoral tunnel, all-inside technique: the tip of the guide is positioned at the PCL insertion site (**a**); a retrograde drilling system is inserted (**b**) and activated (**c**); a half-tunnel of appropriate size is created (**d**)

fore restore native kinematics more closely than single-bundle technique.

Both tunnels can be performed either with outside-in, inside-out and all-inside techniques, depending on surgeon's preference and experience. A larger tunnel is created for the anterolateral and a smaller one for the posteromedial bundle [45, 95, 124, 137]. The footprint of the PCL is exposed first, and some of the fibres are preserved to aid placement of the femoral socket. The femoral entry point of the posteromedial bundle must be performed at 9 o'clock position and 8 mm from the articular cartilage, and the femoral hole of the anterolateral bundle must be performed at 10:30 position and 13 mm from the articular cartilage (right knee). To avoid tunnel collapse, at least 5 mm of the bone between the two PCL femoral tunnels must be preserved (Fig. 27.10) [79].

27.5.2.4 Graft Fixation Techniques

The purpose of graft fixation is to provide a mechanical link between the graft and the bone during the early post-operative period, until biological incorporation of the graft is complete. A wide variety of techniques for graft fixation in PCL reconstruction can be used [51].

For the femoral tunnel, interference screw within the bone tunnel (metal or bioabsorbable) and suspensory fixation on the cortex of the femoral condyle can be used (Fig. 27.11).

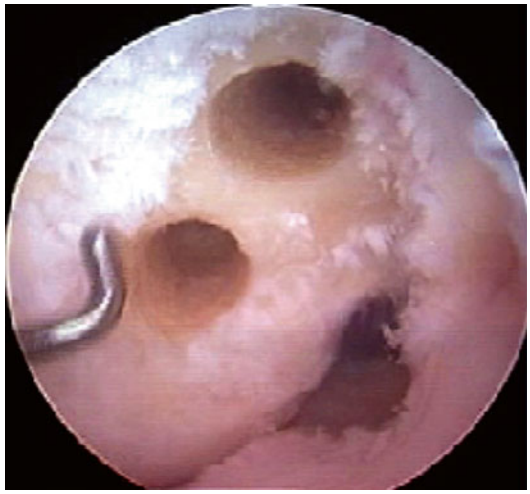

Fig. 27.10 At least 5 mm of bone between the two PCL femoral tunnels must be preserved to avoid tunnel collapse

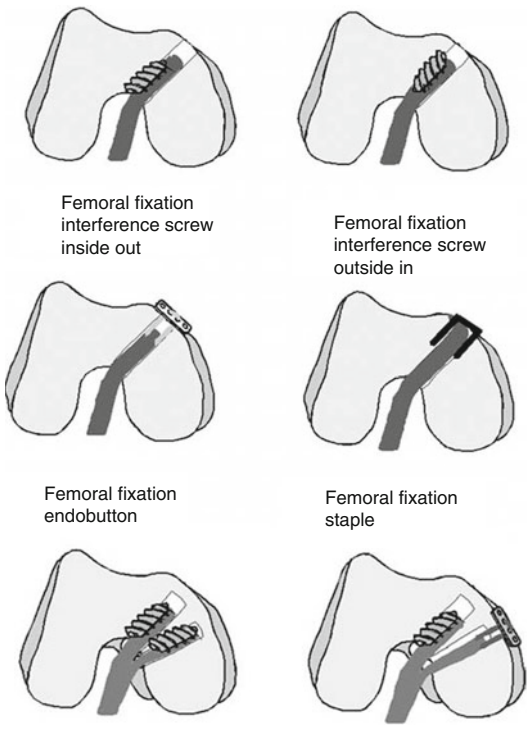

Fig. 27.11 Different options for femoral graft fixation (Reprinted from, Copyright © 2003 Springer, Höher et al. [51], with permission of Springer)

Tibial graft fixation can be achieved by metal or bioabsorbable interference screw, suspensory fixation, bicortical screw and flat washer (Fig. 27.12).

27.5.2.5 Post-operative Care

Rehabilitation plays a fundamental role in determining patient outcomes [25, 72, 138]. Osteointegration and revascularisation of the graft, control of the residual posterior laxity, preservation of correct knee biomechanics, development of optimal response to functional loads, protection of the graft, control of patellofemoral problems and avoidance of deficit in flexion are some of the key points rehabilitation should address.

Since PCL graft healing times have been reported to be almost double the time of anterior cruciate ligament (ACL) graft healing, it has been suggested that PCL reconstruction patients should be kept nonweightbearing for 6 weeks [9, 25, 44, 72]. The authors suggest a brace with posterior support and a pillow during the night.

A progressive, goal-oriented, five-phase rehabilitation program after PCL reconstruction has been proposed to improve stabilisation of posterior tibial translation, varus and external rotation stresses [101, 109].

The authors suggest nonweightbearing for the first week, partial weightbearing for the second and full weightbearing for the third week. Progressive ROM exercises are encouraged to gain full ROM within 4–6 weeks. Proprioception exercises begin at the sixth week, and return to sport is allowed, after dedicated training, from the ninth month.

If combined PCL and posterolateral reconstruction was performed, the brace is kept for 3 months (6 weeks full time), and progressive ROM exercises should proceed slower.

27.6 Complications

Neurovascular injuries can be a direct complication of the initial injury: vascular injury incidence ranges from 16 to 64 %; severity can vary from an intimal tear to a complete transection, requiring vascular surgery intervention. Common peroneal nerve injury incidence ranges from 10 to 40 %; severity can vary from neuropraxia to complete transection [42, 85, 107, 112].

Neurovascular injury is a rare but devastating intraoperative complication: injury may occur if

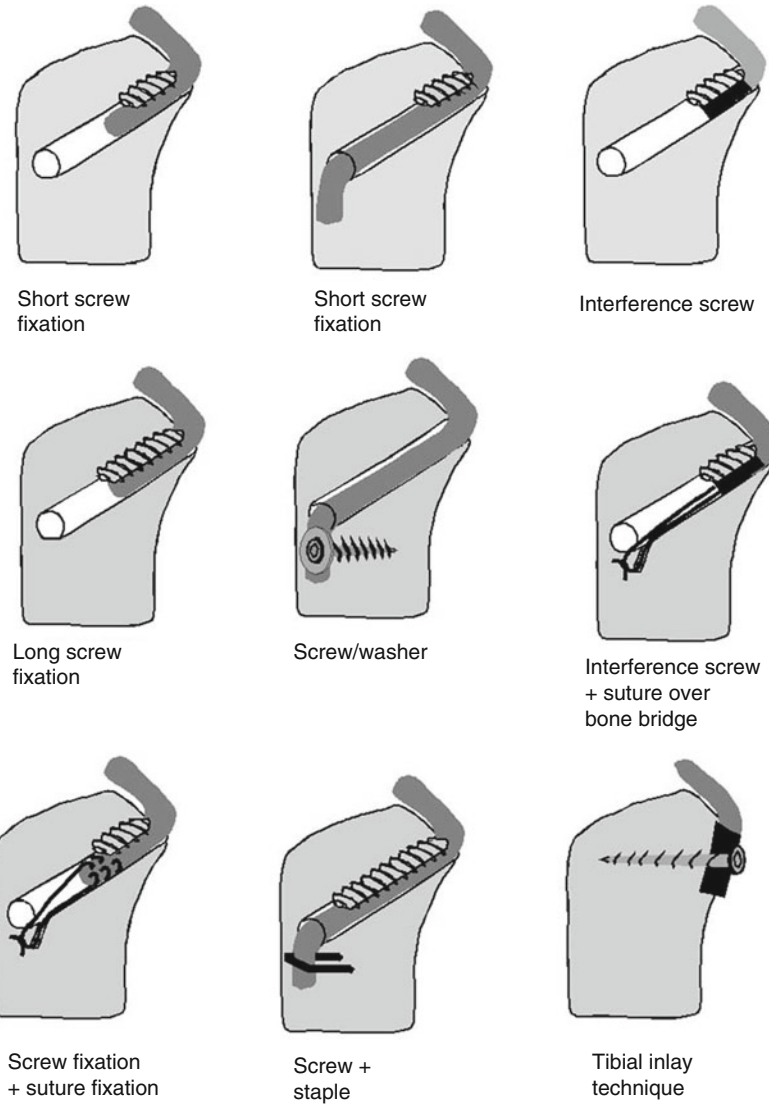

Fig. 27.12 Different options for tibial graft fixation (Reprinted from, Copyright © 2003 Springer, Höher et al. [51], with permission of Springer

the tibial guide pin or reamer overpenetrate the posterior tibial cortex [19, 96, 143]. The popliteal artery and tibial nerve lie posterior to the posterior horn of the lateral meniscus, separated from the knee joint by only the capsule. The popliteal artery passes approximately 7–8 mm posterior to the tibial insertion of the PCL [21, 93, 143]. To increase this distance and therefore lower the risk of injury, knee flexion to 100° and posterior capsular release of the proximal posterior tibia are recommended (Fig. 27.13) [2, 93]. Careful fluoroscopic control is recommended to monitor the position of the guide wire and reamer.

Other rare, specific intraoperative complications include posterior medial or lateral meniscal root avulsions [64], osteonecrosis of the medial femoral condyle [8] and tibial fractures [143].

The most commonly reported complications after PCL reconstructions are residual posterior laxity (usually defined as more than 4 mm of increased posterior translation on PCL stress radiographs) and flexion loss due to prolonged immobilisation of the knee in extension [124, 145].

The rate of ROM deficits ranges from 7 to 30 % [14, 57, 60, 122, 140, 144, 146]. Knee ROM

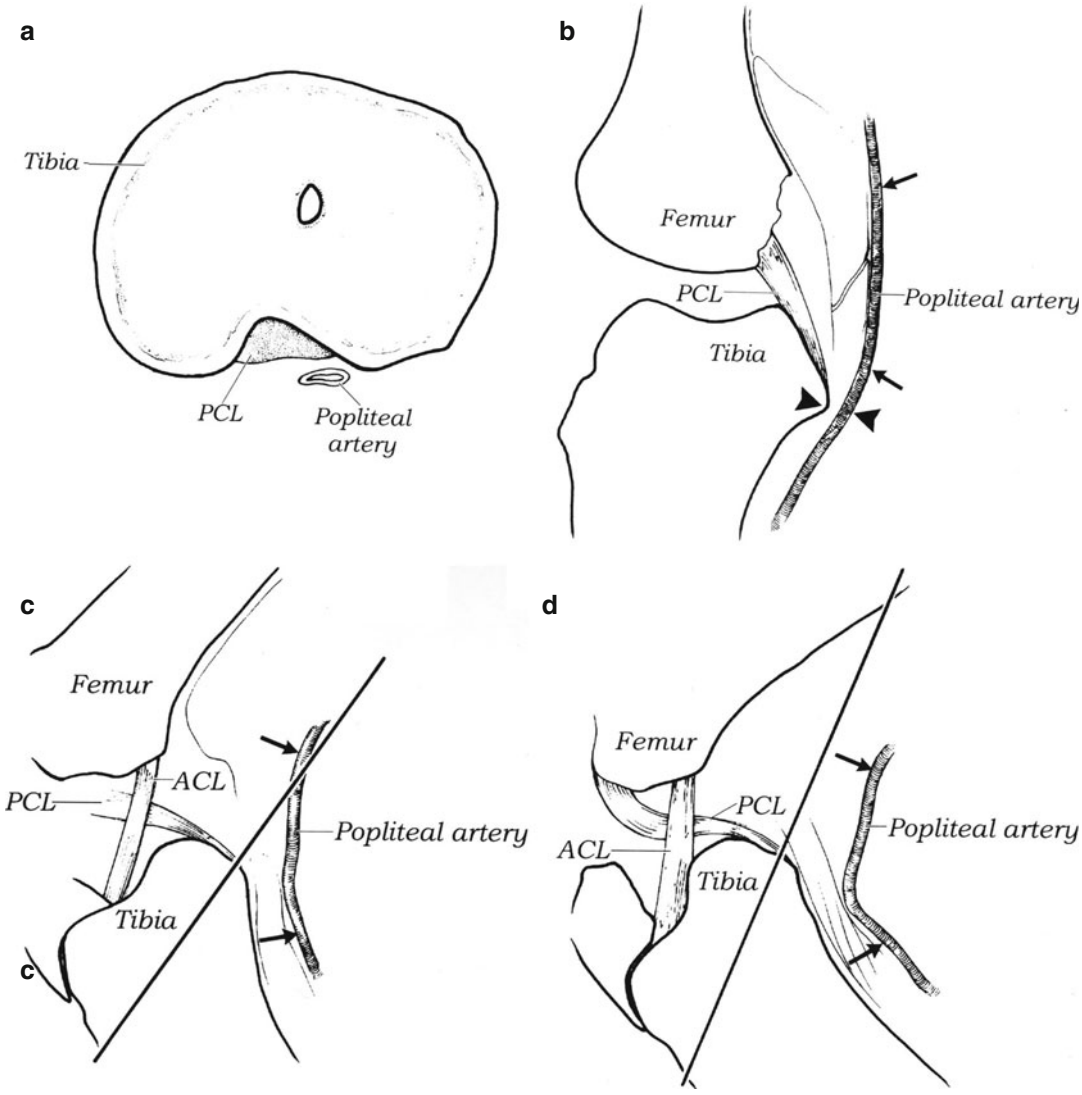

Fig. 27.13 Proximity of the posterior cruciate ligament insertion to the popliteal artery. Axial image showing distance relationships between the posterior edge of the tibial insertion of the PCL and the anterior margin of the popliteal artery (**a**). Knee in extension: the space between the black arrowheads represents the sagittal distance (**b**); knee flexed to 90° (**c**) and 100° (**d**): the line represents the path of a trans-tibial guide pin placed during PCL reconstruction (Reprinted from, Copyright © 2005 Elsevier Inc, Matthew et al. [93], with permission from Elsevier)

loss has been found to be related to the presence of osteoarthritis after ACL reconstruction [119, 121], and we would expect that ROM deficits after PCL reconstruction would also be related to development of osteoarthritis.

Other post-operative complications of PCL surgery are anterior knee pain, painful hardware, heterotopic ossification and infection [85, 143].

27.6.1 Literature Results

27.6.1.1 Nonoperative Treatment

PCL may heal in an attenuated fashion after conservative treatment; however, in spite of good subjective functional scores and a healed appearance of the PCL on magnetic resonance imaging, decreased objective outcomes have been reported at short-term follow-up [37, 125].

Incidence of osteoarthritis at long-term follow-up ranges from 17 to 53 % after nonoperative treatment, as compared with a range of 36–59 % with PCL reconstruction [12, 104, 105, 118, 119].

27.6.1.2 Operative Treatment

Significantly higher post-operative functional scores as compared with the preoperative ones and good rate of normal or nearly normal subjective function can be achieved by arthroscopic single-bundle trans-tibial PCL reconstruction. However, normal knee stability does not appear fully restored in most of the studies reporting this outcome [31, 32, 50, 66, 70, 75].

Significantly improved post-operative subjective scores and significant decrease in post-operative side-to-side posterior tibial translation have also been reported after isolated or combined trans-tibial double-bundle PCL reconstruction with follow-ups ranging from 25 to 45 months [66, 124, 141, 142].

Although early retrospective studies could not indicate differences [66, 71, 132], in more recent prospective studies, post-operative side-to-side posterior translation and objective International Knee Documentation Committee (IKDC) scores were significantly improved for trans-tibial double-bundle compared with single-bundle PCL reconstructions, suggesting that double-bundle PCL reconstruction may be able to more closely and objectively restore the knee to native levels than trans-tibial single-bundle reconstructions [80, 141].

Arthroscopic tibial inlay has showed promising results both in comparison to historical controls and to trans-tibial repairs [67, 68, 88, 134].

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28 Patellofemoral Instability: Classification, Indications for Surgery and Results

Paolo Ferrua, Panagiotis G. Ntagiopoulos, Roch Mader, and David Dejour

28.1 Introduction

Patellofemoral (PF) instability is a very specific area of interest: an often traumatic event is combined with genetic predisposition and congenital abnormalities that form an abnormal PF anatomy, which eventually lead to subjective feeling of instability during sports and daily life activities or even to episodes of true patellar dislocation. Therapeutic indications are only decided after careful clinical and imaging analysis of very specific anatomical predisposing factors that contribute to PF instability. Evaluation of the results of a single surgery is therefore very difficult, since in most of the series reported in literature, a number of different surgical procedures are performed concomitantly. Yet, imaging evaluation with the use of X-rays and cross-sectional imaging (e.g. CT and MRI) dictates a certain algorithm for the surgical treatment of recurrent patellar dislocation.

P. Ferrua
SSD Chirurgia Articolare del Ginocchio, Istituto Ortopedico Gaetano Pini, Milan, Italy

P.G. Ntagiopoulos
Hip & Knee Unit, Mediterraneo Hospital, Athens, Greece

R. Mader
Hôpital Sud, Grenoble, France

D. Dejour (✉)
Lyon-Ortho-Clinic, Clinique de la Sauvegarde, Lyon, France
e-mail: corolyon@wanadoo.fr

28.2 Classification

28.2.1 Clinical Presentation

Patellofemoral instability can present in different clinical forms:

- Objective
  Patellar dislocation (or luxation) is defined as the complete loss of contact between patellar and femoral trochlear articular surface (Fig. 28.1). It represents a true mechanical objective instability and can occur in high-energy activities, frequently associated to a symptomatic hemarthrosis. This loss of contact may be spontaneously reduced or

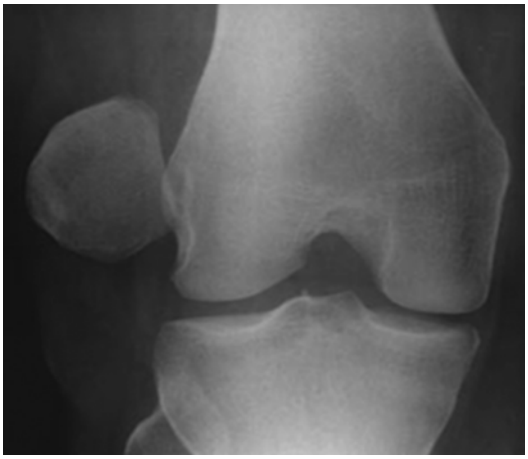

Fig. 28.1 Coronal view showing a lateral patellar dislocation

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irreversibly fixed in a dislocated position that needs immediate medical care.
Subluxation represents a partial loss of contact that is difficult to document, to evaluate and to decide the need for surgical treatment. The patients frequently complain about a knee sprain or a fall but never report a true dislocation. We do not recommend using this term as it defines a condition that is very difficult to evaluate.

- Subjective
Patients report a feeling of instability secondary to inhibition of the quadriceps muscle function by a nociceptive reflex. Patients usually report a rather generic feeling of instability with the knee giving way but without a true dislocation and without hemarthrosis. It occurs frequently during daily living and low-energy activities such as walking, climbing up and down stairs or rising from a seated position.

28.2.2 Specific Patellofemoral Populations

In 1994, Dejour et al. [1] described four different classes in patellofemoral pathology:

- Objective patellar instability (OPI): this group includes patients *with a history of at least one episode of true patellar dislocation*. Most of them present at least one of the major predisposing factors of instability (a pure traumatic dislocation is possible although very rare).
- Potential patellar instability (PPI): patients in this group complain about patellofemoral pain presenting at least one factor of instability *without history of patellar dislocation*. A history of recurrent subluxation or an altered joint kinematic is frequently found in these patients.
- Patellofemoral pain syndrome (PFPS): these patients complain for an anterior knee pain in absence of predisposing factors and without any history of luxation/subluxation.
- Major patellar instability (MPI): patients presenting a habitual or permanent patellofemoral dislocation. Stiffness and shortness of the quadriceps muscle are frequently found in this population:
  1. Recurrent patellar dislocation: the patella dislocates frequently during knee flexion (more than three episodes are required).
  2. Habitual patellar dislocation: the patella dislocates during early knee flexion (<30°) and *every time* the knee flexes.
  3. Permanent patellar dislocation: the patella is always dislocated throughout normal knee range of motion and never faces femoral trochlea.

28.3 Anatomic Factors of PF Instability

28.3.1 Major Instability Factors

From the four instability factors that were originally described in 1987 [1], three of them have a higher significance in PF instability:

- Trochlear dysplasia: it is the abnormally shaped femoral trochlea that becomes flat or convex (instead of concave) and causes loss of joint congruence and abnormal patellar tracking (Fig. 28.2).

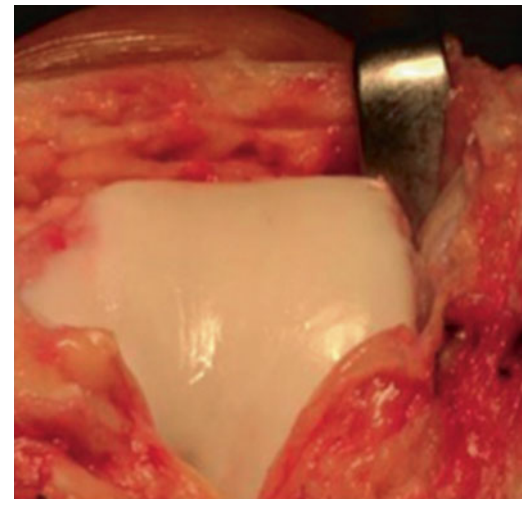

Fig. 28.2 Preoperatory view of a dysplastic trochlea. Proximal trochlea is shallow and prominent

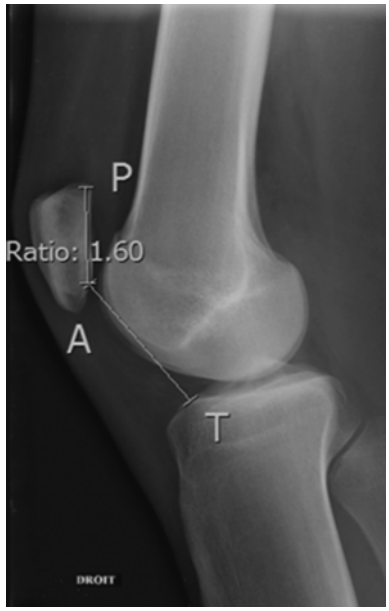

Fig. 28.3 Sagittal view showing a patella alta. Caton-Deschamps index is measured at 1.6

- Patella alta: excessive patellar height keeps the patella away from engaging into the trochlea during flexion predisposing to PF joint instability (Fig. 28.3).
- Excessive tibial tubercle-trochlear groove (TT-TG) distance: this represents an axial malalignment of the extensor mechanism raising valgus stresses on the patella.
- Excessive patellar tilt: previously considered a major factor, it is now considered a resultant of one or more of the other three factors associated to medial patellofemoral ligament (MPFL) rupture.

The genetic and primitive origin of the most consistent major factor and the familiar occurrence of trochlear dysplasia have been shown by C. Tardieu and J.L. Jouve. There is evidence that the asymmetrical trochlear shape in adults exists in the foetus since the third trimester of pregnancy, something that could prove the genetic and primitive roots of trochlear dysplasia [2, 3]. The shape of the articular trochlea is variable in mammals depending on their type of locomotion: unguligrade, digitigrade or plantigrade [4]. The asymmetrical ingression of the patella into the normal trochlea is a characteristic of the modern man. Christine Tardieu's extensive anthropomorphometric studies on this field have showed that the femoral valgus angle, the femoral bicondylar angle and the morphology of the normal trochlea and its articulation with the patella are not present in prime mammals or non-walking children and are the result of human erect stance and bipedalism [4–6]. These anatomic characteristics of the trochlea could have been integrated into the genome during the course of evolution [4, 7]. According to Tardieu, the oblique angle of the femur is the major feature, which initiated the later modifications of the patellofemoral joint that over 3 million years before were never inscribed in the human genome. The elevated lateral femoral facet and the deep trochlear groove are features that 'were first acquired, then once selected, genetically assimilated, and now appear on the foetal cartilaginous epiphysis' [4].

28.3.2 Secondary Instability Factors

Anatomic factors including excessive femoral anteversion, excessive tibial external rotation, knee recurvatum and knee valgus deformity are considered of secondary surgical importance, due to insufficient literature data to confirm pathological values to which they lead to patellar dislocation and values at which they are surgically corrected and lead to treatment of previous patellar dislocation.

More specifically, surgical or conservative management has to be chosen taking into account the recurrence rate, which is very variable, yet their surgical correction is rarely in isolation indicated because no clear thresholds have been shown to predispose to instability. PF instability is more frequent in girls between 10 and 17 years old. Recurrence rate after the first episode of dislocation varies from 15 % to 44 % after conservative treatment and further increases after the second episode [8–10]. Fithian et al. [9] showed in a study on the natural history of PF dislocation that only 17 % of patients experienced a second episode of patellar dislocation during 2–5 years following the first episode of dislocation,

differing from patients presenting a recurrent patellar instability in which recurrence rate in the first 5 years raised to 50%.

28.4 Clinical Evaluation

28.4.1 Medical History

Patient interview must focus on the two most frequent symptoms: instability and pain. Episodes of true patellar dislocation must be carefully investigated asking for evident deformity or evident hemarthrosis after a high-energy trauma. Family history of patellar instability must be investigated. The number of episodes must be quantified in order to address proper treatment.

For the treating surgeon, it is of absolute importance to get the following information from the patient during medical interview:

- If a true patellar dislocation occurred.
- If this dislocation was a result of minor or major trauma.
- If the patellar dislocation was painful.
- And most important, if the dislocation was painlessly reduced by the patient himself or it needed forceful reduction by a medical professional, sedation, etc. A true patella that was reduced without pain by the patient himself usually shows severe underlying pathology, and most definitively, that needs surgical correction.

28.4.2 Physical Examination

There is no pathognomonic sign of PF instability and the physician must focus on knee morphology, patellar kinematics and signs of patellar laxity.

Apprehension test (e.g. *Smillie's test*) [11] is performed in supine position with the knee in full extension. Examiner holds firmly the patella with his fingers applying a lateral directed force, as to reproduce an episode of patellar dislocation. The test is positive if the patient reacts, showing apprehension. The test must be executed bilaterally with relaxed quadriceps and should be avoided in acute setting, as pain and apprehension can be present even before examination. In chronic settings, a positive *apprehension test* reflects the insufficiency of medial patellar passive restraints, namely, MPFL (Fig. 28.4). The *Fithian test* represents a lateral displacement of the patella with the knee flexed at 30°. Examiner tries to displace the patella laterally and the absence of a firm end point confirms MPFL insufficiency. *J-sign* is indicative of abnormal tracking of the patella, which lacks engagement in the femoral trochlea; during active extension, the patella dislocates laterally in full knee extension and as soon as the trochlear restraint fails to contain the patella. It is very important to differentiate *J-sign* from abnormal patellar tracking occurring in passive flexion or in extension. High-grade trochlear dysplasia is almost always present in these settings, but extensor apparel retractions are only typical of abnormal tracking in flexion. *Divergent patellar squint*, also called *grasshopper*, corresponds to high and laterally subluxated aspect of the patella at 90° of flexion. *Lateral patellar tilt test* is performed in full extension: the examiner tries to reduce lateral patellar tilt by elevating its medial facet and correcting the tilt. Impossibility of reduction is related to lateral retinacular tightness. Abnormal tilt recorded at clinical examination positively correlates with excessive tilt values measured with CT scan or MRI [12].

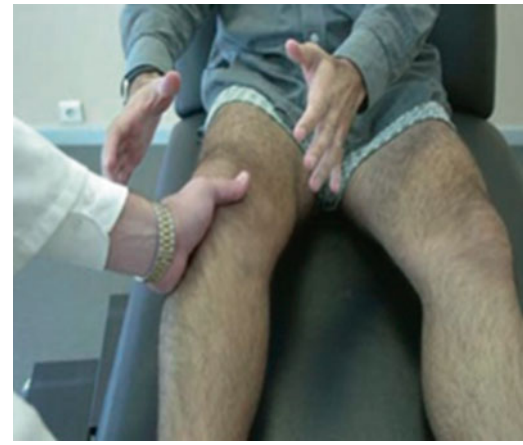

Fig. 28.4 Smillie's test or apprehension test. It is positive in the presence of an antecedent of instability

Other important features to research are genu valgum, presence of an excessive Q-angle, genu recurvatum and lower extremity torsional abnormalities. Dynamic gait analysis is another very important element in clinical assessment of patellofemoral instability, although this element is rarely taken into account in decision-making process.

28.5 Imaging Analysis

In the case of a recorded patellar dislocation, the imaging analysis of anatomic abnormalities is mandatory. Screening of instability factors includes on a standard radiographic analysis with a standard coronal (AP) view, a 'true' sagittal view and an axial view at 30° of flexion and a monopodal weight-bearing sagittal view with the knee in 20° of flexion and the posterior femoral condyles superimposed ('true profile view'). CT scan analysis or MRI should be performed as a second-level exam with a specific protocol. MRI is very interesting in acute phase as it allows to recognize MPFL lesion and to assess the eventual presence of osteochondral lesions.

28.6 Radiographic Exam

28.6.1 Coronal View

Coronal view X-rays should be performed in a monopodal weight-bearing way, if tolerated by the patient, in full extension. This view is rarely contributory for the analysis of PF joint, but it is very important for evaluating femorotibial alignment and for identifying eventual presence of osteochondral loose bodies following a dislocation. In rare cases, this view can show a lateral luxation/subluxation of the patella (Fig. 28.5).

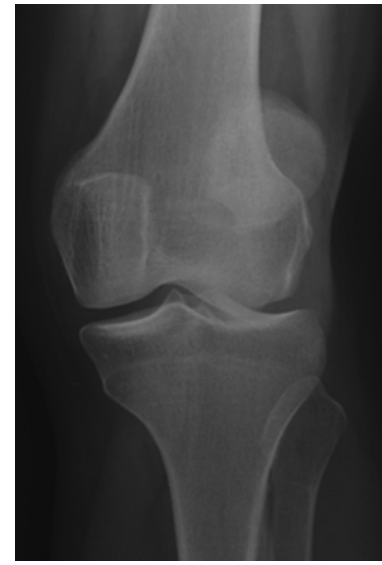

Fig. 28.5 In rare cases, tilt and subluxation are so important that are visible also in a coronal view. In this case, an excessive patellar height is also evident

28.6.2 Sagittal View

It is by far the most important view in PF joint analysis. Reliability of the exam is deeply related to the quality of images and identification of major instability factors. It is of outmost importance to obtain a perfect superimposition of the femoral condyles with the knee flexed between 15 and 20°. Some authors advocate the use of full extension lateral view, but its precision in determining patellar height is controversial. Different degrees of quadriceps contraction or a hyperextended knee (recurvatum) could modify patellar height affecting correct evaluation of the sagittal engagement. A systematic analysis should be performed on this view evaluating:

28.6.3 The Trochlea

In a normal knee, Blumensaat line continues in the trochlear groove bottom line, staying behind the anterior aspect of femoral condyles. Dejour and Walch described in 1987 the *crossing sign*, which is pathognomonic for trochlear dysplasia on lateral view [1]. It represents progressive filling of the trochlear groove that leads to a shallow or even convex trochlea. In the sagittal view, the crossing between trochlear groove line and the anterior aspect of the femoral condyles represent the exact point in which the femoral trochlea is completely flat (Fig. 28.6).

A dysplastic trochlea can also present an abnormal prominence on the anterior femoral cortex; in a study by Dejour et al., trochlear groove line was positioned 0.8 mm average *under* the anterior cortex in controls, while in dysplastic trochleas, the average prominence of the groove was 3.2 *in front of* the anterior femoral cortex [1, 13]. This can raise stresses on PF joint defining the so-called anti-Maquet effect (Fig. 28.7). Crossing sign was found in 96 % of objective patellofemoral instabilities and only in 3 % of healthy controls [1, 13]. Trochlear dysplasia was initially classified in three stages depending on height of crossing sign [1, 13]. A second study performed on 177 patients with objective patellar instability allowed the authors to perform a better analysis of trochlear dysplasia on conventional X-rays and CT scan; trochlear dysplasia classification became more precise and reproducible and four stages were described [14]. Two additional radiographic signs were described on the lateral view (Fig. 28.8).

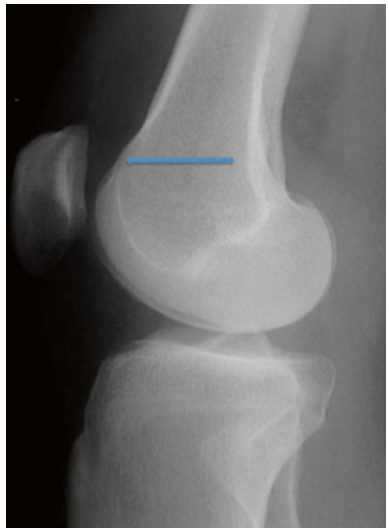

Fig. 28.6 Crossing sign, shown on this sagittal view, represents the point where the trochlear groove bottom line and the anterior border of femoral condyles meet

- The supratrochlear spur found in the superolateral aspect of the trochlea, which represents a global prominence of the groove
- The double contour sign, which represents the medial hypoplastic facet found posteriorly to both the lateral facet and the groove

Four types of trochlear dysplasia were described (Fig. 28.9):

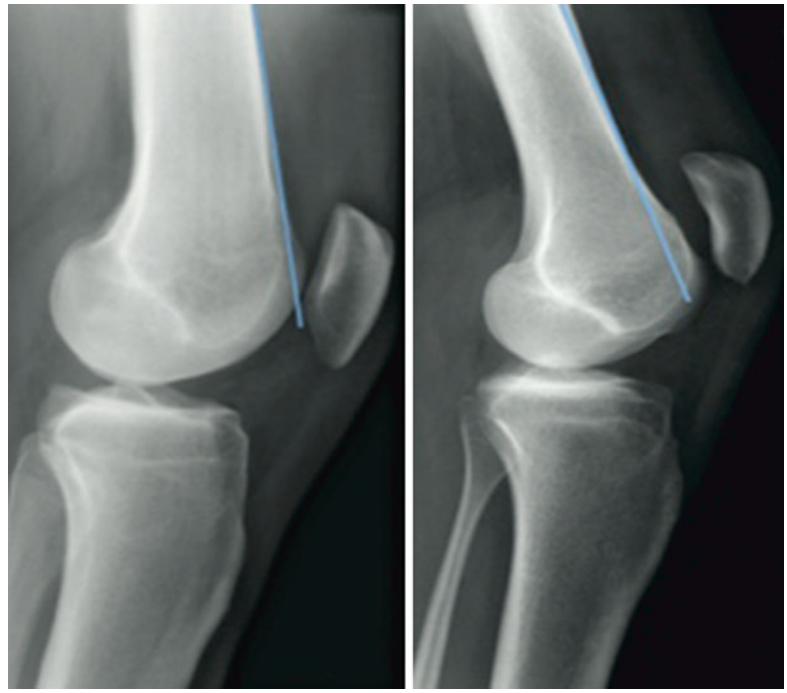

Fig. 28.7 In dysplasia, the trochlea can be prominent. In right image, there is an evident prominence on the anterior femoral cortex

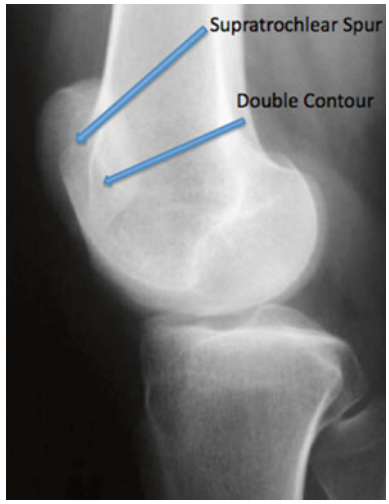

Fig. 28.8 Supratrochlear bump is visible as a spur on the upper part of the trochlea. It corresponds to a global trochlear prominence. Double contour is the projection of medial trochlear facet. It is considered as pathologic if identifiable below the crossing sign. It is identifiable in type C and D dysplasia

- Type A: Presence of crossing sign. The trochlea is shallower than normal but still concave. Sulcus angle is greater than 145°.
- Type B: Crossing sign and supratrochlear spur. The trochlea is flat on CT scan. Pathology is due to elevated groove.
- Type C: Crossing sign and double contour sign. Medial facet is hypoplastic and lateral facet is convex on CT scan. Pathology is due to mostly the diminished size of the facets rather than the elevated groove.
- Type D: Crossing sign, supratrochlear spur and double contour. There is a clear asymmetry of the facets with a steep transition known as cliff pattern. Pathology is due to elevated groove and diminished size of the facets.

Other authors described trochlear dysplasia according to other radiographic criteria. Maldague and Malghem analysed trochlear deepness measured 1 cm below its most proximal point. This measure corresponds to the mean distance between trochlear groove and medial and lateral facets. The mean value was 6 ± 1.5 mm. Dysplastic trochlea is defined below the threshold of 5 mm of depth [15, 16].

28.7 The Patella

Measurement of patellar height: Patella alta and patella infera are diagnosed on 'true' sagittal views. Patellar height has to be measured using one of the principal indexes described in literature:

- *Caton-Deschamps* index represents the ratio between the distance from the lower edge of the patellar articular surface to the anterior angle of the tibial plateau (AT) and the length of the articular surface of the patella (AP). A ratio (AT/AP) of 0.6 or smaller defines patella infera and a ratio greater than 1.2 defines patella alta (Fig. 28.10) [17, 18].
- *Blackburne-Peel* index is the ratio between the length of the perpendicular line drawn from the tangent to the tibial plateau until the inferior pole of the articular surface of the patella (A) and the length of the articular surface of the patella (B). The normal ratio (A/B) is defined as 0.8. The patella is considered infera if the ratio is below 0.5 and alta if greater than 1 (Fig. 28.11) [19].
- *Insall-Salvati* index is the ratio between the length of the patellar tendon (LT) and the longest sagittal diameter of the patella (LP). Patella infera is defined below value of 0.8 and value greater than 1.2 indicates a patella alta (Fig. 28.12) [20].

Many factors have to be analysed when choosing an index for measuring patellar height. Blackburne and Peel method, which is frequently employed in international literature, needs a perfect superposition of both medial and lateral tibial plateau. Caton-Deschamps index seems the most easy and the most 'surgical' index to use for accurate preoperative planning.

28.8 The Patellar Tilt

Patellar shape on sagittal view is correlated to its tilt and global morphology. In a normal, non-tilted patella, most posterior visible part on sagittal view should be patellar crest. Lateral patellar facet projection should be slightly posterior to the medial.

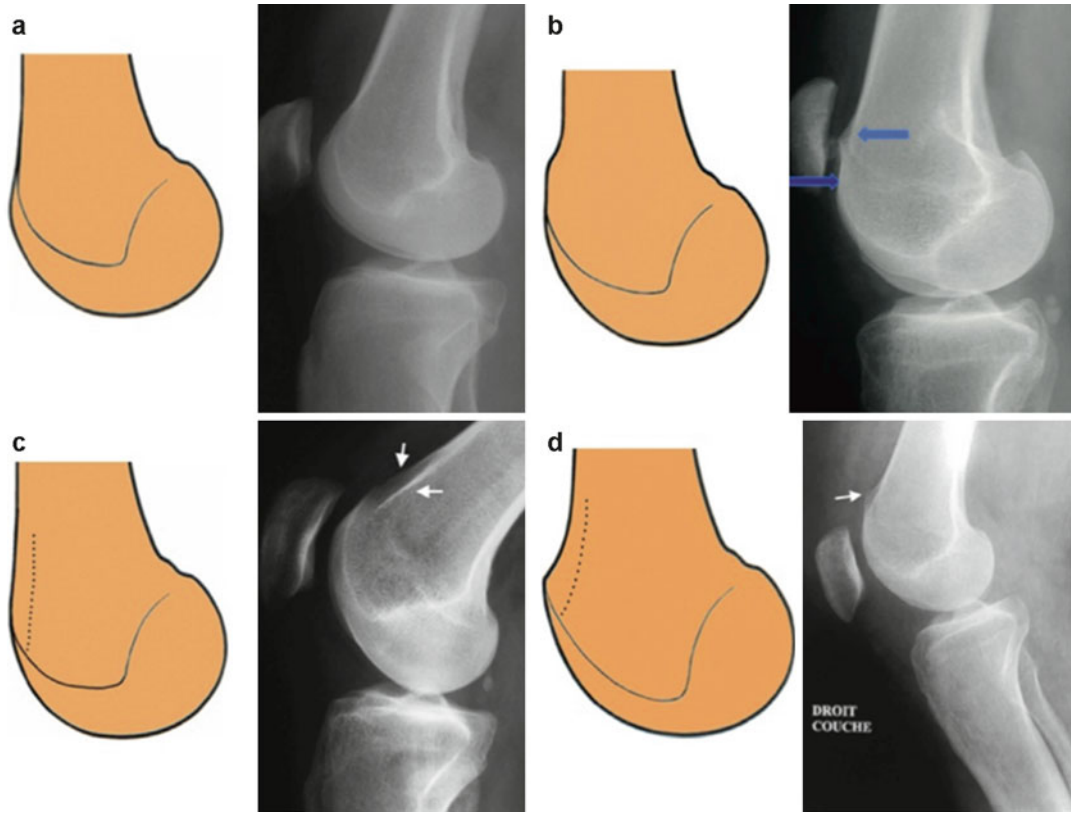

Fig. 28.9 Dejour's classification of trochlear dysplasia. (**a**) Type A: Crossing sign but a normal morphology at CT scan. The trochlear angle is >145°. (**b**) Type B: Crossing sign, supratrochlear spur and flat trochlea at CT scan. (**c**) Type C: Crossing sign and double contour. Medial facet is hypoplastic and lateral facet appears convex at CT scan. (**d**) Type D: Crossing sign, supratrochlear spur and double contour. Medial facet is severely hypoplastic and lateral facet is convex. The transition between the two facets is very steep (cliff pattern)

If a patellar tilt exists, these references change and patellar thickness seems increased. Patellar tilt evaluation has been described by Maldague and Malghem [15, 16]. Three positions were described; in normal position, lateral facet is anterior to the crest. In the presence of a mild tilt, the lateral facet and crest are superimposed with the aspect of a 'false lateral view'. When there is severe lateral tilt, the patellar crest (concave) appears anteriorly to the lateral facet (convex) (Fig. 28.13).

28.9 Axial View

Axial view has been described using different angles of knee flexion and different orientation of X-ray beam. Reference images should be done at 30° of flexion, as superior part of the trochlea and the presence of an eventual dysplasia are better shown (Fig. 28.14): the knee is flexed at 30° of flexion and X-ray beam is directed from distal to proximal on a perpendicularly positioned film. Images obtained in angles of flexion greater than 45° are less indicative, as they show the distal part of the trochlea which is deeper even in severe dysplasia and in which the patella is normally engaged in deep knee flexion. When images are promptly performed, one can evaluate the relationship between the femoral trochlea (at 30°, the width of the lateral facet is two thirds of the total trochlear width) (Fig. 28.15) and the patella (also the two thirds of the patellar width are 'mirrored' by the lateral facet). In axial view, the presence of avulsion fracture from the medial patellar side,

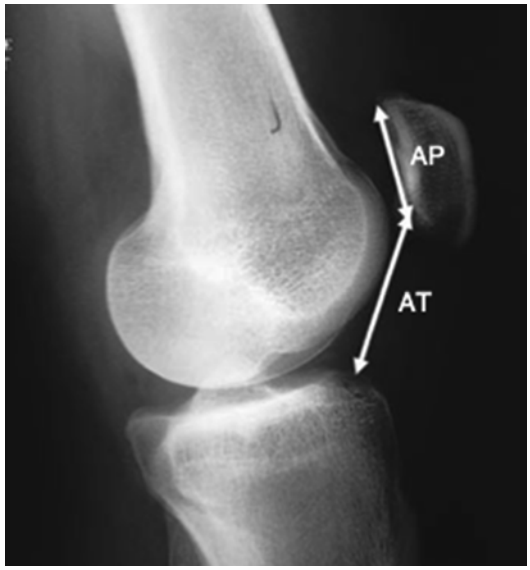

Fig. 28.10 Caton-Deschamps index is defined as the ratio between the distance from the lower edge of the patellar articular surface to the anterosuperior angle of the tibia outline (*AT*) and the length of the articular surface of the patella

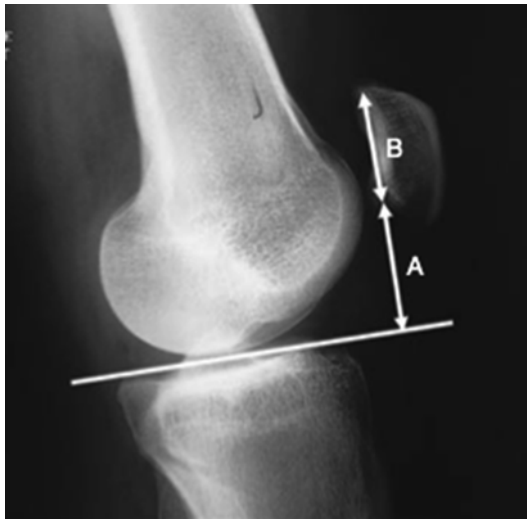

Fig. 28.11 Blackburne-Peel index is defined as the ratio between the length of the perpendicular line drawn from the tangent to the tibial plateau until the inferior pole of the articular surface of the patella (*A*) and the length of the articular surface of the patella (*B*)

the articular congruence and cartilage thickness or the presence of PF arthritis can also be evaluated.

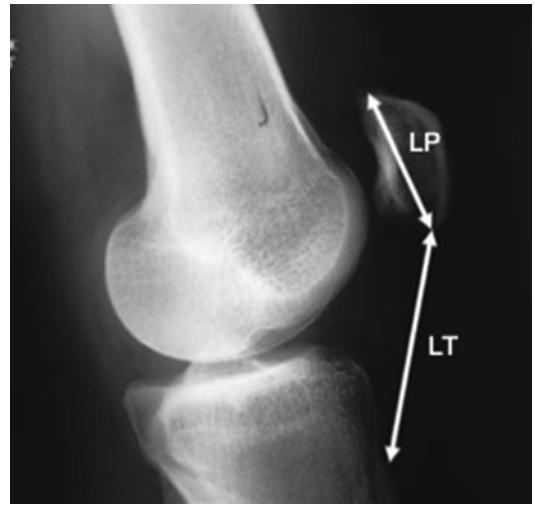

Fig. 28.12 Patellar height measure according to Insall-Salvati

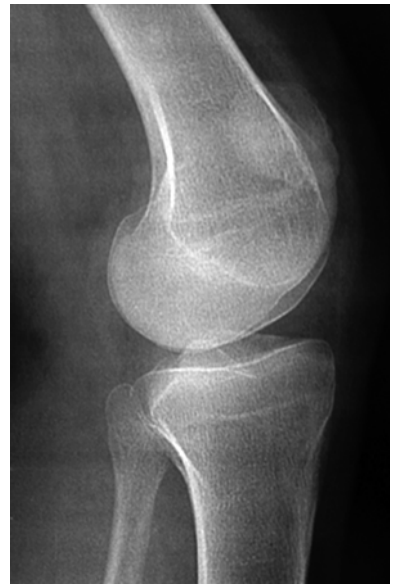

Fig. 28.13 In the presence of an excessive pathologic tilt, the patella is no more visible on sagittal views

Trochlear angle (Fig. 28.16), introduced by Brattström, is defined as the angle between the two trochlear facets in the axial view [21]. The greater is the angle, and the more shallow and dysplastic is the trochlea. Bernageau and Buard, respectively, found a mean angle of 136° (SD of 7.14°) and 144° (SD of 6.75°) on 30° axial view [22]. According to them, an angle greater than

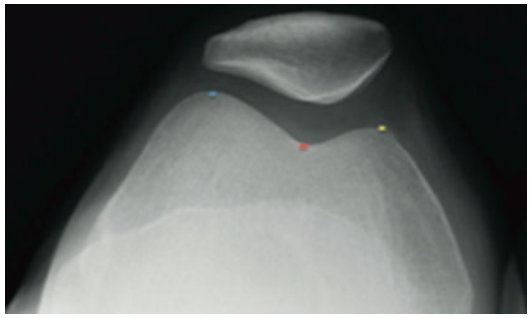

Fig. 28.14 Axial views at 30° of flexion

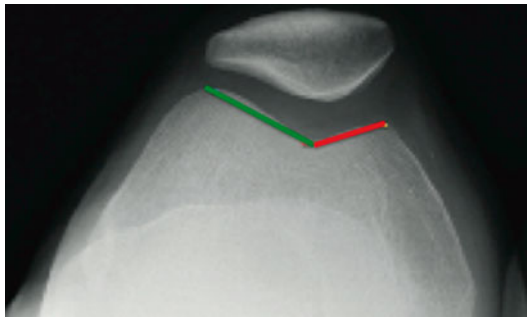

Fig. 28.15 On a 30° axial view of a normal trochlea, lateral facet represents the two third of trochlear width

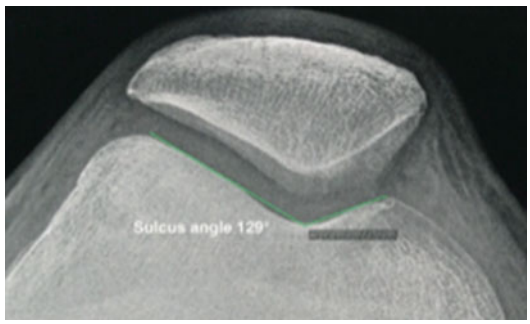

Fig. 28.16 Trochlear angle according to Brattström is defined by the intersection of the two trochlear facets. The more important the angle, the more dysplastic the trochlea

150° is indicative of a dysplastic trochlea. Superior trochlear dysplasia is very well detected using this value, but there is a high incidence of false-negative values caused by images wrongly performed at higher degrees of knee flexion. In acute and chronic PF instability, avulsions of the medial patellar edge can appear on this view and

Fig. 28.17 Axial view showing an osteochondral avulsion of the medial patellar border, direct consequence of a dislocation

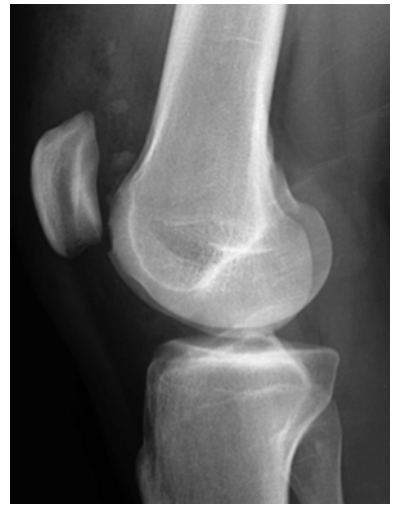

Fig. 28.18 Loose body corresponding to an osteochondral fracture of the trochlear lateral facet

should not be confused with patella bipartita (Fig. 28.17). It is also possible to find osteochondral fractures of the lateral trochlear facet or femoral condyle and even purely chondral avulsions (Fig. 28.18). Finally, patellar morphology can be evaluated using the Wiberg classification using these images.

28.10 Computed Tomography

CT scan performed in extension allows obtaining images that are both reliable and reproducible. This tool is particularly useful for measuring patellar tilt, as knee flexion causes a progressive

engagement of the patella into the trochlear groove, correcting or reducing a pathologic tilt [23, 24]. CT scans also provide a constant measuring reference point, the posterior femoral condyles. The other major interest of CT scan is the possibility of images superposition in analysis of torsional deformities such as femoral anteversion and external tibial torsion using the posterior femoral condyles as reference. Also, TT-TG distance and patellar tilt are well measured using the posterior femoral condyles, which is more accurate than trochlear facets that can be very variable in dysplastic patients. Dejour et al. defined measurement methods and thresholds for normal and pathological values [1].

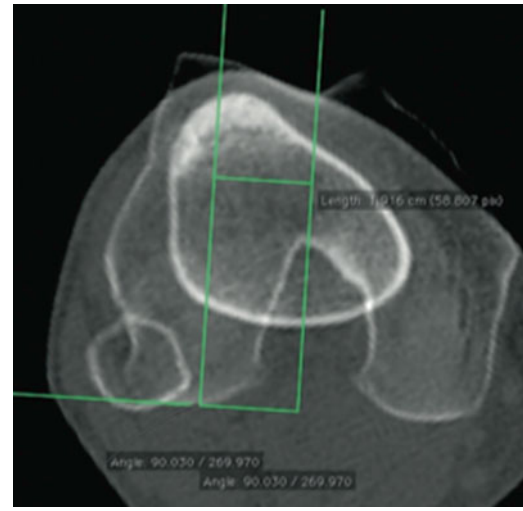

Fig. 28.19 TT-TG measure performed on CT scan. The first cut is the reference cut that passes through the proximal trochlea at the level where the intercondylar notch has the shape of a roman arch. The second cut goes through the proximal part of anterior tibial tuberosity

28.10.1 TT-TG Distance

Initially described by Goutallier and Bernageau in 1978 on X-ray axial views, this measurement quantifies the distance in millimetres between the patellar tendon insertion and the bottom of the most proximal part of the trochlear groove [25]. Since 1994, Dejour et al. started measuring TT-TG distance by using two superimposed CT scan cuts: the first is through the proximal trochlea where the notch is roman arch shaped (first cut with articular cartilage) and the second passes through the centre of anterior tibial tuberosity (Fig. 28.19) [1]. TT-TG distance allows to quantify the coronal alignment of the extensor mechanism, the so-called Q-angle. Values greater than 20 mm – in CT scans – are considered abnormal as this value was observed in 56 % of patellar instability and only 3 % of controls [1]. Standard deviation is very high and abnormality of these values should always be confronted to trochlear morphology.

28.10.2 Patellar Tilt

Patellar tilt is evaluated on CT scans with and without quadriceps contraction and the measurement method is different if compared to traditional 30° axial views. It is defined as the angle between the transverse axis of the patella and a line tangent to the posterior femoral condyles (Fig. 28.20). In 97 % of control population, the mean value ranges from 10 to 20°. In 83 % of patients with objective patellar instability, the value was greater than 20° [1, 26]. Obtaining the mean values between measures performed with and without quadriceps contraction raises the sensibility and specificity of the exam. Using this protocol, we can find values greater than 20° in more than 90 % of patients and only 3 % of healthy controls (Fig. 28.21a, b) [1, 26].

Patellar tilt is a direct consequence of quadriceps dysplasia, patellar height and above all trochlear dysplasia. Quadriceps dysplasia is the result of an abnormality of the vastus medialis, which oblique fibres normally insert on the medial side of the patella: on the contrary, in the presence of a quadriceps dysplasia, the insertion of the muscle fibres is formed only by vertical fibres which are far from the medial patellar side. This concept of dysplasia is very important [1]. This can explain why any muscular strengthening alone to correct patellar instability would only have a limited effect on instability as the lever arm is weak in dysplastic quadriceps. Another frequently observed associated factor is

the retraction of vastus lateralis and lateral retinaculum. A strong association between high-grade trochlear dysplasia (types B, C and D) and pathological patellar tilt has been observed: the more dysplastic is the trochlea, the higher is the tilt [27].

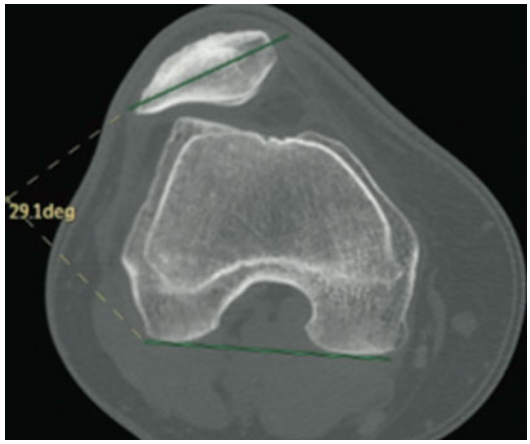

Fig. 28.20 Patellar tilt measure corresponding to the angle between the line tangent to posterior condyles and the line passing through the major transverse axis of the patella

28.10.3 Femoral Anteversion

In order to measure femoral anteversion, two cuts are superimposed: the first one is the knee reference cut (i.e. the one in which the intercondylar notch has the shape of a roman arch), and the second one is a cut centred on femoral neck, where a line passing through the centre of femoral head and neck is traced. The intersection of these two lines defines the femoral anteversion angle (Fig. 28.22). In a study by Dejour et al., a mean anteversion angle was 10.8±8.7° in control population and 15.6±9° in an objective patellofemoral instability population [1]. Even with these differences, the SD values did not permit to find a statistically significant difference, so correction of femoral anteversion alone for the treatment of patellar instability is rarely advised.

28.10.4 Tibial External Rotation

Tibial external rotation is measured on two superimposed cuts: the first centred on the tibial plateau and the second on the distal ankle. Two lines are drawn, one tangent to the posterior aspect of tibial plateau and one passing through

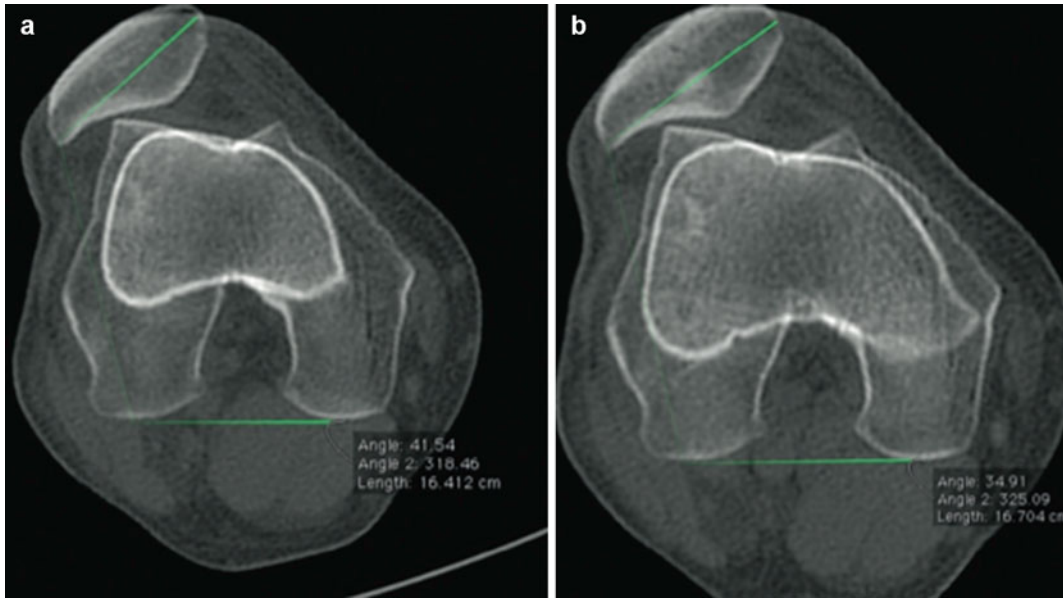

Fig. 28.21 (**a**, **b**) Measure of patellar tilt is performed with contracted and relaxed quadriceps in order to raise sensibility and specificity of the exam

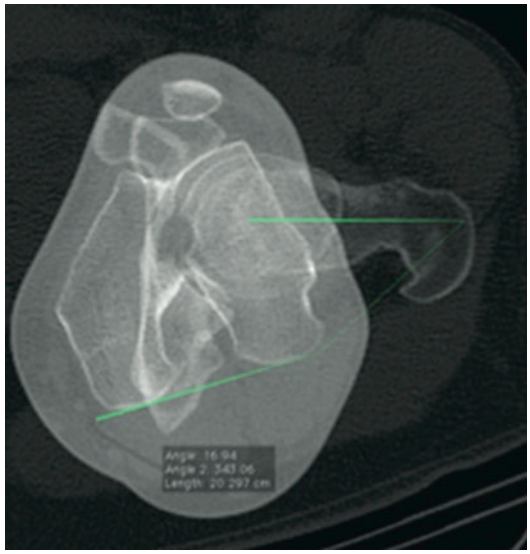

Fig. 28.22 Measure of femoral anteversion by superposition of knee reference cut and a cut passing through femoral neck and head

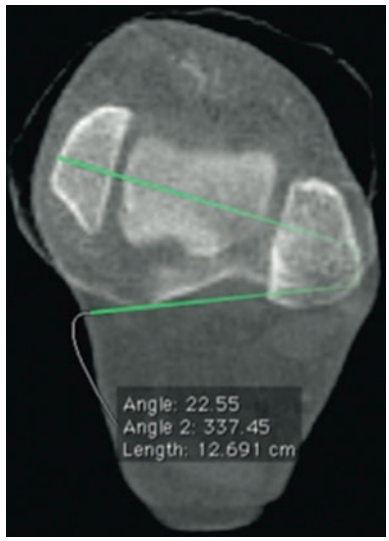

Fig. 28.23 Measure of tibial torsion by superposition of the line tangent to the posterior tibial plateau and the line passing through bimalleolar axis at the centre of the ankle

the bimalleolar axis. The intersection between these two lines defines the external tibial rotation angle [28–30]. In the study by Dejour et al., mean external rotation was 33° in the instability group and 35° in the control population [1]. Nonstatistically significant difference was found (Fig. 28.23), so correction of tibial external torsion alone for the treatment of patellar instability is rarely advised.

28.10.5 Other Findings on CT Scans

CT scan also allows a good morphological evaluation of anatomic abnormalities. Trochlear dysplasia is well visualized on axial and sagittal views (Fig. 28.24), and three-dimensional reconstructions can be very precise in analysing trochlear shape. A further analysis of the status of articular cartilage and loose body identification can be performed with injection of intra-articular iodinated contrast (Arthro-CT) (Fig. 28.25).

28.11 Magnetic Resonance Imaging (MRI)

MRI allows a better visualization of soft tissues and articular cartilage, and it is particularly indicated in detecting bone bruises or subchondral bone marrow oedema. Similarly to CT scan, MRI allows an objective and complete evaluation of the patellofemoral joint. Measurements conceived for standard X-rays and CT scan for quantifying instability factors are also applicable to MRI images.

Landmarks are different from CT scan as cartilaginous surfaces are employed instead of subchondral bone [31]. There can be a good concordance between bony and chondral landmarks, as it frequently happens in trochlear dysplasia, where cartilage homogeneously covers the underlying subchondral bone (Fig. 28.26). Recent studies on PF instability have been performed using MRI and this method will surely develop further in the future [32–37]. Despite these considerations, there is still no consensus for threshold values to be adopted in defining normal and pathologic patellofemoral joint using MRI as a reference.

28.11.1 MRI in Acute Dislocations

MR imaging is particularly helpful in acute dislocation recognition and evaluation of associated

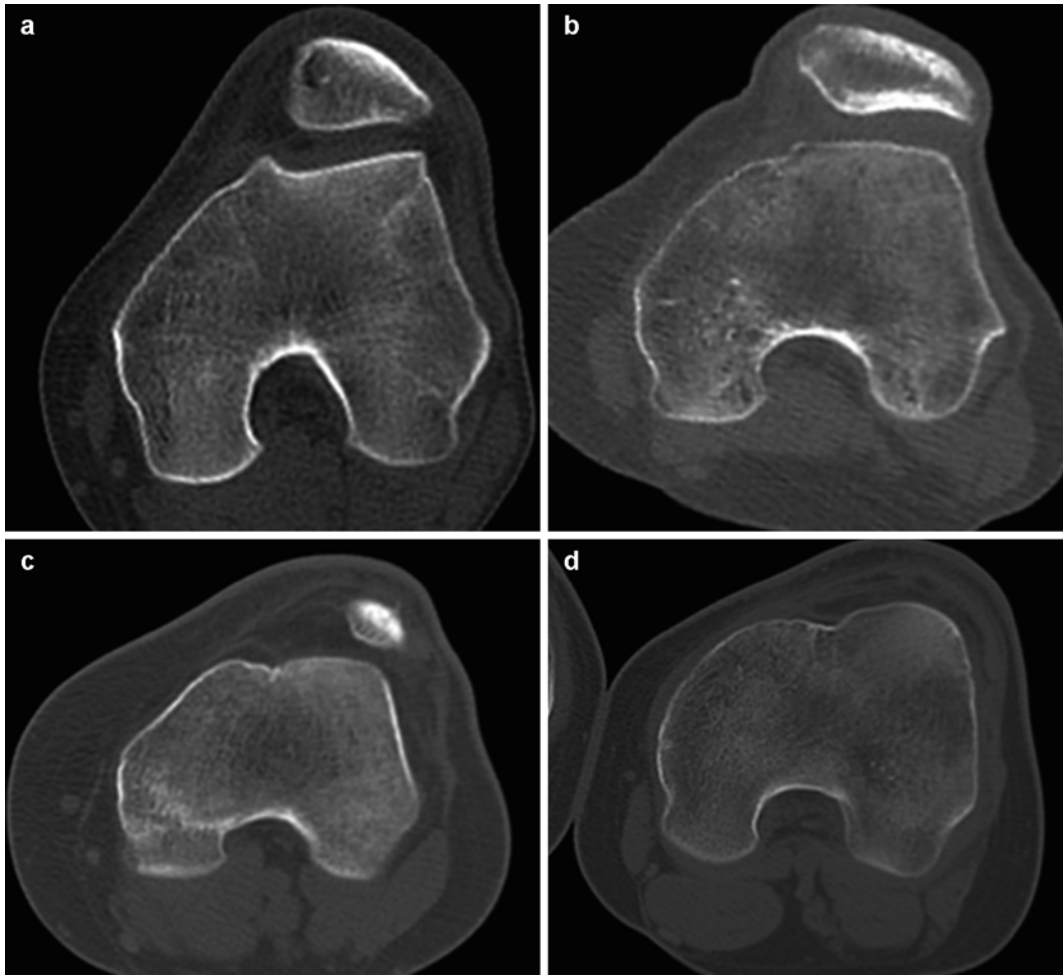

Fig. 28.24 (**a**) Type A: normal morphology of both trochlear facets on CT scan. Trochlear angle > 145°. (**b**) Type B: flat trochlea. (**c**) Type C: medial facet hypoplasia and convexity of lateral facet. (**d**) Type D: medial facet hypoplasia and convexity of lateral facet with an abrupt transition (cliff pattern)

lesions. The following acute findings should be examined:

- Bone bruise and/or osteochondral lesion of the lateral femoral condyle
- Medial patellar facet contusion or osteochondral lesion, sometimes with avulsion of an osteochondral fragment (Fig. 28.27)
- Medial patellofemoral ligament (MPFL) tear in the patellar insertion or midsubstance lesion (Fig. 28.28)
- Tear of the distal insertion of vastus medialis obliquus muscle
- Lesion of the MPFL at its femoral insertion
- Patellar tilt and/or subluxation
- Hemarthrosis determining joint effusion

28.11.2 TT-TG Measure

Reliability of MRI in TT-TG measurement is still questionable. Schottle et al. [36] found an excellent correlation between measures obtained with CT scan and MRI, but more recent studies as the one by Camp et al. [37] showed that in CT measurement, the TT-TG is by mean 7 mm lower than the measurement on MRI.

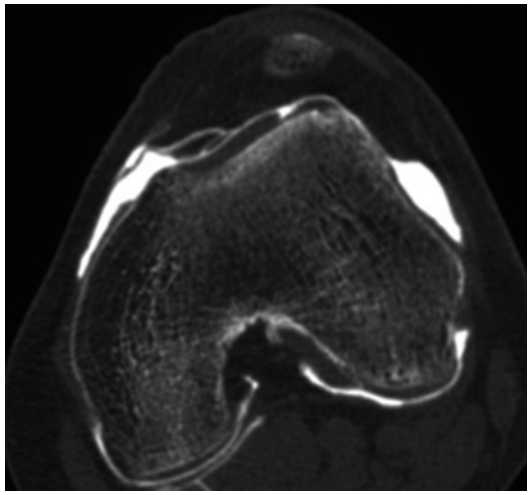

Fig. 28.25 Arthro-CT allows analysis of PF joint articular cartilage

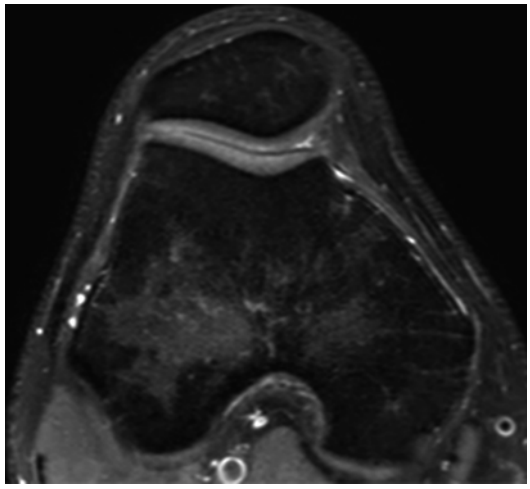

Fig. 28.26 Reliability of MR imaging analysis in trochlear dysplasia. Flat subchondral bone is homogeneously covered by articular cartilage

28.11.3 Patellar Height and Patellar Tendon Length Measurements

On sagittal views, patellar height can be measured using Caton-Deschamps method taking the cut in which the patellar articular cartilage is longest where AP can be measured and the cut in which ACL appears to identify the point T on the tibia and measure AT (14). Neyret et al. measured patellar tendon length on conventional X-rays and MRI in 42 knees with a history of PF instability and 51 controls. On MRI, the mean length was 44 mm in controls and 52 mm in the instability group. There was nonstatistical difference between measures obtained with MRI and X-rays. They concluded that patella alta is caused by an elongated patellar tendon rather than by its abnormal more distal insertion into the tibia (Fig. 28.29) [38].

28.12 Patellar Engagement Index

28.12.1 Sagittal Patellofemoral Engagement

Dejour et al. measured the 'functional' engagement between the two articulating bones: the patella and the trochlea [35]. Measurement of the index is performed on two different MRI slices: one in which the patellar articular cartilage is the longest (PL) and a second one in which the trochlear cartilage is ascending most proximally (TL); the two lengths are then superimposed. The index is defined as the ratio between TL and PL: values between 0 and 1 show that the patella is sagittally engaged with the trochlea. If the value is negative, there is no engagement on the sagittal plan (Fig. 28.30) [35].

28.12.2 Axial Patellofemoral Engagement

This measure is performed on axial MRI views using the posterior femoral condyle line as a reference. First, the slice in which the trochlear articular cartilage is most lateral is identified and a line perpendicular to the other reference line is traced (line L). Then, the slice in which patellar articular surface is largest is identified. If in this slice, the patella is medial to the L line, the axial engagement is complete; values between 0 and 1 represent a partial engagement, and negative values (with the patella positioned laterally to line L) represent a complete dislocation (Fig. 28.31) [39].

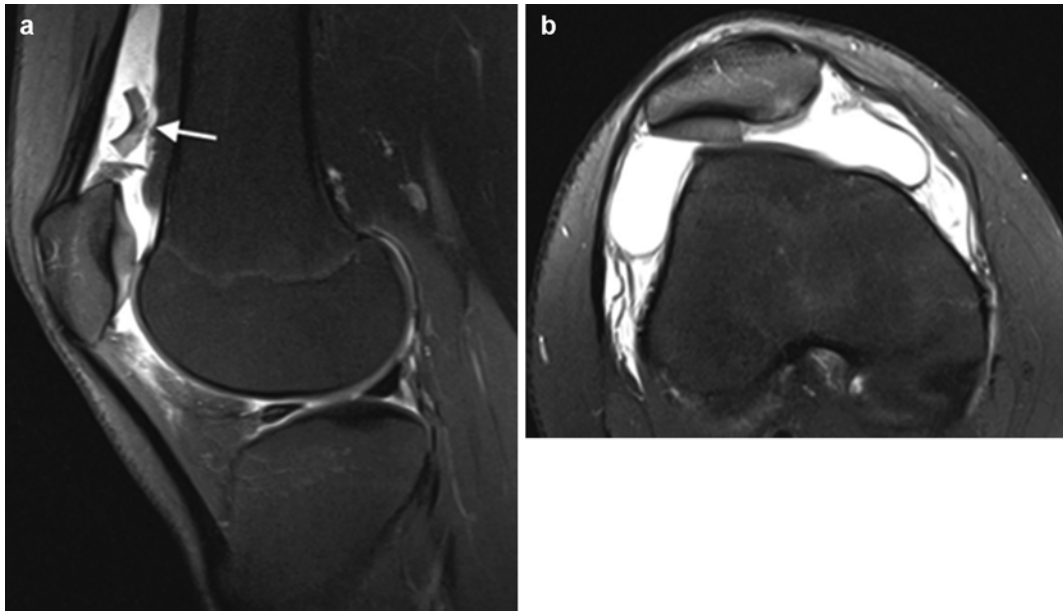

Fig. 28.27 (**a**) Osteochondral loose bodies are identified with MRI. (**b**) Axial views showing an osteochondral lesion of trochlear articular cartilage

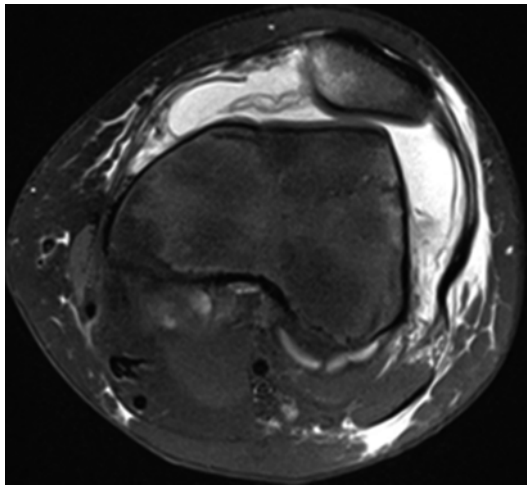

Fig. 28.28 Midsubstance lesion of the MPFL visible on MRI axial views

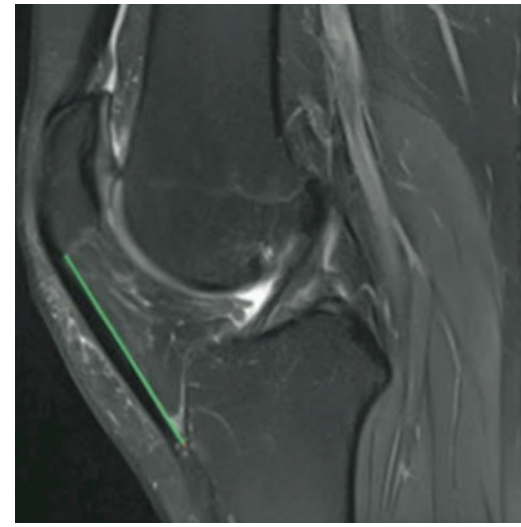

Fig. 28.29 Patellar tendon length measured with MRI

28.13 Kinematic MRI

Dynamic MRI evaluation of patellofemoral joint kinematic at different degrees of flexion has been described. These images can be shown in a static fashion or dynamically, allowing precise analysis of patellar tracking throughout the range of motion. Despite a number of studies realized, there is no consensus about the imaging acquisition protocol and engagement measure. For this reason, kinematic MRI is a very interesting tool but lacks clinical applicability and reproducibility.

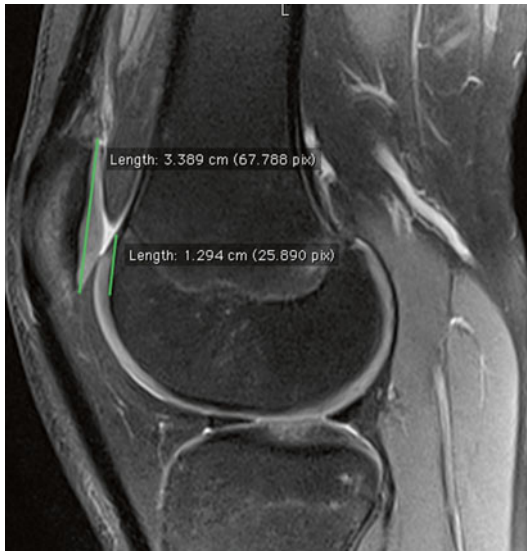

Fig. 28.30 Measure of sagittal patellofemoral engagement

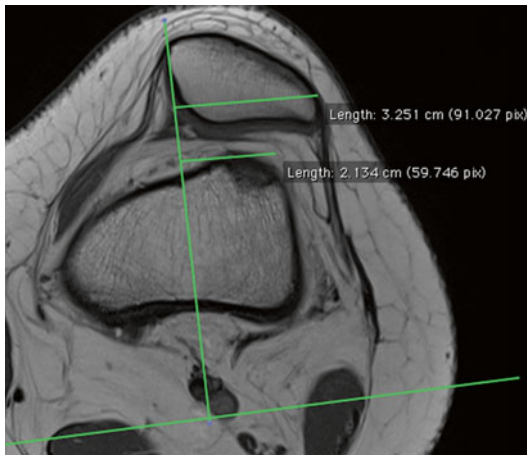

Fig. 28.31 Measure of axial patellofemoral engagement

28.14 Surgical Therapy for Patellofemoral Instability: Indications and Results

It is very difficult to find in literature homogeneous group of patients. Surgery for PF instability is often the result of the association of different procedures and for different indications (dislocation versus pain). In most of the studies, a main intervention is usually identifiable. A more detailed analysis of their results follows.

28.15 Soft Tissue Surgery

This group includes lateral release, vastus medialis obliquus plasty and above all MPFL reconstruction.

28.15.1 Lateral Release: Indication and Results

Lateral retinaculum release has been and still continues to be widely employed in treating different PF pathologies such as pain, instability, so-called lateral hyperpressure syndromes and patellofemoral osteoarthritis. This variety of indications with controversial results has been deeply analysed in the past few years. Recent studies on the long-term results of isolated lateral release (LR) are *against* the use of this procedure in treating PF instability. Verdonk et al. reported good results after isolated lateral release in treating 'lateral hyperpressure syndromes' in stable knee [40]. Panni et al. recommend against this procedure in patellofemoral instability, but they keep the indication for isolated PF osteoarthritis where they observe good results, albeit temporary [41]. More frequent complications are persistent anterior knee pain, hematomas, subcutaneous tissue atrophy, algodystrophy/complex regional pain syndrome and iatrogenic medial patellar instability [42, 43].

Hughston et al. reported a series of 65 medial patellar subluxations (89 % of them had previously underwent a lateral release), which had necessitated a lateral retinaculum reconstruction [44]. Recently, Heyworth et al. proposed to close lateral retinaculum breach as revision surgery for failed lateral release with persistent pain or medial instability [45]. Twenty-two patients with positive apprehension sign during medicalization of the patella were operated. Lysholm score significantly improved from 46 to 86 after the

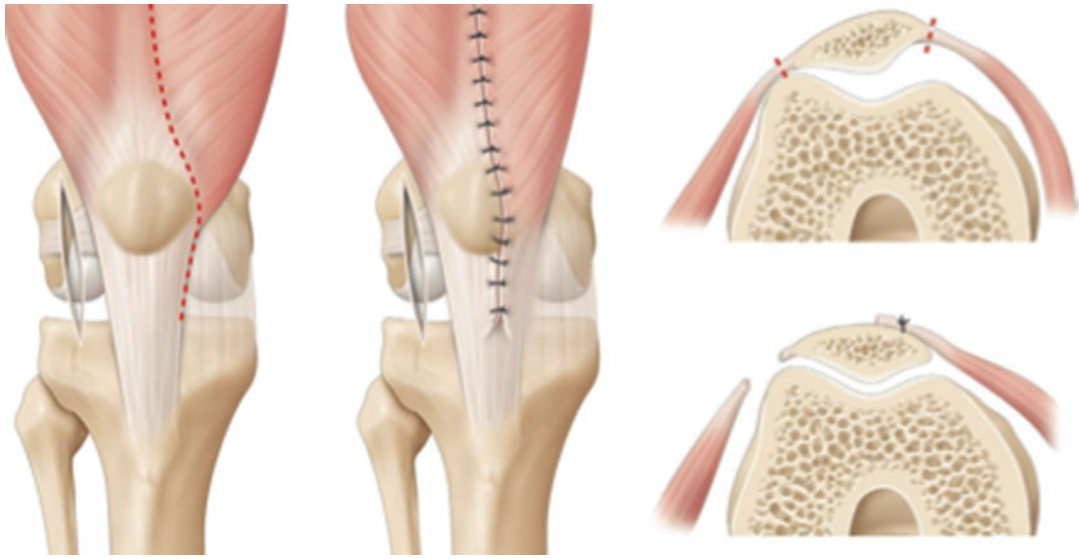

Fig. 28.32 Soft tissue surgery: lateral retinaculum release and vastus medialis plasty

procedure. Causes of failure of the primary surgery could not be identified. Failure after isolated LR occurs because this procedure corrects neither predisposing anatomic factor responsible for PF instability, and for that, it is logical to observe a high recurrence rate.

28.15.2 Lateral Release with Associated Procedures on Medial Soft Tissue

Ricchetti et al. realized a literature review to compare results of LR performed isolated or in association with a medial procedure, namely, vastus medialis obliquus plasty (Fig. 28.32) [46]. They selected 14 studies obtaining two groups of patient with a minimum follow-up of 2 years: first with 274 patients who underwent an isolated LR and the second with 220 patients who underwent LR in association to a medial procedure. Twenty-six patients of the first group experienced a recurrence of dislocation against only 12 in the associated group. The authors concluded that long-term results of isolated lateral release were inferior to the ones obtained with the association of a medial procedure. This association is very interesting in the presence of an abnormal tilt and a positive lateral patellar tilt test, as it permits patellar rebalancing and recentring, allowing a better engagement with the trochlea. Indications have to be limited to PF instability without high-grade trochlear dysplasia and no excessive patellar height or TT-TG distance.

28.15.3 Medial Patellofemoral Ligament (MPFL) Reconstruction

Since its early description in the literature, MPFL has gained enormous popularity among orthopaedic surgeons [47]. First, it was well established that MPFL is a consistent and present anatomic structure in patellofemoral anatomy and then, its importance in patellar stability was emphasized as the primary static restrain to lateral patellar translation, providing more than 50 % of the medial stabilization [48]. Consequently, it has been widely reported that MPFL deficiency is a consistent result of pathological lateral patellar translation. This led to a more detailed description of the ligament's anatomy: Steensen et al. [49] defended the isometric pattern and described the insertions of MPFL under layer 2 of the knee, from the second proximal third of the medial patella to a fan-shaped insertion between the medial femoral

epicondyle and the proximal adductor tubercle. Amis et al. [50] described the MPFL more like a non-isometric structure; he found that MPFL is interdigitated and closely working in concert with the deep fibres of the vastus medialis obliquus, which acts as a dynamic medial stabilizer. MPFL is tight in full knee extension and acts as a static medial stabilizer during early degrees of flexion (15–20°), bringing the patella into the trochlear grove, and in greater degrees of flexion (>30°) is loose and the trochlea serves as a guide for normal patellar kinematics.

The results of the present study also support that the specific reconstruction does not lead to excessive patellar tilt on the horizontal plane during knee flexion. The femoral insertion of the original MPFL is *fan shaped* and of larger diameter in the specimens studied *than the cylindrical usually 7 mm graft used for the reconstruction*. In every technique for reconstruction, the femoral insertion is identified either by anatomic (palpation) or by radiological landmarks. The difference of the original diameter and shape between the intact and the reconstructed MPFL and the position of the graft results in a non-anatomic insertion in the femur. The biomechanical properties of the reconstructed graft are different than the intact MPFL, and these could be strong factors for the inability to restore prior-to-injury MPFL biomechanics.

With the present reconstruction techniques, the role of MPFL is to prevent excessive lateral translation during extension and early flexion and then to deliver the patella into the trochlea for the remaining of flexion. This can be attributed to cyclical pre-tensioning of the graft prior fixation and the fixation of the femur in 70° of knee flexion and to permit the graft to gain adequate length so that it allows greater degrees of flexion, during which the patella is mostly stabilized by a normal trochlear groove.

The authors believe that the most important steps for the reconstruction will be the correct identification of both the original patellar and femoral insertion and the ability of the reconstruction to produce a similar size and fan-shaped construct in the femoral insertion of the native MPFL. The patellar insertion is easy to identify because it usually involves an open technique, but for the femoral insertion, the identification is more controversial and the use of the fluoroscopy is recommended. It is very important that the new reconstructed ligament would be tensioned in a way to prevent pathological lateral patellar translation in full extension and in early degrees of flexion, while not being overconstrained [51] in order to allow for further knee flexion and to allow for the normal lateral to medial engagement of the patella on the proximal trochlea.

Regardless of the technique followed for MPFL reconstruction, after establishing the proper anatomic sites for femoral and patellar insertion, there is some scepticism on the ideal degrees of knee flexion and the amount of tension applied to the graft for isometric fixation. According to biomechanical studies, most surgeons choose to tension the ligament at 20–30° of flexion where the greatest amount of patellar instability occurs [1], but others chose to tension the reconstructed ligament in greater degrees of flexion, when the patella is more fully captured by the trochlea. But in order for this to succeed, a normal trochlear anatomy is of paramount importance, and therefore in cases of trochlear dysplasia (which account for 96% of the objective patellar instability population [1]), the lack of trochlear depth and patella containment must be taken into account. In these cases, there is a trend towards overtensioning the graft to avoid lateral patellar translation [52]. The authors do not recommend the traditional graft tensioning between 20 and 30° of flexion. The exact knee position during fixation is less important if knee cycling and graft pre-tensioning precede the final fixation. Testing the lateral patellar translation in extension (in order not to exceed one third of patellar width), graft pre-tensioning and making the femoral fixation last in order were the key steps of the reconstruction.

The orientation of the graft towards the femoral insertion creates a simultaneous posteromedially directed force on the medial side of the patella, thus increasing medial facet contact pressures and elevating the lateral facet [52]. This subsequently could lead to early degenerative cartilage damage that commonly exists in patients with patellar instability and deteriorates future results. There have been some biomechanical

reports that test patellar translation and contact pressures after MPFL reconstruction [53]. Although it is clear that MPFL reconstruction restores the pathological lateral patellar translation, the contact patellofemoral pressure changes remain still to be further studied.

For the treating surgeon, the following pearls are to be considered before and during MPFL reconstruction:

1. MPFL tear is not the real cause but the result of excessive patellar translation (e.g. patellar dislocation). Therefore, other and usually bony abnormalities must be first corrected (trochleoplasty, tuberosity osteotomy, etc.). This means that surgeons must be very careful when isolated MPFL reconstruction is advised for treating patellar dislocation without first correcting trochlear dysplasia or patella alta.
2. When MPFL reconstruction is performed, a well-harvested and strong cylindrical graft of hamstring tendon must ensure patellar stability; semitendinous graft or quadriceps tendon graft may be more suitable in isolated MPFL reconstruction.
3. Patellar positioning and fixation of the graft are of less importance (the use of fixation devices or not) than the femoral positioning, because the former is done in an open fashion. On the other hand, femoral positioning is of absolute importance to be done under fluoroscopy (Fig. 28.33).
4. During femoral MPFL positioning, obtaining a true profile view prior to any fixation is mandatory in order to identify and fix the graft in the ideal point suggested by Schottle et al. [54] (Fig. 28.34).
5. The degree of knee flexion during MPFL graft fixation must be done in a way that our fixation does not compromise deep knee flexion, while it prevents excessive patellar dislocation. This means that temporary graft fixation in the femur must be checked that it does not prevent knee flexion and at the same time it prevent excessive lateral patellar translation in extension.

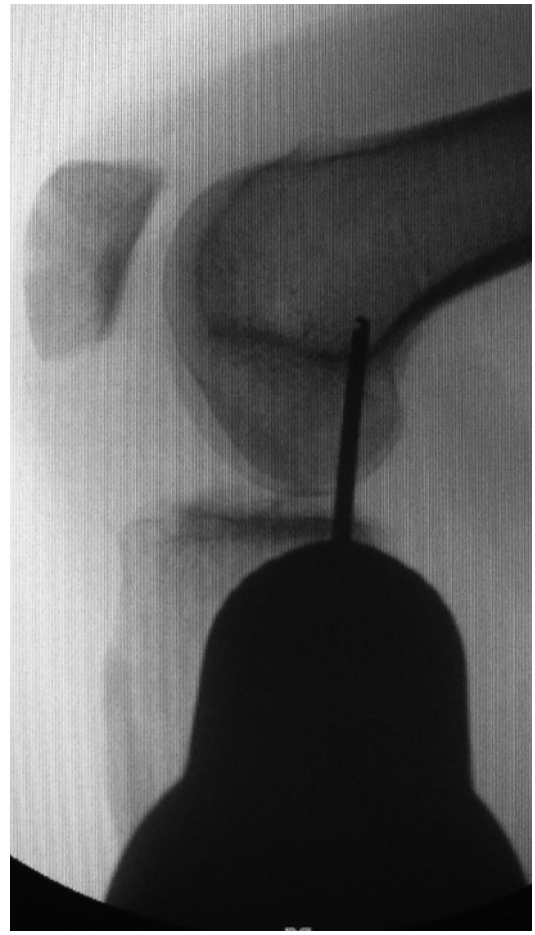

Fig. 28.33 Identification of femoral insertion with fluoroscopy: intraoperative view

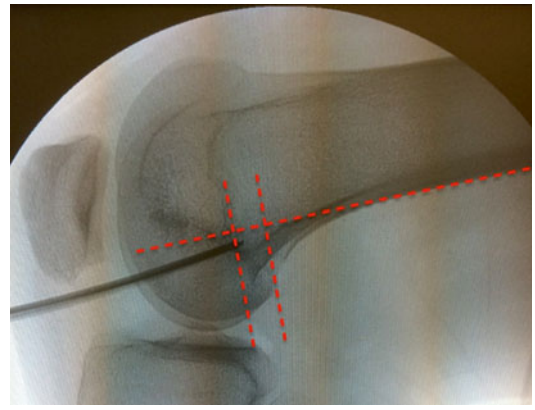

Fig. 28.34 Identification of femoral insertion with fluoroscopy according to Schottle

28.15.4 Vastus Medialis Plasty

It is very difficult to analyse the results of this procedure first described by Insall [27] as it is performed almost always in association to other procedures. In the past few years, this procedure has been almost completely replaced by MPFL reconstruction. The Judet procedure consists in complete liberation of the extensor apparel, which is rarely indicated and only in the presence of a severe stiffness of the extensor apparel as it is observable in habitual or permanent patellar dislocation.

28.16 Bony Procedures

28.16.1 Tibial Tuberosity Osteotomy (Fig. 28.35)

28.16.1.1 Indications

Tibial tuberosity (TT) osteotomies are indicated in the presence of a malalignment of the extensor apparel. Definition of malalignment is very difficult, but using both clinical exam and mostly imaging criteria, the accuracy of the indication can be improved. TT-TG distance can be measured on CT scan and MRI, and it is the most precise and exact criteria to define an axial malalignment of extensor mechanism. The aim of a TT osteotomy is to reduce the TT-TG distance between 10 and 15 mm. Goutallier underlined the importance of trochlear shape in TT-TG correction: in the presence of a dysplastic trochlea, medialization can be increased as there is a lesser risk of medial conflict [25]. In the presence of patella alta, TT should be positioned more distally in order to correct the index to normal values but avoiding causing an iatrogenic patella infera. TT anteriorization should lower stresses on PF joint as shown in biomechanical studies [55], but TT prominence is anaesthetic and causes discomfort in kneeling. Results of antero-medialization did not show any superiority of this procedure compared to medialization alone [56, 57], and for this reason, the use of this procedure is not recommended.

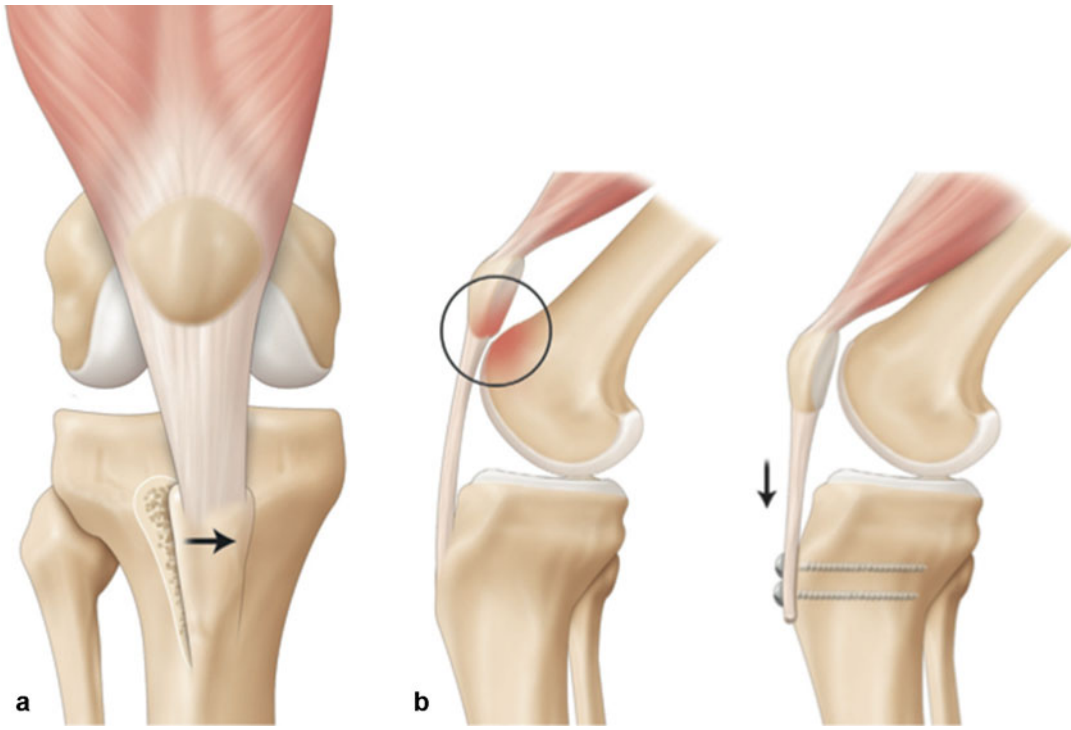

Fig. 28.35 (**a**) Medialization ATT osteotomy; (**b**) distalization ATT osteotomy

28.16.1.2 Results

TT osteotomies were the first bony procedure described and were also the first to prove their effectiveness. The results of these procedures are very variable. These techniques are very efficient at midterm follow-up in correcting axial malalignment and preventing recurrence of instability, but the results tend to worsen at long term. At 10 years follow-up, good excellent results are only in 60–70 % of the cases. Caton et al. reported on TT distalization in cases with objective patellar instability and patella alta (mean Caton-Deschamps index of 1.34) [18]. Half of the patients underwent an isolated distalization osteotomy and the other half underwent a combined distalization/medialization. Mean distalization was 7 mm and mean medialization was 9.5 mm, obtaining good patellofemoral stability in 76.8 % of the patients. Pritsch et al. reviewed 63 knees with PF instability that underwent a TT osteotomy [58]. Medialization was systematic and distalization was performed in 90 % of the series. At 6.2 years of mean follow-up, 72.5 % of patients reported a good-to-excellent result according to Lysholm criteria. The best results were recorded in patients with no chondral damage and in male patients. Servien et al. published a series of 110 knees operated for PF instability with Elmslie-Trillat procedure between 1988 and 1999 [59]. Mean follow-up was 5 years (range, 24–152 months); 95.4 % were satisfied or very satisfied, but 5.4 % experienced a recurrence of instability and more than one third of them reported anterior knee pain or discomfort. At longer term follow-up, Nakagawa et al. reported a series of 45 knees after an Elmslie-Trillat procedure, observing at 10-year follow-up with only 64 % of good results [60]. Long-term worsening of the results of TT osteotomies can be explained with the fact that for several years, these procedures were applied to every PF instability case, no matter the underlying anatomic abnormalities. Some osteoarthritis-related pain could appear at long term in the presence of hypercorrection (hypermedialization or excessive ATT lowering). Progression of chondral damage related to instability can also be an explanation for worsening of long-term results of this procedure. Barber et al. reviewed 35 patients operated for PF instability (at least three episodes) at 8 years follow-up with good-to-excellent results in 91.4 % of patients [61]. Recurrence of instability was observed in two patients and mean Lysholm score improved from 44.5 to 83.4. TT-TG distance was not measured preoperatively, so results could possibly be worse after excessive TT medialization. Evaluation of the results after isolated TT osteotomy shows that there are recurrences of PF instability and redislocation. The association of TT osteotomy with other procedures could be useful in reducing this recurrence rate. Another consideration is that these procedures were frequently performed also in the absence of excessive TT-TG distance or patellar height, resulting in alteration of knee kinematics, possibly causing future osteoarthritis at mid- and long-term follow-up.

28.16.1.3 Patellar Tendon Tenodesis Associated with TT Osteotomy

Mayer et al. showed that a patella alta could be caused by an excessive patellar tendon length instead of a too distal TT insertion [62]. Normal length is 44 mm and a tendon longer than 52 mm is considered pathological. In this case, patellar tendon tenodesis could be associated with TT distalization (Fig. 28.36). Results at 9-year follow-up of this procedure performed on 27 knees showed satisfactory shortening of patellar tendon (from 56.3 to 44.3 mm) and reduction of patellar height (Caton-Deschamps from 1.22 to 0.95). Ninety-two per cent of patients were satisfied, albeit a persistent positive apprehension test in one third of them.

28.17 Trochleoplasties

28.17.1 Indications

Trochleoplasties hold a particular place in the therapeutical arsenal for PF instability. They can be employed as revision surgery for failed PF instability surgery, but precision in analysis of trochlear dysplasia has improved and now trochleoplasties are routinely employed in the presence of a high-grade (B, C and D) trochlear

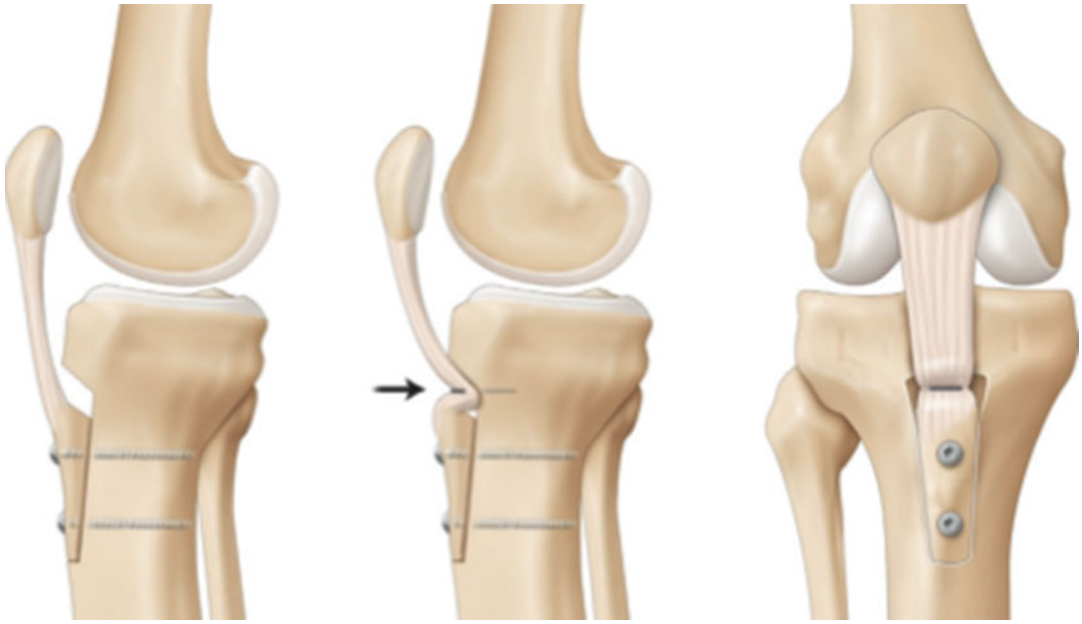

Fig. 28.36 Association of ATT osteotomy and patellar tendon tenodesis

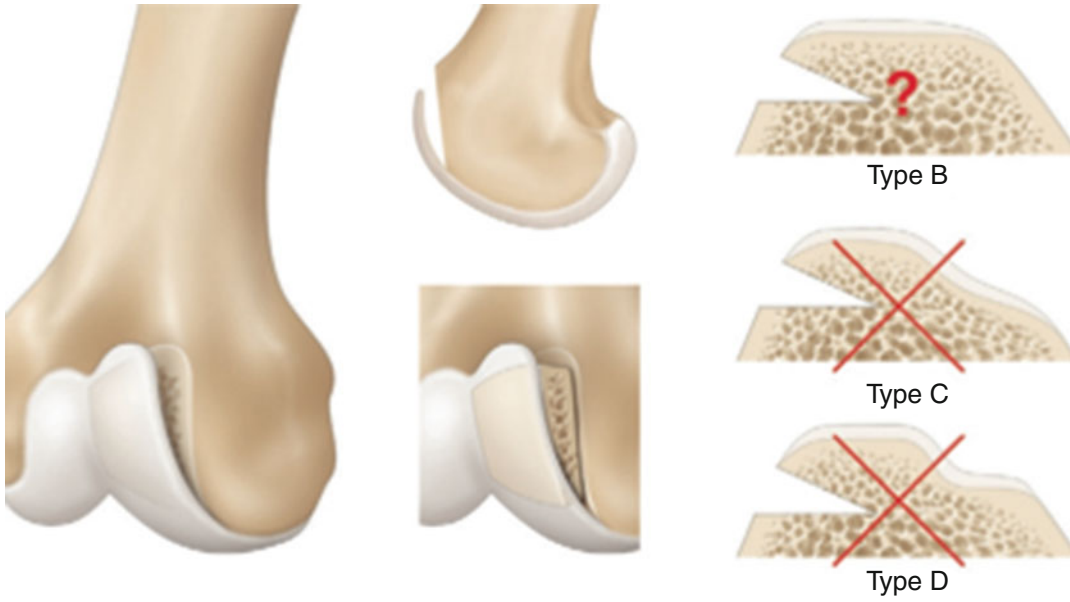

Fig. 28.37 Lateral facet elevating trochleoplasty according to Albee

dysplasia as a primary surgery. Femoral trochlea is defined as dysplastic when it becomes shallow or even convex and loses its congruence with the patella. This congruency can be improved by raising the lateral trochlear facet or by deepening the trochlear groove depending on the type of dysplasia. Lateral facet elevation trochleoplasty (Fig. 28.37) is indicated in patients presenting a shallow trochlea without supratrochlear bump and other important factors of instability. This procedure has to be performed very carefully in order to avoid creating an excessive prominence

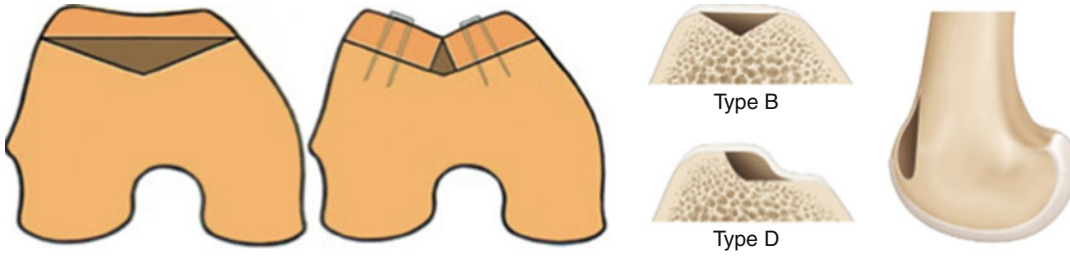

Fig. 28.38 Sulcus-deepening trochleoplasty

that can raise pressures on the PF joint in flexion, especially if MPFL reconstruction is performed with overtension of the new ligament. This procedure is effective for stability albeit possible cause of increased osteoarthritic degeneration. Sulcus-deepening trochleoplasty, which provides a more anatomical correction, is indicated in severe grade B and D trochlear dysplasia presenting a supratrochlear bump. The ideal indication is in patients with also an abnormal patellar tracking and a J-sign. Sulcus-deepening trochleoplasty is effective in reducing excessive TT-TG distance acting as a proximal realignment procedure, and for this reason, a concomitant TT medialization is rarely necessary. It is possible to associate trochleoplasty with soft tissue surgery, such as MPFL reconstruction or TT distalization in the presence of patella alta (Fig. 28.38) [63–69].

28.17.2 Results

28.17.2.1 Sulcus-deepening Trochleoplasty

Fucentese et al. reported a series of 44 sulcus-deepening trochleoplasties evaluated at a mean follow-up of 4 years [68]. Kujala score improved more in the presence of a type B and D trochlea (with supratrochlear bump) than in trochleas in types A and C. Ntagiopoulos et al. presented the results of a series of 31 knees (27 patients) presenting an objective PF instability with associated high-grade trochlear dysplasia without any surgical antecedent [67]. Sulcus-deepening trochleoplasty was performed in association to other procedures following the so-called menù à la carte: during the study period, MPFL reconstruction was not yet so popular and was associated in 16.1 % of procedures, VMO plasty in 83.8 %, TT distalization in 51.6 %, TT medialization in 67.7 % and LR in 67.6 %. Mean follow-up was 7 years (range, 2–9 years). Radiological analysis showed a normalization of sulcus angle, TT-TG and patellar tilt. No recurrence of instability was observed although 19.3 % reported a persistent subjective apprehension. Clinical analysis showed an improvement on the IKDC score from mean 51 preoperatively to 82 at the last follow-up and a mean Kujala score that rose from 59 to 87. No radiographic signs of osteoarthritis were noticeable at the last follow-up.

Dejour et al. studied two different groups of patients that underwent sulcus-deepening trochleoplasty: a first group of 18 patients with surgical antecedents of failed surgical intervention and a second group of 44 patients without antecedents [69]. Mean follow-up was 6 years (range, 2–9) in both groups. Patient who had trochleoplasty as a primary procedure were more satisfied (85 % good and excellent vs. 65 % in the revision group) and experienced less residual pain (5 % vs. 28 %).

More recently, Dejour et al. presented a retrospective series of 22 patients (24 knees) who had sulcus-deepening trochleoplasty between 1993 and 2006 for recurrence of patellofemoral instability after failed previous surgeries [70]. Mean follow-up was 66 months (range, 24–191 months); 29.1 % had type B dysplasia and 70.9 % type D. Post-operative analysis showed correction of the sulcus angle from 153° ± 14 to 141 ± 10° ($p < 0.01$); TT-TG decreased from 16 ± 6 to 12 ± 2 mm ($p < 0.001$) and patellar tilt was reduced from 31 ± 14 to 11 ± 8° ($p < 0.0001$). Kujala score increased significantly from 44 (25–73) preoperatively to 81 (53–100) at the last follow-up

($p<0.001$). No recurrence of instability or PF osteoarthritis was observed at the last follow-up.

Banke et al. published the results of trochleoplasty associated with MPFL in 18 patients with high-grade trochlear dysplasia (B, C and D) and positive apprehension sign [71]. Mean follow-up was 30 months. Results showed a significant decrease of pain (VAS score from 5.6 to 2.5) and improvement of Tegner score (from 2 to 6), Kujala score (from 51.1 to 87.9) and IKDC score (49.5 vs. 80.2 post-operatively). No recurrence of instability, PF osteoarthritis or apprehension sign was recorded.

Blønd and Schottle described a technique of sulcus-deepening trochleoplasty performed arthroscopically [72]. The authors presented a series of eight patients with operative time between 105 and 170 min with a rapid diminution of pain observed few weeks after surgery. In a later report, Blønd et al. [73] showed results after arthroscopic sulcus-deepening trochleoplasty with MPFL reconstruction in 29 knees with a minimum follow-up of 12 months. No complications, redislocations or arthrofibrosis was recorded. Five patients needed further surgery. The median pre- and post-operative scores (range) were Kujala of 64 (12–90) to 95 (47–100), Tegner of 4 (1–6) to 6 (4–9) and KOOS pain of 86–94 ($p<0.001$).

Trochleoplasty procedures pose a theoretical risk that damage to the subchondral bone will create a thin flap under the cartilage with impaired vascularization and future PF arthritis. Schottle et al. [74] demonstrated viability of articular cartilage after trochleoplasty. An osteochondral biopsy was performed 6–9 months following the procedure showing a normal histology of both cartilage and subchondral bone. These results can possibly demonstrate the lower incidence of osteoarthritis in the absence of preoperative chondral damage. It is interesting to notice that the results in terms of the post-operative development of PF osteoarthritis are similar to the ones after sulcus deepening [67, 70, 75, 76] or the 'Bereiter' trochleoplasty [77–79], where the cartilage is actually 'osteotomized' or elevated as a flap, respectively. This along with the data of Fucentese et al. [77] and Schöttle et al. [74] on the good early cartilage viability after trochleoplasty probably put emphasis on the higher significance of the already established preoperative degenerative changes and the effect of patellar dislocation on PF cartilage rather than the consequence of trochleoplasty on the long-term development of patellofemoral arthritis.

28.17.2.2 Bereiter Trochleoplasty

Von Knoch et al. analysed at a mean follow-up of 8.3 (range, 4–14) years the clinical and radiological results of the Bereiter trochleoplasty on 45 knees with objective PF instability with a trochlear dysplasia [79]. At last follow-up, no patient experienced recurrence of instability and the mean Kujala score was 94.9. Despite these good results, 49 % of patients experienced more pain than preoperatively, and osteoarthritic radiographic signs were present in 42.4 % of the series. The authors concluded that Bereiter trochleoplasty is very effective in correcting trochlear dysplasia although it may be a possible cause of anterior pain and future PF osteoarthritis.

Utting et al. reported the results of the same procedure on 59 patients at a mean follow-up of 2 years; 16 knees were previously operated and trochleoplasty was performed in 27 knees [78]. Ninety-two per cent of patients were satisfied or very satisfied. Kujala score improved from 62 to 76 at the last follow-up, IKDC from 54 to 72 and Lysholm from 57 to 78.

28.17.2.3 Recession Wedge Trochleoplasty

This technique is easier than sulcus-deepening trochleoplasty. Its objective is not to reshape the trochlear sulcus but only to reduce the prominence without changing articular incongruence. Thaunat et al. analysed the short-term results of this procedure on 19 knees (17 patients) [80]. In 18 cases, a TT osteotomy was performed as an associated procedure. Mean follow-up was 34 months (12–71). At the last follow-up, mean Kujala score was 80 ± 17, KOOS score was 70 ± 18, and IKDC was 67 ± 17. Mean patellar tilt decreased from 14 to 6°. Two patients in this series experienced a recurrence of instability and three revision surgeries were necessary for post-operative minor complications.

28.18 Indications for Tibial and Femoral Osteotomies

In a small number of patients, patellar instability can be caused by a lower limb abnormality such as an excessive valgus or an excessive torsion. Excessive valgus reduces axial engagement and forces lateral patellar dislocation. A valgus greater than 10° should be considered excessive. The deformity lies often in the femur with a hypoplastic lateral femoral condyle that can be addressed by performing a distal femoral osteotomy. Torsional deformities can also be caused by an excessive femoral anteversion and tibial external rotation and these deformities are frequently associated to an excessive valgus. Derotational osteotomies are performed in the subtrochanteric region for the femur and around TT for the tibia. Surgery must be reserved to severe cases as these anomalies are normally well tolerated, and derotational osteotomies are considered very invasive.

28.19 Indications for Patellar Osteotomies

Morscher describes a closing wedge patellar osteotomy fixed with transosseous sutures with the aim to re-create a sharper patellar crest [81]. The procedure is technically demanding, as the patella is small and easy to fracture, not very vascularized with a high proportion of cortical bone. It is also very difficult to determine the amount of correction needed, and the risk of necrosis must be taken into account. For these reasons and given few and rare indications (flat patella Wiberg type III), this procedure should be reserved to selected cases.

28.20 Treatment Options in Patellofemoral Instability

28.20.1 Treatment Guidelines for First Episode of Patellar Dislocation

First episode of patellar dislocation should generally be treated conservatively. The presence of an osteochondral avulsion can indicate surgical treatment for fragment fixation or loose body removal due to knee blocking. Some authors advocate repair of the injured medial structures (i.e. MPFL reconstruction) in the presence of an important patellar tilt and/or lateral subluxation [82]. Main objectives of conservative treatment are reduction of joint effusion, pain relief and recovery of full range of motion. Quadriceps strengthening is also part of the standard conservative approach, although the role of quadriceps strength in preventing recurrence is *very* controversial. A 6-week rehabilitation period allows repair of medial soft tissues, but can also cause stiffness; so knee immobilization is not advised. A soft knee brace can be a good alternative as it allows keeping the patella well positioned and allows the patient to start recovery of range of motion as soon as possible. Some authors advocate MPFL reparation also after the first episode, but this approach is not yet well defined in the literature, especially for children under 6 years old [83, 84]. In case of recurrence of dislocation, surgical approach is advised.

28.20.2 Treatment Guidelines for Recurrent Patellar Dislocation

Objective PF instability presenting as recurrent patellar dislocation has to be treated surgically. It had to be overemphasized that the aim of surgical treatment is to restore PF stability and not to treat anterior knee pain. There is no agreed protocol of treatment; surgeon has to choose the proper association of procedures that are *customized* for each patient.

28.21 Therapeutic Flowchart for Patellofemoral Instability

PF instability is the result of combination of many anatomic abnormalities. First step is to identify the pathologic population whom the patient belongs: objective patellar instability versus patellofemoral pain syndrome. Only patients

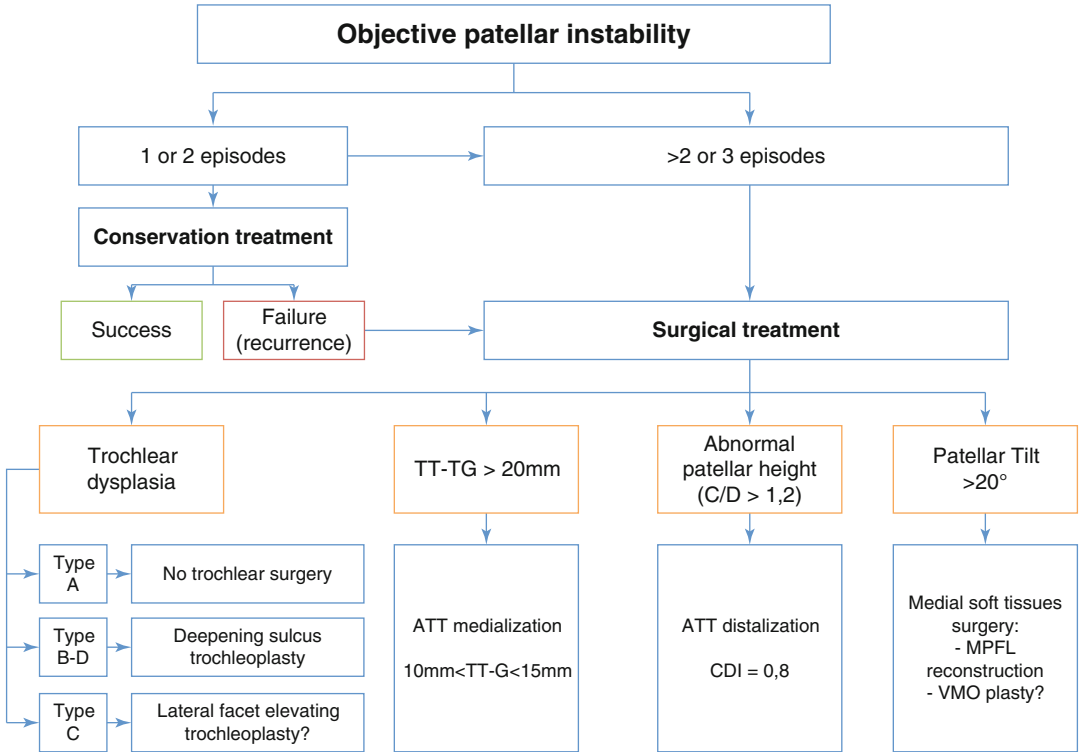

Fig. 28.39 Therapeutic algorithm for recurrent patellar dislocation

with recurrent instability need surgical treatment. Second step is to evaluate and quantify the anatomic abnormalities that are present by the means of complete imaging study with standard X-rays in proper views, CT scan and/or MRI. Last step is to choose among the different procedures and to plan the systematic correction of *all* abnormalities following the 'menù à la carte' rationale (Figs. 28.38 and 28.39).

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Synovitis of the Knee

29

Massimo Berruto, Antonella Murgo,
Paolo Ferrua, Francesco Uboldi, Daniele Tradati,
Stefano Pasqualotto, and Bruno Michele Marelli

29.1 Introduction

Etymologically, the word *synovitis* generally refers to acute or chronic inflammation of the synovial membrane. Today, however, the term is used to refer to a disease process (not necessarily inflammatory) that may originate from the synovial membrane and involve the structures of the joint. Synovitis can have different causes: traumatic, autoimmune, infectious, dysmetabolic or neoplastic, and it is typically characterised by the presence of varying degrees of swelling, pain, redness, heat and functional impairment. The knee is a frequent target of this disease, and it is the joint most likely to be affected by *special forms of synovitis* such as pigmented villonodular synovitis and synovial chondromatosis. Inflammatory and degenerative joint diseases are usually diagnosed on the basis of clinical and imaging data. However, these data are not always sufficient, especially in the event of a monoarticular onset; in such cases, the use of histopathology and a synovitis score will increase the diagnostic accuracy. There exist various histological scoring systems for synovitis, and the one proposed by Krenn, which is essentially applicable to all forms of synovitis, is the most commonly used. It is a numerical scoring system based on semi-quantitative grading of three key features of synovitis: enlargement of the lining cell layer, activation of stromal cells (as shown by the cellular density of the synovial stroma) and leukocytic infiltration. Each of these three components is assigned a score from 0 to 3, resulting in an overall score of between 0 and 9. Through the analysis of numerous large samples, mean Krenn scores have been established for normality (1.0), post-traumatic arthritis (2.0), osteoarthritis (2.0), psoriatic arthritis (3.5), reactive arthritis (5.0) and rheumatoid arthritis (5.0) [15]. A strong correlation has since emerged between the synovitis score, immunohistochemistry findings (Ki-67, CD68) and the clinical severity of the disease [7, 26]. The use of the synovitis score has proved to be useful in defining forms lacking the typical histological features, allowing them to be distinguished on the basis of the intensity and severity of the synovial inflammation.

M. Berruto (✉) • P. Ferrua • F. Uboldi • D. Tradati
S. Pasqualotto
SSD Chirurgia Articolare del Ginocchio
Istituto Ortopedico Gaetano Pini Milan,
Piazza A. Cardinal Ferrari, 1, Milan, Italy
e-mail: massimo.berruto@fastwebnet.it

A. Murgo
UOC Reumatologia Istituto Ortopedico
Gaetano Pini Milan, Milan, Italy

B.M. Marelli
UOC Dipartimento di Ortotraumatologia
Generale e Chirurgie Ortopediche Specialistiche
Istituto Ortopedico Gaetano Pini Milan, Milan, Italy

29.2 Synovitis in Osteoarthritis

Osteoarthritis of the knee is one of the most common and disabling forms of osteoarthritis, and it is often complicated by the presence of synovitis.

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The condition has been estimated to affect around 250 million people worldwide [22]. The prevalence and severity of the synovitis are closely related to progression of the osteoarthritic process.

29.2.1 Pathogenic Mechanism

The origin of the synovitis is closely correlated with the presence of products of cartilage breakdown (especially YKL-39 and collagen II) and meniscal degradation, and it is part of a vicious cycle in which pro-inflammatory protein molecules, or cytokines, i.e. chemokines and adipokines, negatively affect the metabolism of both chondrocytes and synoviocytes. In the course of osteoarthritis, the synovial membrane can show different degrees of activity. When it is moderately active, it has opaque villi, which are numerically superior to those of a normal synovial membrane and show a preserved morphology or, at most, some thickening. Instead, in clearly inflammatory states, the membrane is characterised by increased proliferation and hypertrophy of the villi (the latter due mainly to adipose tissue) and by increased vascularity.

29.2.2 Clinical Presentation and Diagnostic Approach

Joint effusion is the most direct sign of synovitis; it is often accompanied by tenderness and restricted movements.

29.3 Mechanically Induced Synovitis

Synovitis can arise from *mechanical* changes whose origin may be congenital, acquired or post-traumatic (chondral damage, meniscal injury, etc.). Local factors such as biomechanical imbalances (incorrect distribution of mechanical stress in a varus knee or knee extensor mechanism malalignment), as well as intra-articular (aseptic necrosis, osteochondritis dissecans, meniscus disorders) or post-traumatic disorders, can cause synovitis and predispose or lead to secondary osteoarthritis.

29.3.1 Pathogenic Mechanism

The mechanisms underlying the onset of the inflammatory process are the same as those outlined for primary osteoarthritis. In some cases, trauma can act as a trigger, and the inflammation it causes can result in chronic synovitis that will require appropriate clinical diagnosis. In post-traumatic synovitis, in particular, the response of the synovial membrane is characterised by increased vascularity, effusion and swelling. Irritation of the synovial membrane triggers a process of local inflammation characterised by hypertrophy of the villi, which usually show a *plume-like* arrangement, rarely have a fibrin coating, and show increased vascularity.

29.4 Chondrocalcinosis

Chondrocalcinosis is a condition often associated with osteoarthritis; it is characterised by deposition of calcium phosphate crystals in the hyaline cartilage, fibrocartilage and synovial membrane. Not common in young people and frequently associated with a metabolic abnormality, chondrocalcinosis is categorised in three main categories: idiopathic (sporadic), secondary (associated with other diseases) and hereditary. It shows a strong association with age, its prevalence increasing from 3.7 % in subjects aged 55–59 years to 17.5 % in those aged 80–84 years [24]. Chondrocalcinosis can be asymptomatic, complicated by repeated episodes of synovitis (*pseudogout*), or show a disease course similar to that of chronic rheumatoid-like arthritis. The knee is the site most frequently affected both by the asymptomatic and the inflammatory form.

29.4.1 Pathogenic Mechanism

The deposition of crystals seems to occur as a result of a change in inorganic pyrophosphate metabolism, facilitated by a series of factors that interfere with the activity of pyrophosphatase and raise its concentration (hypomagnesaemia, hypophosphataemia, haemochromatosis, hyperparathyroidism, Wilson's disease). The association of chondrocalcinosis with old age is likely a consequence of age-related changes in the proteoglycans in the cartilage matrix that encourage the deposition of calcium phosphate crystals. The inflammation is caused by the deposited crystals, which induce intense irritation of the synovial membrane, a phenomenon characterised by oedema and infiltration of polymorphonuclear cells, and proliferation of synoviocytes which, in rare cases, can lead to the formation of the classic synovial pannus (Figs. 29.1 and 29.2). Indeed, the synovial membrane appears extremely hyperaemic with varying degrees of villous hyperplasia, depending on the duration of the disease. The deposits can be macroscopically visible at the tips of the villi and adhering to the articular cartilage and to the menisci. These features can be confirmed microscopically in sections that, however, must not be treated with formalin or other substances capable of dissolving the crystals.

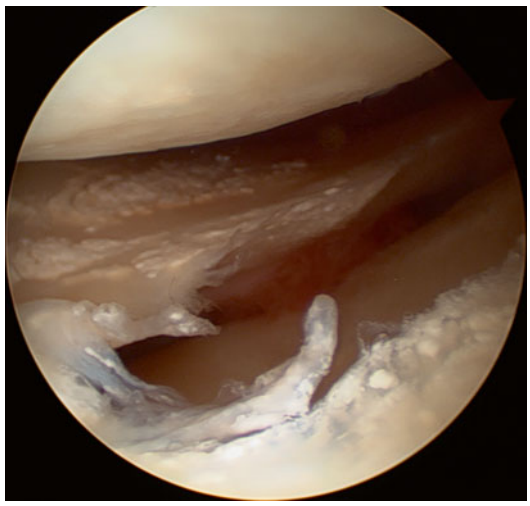

Fig. 29.1 Chondrocalcinosis of the lateral compartment involving the lateral meniscus and submeniscal recess

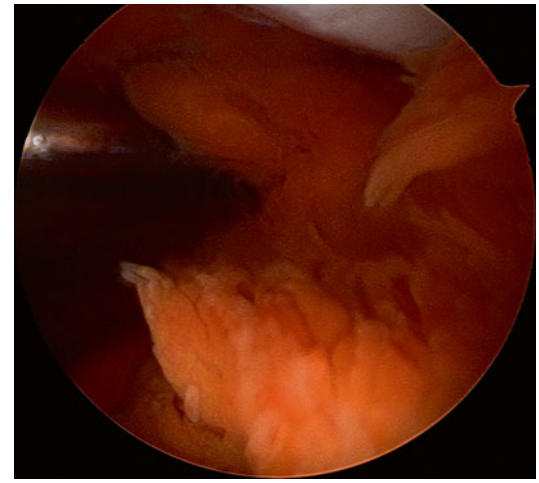

Fig. 29.2 Hypertrophic rheumatoid synovitis

29.5 Synovitis in Rheumatoid Arthritis

Rheumatoid arthritis (RA) is a chronic, immune-mediated inflammatory disease whose main feature is the development of persistent and progressive synovitis primarily affecting the diarthrodial (synovial) joints. RA can evolve into a systemic condition and involve extra-articular structures. Found all over the world and in all ethnicities, it is the most common form of arthritis. The disease can occur at any age, although its incidence peaks between the fourth and sixth decades of life. Women are 2.5 times more likely to be affected than men [17], and the difference between the sexes decreases with increasing age. The juvenile form can affect children and adolescents under the age of 16 years. The onset of RA is typically insidious and characterised by involvement of the small joints (hands, feet); acute polyarticular onsets are less frequent, while acute monoarticular presentations are rare at disease onset. The knee is frequently affected in the course of the disease (>50 %).

29.5.1 Pathogenic Mechanism

Rheumatoid arthritis is regarded as an immune-mediated disease that develops in genetically

predisposed individuals. Although the event triggering the onset of RA remains unknown, the disease-causing agent is thought to bring about an activation of the immune system that in turn leads to the development of an inflammatory process that subsequently becomes self-perpetuating and chronic. A role for genetic predisposition is supported by the fact that over 80% of patients possess the epitope of the HLA-DRB1*04 cluster and those that express two HLA-DRB1* alleles are at high risk of more severe disease [33]. Environmental factors such as smoking and infections can influence the development, severity and progression of RA [14]. The disease has a multifactorial pathogenesis that involves various immune modulators (T cells and B cells) and different signalling pathways. A complex network of interactions between pro-inflammatory cytokines, such as TNFα and IL-6, and effector cells is responsible for the joint damage that originates from the synovial membrane. According to the most recent thinking, synovitis precedes the onset of the clinical manifestations, even by years, and is caused by the convergence and local activation of mononuclear cells (including T cells, B cells, plasma cells, dendritic cells, macrophages and mast cells) and by the activation of angiogenesis. Thickening of the synovial lining results in a hyperplastic synovial membrane which is transformed into the synovial *pannus*; here, osteoclasts resorb bone matrix, while synoviocytes, chondrocytes and neutrophils break down cartilage [19, 29]. The macroscopic features of the synovial membrane in RA are the presence of irregularly shaped (bulbous, sessile, polypoid) and oedematous villi. The shape of the villi depends on the stage of the disease: when the hypertrophy is more advanced, the villi, which can be seen to emerge from an indistinctly and considerably thickened synovial membrane, appear bulkier (club shaped) (Figs. 29.3 and 29.4). The opaque appearance of the villi is due to the thickening of the synovial living and the high cell infiltration; the vascularity appears increased, with the vessels arranged in different patterns depending on the intensity of the inflammation and the type of synovitis. The vascular network generally shows a rectilinear arrangement in RA, while the vessels are tortuous in synovitis associated with psoriatic arthritis.

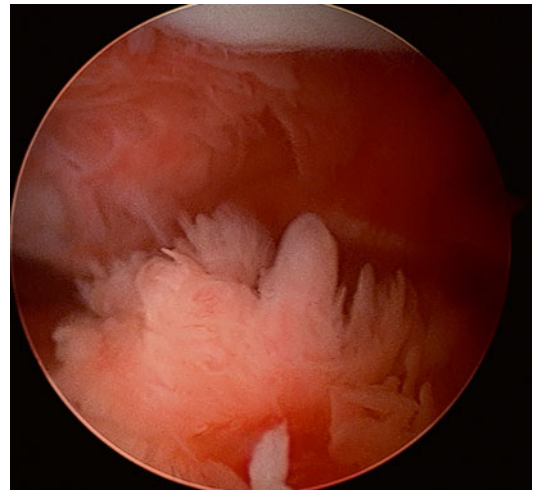

Fig. 29.3 A characteristically thickened pathological synovial membrane

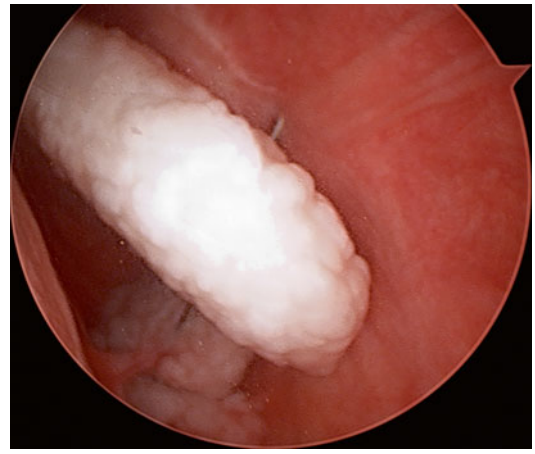

Fig. 29.4 Synovial chondromatosis: metaplastic loose body

29.5.2 Clinical Presentation and Diagnostic Approach

Synovitis in RA manifests itself through the classic symptoms and signs of inflammation. Effusion and synovial thickening are readily detected on clinical examination. A popliteal (or Baker's) cyst can be present, and its rupture produces signs and symptoms suggestive of thrombophlebitis. In addition to morning stiffness, the patient may also show systemic symptoms: fatigue, weight loss, fever and myalgia. In advanced and untreated forms, the chronic

inflammatory process causes gradual and irreversible tissue damage and deformity and instability of joints. RA is associated with the presence of rheumatoid factor (RF) and anti-citrullinated protein antibodies (ACPAs) in the serum. However, cases can occur in which these autoantibodies are not present. Raised erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels generally correlate with the degree of synovial inflammation, although the presence of normal levels of these inflammatory markers is certainly not a basis for excluding a diagnosis of RA. Laboratory tests may show anaemia, hypergammaglobulinaemia, hypocomplementaemia, thrombocytosis and eosinophilia. These abnormalities are usually present in patients with severe polyarticular disease and associated with high RF and ACPA titres. Synovitis in RA, especially in early or monoarticular phases, requires differential diagnosis versus other forms of primary inflammatory arthritis such as psoriatic arthritis, peripheral joint involvement in ankylosing spondylitis, reactive arthritis and microcrystalline arthritis.

29.6 Synovitis in Psoriatic Arthritis

The arthritis that is associated with psoriasis is one of the seronegative spondyloarthropathies, a heterogeneous group of chronic inflammatory diseases characterised by asymmetric oligoarthritis, which may be axial or peripheral, and enthesitis, and it is sometimes associated with ocular, cutaneous, gastrointestinal and systemic complications. RF testing is always negative and there is always a strong association with the HLA-B27 antigen. In cases with peripheral joint involvement, the knee is almost always affected.

29.6.1 Pathogenic Mechanism

Synovitis in psoriatic arthritis shares some pathogenic features with synovitis in RA. In genetically predisposed individuals, various conditions and agents can trigger the onset of psoriasis and/or psoriatic arthritis. Environmental and immunological factors influence susceptibility to the disease. Although the pathogenic mechanisms underlying the development of synovitis in the different forms of arthritis share many similarities, there are differences in the macroscopic morphology. The synovial membrane in psoriatic arthritis, and in seronegative arthritis generally, is typically characterised by inflammation associated with the presence of more rounded and elongated villi, gathered in clusters. The villi usually have a hyperaemic centre surrounded by a white halo, indicating early fibrous involution. The most representative feature is the vascularity, which shows a distinct pattern of very tortuous "corkscrew-like" vessels with numerous perivascular haemorrhages [27].

29.6.2 Clinical Presentation and Diagnostic Approach

In 70 % of cases of psoriatic arthritis, the psoriasis is present before the clinical manifestations of the arthritis, whose onset can be acute and monoarticular (usually involving the knee) or oligoarticular, in which case patients usually present involvement of the knee together with arthritis and tenosynovitis of the distal and proximal interphalangeal joints of the fingers (dactylitis). The arthritis may, in some cases, occur after a trauma, a circumstance that can give rise to diagnostic errors especially when the psoriasis is occult, i.e. not widespread but limited to specific areas. Laboratory tests are non-specific, and raised ESR and CRP levels are not always consistent with the intensity of the clinical picture. The synovial fluid is inflammatory, with white blood cell counts exceeding 5,000 cells per mm^3. Although it may reveal no peculiar features, examination of the synovial fluid is useful for distinguishing psoriatic synovitis from mechanical or degenerative forms. Imaging findings of synovitis in a knee affected by psoriatic arthritis are comparable to those in a knee with RA. No specific scoring system has been developed for application to ultrasound findings in psoriatic arthritis; the methods used are based on the systems used for the assessment of RA.

29.7 Synovial Chondromatosis

Synovial chondromatosis, also called synovial chondrometaplasia or Henderson-Jones syndrome, is a rare benign neoplastic disorder that consists of a tumour-like abnormality of the synovial membrane that is characterised by multiple metaplastic cartilaginous nodules, present both in the subintimal layer and floating freely in the joint space (Figs. 29.5 and 29.6). It is the most common metaplastic disease of the knee, occurring most frequently in men aged between 30 and 50 years. The presence of loose bodies, i.e. loose fragments of bone or cartilage due to osteonecrosis, osteochondral fractures or osteochondritis dissecans, corresponds to a picture of secondary chondromatosis that must not be confused with the primary form, given that it does not include the presence of cartilaginous metaplasia.

Fig. 29.5 Villonodular synovitis

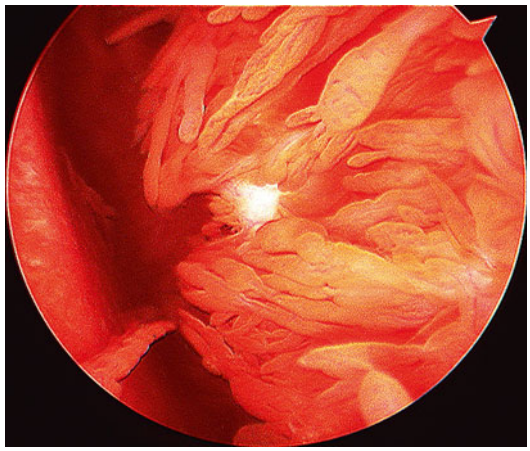

Fig. 29.6 Villonodular synovitis

29.7.1 Pathogenic Mechanism

The aetiology of synovial chondromatosis is still not clearly defined; what is more, trauma, initially indicated as a possible risk factor, is no longer considered to trigger the disease [25]. Specific cytogenetic features seem clearly to indicate a role for clonal proliferation and not only metaplasia [20, 30]. Macroscopically, the synovial membrane shows numerous blue-grey cartilaginous nodules, ranging in size from 2 mm to more than 1 cm. These nodules, also occurring freely in the joint cavity, can show pale yellow areas (expression of a process of ossification) and foci of endochondral ossification. Through the fusion of several elements, these nodules can form sizeable clusters and give rise to severe mechanical conflict. The synovial membrane generally appears hyperaemic. Microscopically, the nodules consist of hypercellular hyaline cartilage, embedded in the synovial connective tissue; the chondrocytes are arranged in small groups and show widely variable sizes and nuclear chromaticity and different degrees of nuclear and cellular atypia. The differential diagnosis of the condition versus chondrosarcoma is based on the greater extension of the lesions, the presence of bone erosions and the loss of the classic cluster-like arrangement of the chondrocytes. Even though the literature contains descriptions of malignant transformation of chondromatosis (in up to 5 % of cases according to some authors), there is still debate over whether chondromatosis can undergo a malignant evolution after years of illness or whether, instead, the literature descriptions actually refer to cases of low-grade malignant chondrosarcoma interpreted as chondromatosis [2, 12, 34]. The disease has three histological stages, which may coexist, (1) an initial stage characterised by active synovitis with nodules of cartilaginous metaplasia, (2) a

transition phase characterised by the presence of intrasynovial cartilaginous nodules and free bodies (loose cartilaginous nodules) and (3) an inactive stage in which the synovitis usually resolves, but there remain free bodies and a variable amount of joint effusion [21]. Calcification followed by ossification of the nodules occurs in 70–90 % of cases.

29.7.2 Clinical Presentation and Diagnostic Approach

Clinically, patients present vague and non-specific symptoms: pain, functional limitation and, rarely, joint locking. As the lesion develops, there appear swelling and effusion with synovial fluid, the components of which are all within normal levels. In the absence of timely treatment, chondromatosis can cause rapidly worsening degenerative processes. The imaging protocol includes conventional radiography that can be diagnostic in the advanced stages of the disease, when calcified or ossified free bodies are typically present; worsening osteoarthritis and pressure erosions are both indirect signs of the disease. CT scans are used to define the extent of the disease and to detect calcified loose bodies (even small ones) and also initial foci of cartilaginous metaplasia (high-density foci). The use of diagnostic MRI depends on the evolution and size of the calcified structures. In the absence of free bodies, the differential diagnosis must include pigmented villonodular synovitis, haemangioma and synovial sarcoma. When free bodies are present, essentially it is necessary to distinguish primary chondromatosis from the secondary forms (osteoarthritis, osteochondritis dissecans, osteochondral fractures, neuropathic arthropathy). Therefore, the diagnosis must always be confirmed histologically.

29.8 Villonodular Synovitis

Pigmented villonodular synovitis is a rare benign proliferative condition that can affect single joints, tendon sheaths and bursae. It is divided into diffuse and nodular circumscribed forms depending on the local extension of the disease. The diffuse form can present local aggressiveness but, despite its destructive potential, does not metastasise; however, it shows a high tendency to relapse. The presentation is monoarticular although the literature contains reports of multifocal cases. The disease, in both the diffuse and the circumscribed forms, mainly affects the knee (80 % of cases) and individuals of both sexes in the third to fourth decades of life. The annual incidence of the disease was previously calculated to be 1.8 new cases per million people, and the rate does not appear to have changed over the years [23].

29.8.1 Pathogenic Mechanism

The pathogenesis of this condition is poorly understood, and the study of animal models has shown the presence of morphologically constant but biologically variable synovitis. There exists evidence pointing to an exclusively chronic inflammatory origin, while other reports suggest that this is a neoplastic disease due to chromosomal abnormalities [10, 18, 32]. The name of the condition reflects its macroscopic characteristics, with the term pigmented referring to the particular colour of the lesions (ranging from yellowish to rusty brown), which is attributable mainly to haemosiderin deposits in the stroma and the presence of macrophages and synovial lining cells. The haemosiderin deposits are the consequence of repeated haemorrhages. The term villonodular describes the peculiar structure of the synovial surface, which is characterised by the presence of villi and nodules of different sizes and shapes sometimes grouped in areas of increased membrane thickness (Figs. 29.7 and 29.8). The nodules consist of villi and fibrous tissue masses covered by hyperplastic synovial lining cells; it is also possible to observe fibrin clusters which may adhere to the surface of the synovial membrane or float freely in the joint space (*restiform bodies*). Microscopic examination confirms the vigorous proliferation of the synovial lining cells in two directions: towards

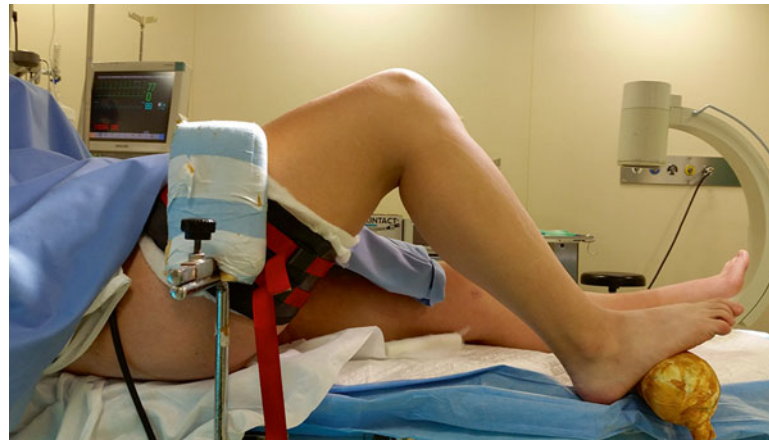

Fig. 29.7 Patient positioning allowing access to the posterior compartments of the knee

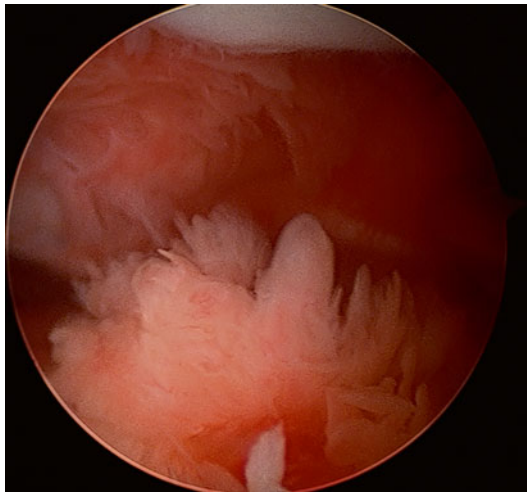

Fig. 29.8 Synovial hypertrophy in suprapatellar pouch (rheumatoid arthritis)

the joint cavity and towards the subsynovial connective tissue layer. Other key features are the foam cells (*of histiocytic origin*), the multinucleated giant cells (*phenotypic osteoclast markers*) and the haemosiderin deposits.

29.8.2 Clinical Presentation and Diagnostic Approach

The symptoms of villonodular synovitis are insidious and non-specific; therefore, months can elapse before it is finally diagnosed. Pain and swelling with effusion are constant findings on clinical examination, and in the nodular form, the masses may be palpable. The effusion will be bloody (if recent) or xanthochromic, with analysis of the fluid giving non-specific findings (a small increase in white blood cells and proteins). MRI is a highly diagnostic test for villonodular synovitis; the haemosiderin deposits alter the intensity of the signal, causing it to be reduced in T2-weighted images in particular. In T1-weighted sequences, pigmented villonodular synovitis shows signal heterogeneity: areas of low signal intensity due to the haemosiderin deposits alternate with areas having a greater fat content that show a higher signal intensity. Most haemosiderin deposits will, in all usable sequences, show a low signal intensity. There nevertheless remains the problem of differential diagnosis versus arthropathies with a haemorrhagic and adipose component (*haemophilic arthropathy*, *synovial haemangioma*, *haemochromatosis*, *trauma-related haemosiderosis).* The diagnosis of the condition must therefore be confirmed histologically.

29.9 Diagnostic and Synovial Biopsy

A rheumatic disease is diagnosed mainly on the basis of the clinical presentation, blood tests, imaging and synovial fluid analysis. Nevertheless, in some cases, it can be useful to obtain a synovial tissue sample for confirmatory diagnosis

and/or evaluation of the appropriateness of medical therapy. Synovial biopsy performed as part of a standard arthroscopy procedure has several advantages over the use of ultrasound-guided techniques or needle biopsy [11], making it possible:

- To evaluate every compartment of the knee and assess the macroscopic appearance of the diseased synovial membrane
- To estimate the extent of any chondral damage (useful for staging) and the involvement of other articular structures (menisci, ligaments)
- To obtain quantitatively and qualitatively valid synovial samples
- To convert the diagnostic procedure into an operative one (synovectomy, excision of local lesions)

Even though the standard two- or three-portal arthroscopic examination usually allows a complete evaluation of the joint and collection of an appropriate synovial membrane sample, it can nevertheless be extended through the use of accessory arthroscopic portals (e.g. posteromedial). In the presence of diffuse synovitis, it is mandatory to take at least six samples from the different compartments in order to obtain complete synovial mapping and reduce the possibility of sampling errors [3]. Samples should be taken with appropriate instruments, taking care during the procedure not to alter the structure of the synovial tissue.

29.10 Arthroscopic Synovectomy

In recent times, arthroscopic synovectomy has become established as the gold standard procedure for surgical therapy of diffuse synovitis of the knee. It is just as radical as open procedures, but at the same time less invasive; as a result, it allows earlier joint mobilisation and shorter hospitalisations and also reduces the stiffness problems traditionally associated with the open approach.

At least five portals are needed to perform a complete arthroscopic synovectomy. Consequently, the patient must be positioned in a way that allows easy access also to the posterior aspect of the knee (Fig. 29.7). A tourniquet should be used during the procedure, particularly in the presence of a pathologically hyperaemic synovial membrane, in order to ensure optimal visualisation of the surgical site and minimise intraoperative bleeding. The procedure starts as a standard two- or three-portal arthroscopy and should be performed as a systematic exploration of:

- *The suprapatellar pouch*: this region, frequently characterised by intense synovial proliferation, is clearly visualised by keeping the knee in full extension, as is the patellofemoral joint. Complete synovectomy of this compartment can be performed through the anteromedial and superomedial portals (Fig. 29.8).
- *The medial and lateral parapatellar recesses*: by flexing the knee to 20° and using a standard anteromedial portal (if necessary, the portals can be reversed), the exploration and possible synovectomy procedure are extended to these compartments.
- *The medial compartment:* access to and visualisation of this compartment are obtained by applying a valgus stress to the extended or slightly flexed knee. It is important to underline the importance, in this phase, of extending the synovectomy to the meniscal recess, a frequent site of pathological synovial proliferation.
- *The anterior chamber:* together with suprapatellar pouch, this is the region that most frequently shows synovial proliferation, which can be clearly seen with the knee at 90° of flexion. Synovectomy must be radical in this compartment, and it is important not to damage the cruciate ligaments during the removal of their synovial lining (Fig. 29.9).
- *The lateral compartment:* with the knee in a figure-of-four position, it is possible to evaluate this compartment and perform synovectomy through the anteromedial portal. As with the medial compartment, the procedure must be extended to the meniscal recess and popliteal hiatus (Fig. 29.10).
- *The posteromedial compartment:* with the knee flexed at 90°, this region can be accessed

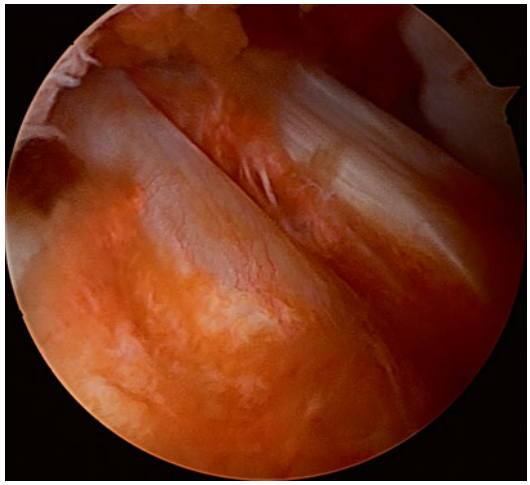

Fig. 29.9 Synovitis of the anterior chamber involving anterior cruciate ligament synovial lining

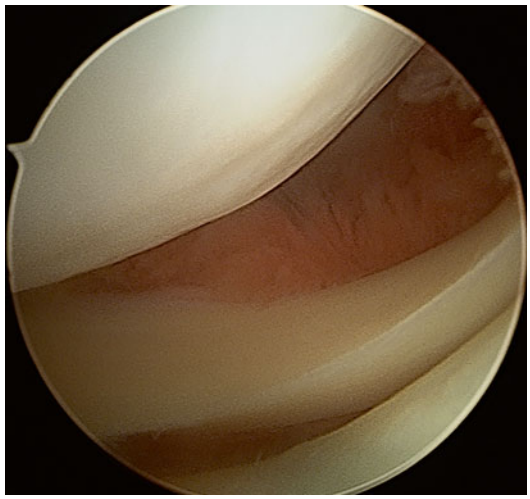

Fig. 29.10 Synovitis involving lateral parameniscal recess

using a transcondylar approach; then, under arthroscopic guidance, the posteromedial accessory portal can be created to allow complete synovectomy of the compartment (Fig. 29.11).

- *The posterolateral compartment:* with the knee flexed and under varus stress, this compartment can be reached via a transcondylar approach, making it possible to create an accessory posterolateral portal and complete the procedure in this region. Alternatively, with the knee flexed at 90° and using a switching stick inserted through a posteromedial portal, access can be obtained through a transseptal approach without the need for arthroscopic control.

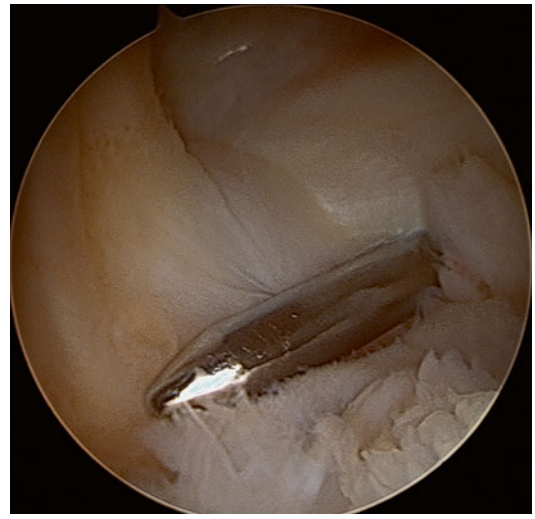

Fig. 29.11 Posteromedial portal created under arthroscopic control (transcondylar view)

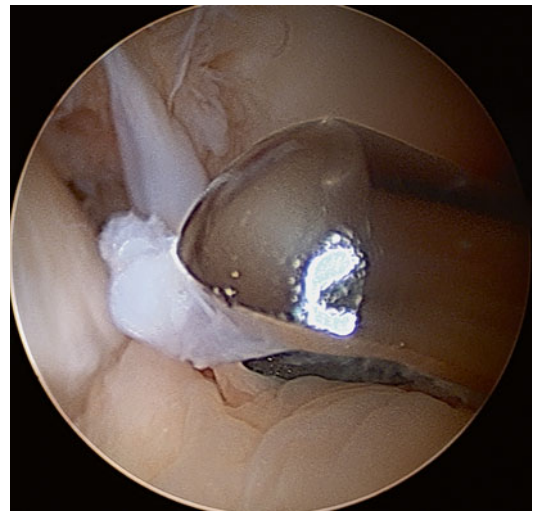

Fig. 29.12 Synovectomy performed using an arthroscopic shaver

Synovectomy can be performed with an arthroscopic shaver (Fig. 29.12) or radiofrequency instrument. The choice depends on the macroscopic features of the synovitis: a shaver allows

radical removal of the hypertrophic synovial membrane at the expense of heavier intra- and postoperative bleeding. The use of radiofrequencies, on the other hand, allows careful haemostasis of synovial blood vessels. For this reason, it is advisable to use both instruments together, in order to perform the procedure quickly and radically while also minimising blood loss. At the end of the procedure, a drain is positioned in the joint; this is removed after 24–48 h. This procedure has a very low incidence of intra- and postoperative complications: 3.2 % (range 1.1–6.2 %). The most frequent minor complications are haemarthrosis (3.5 %) and superficial infection (2 %). Severe postoperative pain persists for 2–3 weeks in 1.5 % of patients. Septic arthritis is a very rare complication (0.5 %) [16]. The recurrence rate after arthroscopic synovectomy is very variable and essentially depends on the extension and aggressiveness of the specific disease. At a mean follow-up of 6.9 years, 24.6 % (18.5–36.2 %) of surgically treated patients reported a recurrence of symptoms that were comparable to or more severe than their preoperative conditions [16]. The outcome of the arthroscopic procedure is comparable to that of open surgery in terms of recurrence rate, while the functional scores, postoperatively and at long-term follow-up, have been found to be significantly superior after arthroscopy [13, 35].

29.11 Open Synovectomy

Prior to the introduction of arthroscopy, open synovectomy was considered the gold standard procedure for the surgical treatment diffuse synovitis; although it is more invasive, it allows accurate and radical removal of pathological tissue. Current indications for this procedure are diffuse hyperproliferative conditions not accessible arthroscopically on account of the size or extra-articular localisation of the lesions. In order to access all the compartments of the knee, the procedure can be performed by performing an anterior arthrotomy, usually medial parapatellar or mid-vastus, to allow synovectomy of the anterior chambers and suprapatellar pouch, and a posterior access for the remaining compartments. The choice of an anterior, anterior-posterior, one-step or two-step approach is determined by the extension and characteristics of the pathology. The two-step approach is adopted only occasionally, when a one-step procedure is not advisable due to its invasiveness or the presence of comorbidities.

29.11.1 Open Anterior Synovectomy

The knee joint is approached through an anteromedial arthrotomy (medial parapatellar or mid-vastus). It is advisable to use a tourniquet and carry out periarticular vessel haemostasis from the very beginning of the procedure in order to minimise blood loss given that this can sometimes be very severe. The synovectomy can be performed through the anterior approach according to the following sequence: suprapatellar pouch, medial and lateral parapatellar recesses, medial compartment, anterior chamber and lateral compartment. All the removed tissue must be sent to pathology for tissue typing and histological analysis (Fig. 29.13). It is advisable to position one or two intra-articular drains which must be removed 48 h after the procedure.

29.11.2 Open Posterior Synovectomy

The patient is positioned in prone decubitus, and the site is accessed via a Trickey's posterior approach, taking care to obtain good exposure while preserving the popliteal neurovascular bundle. This approach, if correctly performed, allows good exposure of both the posteromedial and posterolateral compartments (Fig. 29.14). Since the incidence of cutaneous complications is very high in this district, the reconstruction and suturing must be carried out with great care, avoiding creating excessive tightness liable to give rise to stiffness and subsequent range-of-motion limitation postoperatively.

Even though it allows optimal and rapid exposure of the surgical site, the open procedure is associated with a high rate of complications including postoperative stiffness (8–32 %),

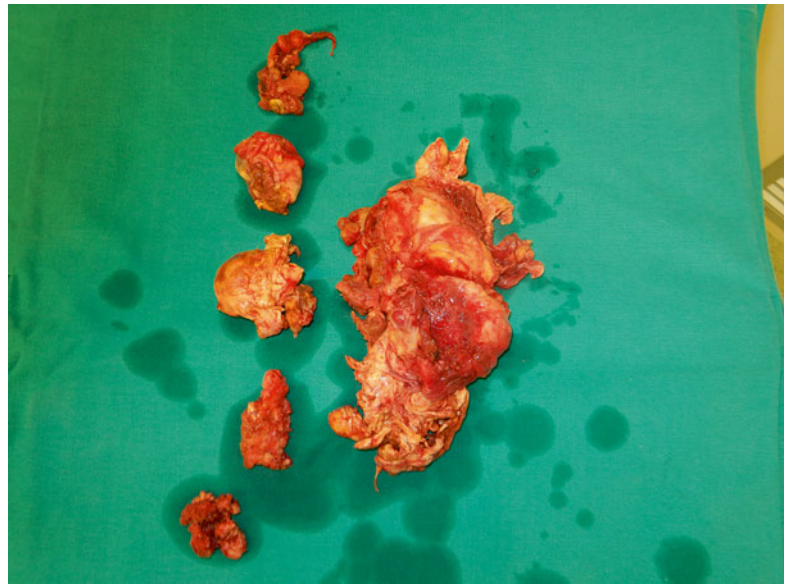

Fig. 29.13 Diffuse villonodular synovitis: surgical specimen

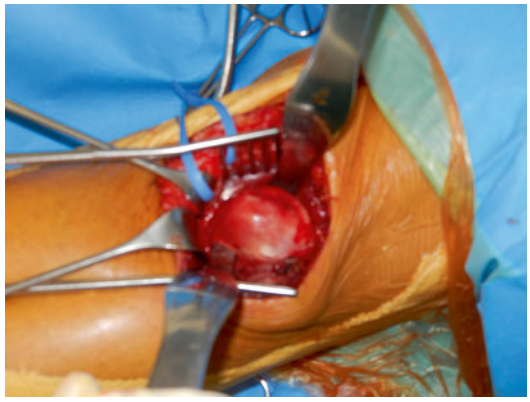

Fig. 29.14 Synovial chondromatosis: open posterior approach

haemarthrosis (8–9 %), surgical wound dehiscence and DVT [5, 9, 36].

Because of the higher incidence of intra- and postoperative complications, which are associated with the degree of invasiveness, the functional scores of the open procedure are lower than those recorded after arthroscopic surgery [35]. The reported recurrence rates range from 0 % [8] to 15 % [4] and 29 % [31]; this high variability can be explained by the heterogeneity of synovitis but also by the association (mostly in severe cases) of non-surgical therapy (i.e. radiotherapy). Despite the variability of the results, the open procedure is generally regarded as equivalent to arthroscopy in the surgical treatment of synovitis [1, 6, 28].

29.12 Mixed Procedures

The open technique can be combined with arthroscopy in certain circumstances. For example, the presence of pathological tissue in the semimembranosus-gastrocnemius popliteal bursa (a condition known as a Baker's cyst) requires a posterior open approach combined with arthroscopic synovectomy, as allowing pathological tissue to remain inside or in communication with the joint could increase the recurrence rate of synovitis.

29.13 Rehabilitation Protocol

Patients start a programme of passive and active mobilisation, including the use of CPM, from as early as the first postoperative day in order to obtain a progressive recovery of their range of motion. Partial weight bearing with crutches is allowed immediately. The partial weight bearing stage lasts for at least 3 weeks after surgery. In the event of postoperative pain or effusion

developing, resumption of full weight bearing must be delayed until the symptoms have resolved. Once the surgical wounds have healed, the patient can undergo hydrokinesitherapy and begin low-resistance cycling.

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Arthroscopic Treatment of Knee Stiffness

30

Massimo Berruto, Paolo Ferrua,
Stefano Pasqualotto, Andrea Parente,
Francesco Uboldi, Eva Usellini, and Bruno Marelli

30.1 Diagnosis and Classification

A loss of range of motion, commonly defined as stiffness, is a relatively common complication after knee surgery or traumatic injury [1]. The high incidence of postoperative knee stiffness observable in the past reduced significantly with improvement of surgical techniques and rehabilitation protocols [2]. Any symptomatic loss of knee flexion or extension compared with the opposite normal knee should be considered and treated as knee stiffness. In order to address conservative or surgical therapy, the cause, the type and the degree of stiffness must be identified and staged.

30.1.1 Causes of Stiffness

Knee stiffness can be etiologically divided in two groups: *posttraumatic* and *postoperative*. *Posttraumatic* stiffness is observable after articular or periarticular fractures, ligament injuries, prolonged immobilisation, haemarthrosis and complex regional pain syndrome. *Postoperative* stiffness occurs most frequently after open surgery as internal/external fixation for fractures around the knee, osteotomies, extra-articular plasties and infections, but it is observable also after arthroscopic surgery, namely, ligament reconstruction [3] or meniscus grafting or repairing.

The stiffness of the knee recognises two aetiopathogenetic sources, *intra-articular* and *extra-articular*, which can be present in isolated or associated fashion. *Intra-articular* component is caused by excessive proliferation of scar tissue in the joint (Fig. 30.1a, b), retraction of the capsular structures and Hoffa fat pad. *Extra-articular* component is caused mainly by extensor apparel contracture and retraction of subcutaneous tissue surrounding the joint (Table 30.1).

30.1.2 Type of Stiffness

According to the clinical presentation of stiffness, one can identify three types of knee stiffness: *flexion deformity*, *extension deformity* and *mixed*. *Flexion deformity* (*loss of extension*) is associated to anterior impingement which can be observed after a fracture of the anterior tibial intercondylar eminence fracture (Fig. 30.2) or a malpositioned ACL graft [4] (Fig. 30.3) or a posterior contracture caused by a posterior capsular retraction or stiffness of posterior flexor muscles, hamstrings and gastrocnemius (Fig. 30.4).

M. Berruto (✉) • P. Ferrua • S. Pasqualotto
A. Parente • F. Uboldi • E. Usellini
SSD Chirurgia Articolare del Ginocchio Istituto Ortopedico Gaetano Pini, Orthopaedic Hospital Gaetano Pini, Milan, Italy
e-mail: massimo.berruto@fastwebnet.it

B. Marelli
UOC Dipartimento di Ortotraumatologia Generale e Chirurgie Ortopediche Specialistiche, Istituto Ortopedico Gaetano Pini, Orthopaedic Hospital Gaetano Pini, Milan, Italy

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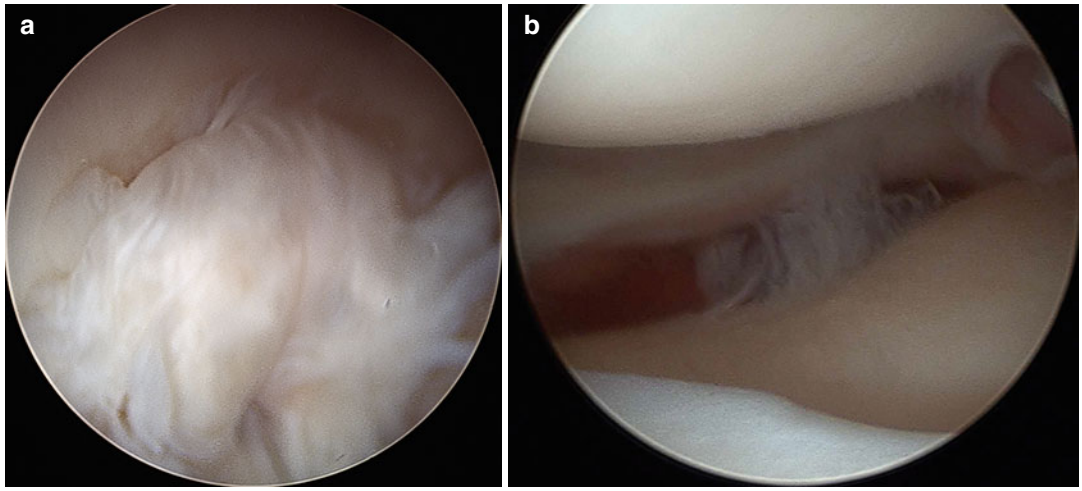


Fig. 30.1 (**a**) Abundant formation of scar tissue closing the notch. (**b**) Scar formation between the posterior horn of the lateral meniscus and tibial plateau

Table 30.1 Possible causes of knee stiffness

Intra-articular	Extra-articular
Nonanatomic positioning or excessive tensioning of intra-articular graft (ACL-PCL) [4]	Mid-shaft or distal femoral fractures
Cyclops syndrome [5]	Mid-shaft or proximal tibia fractures
Acute ligamentous surgery	Osteotomies around the knee
Multiligamentous surgery	External fixator for fractures or limb lengthening
Malunion of intra-articular fractures (i.e. tibial eminence or patellar fractures)	Patella infera (posttraumatic or postsurgical)
Extensive synovectomy	
Infrapatellar contracture syndrome [6]	
Complex regional pain syndrome	
Prolonged immobilisation and improper rehabilitation protocol	

Anterior impingement and posterior contracture are frequently observed associated, but each one is a sufficient cause of flexion deformity. *Extension deformity* (*loss of flexion*) can be caused by a posterior impingement (observable in malunion of distal femoral fracture or osteotomy) or by a too posterior positioning of the graft in ACL reconstruction, but the most frequent cause is an anterior retraction as observable in postoperative patella infera or quadriceps contracture (Fig. 30.5). Patellar height and sagittal engagement should be carefully measured in these settings in order to identify and assess the cause of extension deformity [7, 8]. In *mixed deformities*, the loss of flexion and extension occurs associated and recognises a broad spectrum of gravity from minor loss of range of motion to severe forms of stiffness-ankylosis.

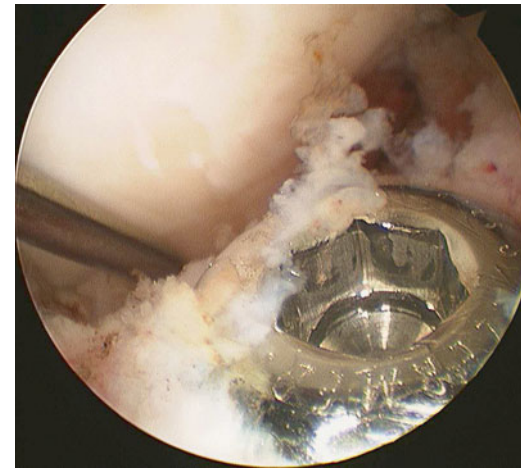


Fig. 30.2 Anterior impingement due to fixation of an intercondylar eminence fracture

30.1.3 Grading

Passive range of motion should be recorded as a/b/c where:

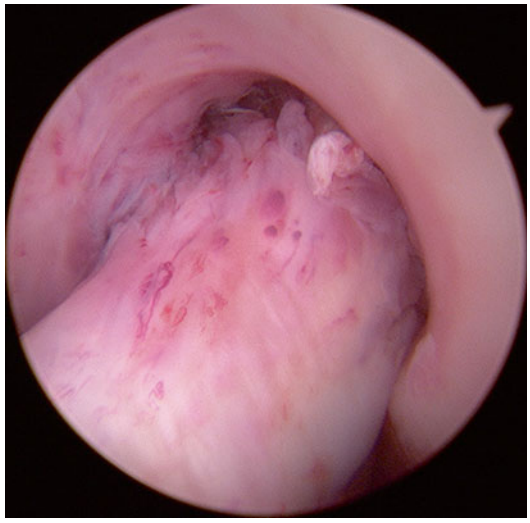


Fig. 30.3 Loss of extension in the presence of a vertically positioned ACL graft

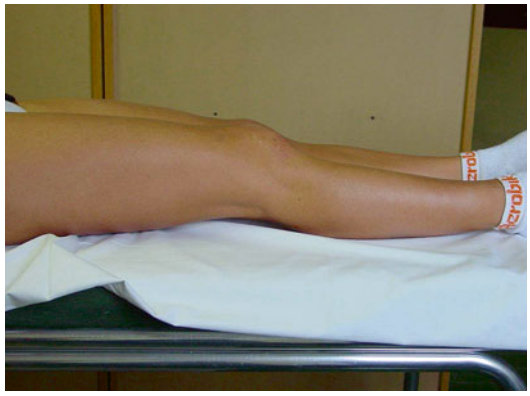


Fig. 30.4 Flexion deformity: loss of complete extension after ACL reconstruction

(a) represents the degree of hyperextension, (b) the degree of extension (0° in the normal knee) and (c) the maximum degree of flexion [9]. For example, a patient with no hyperextension, complete extension and maximum flexion of 90° has to be recorded as 0/0/90°. Sprague et al. [10] described an arthroscopic topographic classification in three groups:

1. Fibrosis localised only in the suprapatellar pouch
2. Complete obliteration of suprapatellar pouch and peripatellar gutters
3. Group 2 combined with extra-articular involvement

Fig. 30.5 Extension deformity: loss of flexion after cartilage reparative procedure

Shelbourne et al. [11] described a grading system conceived for post ACL reconstruction arthrofibrosis but suitable for all loss of range of motion:

Type 1: ≤10° extension loss and normal flexion
Type 2: ≥10° of extension loss and normal flexion
Type 3: >10° of extension loss and >25° flexion loss with decreased medial and lateral movement of the patella (patellar tightness)
Type 4: >10° extension loss and ≥30° of flexion loss and patella infera with marked patellar tightness

It is very difficult to fit all the patients presenting a stiffness in one of these groups, and for this reason, it is reasonable to use an 'à la carte' approach identifying in all patients the cause, the type and the gravity of the loss of motion in order to address the correct therapeutical indication.

30.2 Treatment

30.2.1 Prevention and Conservative Treatment

In most cases of the postoperative stiffness, the development of arthrofibrosis can be prevented with an accurate surgical technique, avoiding prolonged immobilisation and stimulating ROM recovery exercises from the immediate postoperative. Given these preliminary considerations, the

first-line treatment of stiffness is always conservative. The objective of conservative treatment is to regain full ROM without stimulating inflammatory response, by avoiding forceful manoeuvres of mobilisation. Quadriceps strength should be maintained with isometric exercise as straight leg raise and static contracture should be preferred to open chain exercise as leg extension that could worsen pain and increase inflammatory response. The use of continuous passive motion (CPM) device is useful in loss of flexion, and an extension knee brace for flexion deformity can also be useful as an adjuvant to physical therapy, but the application should never be painful and traumatic. The use of NSAIDs and oral corticosteroids is recommended in order to reduce inflammation and improve symptoms; there is no consensus instead to the use of intra-articular corticosteroids.

30.2.2 Surgical Treatment

The surgical indication timing is crucial in obtaining recovery of range of motion, no matter the technique employed. Every case of stiffness must be evaluated individually. Cosgarea et al. [12] proposed a loss of 10° of extension as the threshold for surgical arthrolysis. Shelbourne proposed instead 15° of extension gap as the cut-off for surgical indication [13]. Given these initial considerations, every clinically evident loss of range of motion persisting at least from 8 to 12 weeks after surgery, not responding to a correct rehabilitation protocol and determining a gait alteration, at least should be surgically treated [14, 15]. The aim of every treatment should be regaining full extension in the presence of a flexion deformity and the maximum degree of flexion in the presence of an extension deformity, measured as passive antigravitary flexion of the knee with the ankle and hip flexed. It is important to inform the patient that not always the result of surgical treatment is predictable and that a percentage of 20–25 % of failure without reaching the original ROM does occur.

30.2.2.1 Treatment of Intra-articular Stiffness

Manipulation Under Anaesthesia

This procedure recognised a loss of popularity in the past few years as associated with many intra- and postoperative complications, namely, fractures or extensor apparel damage [16]. It still plays a role for minor stiffnesses occurring in the early postoperative period or after a short period of immobilisation, taking care to perform the procedure gently and progressively, without forceful movements, and firmly stabilising the patella in order to smoothly obtain the range of motion recovery and minimise the risk of complications (Fig. 30.6a, b). This procedure is also useful as a diagnostic tool for determining the source of

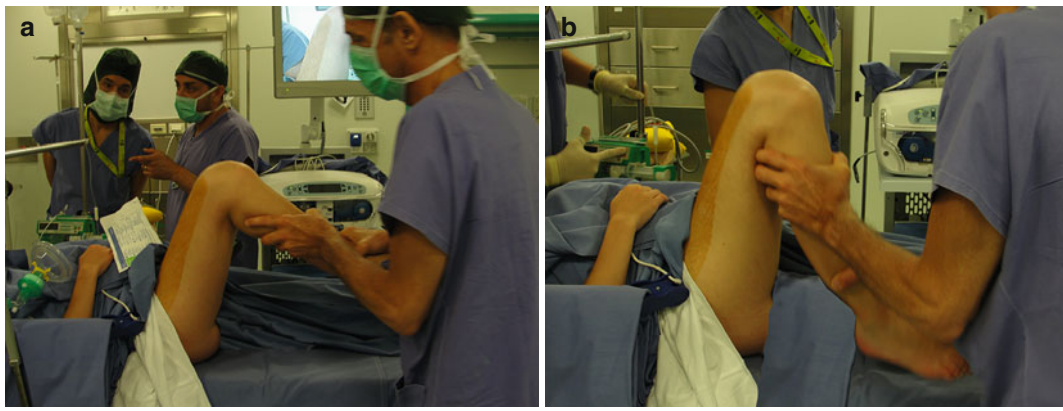


Fig. 30.6 (**a**) Manipulation under anaesthesia must be performed gently and progressively. (**b**) Manipulation under anaesthesia: flexion and extension must be repeated several times in order to obtain the best result possible

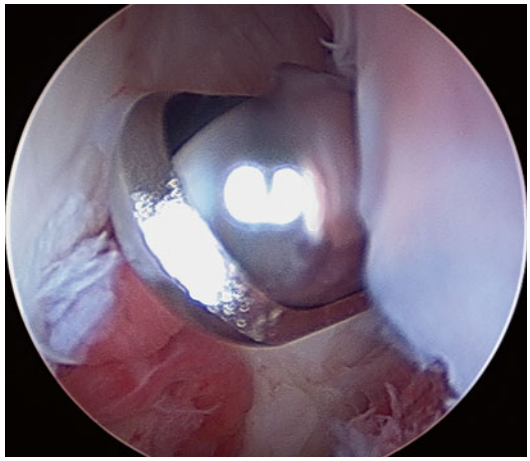


Fig. 30.7 Arthroscopic arthrolysis using a motorised shaver

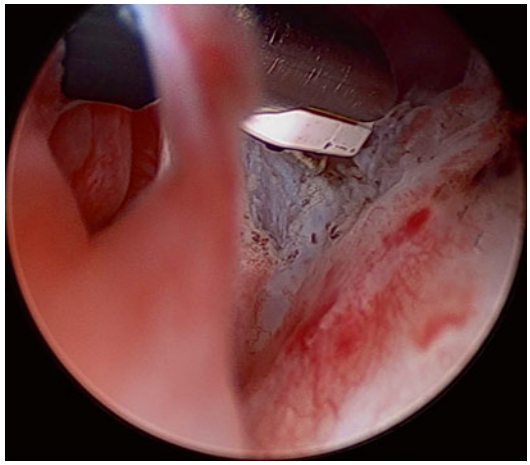


Fig. 30.8 Radio frequencies could be used in order to control intra-articular bleeding

stiffness and its reducibility, giving the possibility to assess real passive ROM and to distinguish between true stiffnesses and pseudo-stiffnesses related to antalgic muscle contracture.

Arthroscopic Arthrolysis

This surgical technique is indicated in treatment of both extension and flexion deformity after failure of a well-conducted conservative treatment lasting 8–12 weeks from surgery or index injury. The installation of the knee must allow access to posterior compartments and full mobilisation of the joint all throughout the procedure. Stiffness of the capsular structures and the difficulty in joint distension make the utilisation of an arthroscopic pump very useful, although non-mandatory. A standard 3 portal arthroscopy is first performed in order to localise and identify the intra-articular cause of stiffness. Once localised, any intra-articular fibrosis is best released using alternatively motorised shaver (Fig. 30.7) and radio frequencies (Fig. 30.8) in order to limit intraoperative and postoperative bleeding.

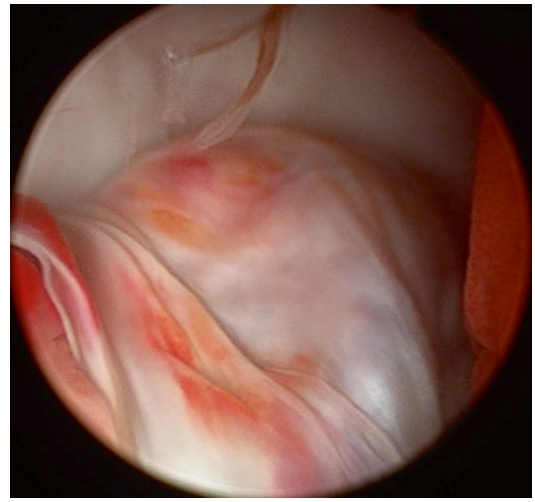


Fig. 30.9 Cyclops syndrome after ACL reconstruction

If the cause of stiffness is very well localised, as, for example, in the presence of a cyclops syndrome, the stiffness can be addressed using the standard portals (Fig. 30.9). When performing an anterior arthroscopic arthrolysis for extension deformity, it is very important to perform an associated superolateral portal. It is mandatory to be able to switch portals for camera and instruments when necessary and to follow a systematic pattern:

- First of all, it is very important to obtain an adequate distension of the joint which is easy in the presence of minor fibrosis but can be very difficult in the presence of very stiff knee with solid adherences. In these cases, it is always possible to insert blunt instruments in order to distend the suprapatellar pouch and make space for arthroscopic instruments,

having care to avoid any damage to articular cartilage (Fig. 30.10).

- Anterior arthrolysis should start from the suprapatellar pouch having care to expose and preserve the anterior femoral cortex and the deep fibres of the quadriceps muscle. A simple basket (Fig. 30.11) could be useful at the beginning to remove the stronger adherencies and to open the way to shaver and electrocautery, which will do the most part of the job.
- If the arthrofibrotic process limits patellar mobility, the lateral and medial retinaculum should be released with electrocautery in order to prevent any damage to the geniculate vessels, associating medio-lateral mobilisation of the patella under arthroscopic guide.
- Peripatellar gutter arthrolysis should then be performed if necessary in slight flexion and from anterior to distal in order to prevent iatrogenic lesions of meniscal and ligament insertion (Fig. 30.12).
- Anterior arthrolysis should end in the intercondylar notch with resection of the infrapatellar plica and lysis of the Hoffa fat pad that should be performed with electrocautery as this structure is very vascularised. Extreme care must be taken in avoiding to damage patellar tendon during this part of the procedure.
- When a flexion deformity occurs due to a too anterior positioning of the graft in ACL reconstruction, a careful evaluation of the relationship between the graft and the roof of the notch must be conducted, and a progressive and often extensive notchplasty need to be performed (Fig. 30.13a, b) in order to eliminate any impingement. In some cases if at the end of this procedure a full extension has not been regained, the removal of the graft should be performed.
- At the end of the procedure, after releasing the tourniquet if employed, some cycles of a gradual, smooth and progressive mobilisation should be performed. The amount of ROM that the knee is able to reach passively under anaesthesia at the end of surgery is exactly the same that the patient can obtain at the end of the postoperative rehabilitation protocol.

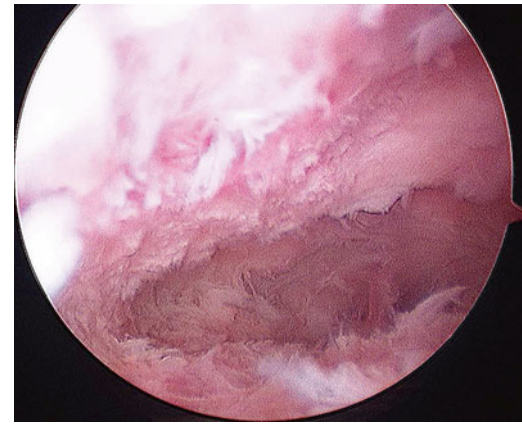


Fig. 30.10 Detensioning of suprapatellar pouch after insertion of blunt trochar

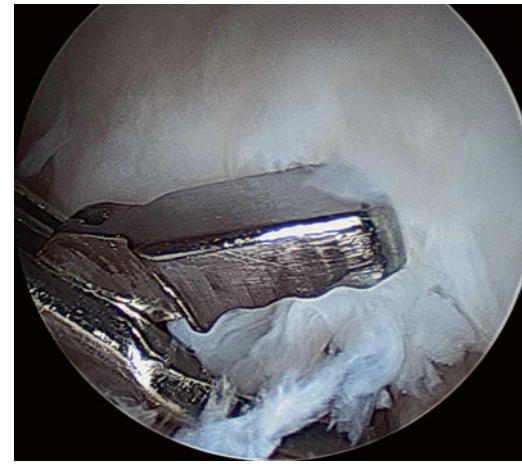


Fig. 30.11 Beginning the scar removal using a basket could be useful to open the way to the other instruments

If an arthroscopic posterior arthrolysis is needed for a loss of extension or mixed stiffness and after the previous passages have been correctly performed, the posterior procedure can be performed with these steps:

- First of all, the scope is introduced in the posteromedial space passing between PCL and medial femoral condyle.
- A posteromedial portal is performed under arthroscopic control taking care to avoid damages to the saphenous nerve and vessels.

- If necessary, in order to achieve complete extension recovery, a posterolateral portal or a transseptal portal can be performed. Every procedure performed in the posterior compartment must be done carefully, given the proximity of the posterior popliteal structures.

Arthroscopic arthrolysis is the first choice in treatment of almost all the clinical presentations of knee stiffness and, if correctly performed, allows to obtain good results in both flexion and extension deformities [17–21].

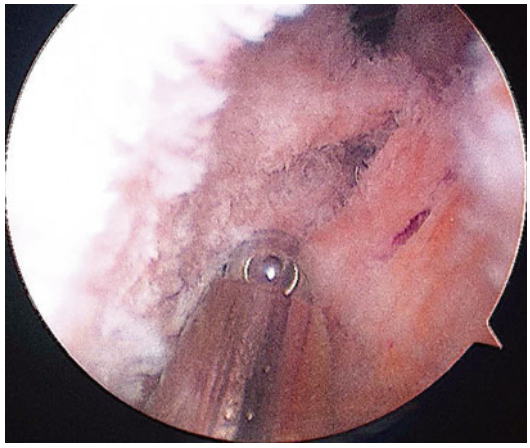


Fig. 30.12 Arthroscopic resection of adherences in medial peripatellar gutter using motorised shaver

30.2.2.2 Treatment of Extra-articular and Mixed Stiffness

In the presence of a mixed stiffness, the intra-articular procedure should be performed first as it frequently allows to have a partial recovery of range of motion sparing the patient from more invasive procedures. All the procedure must be planned and executed stepwise, and every surgical step should be performed only if range of motion recovery is insufficient after performing the previous one:

1. Evaluation under anaesthesia and record of the maximum degrees of flexion and extension
2. Extensive arthroscopic arthrolysis
3. Open arthrolysis if necessary (anterior or posterior)
4. Tibial tuberosity osteotomy in the presence of a patella infera
5. Arthromyolisis

Open Anterior Arthrolysis

This procedure has almost completely lost any role in treating extension deformities as the standard treatment is by now arthroscopic. It could be helpful when a complete release of lateral and medial patellofemoral ligaments is needed. It can be employed in severe stiffnesses in association

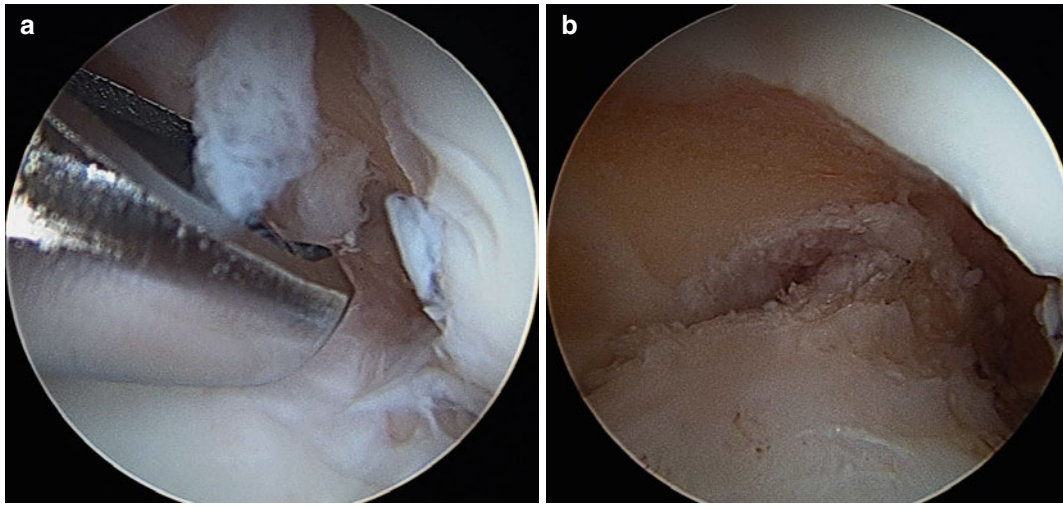


Fig. 30.13 (**a**) Notchplasty for impingement of ACL graft in the notch. (**b**) Extended notchplasty completed with no more impingement

with another open procedure scheduled, namely, proximalisation of tibial tuberosity or arthromyolysis, in order to address concomitant intra-articular stiffness through the same surgical approach.

Open Posterior Arthrolysis

The use of this procedure is reserved to the treatment of severe loss of extension non-treatable through arthroscopy and can be performed through a posteromedial arthrotomy or even with a combined medial and lateral arthrotomy as described by Pujol et al. [22], by dissecting the posterior capsule from the femur and in severe cases dividing the gastrocnemius muscle aponeurosis.

Proximalisation of the Tibial Tuberosity

In case of a postoperative patella infera determining a loss of flexion after an arthroscopic arthrolysis, the pathological patellar height should be addressed by a lengthening of the patellar tendon, as described by Dejour et al. [23] or by a proximalisation osteotomy of the anterior tibial tuberosity [24]. The aim of the correction is to have a normal patella height according to Caton-Deschamps (between 0.8 and 1). The tibial tuberosity is completely detached and after releasing the medial and lateral retinacula positioned as proximally as required for normalising patellar height under fluoroscopic control. The tuberosity is then fixed using two 4.5 mm cortical screws.

Arthromyolysis

First described by Judet et al. [25], it consists in a complete quadriceps muscle release through a wide lateral access. The patient is positioned supine without tourniquet and the incision is performed on the lateral aspect of the thigh (Fig. 30.14). This surgery recognises a stepwise approach, and between every step, a cautious mobilisation should be performed in order to evaluate the achieved degree of flexion and decide to proceed eventually to the next step:

- A longitudinal incision is performed on the fascia lata detaching it from the quadriceps muscle.
- Perforating blood vessels should be identified and ligated.
- The vastus lateralis and intermedius are completely detached from the femoral shaft from distal to proximal and from lateral to medial having care to protect both posterior and medial neurovascular structures (Figs. 30.15 and 30.16).

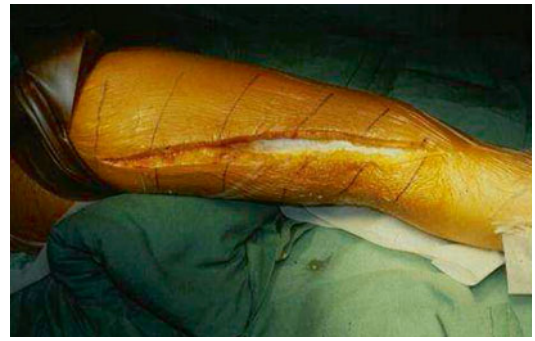


Fig. 30.14 Arthromyolysis: cutaneous incision

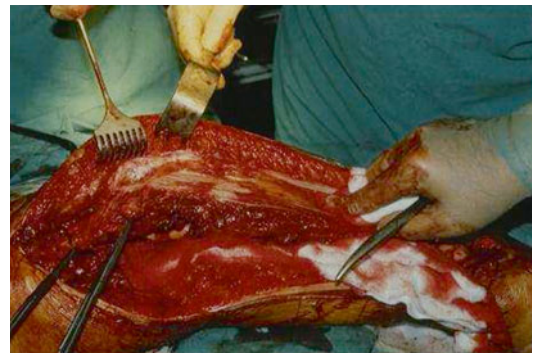


Fig. 30.15 Arthromyolysis: complete detachment of vastus lateralis and intermedius from the femoral shaft

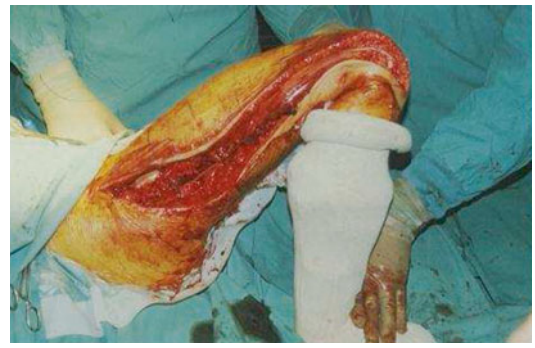


Fig. 30.16 Arthromyolysis: recovery of flexion superior to 110° at the end of the procedure

- If necessary, the vastus lateralis proximal origin is detached and the vastus medialis separated from the proximal femoral shaft.
- As a final procedure, the rectus femoris tendon can be resected on the anterior aspect of the hip.

Given the invasiveness of this procedure, it has to be considered as a salvage procedure to employ only in severe cases of posttraumatic or postsurgical loss of flexion [26, 27]. Although performing a correct haemostasis all throughout the procedure, the expected blood loss is very high, and preoperative autologous blood donation should be considered.

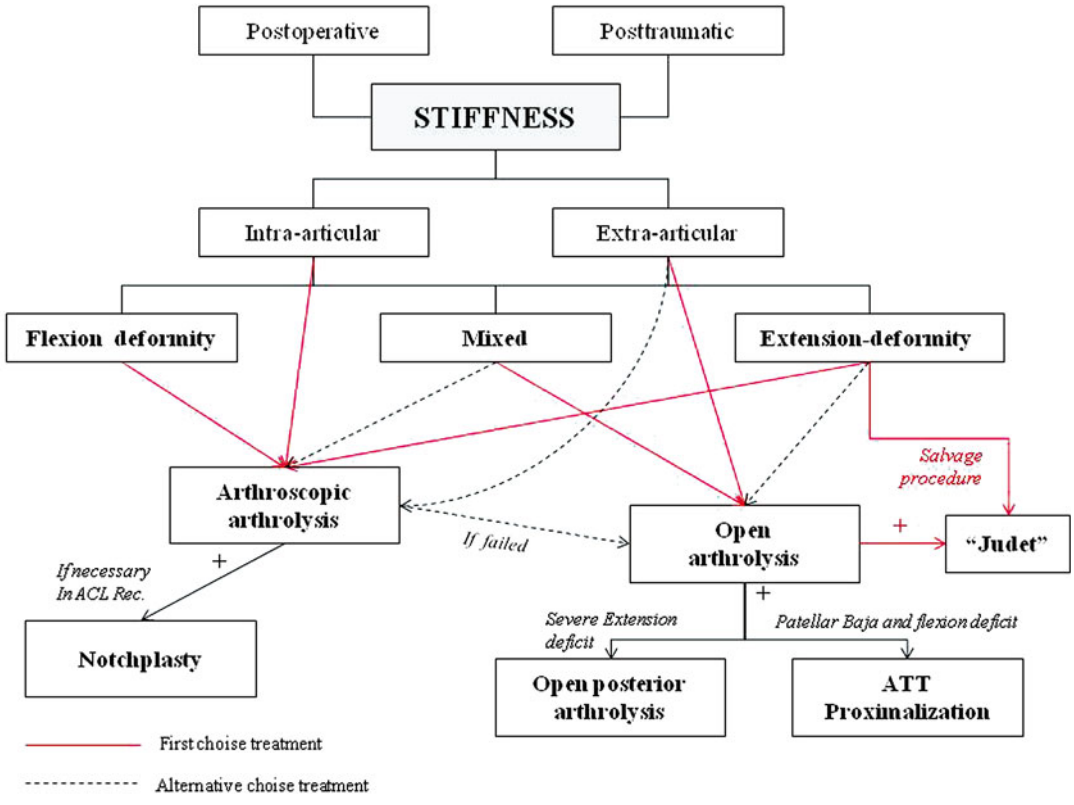
Surgical Therapy Algorithm (Table 30.2)

Postoperative Treatment

The rehabilitation protocol should start in immediate postoperative and conducted in a systematic way. These patients must be followed at short follow-up in order to prevent recurrence of stiffness and address the correct evolution of recovery. Because of the elevated postoperative pain that these procedures may produce, a concomitant and deep analgesia must be planned in the first weeks in order to obtain a complete cooperation by patients. After a procedure performed for an extension deformity, the use of CPM 4 h per day should be encouraged using the maximum degree of flexion reached at the end of the procedure as reference. Passive and auto-assisted flexion recovery exercises, along with isometric strengthening of quadriceps muscle and active stretching of both quadriceps and hamstrings, should start as soon as possible after surgery.

After an extension release, the patient will start with extension postures lasting as tolerated and intensive stretching of hamstring muscles. An extension brace has to be employed at night.

Table 30.2 Surgical therapy algorithm



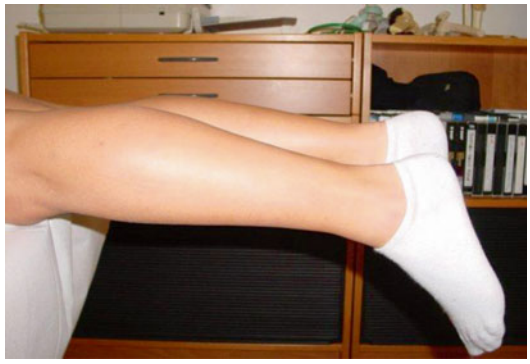


Fig. 30.17 Loss of extension results more evident in prone decubitus

Extension recovery is best evaluated in prone decubitus (Fig. 30.17), while flexion is assessed with patient lying supine and the ankle and hip flexed using only limb weight as only applied flexing force. After 12 weeks, results normally reach a plateau, although it is common to observe a slowdown of the progresses, or even a recurrence of stiffness after 6–8 weeks. Continuous improvement of the results could be recorded during the entire first year after surgery This makes even more important to evaluate the patient at regular follow-up until 1 year postoperative in order to maintain surgical results.

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Arthroscopic Fixation of Fractures Around the Knee

31

Pietro Randelli, Davide Cucchi, Filippo Randelli, Chiara Fossati, and Paolo Cabitza

31.1 Tibial Eminence Avulsion Fractures

Pietro Randelli, Davide Cucchi, Chiara Fossati
Paolo Cabitza

31.1.1 Epidemiology and Mechanism of Injury

Tibial eminence avulsion fractures occur most commonly in children and adolescents aged between 8 and 14 years (3/100,000 children [74]). Falls from a bike, motor vehicle accidents and sport activities (mostly soccer and skiing) are the most frequent causes in paediatric population; in these cases, a valgus-directed force associated with an external torsion when the knee is in hyperextension is the most frequently referred mechanism, which closely resembles the one for anterior cruciate ligament (ACL) tears. In adults, this lesion is rare and associated either with high-energy trauma, boot-induced injuries in skiers or forced internal rotation with flexed knee [10, 11, 17, 27, 35, 41, 48, 51, 60].

Tibial eminence avulsion fractures are often considered the paediatric equivalent to ruptures of the ACL. This happens because the epiphyseal ossification process reaches the tibial eminence only in late childhood or adolescence, leaving this area more vulnerable to tensile forces than the ACL itself [1, 5, 39, 61]. A greater ligamentous elasticity in children has also been advocated as possible aetiology for this fracture [55, 83].

Avulsion fractures may either involve the intercondylar depression where the ACL insertion lies only or, less frequently, the entire tibial spine with medial and lateral plateau [16].

31.1.1.1 Associated Lesions

Tibial eminence avulsion fractures are associated with a high incidence of bony contusions, typically on the lateral femoral condyle and the posterior tibia, especially in children [71]. Meniscal

P. Randelli (✉) • D. Cucchi
Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Via Mangiagalli 31, Milan 20133, Italy

2nd Department of Orthopedics and Traumatology, IRCCS Policlinico San Donato, Via Morandi 30, San Donato Milanese, Milan 20097, Italy
e-mail: pietro.randelli@unimi.it

F. Randelli • C. Fossati
5th Department of Orthopedics and Traumatology, IRCCS Policlinico San Donato, Via Morandi 30, San Donato Milanese 20097, Italy

P. Cabitza
Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Via Mangiagalli 31, Milan 20133, Italy

Scientific Direction - 1st Department of Orthopedics and Traumatology, IRCCS Policlinico San Donato, Via Morandi 30, San Donato Milanese 20097, Italy

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tear incidence ranges from less than 5 % to up to 40 % across different studies [30, 47, 50–52]. In older patients, tibial eminence fractures are often combined with lesions of the menisci, capsula or collateral ligaments [51, 65]. In addition to intra-articular pathology, tibial eminence fractures may be associated with tibial plateau fractures, specifically Schatzker type V and VI fractures [38, 66].

31.1.2 Diagnosis

31.1.2.1 History and Presentation

Presentation of acute and chronic avulsions may vary. In acute cases, pain, knee swelling and inability to bear weight are the most frequent complaints. Restricted range of motion may be present due to pain and swelling, loose bodies, impingement of the bone fragment or associated meniscal lesions. Patients affected by chronic tibial eminence avulsion fractures may complain about joint instability, recurrent effusion and restriction in passive and active knee extension [39, 46, 49, 73].

31.1.2.2 Clinical Examination

Reduced active and passive range of motion is often reported; swelling, guarding reactions or spasms may complicate clinical examination in acute lesions, making some tests for ligament stability impossible to perform. Depending on patient reaction and time to presentation, Lachman, anterior drawer and pivot shift tests may be slightly or clearly positive. Collateral ligament and posterior cruciate ligament stability should be tested; meniscal injuries may be suspected after a careful clinical examination. Assessment of neurological and vascular status completes the clinical examination [21, 30, 65, 73].

31.1.2.3 Imaging

A complete radiographic evaluation of the injured knee, including standard anteroposterior, lateral and oblique radiographic views, is usually diagnostic. Computed tomography (CT) surely helps to better define bony architecture and precisely identify the fracture anatomy (Fig. 31.1). Magnetic resonance imaging (MRI) offers a good visualisation of soft tissues: this permits to determine the substance quality of the ACL, assess other ligaments' integrity and identify possible meniscal or chondral injuries. Doppler ultrasonography, arteriography and subsequent vascular surgery consultation must be considered in the presence of diminished pulses, if dislocation is suspected or in cases of abnormal vascular examination [39, 46, 65, 73].

31.1.3 Classification

The system suggested by Meyers and McKeever in 1959 is still today the most commonly used (Fig. 31.2 and Table 31.1 [51]). Zaricznyj implemented this classification with a type IV for comminuted fractures [85].

Later, Zifo and Gaudernak proposed another scheme, which distinguished between isolated ACL avulsions and fractures including the intercondylar eminence [86].

31.1.4 Management

31.1.4.1 Principles

Anatomic reduction is the goal of tibial intercondylar eminence avulsion treatment. Isometry and tension are fundamental to restore ACL and knee kinematics and must be obtained with the surgical operation. A generally accepted rule is that over-reduction should be avoided to prevent excessive tightening of the ACL, resulting in limitation of knee motion [41]. However, some authors believe that permanent intersubstance stretching of the ACL occurs before the fracture and therefore recommend over-reduction; this is supported also by the evidence that long-term evaluation of well-reduced tibial eminence fractures reveals subtle increases in anteroposterior knee laxity but that slight laxity can be tolerated without limitations in daily life and sports [37, 64, 75, 81, 82].

31.1.4.2 Indications

Meyers type I fractures are treated conservatively; no consensus is obtained on the better

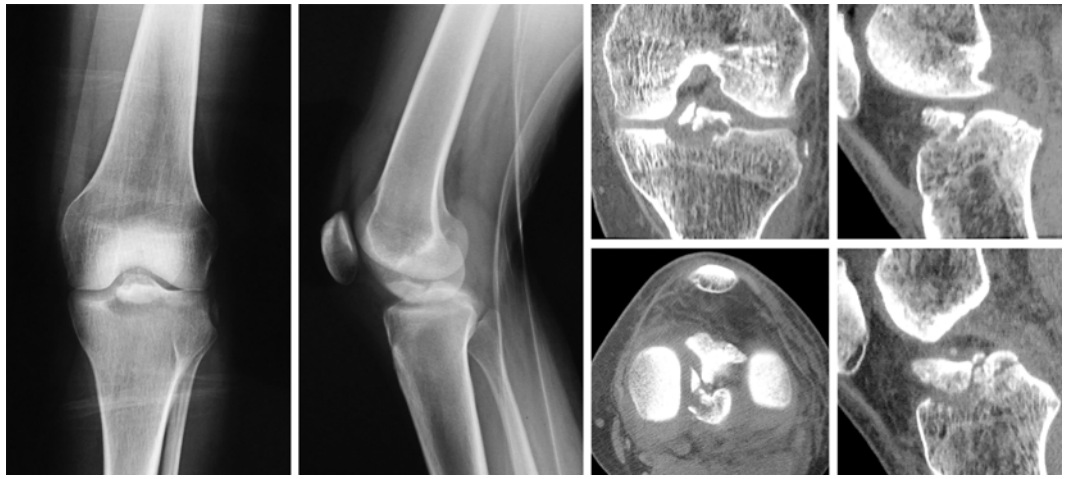

Fig. 31.1 Preoperative radiographs and CT scan in a Meyers and McKeever type III B fracture and Segond bony avulsion

immobilisation technique and the correct knee extension to maintain. Some authors prefer to hold the knee in slight flexion, a condition in which ligament tension is minimal, to allow maintenance of reduction [5, 16, 47, 50, 51]. Some others prefer to hold the knee in full extension to avoid extension deficit [21]. Full weight bearing is allowed if tolerated; follow-up of the patient is required with radiographs every 2 weeks to monitor possible displacement.

Treatment for Meyers type II fractures is controversial; an attempt to close reduction with knee extension or hyperextension after aspiration of the haemarthrosis is generally performed, although the rationale has been criticised. Anteroposterior and lateral radiographs (and CT or MRI if the radiograph is difficult to interpret) are required to assess reduction. Reduction might not be obtained due to meniscal interposition or insufficient congruency between condyles and avulsed tibial eminence [30, 48]. Nowadays, if persistent displacement of the anterior aspect is present, the old indication of cast immobilisation has been in most cases substituted by arthroscopic revision and fixation [3, 17, 39, 50, 51, 73].

Close reduction of Meyers type III fractures may be unsuccessful due to displacement of the osseous fragment; several papers have reported worse results for type III fractures treated non-operatively [25, 37, 47, 57, 76, 79]; therefore, arthroscopic reduction and internal fixation (ARIF) has become the standard procedure for this type of fractures.

Open reduction and fixation of tibial eminence avulsion fractures is never recommended, unless other lesions requiring open surgery are present [11].

31.1.4.3 Timing

Acute definitive treatment for tibial eminence avulsion fractures showed an earlier return to full preinjury activity and is therefore recommended, in combination with modern surgical techniques and accelerated rehabilitation protocols which reduce significantly the incidence of arthrofibrosis [56, 62].

31.1.4.4 Procedures

Setting, Portals and Diagnostic

McLennan in the 1980s and Van Loon and Lubowitz in the 1990s were the first to introduce ARIF to treat tibial avulsion fractures [35, 41, 48]. Currently, ARIF is considered the gold standard in the treatment of tibial eminence avulsion fractures.

The patient is placed supine. General or epidural anaesthesia may be used. Examination under anaesthesia may be useful to confirm ligamentous injuries. A leg holder may be used and a tourniquet

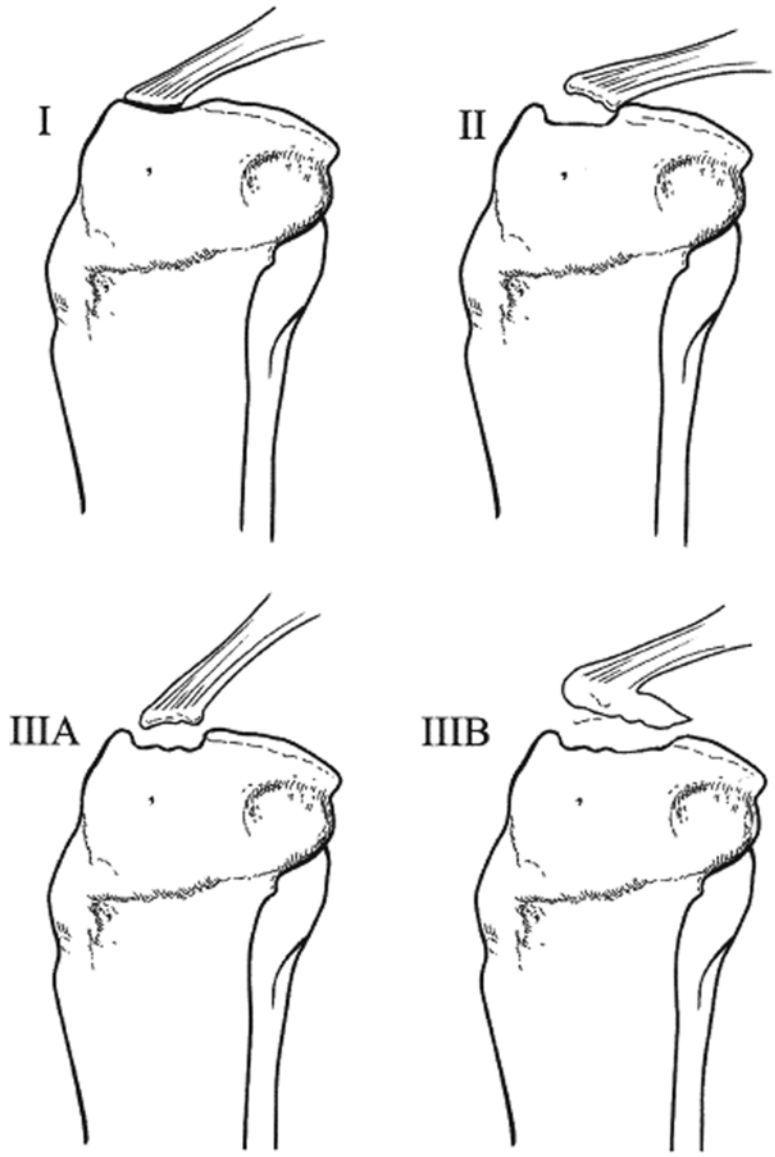

Fig. 31.2 The Meyers and McKeever classification of tibial eminence avulsion fractures (Reprinted from Lubowitz et al. [40], Copyright © 2005 Elsevier Inc, with permission from Elsevier). Type I: non-displaced or associated with minimal displacement of the anterior margin. Type II: superior displacement of the anterior aspect with an intact posterior hinge (bird's beak). Type IIIA: completely displaced, involves the ACL insertion only. Type IIIB: completely displaced, includes the entire intercondylar eminence

Table 31.1 Meyers and McKeever tibial eminence avulsion fractures classification

Type	Pattern
I	No or minimal displacement
II	Superior displacement of anterior aspect with intact posterior hinge
IIIA	Complete displacement only of ACL insertion
IIIB	Complete displacement of the entire inter condylar eminence
IV[a]	Comminuted fracture

[a]Type IV added by Zaricznyj [85]

may facilitate visualisation. Fluoroscopic imaging is not always required but may help confirm correct positioning of fixation devices.

Standard anterolateral and anteromedial portals are used. An accessory central transpatellar portal may facilitate reduction and fixation [39]; other additional portals for instrumentation may be established if necessary. Irrigation and debridement are performed first, to evacuate blood clots and loose bodies. Diagnostic arthros-

copy is performed to document the pattern of the fracture and identify possible associated meniscal, ligamentous and chondral injuries. Capsular or meniscal lesions may be treated before or after fracture fixation, depending on specific situation and surgeon's preference [39, 73].

Reduction Techniques

The anterior horn of the medial or lateral meniscus or the intermeniscal ligament a frequently trapped within the fracture site. A probe or a meniscal hook may be used to retract it and free the fracture site; a temporary meniscal suture loop may also be used to facilitate retraction. The intermeniscal ligament can be resected if mobilisation is not possible. Once the fracture site has been debrided, a ligamentoplasty aiming guide or a probe is used to attempt fracture reduction. Depending on the chosen fixation technique, the surgeon may directly proceed with definitive fixation or may obtain a temporary fixation with a Kirschner wire or a Steinmann pin [15, 22, 30, 42, 60, 62, 72, 79, 82].

Fixation Techniques

Screw Fixation

Anterograde or retrograde screw fixation techniques have been described. The screw must not be larger than one third of the fragment diameter, to prevent comminution [6]. A single 3.5 or 4.0 mm anterograde transepiphyseal screw (with or without washer) has been indicated as sufficient to hold the fragment in anatomic position [6, 22, 41, 53, 68]. The screw may be inserted from a superior anteromedial or a transpatellar portal, with the knee in 100–120° flexion. If cannulated screws are used, the wire or pin used for temporary fixation may also serve as a guide (Fig. 31.3) [41, 68].

Physeal-sparing fixation can be achieved with a more horizontal positioning of the screw; in this case, fluoroscopy is fundamental to prevent transepiphyseal fixation. Fixation with two screws has also been proposed as physeal-sparing technique [2, 29].

Before closure, full range of motion must be checked to avoid impingement. Screw removal is not compulsory but recommended, between 8 and 12 weeks postoperatively (Fig. 31.4) [68].

Suture Pull-Out Fixation

Suture pull-out technique can be used when the fracture is small or comminuted. some cases of growth defects have been observed when this technique is used with still opened growth plates; transphyseal tunnel placement may in these cases be considered as an alternative to transepiphyseal tunnels [32, 39, 58, 67].

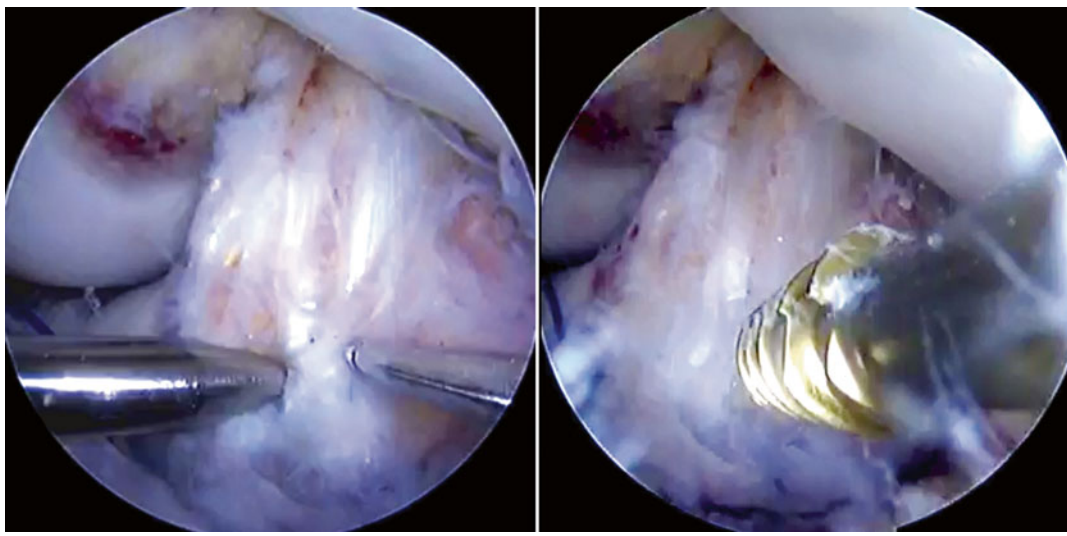

Fig. 31.3 Reduction and fixation with a cannulated screw. The Segond bony avulsion has been treated conservatively

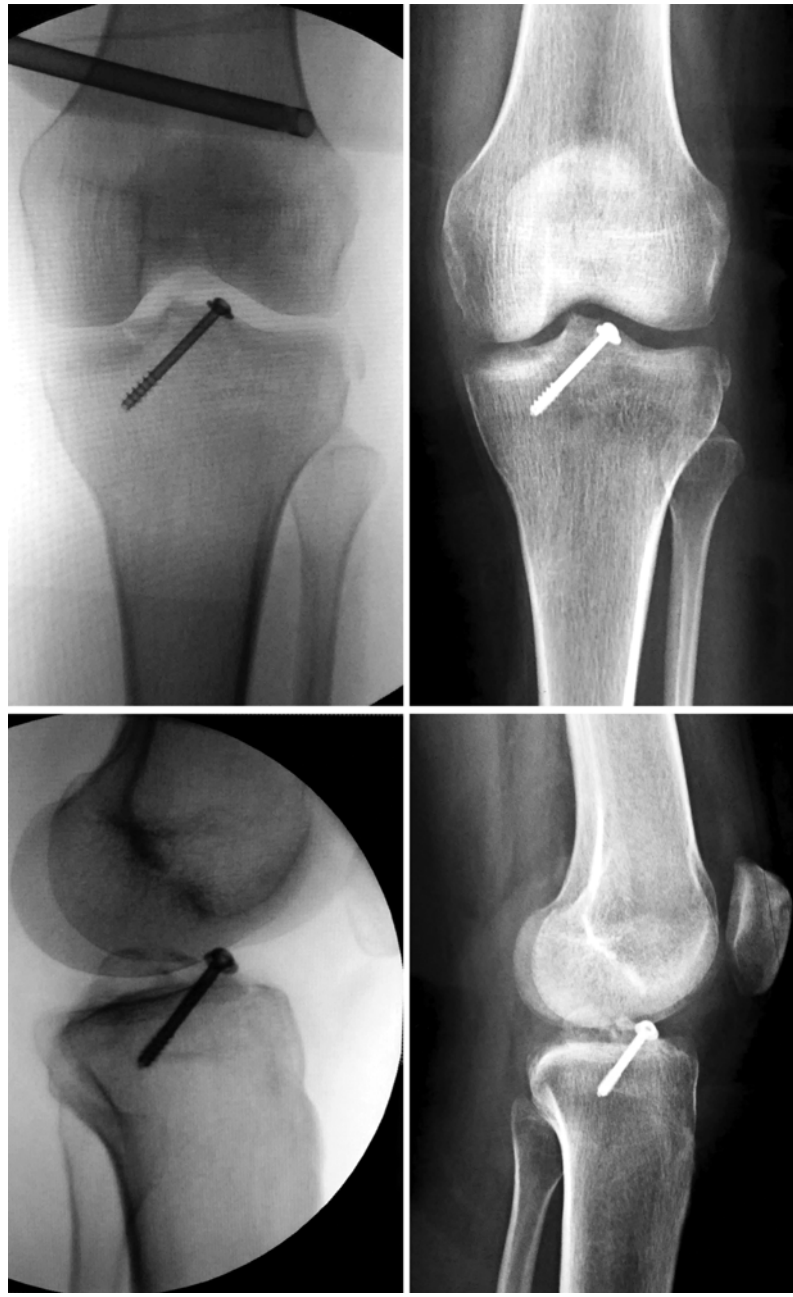

Fig. 31.4 Radiographic results of screw fixation: immediately after screw positioning and 8 weeks after surgery, when full ROM and weight bearing has been reached

One or more high-resistance sutures are passed through the ACL fibres or the fracture fragment with the help of a curved suture lasso, a hook or a bended cannula, percutaneously or through an accessory portal. From a short longitudinal incision centred over the tibial tubercle, two 2.4 mm tibial bone tunnels are then drilled from the anterior aspect of the tibia, 1–2 cm apart from each other; a ligamentoplasty guide aids in obtaining the correct exit points, at the medial and the lateral edges of the fracture bed in its midcoronal plane. A suture retriever or a wire loop is passed through each tunnel to pull down the ends of the reduction sutures. These are finally tied together or tied to a screw, checking for appropriate reduction, with the knee flexed at approximately 30° [2, 7, 20, 23, 39, 45, 46].

Suture Anchor Fixation

Suture anchor fixation has been first advocated as a physeal-sparing technique. Titanium or biocomposite screws loaded with two or three high-resistance sutures are introduced through the anteromedial portal and placed either 2–3 mm anterior to the fracture site, with 45° inclination to the frontal plane to avoid physis penetration and ensure minimal pull-out risk. Placement in the posterior aspect of the fracture or all around the fracture site has also been described. The sutures are then passed through the ACL fibres and tied, with the knee flexed between 20 and 45°, with a simple arthroscopic sliding knot or different arthroscopic suture patterns, such as a mattress suture [24, 44, 80].

Other Fixation Techniques

Fixation with one or two Kirschner wires has also been described; hardware removal is recommended after 6 months [4, 9, 81].

Staple fixation has been proposed, with the advantage of not requiring tibial incision [28, 77].

Short bioabsorbable nails [34], meniscus arrows [84] and suture-button systems [14] have also been described for treatment of tibial eminence avulsion fractures.

A variation of the suture pull-out technique with metal wires instead of high-resistance sutures has been described [59].

31.1.4.5 Postoperative Care

Drainage is usually unnecessary. Surgery may be on outpatient basis or be followed by a short hospital stay. Crutches are optional and recommended at first, and patients are then permitted to bear full weight, unless additional procedures as meniscal repair or microfractures have been performed. An accelerated rehabilitation to reduce stiffness should be weighed against the possibility of displacement an malunion [19]. Some authors still recommend cast immobilisation for 3–6 weeks [22, 26, 63, 69, 72], while others suggest early range of motion exercise in a hinged brace, with the knee first locked in a brace in full extension and gradual unlocking to full range of motion by 6 weeks [19, 27, 39, 42, 62, 64, 68, 79]. Rehabilitation techniques are heterogeneous and not well described in the literature. Time to return to sport also varied from 4 weeks to 5 months [11]. Cycling can be permitted as soon as the range of motion is sufficient, followed by light jogging. Pivot-twist manoeuvres should be avoided until 12 weeks after surgery. After 6 weeks, the brace is discontinued, resisted flexion is permitted through a full range of motion, and resisted extension is permitted through a range of 30–90°. Terminal resisted extension should not be performed until 3 months, when quadriceps usually reach the preoperative strength [39, 46, 73].

31.1.5 Complications

Residual laxity may be found after arthroscopic reduction and fixation of tibial eminence avulsion fractures; nevertheless, the majority of patients have functional stability and are not adversely affected. Revision surgery with ACL reconstruction should be considered if persistent complaints of instability are reported, which can be caused by displacement, malunion, non-union or ACL substance injury [6, 22, 29, 42, 46, 48, 52, 53, 73, 81].

Pain or discomfort due to metal hardware is common with the use of cannulated screws; implant malpositioning may lead to loss of full knee extension or secondary osteoarthritis. Limited range of motion can also result as a consequence of abundant scar tissue formation in the intercondylar notch [46].

Arthrofibrosis is rare if the patient undergoes early ARIF and early active range of motion rehabilitation [19, 62].

Growth disturbances are rare but worrying complications in paediatric tibial eminence avulsion fracture fixation. The most severe cases with coronal and sagittal plane deformities have been reported following transepiphyseal screw fixation; screw removal is fundamental and may be followed by hemiepiphysiodesis or corrective osteotomy [2, 13, 31, 54].

Residual quadriceps weakness and persistent retropatellar pain may be observed. Meniscal entrapment can be a cause of residual pain, requiring revision surgery [10].

31.1.6 Literature Results

No systematic reviews or meta-analyses have been produced regarding tibial eminence avulsion fracture treatment in adults. Coyle et al. and Leeberg et al. published two systematic reviews on tibial eminence fractures in paediatric population, in which better long-term results are reported with arthroscopic surgery, compared to open surgery; no indication on the best type of fixation was specified [11, 33]. Papers describing outcomes of tibial eminence fractures at more than 5 years follow-up show an improvement in results with the transition from open to arthroscopic approach [11, 36, 63, 72].

Comparisons between screw and suture fixation showed ambiguous results. Sharma et al. found slightly superior clinical results for absorbable sutures in comparison to non-absorbable materials; a statistically significant difference was found for adults but not for children in knee laxity after a mean of 44 months follow-up [70]. Seon et al. found no significant differences between screw and suture fixation in terms of average Lysholm knee scores and stability at a minimum of 2 years follow-up [69]. Biomechanical studies showed controversial results, sometimes favouring metal implants or sutures, sometimes showing no significant differences between them [8, 12, 18, 43, 78].

31.2 Tibial Plateau Fractures

Pietro Randelli, Davide Cucchi, Filippo Randelli, Chiara Fossati, Paolo Cabitza

31.2.1 Mechanism of Injury and Epidemiology

Fractures of the tibial plateau represent approximately 1–2% of all fractures; the vast majority of them are related to traffic injuries, falls from height, sports or trauma of other kind. Sport-related injuries, most of which affect skiers, account for 5–10% of all cases [88, 109, 113, 115, 136].

Tibial plateau fractures may occur as a result of an axial compressive force, a valgus force or a varus force; combinations of these forces are also possible and may produce more complex fractures. The direction, magnitude and location of the force, as well as the position of the knee at impact, determine the fracture pattern, location and degree of displacement. In most cases, the medial or lateral femoral condyle act as an anvil imparting a combination of both shearing and compressive forces to the underlying tibial plateau [104, 134, 152]. Either one or both compartments of the tibial plateau may be involved; due to the anatomic axis at the knee joint and the predominance of injuries caused by a lateral-to-medial-directed force, when a single compartment is involved, it is usually the lateral plateau [131, 147].

Older patients with reduced bone mineral density are prone to sustain depression-type fractures because their subchondral bone is less resistant to axially directed loads. In contrast, younger patients with denser bone sustain more likely split-type fractures and have associated ligamentous disruption [92, 125, 128, 129, 152].

31.2.1.1 Associated Lesions

Fractures of the tibial plateau compromise the blood supply from the intramedullary arterial network but usually leave the periosteal network intact [119]. The popliteal vessels and nerves may be also damaged, especially in the event of a high-energy trauma [147].

These fractures are frequently associated with other bony or soft tissue lesions. The tibial intercondylar eminence is often avulsed in association with fractures of the tibial plateau [138]. Fractures of the femoral, tibial or peroneal shafts or epiphyses of the patella or other bones of upper or lower limbs have been reported, especially after high-energy trauma [88].

The frequency of meniscal lesions varies widely across studies (2–47%). Vangsness et al. reported the highest rate of associated meniscal lesions, with almost half of the knees with closed tibial plateau fractures requiring surgical meniscal repair [121, 155].

Up to one third of knees with tibial plateau fractures may have complete or partial tears of the anterior cruciate ligament [115]. Lesions of the collateral ligaments and of the posterior cruciate ligament may be present and should be sought routinely. Ligamentous injury occur more frequently in case of split-type fractures of the lateral plateau, in which energy is transmitted from the rigid cancellous fragment to the ligaments without dissipation [147].

31.2.2 Diagnosis

31.2.2.1 History and Presentation

Frequent presentation signs and symptoms are pain, knee swelling and inability to bear weight on the affected leg. Trauma history and mechanism of injury may be precisely described by the patient or may not be reported or available. It is always important to confirm the level of energy involved in the injury; associated injuries are most often present after high-energy trauma [113, 134, 147].

31.2.2.2 Clinical Examination

Clinical examination may be complicated by swelling, apprehension or spasms; reduced active and passive range of motion is usually reported, and haemarthrosis is generally present. If possible, tests for ligament stability or meniscal integrity should be performed. Any open wounds must be evaluated; injection of at least 50 ml sterile saline solution in the knee may help to ascertain if the wound communicates with the joint space [131]. Popliteal, dorsalis pedis and posterior tibial pulses must be palpated; if absent and in any case of suspected knee dislocation or blood vessel injury, Doppler ultrasonography, angiography and vascular surgery consultation must be considered. Disproportionate pain, pain arising with passive toe movement or a swollen leg in an unconscious patient may suggest an impending compartment syndrome and require compartment pressure monitoring. Evaluation of the peroneal and tibial nerve function completes the clinical examination [113, 134, 147].

31.2.2.3 Imaging

Radiographic evaluation of the injured knee is mandatory (Fig. 31.5); complete radiographic evaluation includes standard anteroposterior, lateral, two oblique projections and a 10–15° caudally tilted tibial plateau view [104, 134, 147].

Computed tomography (CT) provides a very detailed visualisation of the fracture pattern, permitting to identify the extent of the articular involvement and the presence of intra-articular fragments. CT must be routinely performed in these fractures. Magnetic resonance imaging (MRI) offers a better visualisation of soft tissues; this permits to identify ligamentous, meniscal or chondral injuries and to plan the surgical intervention accordingly. CT and MRI scans have been demonstrated to provide a far more superior accuracy than plain radiography; in fact, they have partially substituted plain radiography and are considered the gold standard for bony and soft tissue injuries [100, 135, 157].

31.2.2.4 Arthroscopic Evaluation

Diagnostic arthroscopy is considered a valid tool to allow direct visualisation of the articular surface. Soft tissue injuries are commonly associated with tibial plateau fractures and can be diagnosed by arthroscopic evaluation [87, 99, 134, 141].

31.2.3 Classification

Different classification systems are available for tibial plateau fractures. The majority of these systems recognise split/wedge, compression and bicondylar types.

Gerard-Marchant and Duparc described the first classification systems for proximal tibial fractures, which established the basis for current classifications [112, 114]. Hohl proposed the first widely accepted classification of tibial plateau fractures, later expanded by Moore [120, 140]. In 1992, Schatzker described the currently most frequently used classification for tibial plateau fractures (Fig. 31.6 and Table 31.2) [94, 134, 152].

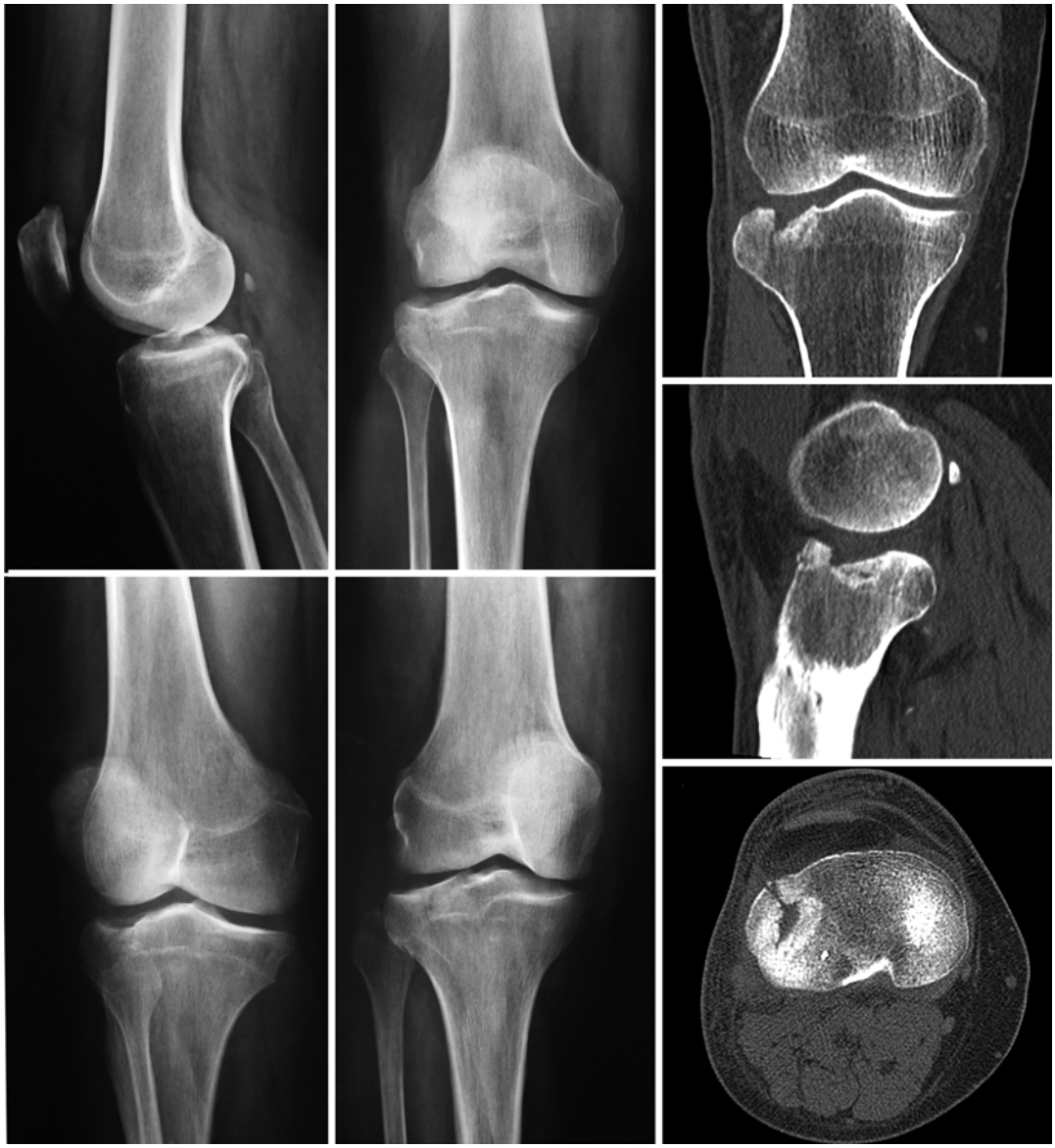

Fig. 31.5 Preoperative radiographs and CT scan in a Schatzker type III fracture

In the AO/ASIF classification, proximal tibia is denoted as segment 43, and its fractures are divided into three main categories [150].

31.2.4 Management

31.2.4.1 Principles

The ultimate goals of tibial plateau fracture treatment are to restore a painless knee function and prevent post-traumatic arthritis; this can be obtained by re-establishing joint stability, alignment and joint surface congruity while preserving full range of motion. Different types of conservative or surgical therapy are available, depending on articular damage, depression or comminution of the fracture and soft tissue conditions [94, 104, 122, 137].

31.2.4.2 Indications

Although the indications for nonoperative versus operative treatment of tibial plateau fractures

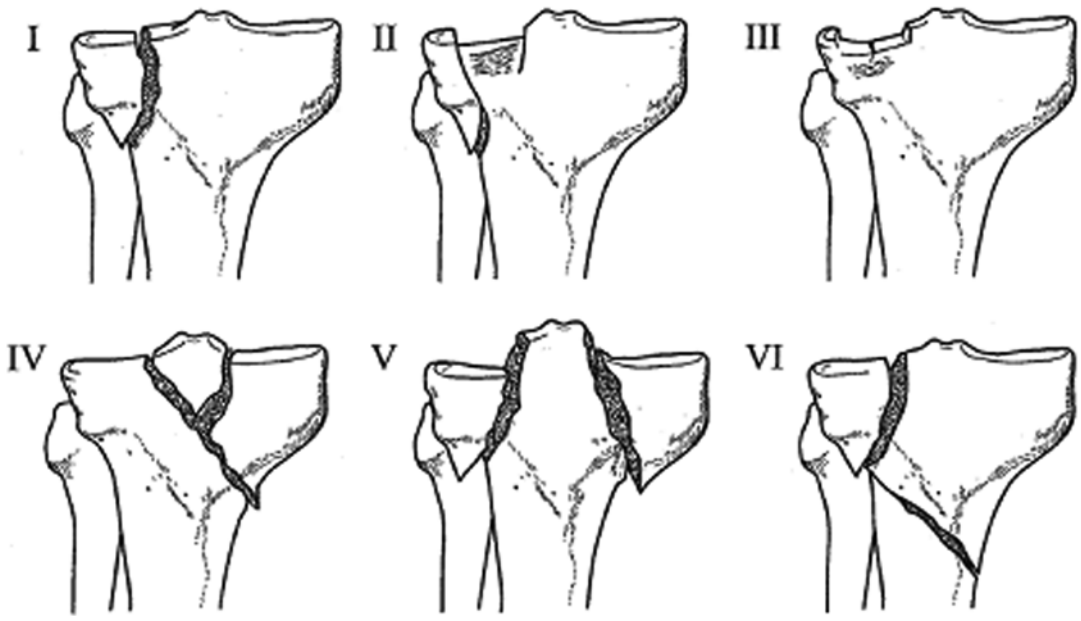

Fig. 31.6 The Schatzker classification of tibial plateau fractures (Reprinted from: Lubowitz et al. [134], Copyright © 2004 Elsevier Inc, with permission from Elsevier). Type I: wedge or split fracture of the lateral aspect of the plateau. Type II: lateral wedge or split fracture associated with compression. Type III: pure compression fracture of the lateral plateau. Type IV: fracture of the medial plateau, either split or split and compression. Type V: fracture of the medial and lateral aspects of the plateau, either split or split and compression. Type VI: fracture of the medial and lateral aspects of the plateau, complex

Table 31.2 Schatzker tibial plateau fractures classification

Type	Plateau involved	Pattern	Force direction
I	Lateral	Wedge/split	Valgus and axial
II	Lateral	Wedge/split + compression	Valgus and axial
III	Lateral	Pure compression	Axial
IV	Medial	Split ± compression	Varus or axial
V	Lateral + medial	Split ± compression	Axial (high energy)
VI	Lateral + medial	Complex fracture	Combinations of forces (high energy)

vary widely in the literature, there is consensus on nonoperative treatment for non-displaced or minimally displaced and stable fractures with no absolute indications for surgery (as neurovascular injury or compartment syndrome). Advantages of nonsurgical treatment include a short hospitalisation and no risk of infection; disadvantages are possible displacement and joint stiffness after prolonged immobilisation. If nonoperative management is pursued, it is recommended to use a hinged brace and start early active range of motion as soon as possible; close follow-up of the patient with radiographs every 2 weeks for the first 6 weeks is required to monitor depression, displacement and axis deviation [136, 141, 147, 150].

If displacement or articular compression are present, surgery is required to restore limb alignment, articular congruity and knee stability.

Arthroscopic treatment of tibial plateau fractures is generally accepted for Schatzker types I, II, III and IV fractures. Authors favouring arthroscopically assisted procedures claim numerous advantages when comparing them to open reduction and internal fixation (ORIF): arthroscopic treatment is less invasive, and a better visualisation of the entire articular surface is achieved. Moreover, it allows accurate fracture reduction; it is easy to evacuate blood clots or debris and to treat meniscal or ligamentous injuries. Finally, hospitalisation and rehabilitation are faster and with less pain [95, 115, 136].

More complex fracture patterns (Schatzker types V or VI) may not be suitable for arthroscopic treatment. In these cases, ORIF is preferred; the use of arthroscopy in complex proximal tibial fractures has also been suggested, to improve the quality of the reduction [95, 101, 102, 139].

31.2.4.3 Timing

No published studies have produced evidence-based recommendations on surgical timing for arthroscopic treatment of tibial plateau fractures. Studies on open treatment suggest lower wound complication rate if surgery is performed within 4 h after trauma or after 5 days [156]. In type V and VI fractures, the degree of soft tissue swelling dictates the timing of definitive surgery and the need for provisional stabilisation with an external fixator [135].

31.2.4.4 Procedures

Setting, Portals and Diagnostic

Arthroscopically assisted reduction and internal fixation in the treatment of tibial plateau fractures was first introduced by Caspari and Jennings in the 1980s [98, 126]. Currently, arthroscopically assisted approaches are being widely used in the treatment of tibial plateau fractures [89, 97, 102, 103, 107, 110, 111, 115, 116, 123, 124, 127, 130, 133, 142, 146, 148, 149, 151, 153].

The patient is placed supine. General or epidural anaesthesia may be used. If autologous iliac bone graft or concomitant ligament reconstruction procedures are planned, draping must consider the donor sites as well. Examination under anaesthesia may be useful to confirm ligamentous injuries. Gentleness is crucial, to avoid increasing the displacement of the bone fragments. A leg holder may be used and a tourniquet may facilitate visualisation.

Standard anterolateral and anteromedial portals are used. An accessory lateral portal, lateral to the standard anterolateral one and at the level of the joint line, may be useful to retract the meniscus with a loop or with a hook and improve anterior plateau view [145]. Irrigation and debridement are performed as a first step, to evacuate blood clots and loose bodies. Diagnostic arthroscopy is performed, the articular pattern of the fracture and the amount of depression are identified, and meniscal, ligamentous and chondral injuries are documented.

Reduction Techniques

Schatzker type I fractures (fractures characterised by pure cleavage) may be reduced via external traction or with a reduction forceps. Temporary fixation is achieved using one or two Kirschner wires, which should be placed approximately 1 cm under the joint surface. These wires may also be used as a joystick to elevate the fragment and to correct rotational displacement. If the apex of the split is displaced, a small incision can be made to allow anatomic reduction of the distal fracture spike. If traction is insufficient to achieve reduction, a palpation hook can be used to disimpact the bone fragments. Arthroscopy is used to verify reduction and fluoroscopy to confirm the adequate placement of wires. Two percutaneous cannulated screws with washers are placed for definitive fixation. In case of comminution or instability, a buttress plate, with or without additional compression screws, is required and can be placed percutaneously or with a standard extra-articular incision [96, 134].

Schatzker type III fractures (characterised by isolated depression) and fractures in which depression is combined with cleavage (type II and IV) require reduction of all depressed elements first. To elevate the subchondral bone and the joint surface, a tool is inserted through the metaphysis, under fluoroscopic and arthroscopic control.

The elevating force must be applied from the centre of the depressed area; this may be performed directly, by means of an osteotome introduced through an anterolateral cortical window or through the fracture site or with the help of a ligamentoplasty aiming system, which can be used to place a drill-guide pin in the centre of the depressed fragment (Fig. 31.7). A 9 or 10 mm drill is then used to penetrate the cortex, either anterolateral or anteromedially, manually or using a power tool. Careful manoeuvres under arthroscopic and fluoroscopic control must avoid

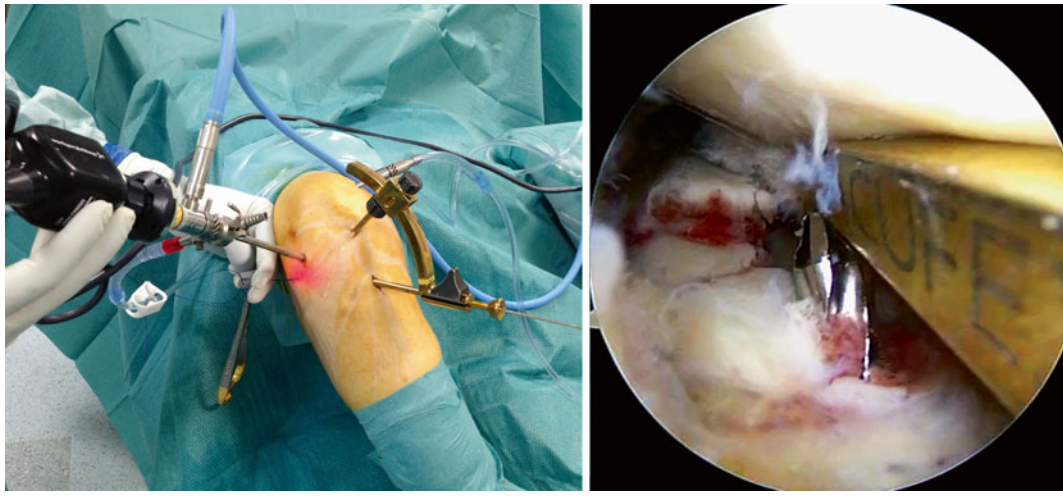

Fig. 31.7 Ligamentoplasty guide to place the drill-guide pin in the centre of the depressed fragment; external and arthroscopic view

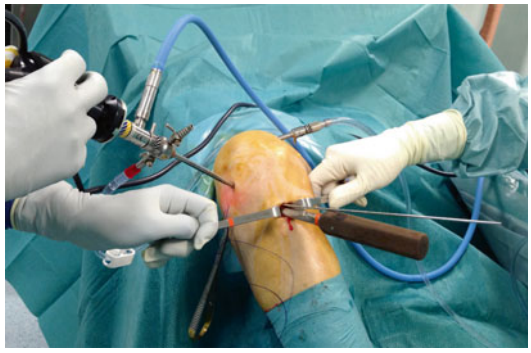

Fig. 31.8 An impactor is used to elevate the fracture site, under arthroscopic control

worsening the displacement or violating the joint surface [98, 126, 145].

A cannulated tamp or impactor is used to elevate the fracture site (Fig. 31.8). A spatula may be useful to correct the reduction from the articular side. Slight overcorrection of the joint surface depression followed by flexion of the knee is desirable to allow the femoral condyle to shape the joint surface.

Temporary stabilisation is achieved using one or two pins introduced 1 cm below the joint surface, either under fluoroscopic guidance or with automatic pinning systems (Fig. 31.9) [154].

The bone defect created in the metaphysis may then be grafted. Fixation occurs under arthroscopic and fluoroscopic control and associated lesions are treated [96, 134].

Fixation Techniques

Lateral tibial plateau fractures should be stabilised using two or three large-diameter (6.5 mm) cannulated titanium screws with washers, inserted percutaneously (Fig. 31.9). Screw length and position must be checked fluoroscopically.

Since the first cannulated screw acts also to close the fracture widening, it might result too long and medially prominent. If this happens, to avoid postoperative pain, this screw should be replaced with a shorter one, once stable fixation is obtained with the second screw. Fractures of the medial compartment are exposed to a higher load than those of the lateral; biomechanical studies have suggested that better stability may be achieved by plate-screw fixation rather than by screw fixation [108], but at present no studies compared the clinical outcomes of these different techniques. Extensive and invasive fixation can be used in comminuted fractures and in patients with reduced bone mineral density. A buttress screw at the inferior apex of the fracture or a buttress plate may be needed for additional stability in Schatzker types I, II and IV frac-

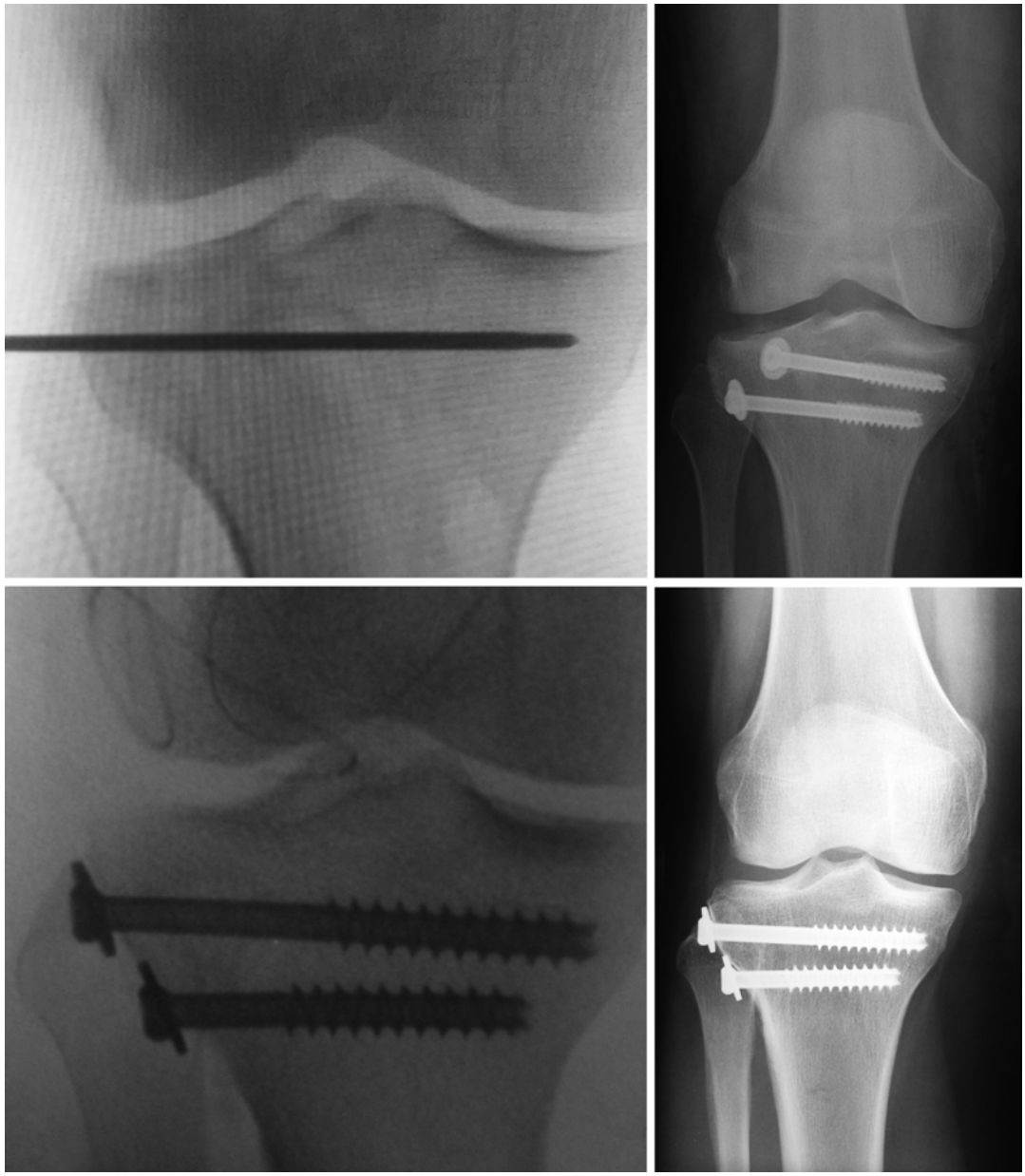

Fig. 31.9 Temporary fixation of a Schatzker III fracture with a Kirschner wire and definitive fixation with two cannulated screws with washer

tures. In Schatzker type III fractures, cannulated screws with washers placed directly under the subchondral plate are usually enough to maintain elevated the depressed fragments. Although clinical studies support the use of screws to stabilise tibial plateau fractures, biomechanical studies present controversial results [93, 108, 132, 144].

Bone Graft Sources

Bone grafts are divided into biological and synthetic materials. Despite a lack of good quality

randomised control trials, there is sufficient evidence supporting the use of bone graft substitutes in depressed plateau fractures [117]. The most frequently used grafts include autograft from the comminuted metaphysis or the iliac crest, allograft freeze-dried croutons, demineralised bone matrix and tricalcium phosphate. Poly-methyl methacrylate is also used to fill bone defects; it provides immediate mechanical strength but may cause problems in the event of infection or revision surgery. Hydroxyapatite combines the immediate mechanical strength of cement and the osteoinductive properties of biological grafts [118, 143].

31.2.4.5 Postoperative Care

Drainage is usually unnecessary. Hospitalisation is 3–7 days long. The patient is kept in a hinged brace, and mobilisation is started immediately on the day after surgery. Early passive and active range of motion should be encouraged with a goal of 0–90° to be achieved by the first week. Full range of motion should be obtained by the sixth postoperative week. Weight bearing is restricted for 6–12 weeks, with this range depending on the fracture pattern and the patient's bone quality and needs. Radiographic follow-up is recommended and should guide the progression from non-weight bearing to partial and full weight bearing. Thromboembolism prophylaxis is given until the resumption of weight bearing [92, 96, 137].

31.2.5 Complications

Compartment syndrome, due to fluid extravasation, is a worrying but rare early complication after tibial plateau arthroscopicaly assisted reduction and internal fixation. We suggest to avoid any excessive increase in the pump pressure during the procedure. Deep venous thrombosis and pulmonary embolism may complicate every fracture of the lower limb treated with a surgical procedure followed by non-weight bearing or immobilisation. Misalignment, infection, malunion, non-union and stiffness may complicate the procedure at long-term follow-up [90, 91, 94, 96, 130].

31.2.6 Literature Results

The most recent available high evidence literature reports on arthroscopicaly assisted reduction and internal fixation for tibial plateau fractures are two systematic reviews by H. Chen et al. [105] and X. Chen et al. [106]. The first review analysed 12 studies, five prospective and seven retrospective, involving 353 patients, most of which are affected by Schatzker type I–III fractures. At least 80 % of patients had excellent or good clinical results measured with the Rasmussen scores, and more than 63 % of patients had excellent or good radiological outcomes. Postoperative osteoarthritis complicated a variable number of procedures, ranging from 0 to 47.6 % across the studies considered. The authors indicate ARIF as an effective procedure.

X. Chen et al. included in their review two retrospective comparative studies, 16 case series studies and one clinical series based on a technical note, involving 609 patients, most of which are affected by Schatzker type II–III fractures. Incidence of associated lesions was 42.2 % for meniscal injuries and 21.3 % for anterior cruciate ligament injuries. 90.5 % of patients had excellent or good clinical results, and 90.9 % of the patients were satisfied. Secondary osteoarthritis at a mean follow-up of 52.5 months ranged between 3.2 and 63.0 % across the studies. There were six cases of severe complications: one case of compartment syndrome, three cases of deep infection and two cases of deep venous thrombosis [89, 110, 130]. The authors concluded that ARIF is a reliable, effective and safe method for the treatment of tibial plateau fractures, especially when presented with concomitant injuries.

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Tibial Plateau Fractures

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Part III

Shoulder

Pietro Randelli

32 Shoulder Arthroscopy: General Setup, Portal Options, and How to Manage a Complete Shoulder Investigation

Radu Prejbeanu, Ion Bogdan Codorean, and Stefania Tanase

32.1 General Setup

32.1.1 Preparation

Patient positioning and a properly equipped operating room are fundamental in achieving good results in shoulder arthroscopy. The basic equipment needed in shoulder arthroscopy is similar to that used in knee arthroscopy, but shoulder arthroscopy needs a traction or an articulated forearm-positioning device [1–3].

32.1.2 Operating Room

The operating room should be fully equipped and staffed with an educated surgical staff. The arthroscopy cart is arranged so that the monitor can be seen with ease by the surgeons. The basic and most frequent used equipments are arthroscope, camera, trocar, shaver, and/or burr. Epinephrine can be added to the irrigation solution to reduce bleeding and to obtain a clear view. After anesthesia is induced, a mechanical joint exam should to be done to assess range of motion and instability [1–3].

32.1.3 Patient Positioning

The patient is anesthetized prior to the final positioning on the operating table and depending on the preference of the surgeon; the patient can be positioned in lateral decubitus or in beach chair position. Both positions present advantages, disadvantages, and complications.

The lateral decubitus position is more frequently used due to the excellent visualization provided and the possibility to allow several accesses (Fig. 32.1). A good suspension can be achieved without the use of an assistant. Distraction can be achieved by manual force or by increasing the suspended weight, traction should not be over 4 kg. After that the patient is lifted and turned on the healthy side, he is positioned on the center of the operating table, and he is kept into position with the help of kidney rests attached to the table. The operating table is tilted 30° posteriorly to bring the glenoid into a position parallel with the floor. All bony prominences and bony points are padded. The forearm and hand are

R. Prejbeanu, MD, PhD (✉)
Department no.1 Timisoara, University of Medicine and Pharmacy "Victor Babes", Bd. Iosif Bulbuca 10, Timisoara 300736, Romania

"Pius Brinzeu" Emergency County Hospital Timisoara, Bd. Iosif Bulbuca 10, Timisoara 300736, Romania
e-mail: raduprejbeanu@gmail.com; http://www.ortopedietimisoara.ro

I.B. Codorean, MD, PhD • S. Tanase, MD
Orthopedic and Traumatology Department, Central Military Hospital "Dr. Carol Davila" Bucharest, University of Medicine and Pharmacy "Carol Davila" Bucharest, Bucharest, Romania

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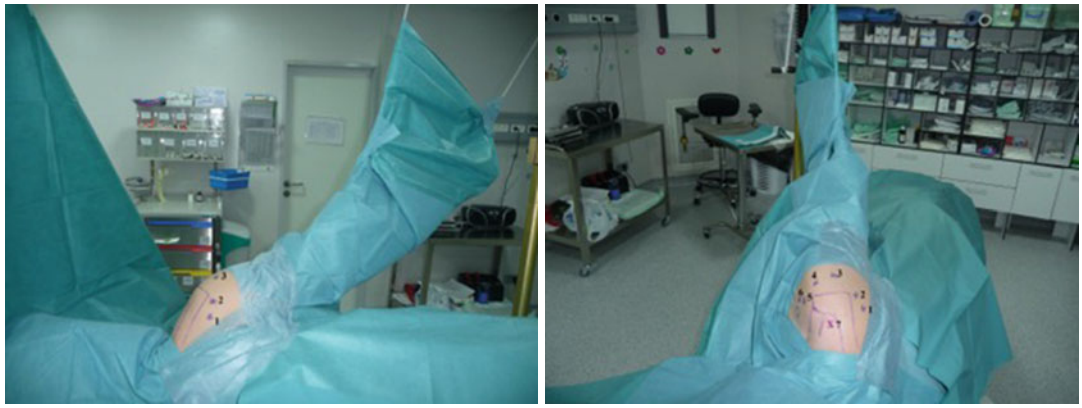

Fig. 32.1 (*Left and right image*) Lateral decubitus position

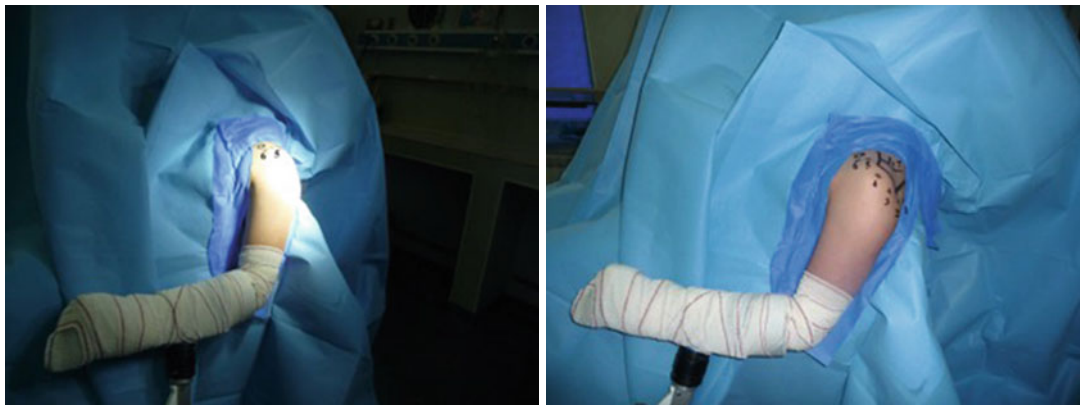

Fig. 32.2 (*Left and right image*) Beach chair position

placed into a prefabricated traction device. The entire shoulder and the entire upper extremity are scrubbed, prepped, and draped. After draping is complete, traction is applied by attaching on average 3 kg, but depending on the patient, the weight can be adjusted. Disadvantages include the use of a larger staff since the patient needs to be turned and lifted, the possibility of nerve damage, and the tendency of the wrist gauntlet to place the patient's arm in internal rotation with the risk to lose external rotation postoperatively. Another problem that is represented in case surgery should be switched to an anterior open procedure with the need to reposition the patient. This position is preferred in anterior and posterior shoulder instability cases [1, 4].

In the traditional beach chair position, the operating table is flexed to approximatively 45°, but many surgeons prefer the modified beach chair position in which the operating table is in a more upright position so that the anatomy of the patient can imitate the upright posture of the physical examination (Fig. 32.2). A foot stand is positioned perpendicular to the table to support the patient's feet. Attention must be given to the neck and head so as to prevent cervical flexion or rotation. General anesthesia or interscalene block can be used. The advantages of this approach include the use of few personnel to position the patient and an easy approach to the front of the shoulder if open surgery is required. Interpretation of the patient's blood pressure is important, especially when the blood pressure cuff is placed on the patient's calf [1, 5].

Complications can appear in both the positions used. A common occurrence of both positions is

a compressive neuropraxia due to an inadequate patient position or padding. Most frequent complications when using beach chair position are hypotensive events, stroke, and cardiac events, while that of lateral decubitus is brachial plexus neuropathy.

32.2 Portal Options

After positioning the next steps include scrubbing, prepping, and draping the shoulder. Using a sterile marker, the bony landmarks and the portals needed are outlined on the skin [6–10] (Figs. 32.3, 32.4, 32.5, 32.6, 32.7, 32.8, and 32.9).

The first and primary entry portal in shoulder arthroscopy is the posterior portal. Using this portal most of the joint can be examined and other accessory portals can be established. The most common place to position this portal is 1 cm medial and 1.5–3 cm inferior to the posterolateral tip of the acromion in the soft spot between the acromion, glenoid, and humeral head. Nerve damage can occur if the portal is placed too medial, injuring the suprascapular nerve, while if the portal is placed too inferior or lateral, the axillary nerve can be damaged. After the introduction of the arthroscopic sleeve between the infraspinatus and teres minor interval and the blunt trocar is removed, the camera is inserted into the joint so it is oriented perpendicular to the floor. This placement of the camera allows an "anatomic" orientation on the monitor, while the intra-articular portion of the biceps tendon provides the landmark in the orientation process.

The anterior portal is located lateral to the halfway point between the coracoid process and the anterolateral tip of the acromion. This portal is used to complete the diagnostic examination of the shoulder and to observe the posterior capsule, rotator cuff, glenohumeral ligaments, and the subscapularis tendon. This portal is made using the posterior portal and can be established through two methods: antegrade, using a spinal needle from outside in, visualized with the help of the arthroscope, and retrograde, using a Wissinger rod or switching stick driven through the arthroscope sheath (inside out). The portal is located between the pectoralis major muscle and the deltoid muscle. The musculocutaneous nerve and subscapular nerve can be damaged when creating this portal if it is placed too inferior, while if it is placed too medial, there is a risk of lesioning the brachial plexus, axillary vein, and artery.

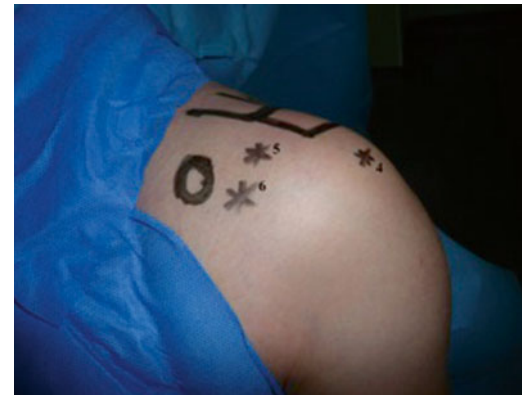

Fig. 32.3 Beach chair position. Anterior view of the *left* shoulder with acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*4*) 5 o'clock portal, (*5*) anterior, and (*6*) anteroinferior

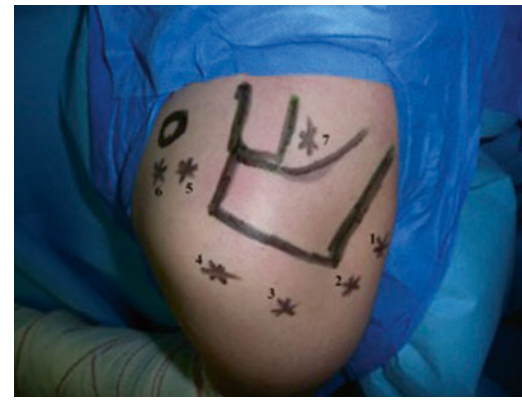

Fig. 32.4 Beach chair position. Superior view of the *left* shoulder with the scapular spine, acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*1*) posterior, (*2*) 7 o'clock portal, (*3*) lateral, (*4*) 5 o'clock portal, (*5*) anterior, (*6*) anteroinferior, and (*7*) Neviaser (supraspinatus)

The lateral portal passes through the deltoid muscle and is located 3 cm lateral to the lateral edge of the acromion. Its primary use is in the surgery of the subacromial space. Attention must

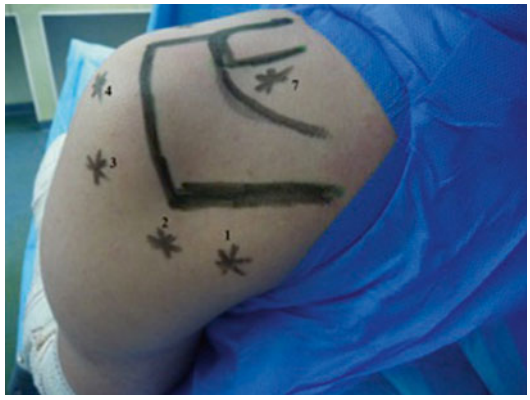

Fig. 32.5 Beach chair position. Posterior view of the *left* shoulder with the scapular spine, acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*1*) posterior, (*2*) 7 o'clock portal, (*3*) lateral, (*4*) 5 o'clock portal, and (*7*) Neviaser (supraspinatus)

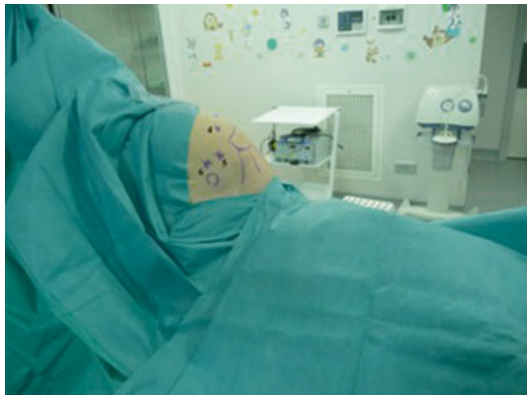

Fig. 32.6 Lateral decubitus. Anterior view of the *right* shoulder with the acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*4*) 5 o'clock portal, (*5*) anterior, and (*6*) anteroinferior

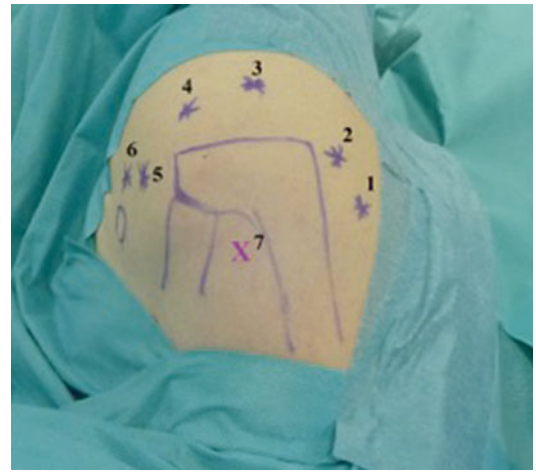

Fig. 32.7 Lateral decubitus. Superior view of the *right* shoulder with the scapular spine, acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*1*) posterior, (*2*) 7 o'clock portal, (*3*) lateral, (*4*) 5 o'clock portal, (*5*) anterior, and (*6*) anteroinferior

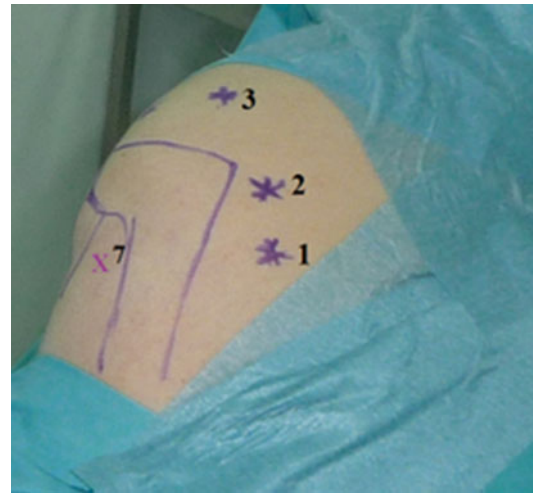

Fig. 32.8 Lateral decubitus. Posterior view of the *right* shoulder with the scapular spine, acromion, acromioclavicular joint, and clavicle outlined. The * represents potential portal sites: (*1*) posterior, (*2*) 7 o'clock portal, and (*3*) lateral

be paid to the axillary nerve that lies 5 cm distal to the lateral border of the acromion.

After these three working portals, other accessory portals can be spread out anteriorly and posteriorly as necessary, usually using a spinal needle and under the direct visualization.

The 5 o'clock portal or the anteroinferior portal is established approximatively 1 cm inferior to the low anterior portal through the subscapularis tendon, lateral to the conjoined tendon, slightly inferior to the coracoid process. Its main function is in repairing anterior labral lesions. Anatomy at risk making this portal is the cephalic vein and the anterior humeral circumflex artery, as well as musculocutaneous nerve and axillary nerve.

The Neviaser portal known also as suprascapular or supraclavicular portal is placed in the notch between the spine of the scapula and posteriorly to the acromioclavicular joint. The function

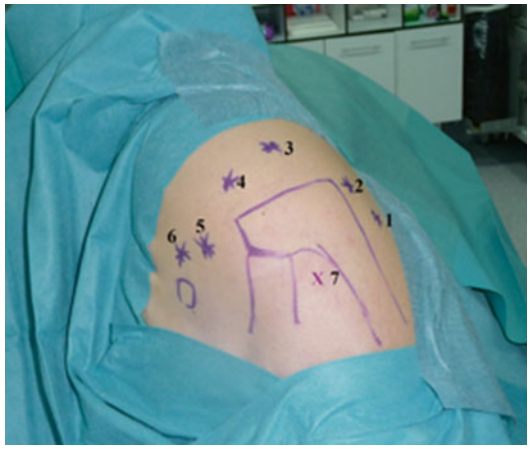

Fig. 32.9 Lateral decubitus. Anterior and superior view of the *right* shoulder with the scapular spine, acromion, acromioclavicular joint, clavicle, and coracoid process outlined. The * represents potential portal sites: (*1*) posterior, (*2*) 7 o'clock portal, (*3*) lateral, (*4*) 5 o'clock portal, (*5*) anterior, and (*6*) anteroinferior

of this portal is in treating SLAP lesions and Bankart repair, but it is most useful in passing suture retrieval devices in rotator cuff repairs. At risk when making this portal are the suprascapular nerve and artery.

The port of Wilmington is placed at 1 cm anterior and 1 cm lateral to the posterolateral corner of the acromion. The main function of this portal is in evaluating and repairing posterior SLAP lesions.

The posterolateral inferior portal or the 7 o'clock portal is located approximatively 2–3 cm inferior to the posterolateral corner of the acromion and 2 cm lateral to the posterior portal. It is used in the treatment of reverse Bankart lesion.

Another accessory portal is the suprascapular nerve portal described by Lafosse, it is located approximatively 2 cm medial to Neviaser portal, and it is used to approach the suprascapular notch. The portal is established at approximatively 7 cm medial to the lateral border of the acromion.

32.3 How to Manage a Complete Shoulder Diagnosis

To complete a diagnosis, after taking a complete history and physical exam, imaging techniques need to be used. These include X-rays, ultrasound, CT, and MRI (ev. for both arthrograms).

X-ray is the easiest and cheapest imaging technique needed. There are many views that can be used. To start, one should ask for trauma series. A trauma series consists of a true anteroposterior view, with the arm in external and internal rotation, and a lateral axillary view or scapulothoracic view.

The true anteroposterior view can be obtained by angling the X-ray beam at 45° in a medial to lateral direction due to the position of the scapula. This anteroposterior view is better than the anteroposterior view taken in the plane of the thorax due to better viewing of the anterior and posterior rim of the glenoid; in a normal shoulder, the humeral head is separated from the humeral head, and the coracoid process overlaps the glenohumeral joint.

The axillary lateral view can be performed with the patient standing or in supine position with his arm abducted at 90°. In the cases in which the patient cannot fully abduct his arm, a curved cassette is placed into the axilla and the beam is directed inferiorly. In this view, the glenoid, humeral head, and the relationship between them are well visualized.

In the case in which a true axillary lateral view cannot be obtained, one of the following must be obtained: a scapulothoracic view, one of the modified axillary views, or a CT scan. The scapulothoracic view is also known as the transcapular or Y lateral. The upper arms of the Y are formed by the scapular spine posteriorly and the coracoid process anteriorly, while the inferior part of the Y is formed by the body of the scapula, and the middle of the Y is formed by the glenoid fossa. In a normal scapulothoracic view, the humeral head overlaps the glenoid fossa thus being a good view to determine the relationship between the two. This view can be obtained by aligning the X-ray beam parallel to the spine of the scapula, while the cassette is placed perpendicular to the X-ray beam.

The Velpeau axillary lateral view is one of the modified axillary views. It is taken in acute surroundings with the injured shoulder in a sling without abduction. The patient is placed at the end of the table and leans backward over the table, the cassette being placed beneath the shoulder, while the X-ray beam is positioned directly over the

shoulder, the beam passing vertically superior to inferior. This view reveals the relationship between the head of the humerus and the scapula. The Stripp axial lateral view is similar to the Velpeau view; the cassette and the X-ray beam are reversed, the beam coming from inferior to superior. The trauma axillary lateral view is usually obtained in patients with multiple trauma injuries and reveals the relationship between the glenoid fossa and humeral head. The patient is in a supine position with the arm supported in flexion; the X-ray beam is directed up through the axilla to a cassette placed on the superior aspect of the shoulder [10–16] (Table 32.1).

32.3.1 Special X-Rays

The A-P stress view X-rays evaluate both shoulders at the same time. Two weights are strapped to the patients' wrist, while he is in an erect position.

The Zanca view is used to evaluate the acromioclavicular joint. The X-ray beam is aimed at the acromioclavicular joint with a cephalic tilt of 10°. Also in the diagnosis of acromioclavicular joint pathology is the Alexander view, which is similar to the scapulolateral X-ray; the shoulders are shrugged forward.

The serendipity view or the A-P view with 40° cephalic tilt of both clavicles is used in evaluating the sternoclavicular joint.

West point axillary lateral view is used to obtain a tangential view of the anteroinferior rim of the glenoid. The patient is positioned prone with a pad under the affected shoulder with his head in the other part. The cassette is held against the superior aspect of the shoulder; the X-ray beam is centered at the axilla with 25° medial and downward angulation.

The apical oblique projection also reveals pathology of the glenoid rim. The patient, with his arm in the sling is seated so that the cassette is placed posterior to the spine of the scapula. The X-ray beam is directed toward the cassette at a 45° angle to the plane of the thorax and also tipped 45° caudally.

In the scapular outlet view, the patient is positioned as in the scapulothoracic view with the X-ray beam angled caudally at 10°.

In obtaining Fisk view, the patient leans over the table holding the cassette, while the X-ray beam passes through the bicipital groove in the proximal end of the humerus.

32.3.1.1 Other Imaging Studies Used in Diagnosing Pathology Around the Shoulder

Ultrasound is another imaging technique that can be used for diagnosis or therapeutic treatment. It is a safe, noninvasive, and inexpensive imaging technique and can be easily used to assess both shoulders. It can be useful in patients with prior surgery that included hardware implants, which can create image artifacts on MRI and CT. It is used mostly in soft tissue diseases, such as rotator cuff lesions, long head of biceps pathology, subacromial bursitis, and impingement syndromes, and also joint effusion. It is not useful in the evaluation of capsulolabral or cartilage lesions.

Ultrasound is operator dependent and can lead to false-positive and false-negative results. The normal tendon appears bright (hyperechoic) with a fibrillar pattern. A tear or tendinosis appears as dark (hypoechoic), but also anisotropy as artifacts has the same appearance causing false interpretations. To achieve a good result, the ultrasound beam needs to be positioned perpendicular to the tendon, as the beam in maximally reflected, but when the beam is angled even a few degrees from perpendicular to the long axis of the tendon fibers, fewer reflected sound will be detected by the transductor giving a hypoechoic appearance. This usually happens near the insertion of the tendon due to the curved position.

CT imaging with or without arthrography, along with MRI, can be used to complete the diagnosis. CT is used mostly for a better evaluation of bone detail versus X-ray images due to the cross-sectional nature. Acquired axial plane images can be reconstructed in 2D and 3D. CT permits better detection of fracture and intra-articular loose bodies and also evaluation of fracture healing. The 3D reconstructions can become an important tool in surgical planning due to anatomic demonstration of pathology and accurate measurements. CT arthrography can be used as

Table 32.1 Indicated tests in evaluating shoulder diseases

Disease	X-rays	CT	MRI	Others
Evaluation of the clavicle	A-P X-ray in the plane of the thorax			
	X-ray with 30° cephalic tilt			
	X-ray with 30° caudal tilt			
Evaluation of the acromioclavicular joint and distal clavicle	Trauma series	+	+	
	A-P stress view			
	Zanca view			
	Alexander view			
Evaluation of the sternoclavicular joint and medial clavicle	A-P or P-A chest X-ray	+	+	
	Serendipity view			
Evaluation of the scapula	Trauma series	+	+	
	Stryker notch			
	West point view			
Evaluation of instability		+	+	Arthrogram
Anterior	True A-P X-ray			Arthrotomogram
	West point axillary lateral view			CT arthrography
	Apical oblique projection			
Posterior	Trauma series			
Evaluation of rotator cuff pathology	Trauma series	+	+	Ultrasonography
	X-ray 30° caudal tilt			Arthrography
	Scapular outlet view			Arthrotomography
				Computed tomography arthrography
				Subacromial bursography
Evaluation of calcifying tendinitis	Trauma series	+	+	
Evaluation of biceps tendon	Fisk view	+	+	
Evaluation of glenohumeral arthritis	Trauma series	+	+	

an alternative to MRI to evaluate tendons, labrum, and articular cartilage.

MRI is the ideal imaging technique in evaluating soft tissue injuries around the shoulder such as rotator cuff, labrum, cartilage, glenohumeral ligaments, and capsule, but it can also be used to evaluate the muscle and bone marrow. Some patients cannot undertake MRI examination due to concerns about malfunction due to the strong magnetic field, such as patients with pacemakers or some medical pumps or patients who have undergone recent stent implantation and patients with infraorbital metallic foreign bodies. Patients with orthopedic hardware are not generally excluded, but artifacts can appear and interfere with the final results. The magnet used should be 1.5 tesla (T); in the case of a 3 T magnet, more artifacts can appear. Also claustrophobia is a problem; people need to stand still a long period of time in a supine position with the arm at their side in a slight external rotation. To avoid false-negative or false-positive results, the slices made should be thin, 3–4 mm, small field of view images, 12–14 cm, with a high in plane spatial resolution 0.4×0.3–0.5 mm. Recommended MR examinations of the shoulder include T1- and T2-weighted images and fat-suppressed proton density weighted; the slides used are coronal oblique FS PD-weighted images and T2-weighted images, axial FS PD-weighted images, and sagittal oblique T1-weighted images. In extreme cases, T2-weighted images in abduction and external rotation (ABER) can be acquired in evaluating subtle anteroinferior

Table 32.2 MRI images

T1 weighted	FS PD weighted	T2 weighted
Highlight signal between fat and other tissues	Intermediate weighted	Identify Labrum and normal tendons appear as black (low signal) Articular cartilage appears as gray (intermediate signal)
Fat appears bright white	Similar to FS T2-weighted images	
Identify Fatty infiltration in the muscle Define fracture lines Identify ossifications and loose bodies	Identify lesions of Labrum Articular cartilage Rotator cuff tendons Musculature Bone edema	

Table 32.3 MRI findings

Tendons
Normal: presents as black (low signal) on all MRI sequences
Supraspinatus tendon: coronal and sagittal oblique planes
Inserts superiorly on the greater tuberosity
Infraspinatus tendon: all three planes
Posterior to the supraspinatus insertion on the greater tuberosity
Subscapularis tendon: axial and sagittal images
Inserts on the lesser tuberosity, conjoint with the anterior capsule
Muscle bulk: sagittal oblique images
LHBT: axial images in the bicipital groove
Articular cartilage
Normal appearance as gray (intermediate signal intensity)
T1 and T2 sequences
Chondral defects: coronal and axial planes
Glenohumeral ligaments
Consist of superior (SGHL), inferior (IGHL), middle (MGHL), and coracohumeral ligament (CHL)
Contribute to the stability of the glenohumeral joint
IGHL: axial and sagittal images consist of anterior and posterior bands and axillary pouch
SGHL: axial images adjacent to the origin of the LHBT
MGHL: axial images posterior to the superior margin of the subscapularis muscle
CHL: form with the SGHL the biceps pulley sagittal images
Labrum
Fibrocartilaginosus structure, surrounds the glenoid fossa and deepens it
Variability in shape, size, configuration, attachment, and smooth margins
Cross section is triangular, but it can also be rounded, notched, or even absent
Peripherally blends into capsule and centrally blends into articular cartilage
Posterior labrum is smaller than anterior
Superior portion more loosely attached and more mobile versus the rest of the labrum
Glenoid labrum can be described as the face of a clock, superior labrum 12 o'clock, inferior 6 o'clock, anterior 3 o'clock, and posterior 9 o'clock
Superior and inferior labrum: coronal oblique images
Anterior and posterior labrum: axial images
Anteroinferior labrum and IGHL: ABER position
Bicipitolabral complex (BLC): coronal oblique images
Normal labrum: low signal intensity in all sequences, normal variant in older patient is high signal

labral detachment, rotator cuff impingement, and partial thickness articular-sided infraspinatus and supraspinatus tears. MR arthrography is used in the same situations as MRI, plus to evaluate postoperatively the shoulder (Tables 32.2 and 32.3) [12, 16, 17].

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Arthroscopic Anatomy of the Shoulder

33

Roman Brzóska, Wojciech Solecki, and Adrian Błasiak

33.1 Introduction

Normal anatomy of the shoulder can be seen arthroscopically with many variants. Their knowledge allows successful treatment of the most of the known pathologies and also increases our understanding of shoulder biomechanics. Increasing number of arthroscopic portals used in daily practice requires us to have full knowledge of the shoulder anatomy to avoid neurovascular, cartilage, or tendon iatrogenic injuries.

33.2 Glenohumeral Joint

The glenoid is covered by a smooth hyaline cartilage with the thinnest point located in the center, described by De Palma as "bare spot" [1]. The incisura glenoidalis is located in the central anterior area of the glenoid. Its depth is dependent on the shape of the glenoid and an anatomical variant of the glenohumeral ligament construction. As seen through the posterior portal in a beach chair position, the glenoid should be visible as a vertical wall of cartilage (Fig. 33.1).

33.3 The Long Head of the Biceps

The first distinctive structure visible through the posterior portal is the long head of the biceps (LHB) tendon. In a beach chair position, the LHB emerges from the superior labrum, proceeds over the humeral head (HH), and enters the bicipital groove. There are several different variants of the LHB proximal insertion and a course of its intra-articular portion. Huber and Putz [2] introduced a functional unit: the periarticular fiber system (PAFS). They used a combination of macroscopic and microscopic techniques showing that labrum,

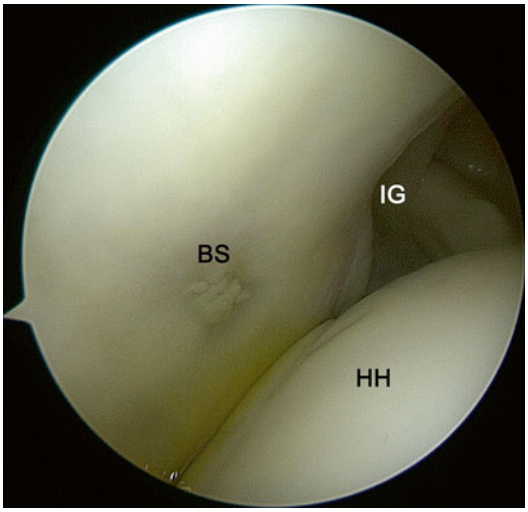

Fig. 33.1 Arthroscopic view of the glenoid (*G*) from the posterior portal. Bare spot (*BS*), incisura glenoidalis (*GS*), humeral head (*HH*)

R. Brzóska (✉) • W. Solecki • A. Błasiak
Department of Shoulder Surgery, St. Luke's Hospital, Bielsko-Biała, Poland
e-mail: rbrzoska13@gmail.com

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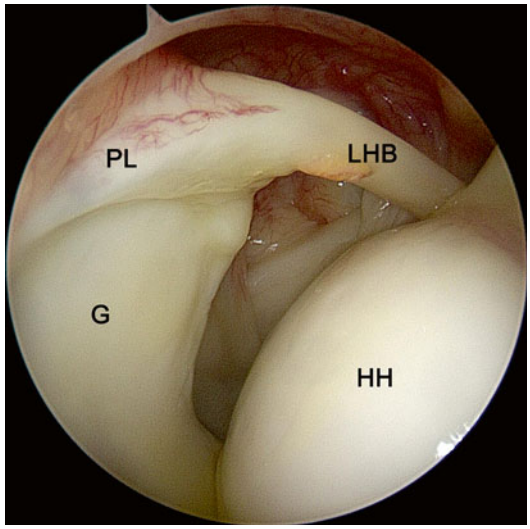


Fig. 33.2 Type I of the long head of the biceps (*LHB*) attachment to the labrum with all fibers arising from the posterior labrum (*PL*); *G* glenoid, *HH* humeral head

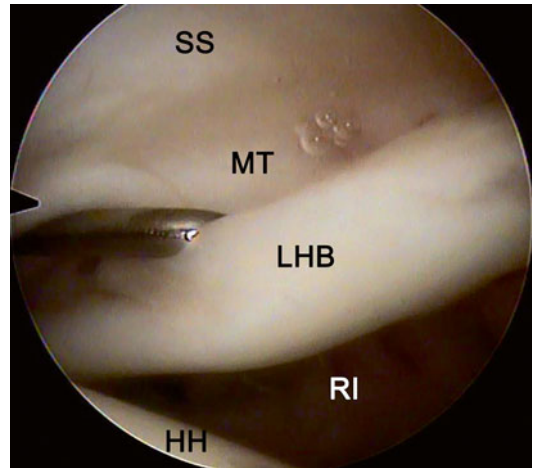


Fig. 33.3 MESO-CO variation of the long head of the biceps (*LHB*) with a complete mesotenon (*MT*). *HH* humeral head, *SS* supraspinatus tendon, *RI* rotator interval

glenohumeral ligaments, and inserting tendons form a system of fibers taking its origin around the neck of the scapula. Vangsness [3] reported four types of biceps attachment to the supraglenoid tubercle, recording the percentage of tendon fibers extending from the posterior labrum, tubercle, and anterior labrum: type I (all fibers arising from posterior labrum) (22 % in this study) (Fig. 33.2), type II (33 %) (like type I but some contribution to the anterior labrum), type III (37 %) (equal: posterior and anterior contribution of the fibers), and type IV (majority of the fibers from anterior labrum with some contribution from posterior labrum) (8 %).

Certain types of intra-articular portion of the biceps were described in literature. Dierickx et al. [4] distinguished the following types: MESO-VI (vinculum), a fine string, providing vascularization to the tendon, and MESO-SB (small band), small synovial band from medial to lateral, connecting the rotator cuff with the LHB. They are never on stress, MESO-PU (pulley-like sling) – pulley- or hammock-like sling, whereby the biceps can move or slide freely up and down. MESO-PA (partial mesotenon) – a hammock-like synovial sling in which the biceps tendon is able to move but not to glide. MESO-CO (complete mesotenon) – the biceps tendon runs in a synovial sheath that is connected, loose woven, but well vascularized, to the inferior surface of the capsule. No sliding is possible (Fig. 33.3). ADH-PM (partially medially adherent to the SSP) – a partial but strong medial adhesion runs cranial and medial to the inferior surface of the capsule – not involving the cable. ADH-PL (partially laterally adherent to SSP) – this type gives an hourglass-type of impingement of the free medial portion of LHB. ADH-CL (complete adherent, attached to the labrum) – no mesotenon is visible. ADH-CO (complete adherent to SSP, not attached to the labrum). ABS (complete absence of the LHB) – no intra-articular biceps portion (Fig. 33.4). Authors have observed one or two accessory heads of the LHB as a congenital variation [5] (Fig. 33.5).

33.4 Biceps Pulley

Biceps pulley is a functional, funnel-shaped structure that stabilizes the LHB tendon in the bicipital groove (Figs. 33.6 and 33.7). It is a complex composed of the superior glenohumeral ligament merging with the coracohumeral ligament, distal insertion of the subscapularis muscle (SSC) tendon, and the anterior part of the supraspinatus

muscle (SS) tendon distal insertion [4]. A variation to the funnel-like shape is a sheath covering the LHB within the entrance to the pulley [6].

33.5 Labrum and Glenohumeral Ligaments

The glenoid labrum is built up of a fibrocartilage tissue. Three sides and an edge can be distinguished within the labrum. The superficial surface is facing the humeral head, the articular surface is attached to the glenoid rim, and the peripheral side is in continuity with the capsule and glenohumeral ligaments. The edge of the labrum is free lying on the articular surface of the glenoid. The labrum adheres close to the inferior and posterior rim of the glenoid and is the thickest and strongest in this region. In the superior region of the glenoid cavity, it is attached loosely and covers the cartilage in a meniscus-like form. The labrum serves as an anchor for the glenohumeral ligaments as well as the long head of the biceps. The long head of the biceps is inserted both to the supraglenoid tubercle and the superior labrum.

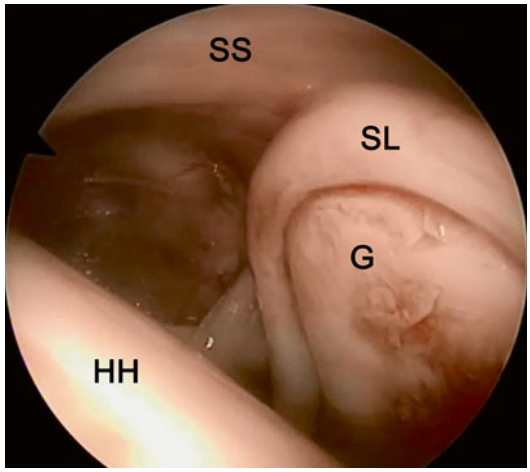


Fig. 33.4 Complete absence of the LHB; *SS* supraspinatus tendon, *SL* superior labrum, *G* glenoid, *HH* humeral head

The glenohumeral joint is enclosed by a very wide capsule with a large axillary pouch. The capsule originates in the labrum and radiates at its base into the glenoid neck. The distal attachment of the capsule follows the anatomical neck of the humerus and overlaps the shaft by one centimeter at the medial side. The capsule is reinforced with the capsular ligaments.

The coracohumeral, superior, middle, and inferior glenohumeral ligaments as well as the capsule contribute to shoulder stability. Two of these ligaments are located at the top of the joint in the rotator interval. These are the coracohumeral ligament (CHL) and superior glenohumeral ligament (SGHL). The CHL originates on

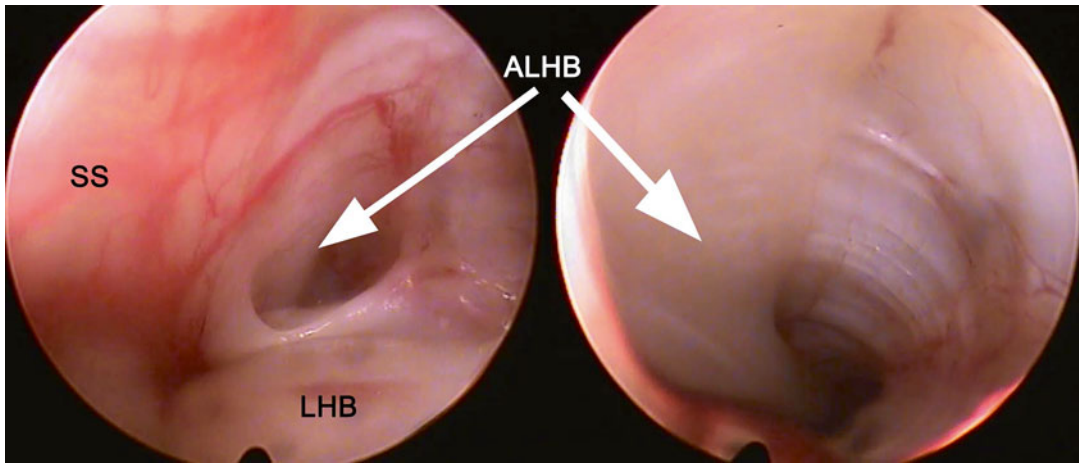


Fig. 33.5 An accessory long head of the biceps (LHB) tendon seen at the entrance to the biceps pulley. *SS* supraspinatus

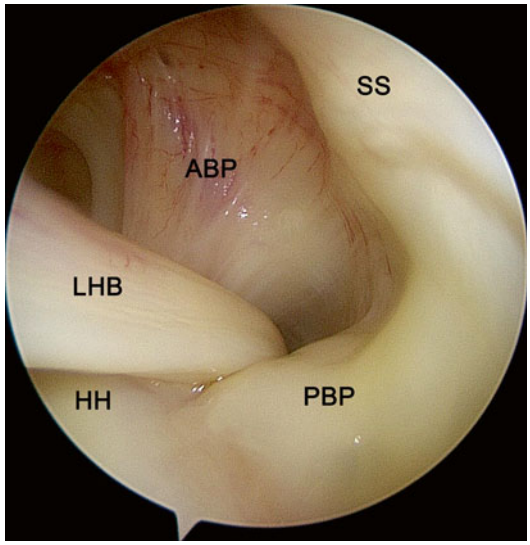


Fig. 33.6 Biceps pulley: *ABP* anterior biceps pulley, *PBP* posterior biceps pulley, *SS* supraspinatus tendon, *LHB* long head of the biceps, *HH* humeral head

the lateral surface of the base of the coracoid process and inserts on the lesser and greater tuberosities, crossing the bicipital groove. The CHL is an extra-articular bursal-sided structure, but could be seen during arthroscopy as part of the rotator cable-crescent complex. The SGHL originates from the labrum and biceps tendon or in common with the middle glenohumeral ligament in the region of the supraglenoid tubercle. It inserts into the fovea capitis line just superior to the lesser tuberosity of the humerus. It lies parallel to the lateral aspect of the coracoid process and is present in more than 90 % of cases.

The middle glenohumeral ligament (MGHL) has a variable origin from the glenoid, scapula, anterosuperior labrum, biceps tendon [7], inferior glenohumeral ligament (IGHL), or superior glenohumeral ligament. It merges with the anterior capsule along the subscapularis muscle and tendon, continuing with the subscapularis tendon to

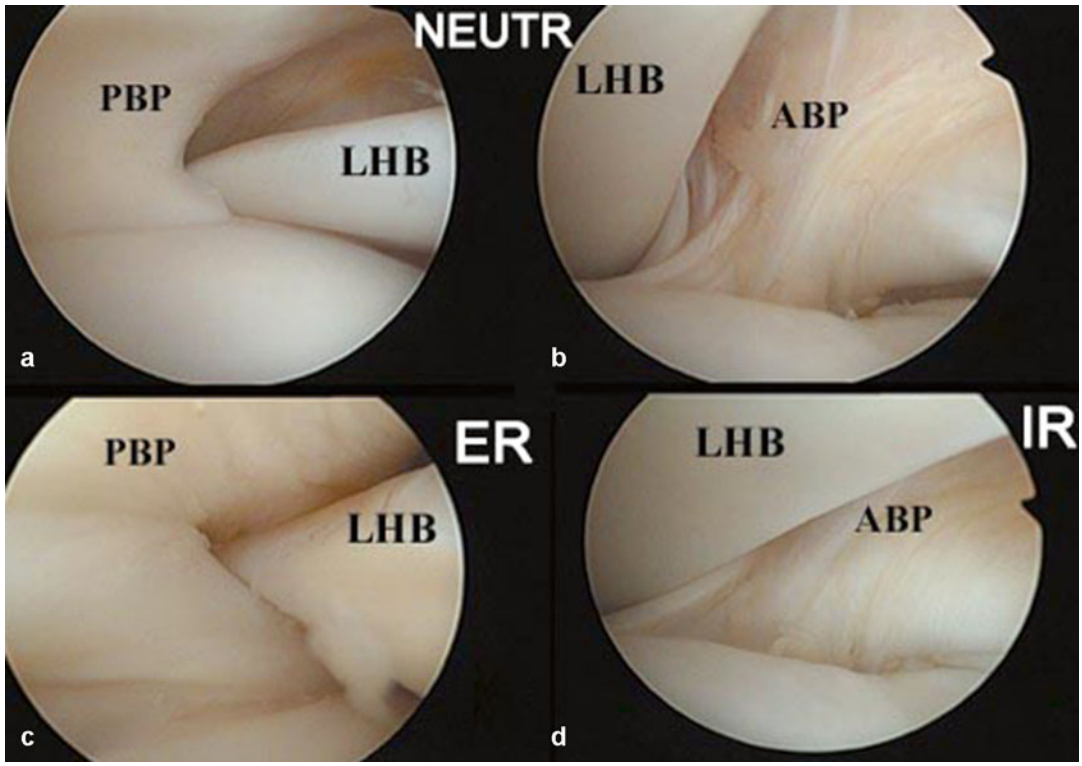


Fig. 33.7 Biceps pulley in neutral rotation (**a**, **b**), external rotation (**c**), and internal rotation (**d**)

the anterior aspect of the proximal humerus just below the attachment of the SGHL on the lesser tuberosity.

The IGHL, considered the most important stabilizer of the glenohumeral joint, is a complex that originates at the mid to inferior portion of the anterior glenoid labrum. It extends for a variable distance from anterior to posterior and inserts on the anatomic neck of the humerus. This ligament is inseparable from the labrum, forming a labroligamentous complex. It is composed of strong collagenous thickenings at its anterior and posterior margins – the anterior and posterior bands, joined by a fibrous thickening of the capsule called the axillary pouch or recess. Some authors distinguish anteroinferior glenohumeral ligament (AIGHL) and posteroinferior glenohumeral ligament (PIGHL).

As all mentioned above, structures play the crucial role in stabilization of the humeral joint; we can regard them as a one biomechanical entity called the labro-ligamento-capsular complex (LLCC).

The main variations occur in the superior-anterior aspect of the glenoid. The upper part of the labrum can be greater than usual with a big sublabral recess reminding a meniscus and is named "meniscoid labrum" (Fig. 33.8). With the age a sublabral recess enlarges, but it can be considered normal as long as there is still cartilage observed in front of the most peripheral insertion of the labral fibers [6].

Variation of the SGHL includes a common origin with the middle glenohumeral ligament and/or biceps tendon. The SGHL can become thickened in patients with an absent middle glenohumeral ligament. The normal glenoid labrum is present and attached to the rim in the anterosuperior zone. A normal middle glenohumeral ligament (MGHL) looks flat. A sublabral foramen is a sulcus between a normally developed anterosuperior portion of the labrum and the glenoid articular rim with a normal or "sheetlike" MGHL. Another variant is a sublabral foramen with a cord-like MGHL. A sublabral foramen is then seen at the anterosuperior quadrant, and the middle glenohumeral ligament appears thickened

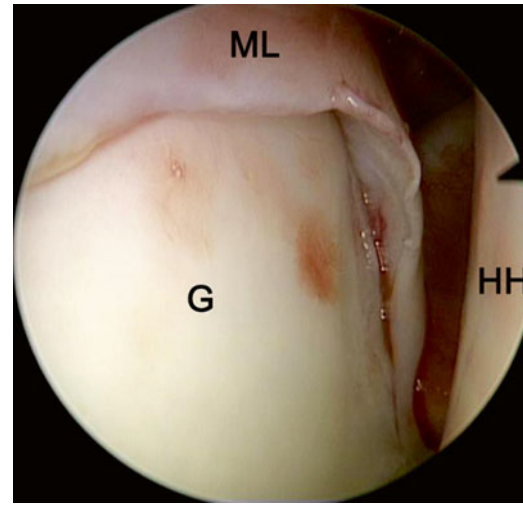


Fig. 33.8 Meniscoid labrum (*ML*)

and cord like in structure. Williams and Snyder reported 1.5 % (3 of 200 shoulders) of another infrequent variant. In those cases a "cord-like" middle glenohumeral ligament was noted [8]. The insertion of this ligament originated from the superior labrum, directly at the biceps origin. Lack of anterosuperior labral tissue between MGHL and the mid-glenoid notch is characteristic for this variation called "Buford complex" (Fig. 33.9). It is very important not to "reattach" this ligament to the glenoid which results in pain and limitation of external rotation. Variants of the IGHL include high origin above the equator of the glenoid, origination from the MGHL, or a band-like attachment between the IGHL and SGHL called the periarticular fiber system. Hypoplastic labrum with discreet appearance of glenohumeral ligaments can be observed in the most individuals presenting with hyperlaxity [2, 9, 10].

33.6 Rotator Cuff

33.6.1 Subscapularis Muscle

The entire rotator cuff insertion can be visualized arthroscopically in the intra- and extra-articular view. The subscapularis insertion to the lesser

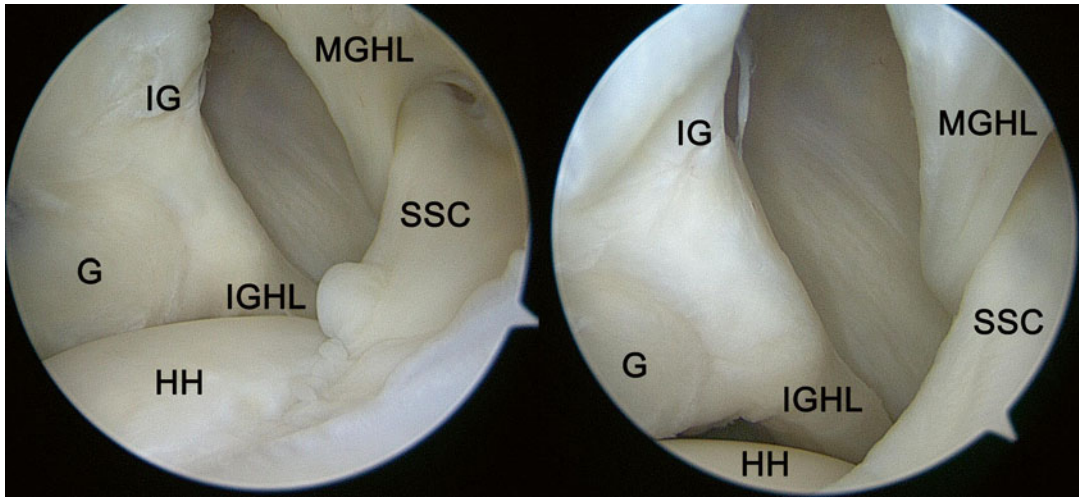


Fig. 33.9 Buford complex: lack of anterosuperior labral tissue and "cord-like" middle glenohumeral ligament (*MGHL*)

tubercle of the humerus is triangular in shape with the base in the superior part. The mean height of the insertion is 25.8 mm and the mean width is 18.1 mm [11]. A part of a subscapularis muscle (SSC) tendon insertion visualized through the posterior portal represents less than half of the whole insertion which was described by Wright et al. [12]. The extra-articular part of SSC tendon insertion can be seen entirely through the anterolateral portal after a thorough subacromial bursectomy. The intra-articular part of SSC is crossed by the middle glenohumeral ligament medially, and the lower part is veiled by the inferior glenohumeral ligament and the capsule (Fig. 33.10). The inferior edge of the SSC lies in the direct proximity of the axillary nerve. The axillary nerve lies anteriorly to the SSC medially to the conjoined tendon and can be visualized by careful blunt dissection of surrounding tissues. Two or three nerves supplying the subscapularis muscle can be seen while approaching the axillary nerve.

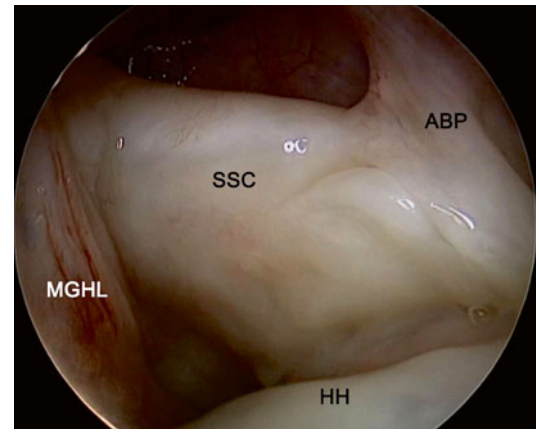


Fig. 33.10 Subscapularis muscle (*SSC*) relations. *MGHL* middle glenohumeral ligament, *ABP* anterior biceps pulley, *HH* humeral head

33.6.2 Supraspinatus Muscle

Supraspinatus muscle tendon inserts to the superior part of the greater tubercle of the humerus. Described by Burkhart [13] rotator cable and crescent can be noticed. The rotator cable serves as the main stabilizer by transferring the strain of the rotator cuff. It protects the thinner part of the tendon within the crescent. Sometimes the cable is barely visible especially in young population. With age due to fatigue changes within the rotator cuff insertion, the cable becomes more pronounced (Fig. 33.11).

33.6.3 Infraspinatus Muscle

The insertion of the infraspinatus muscle (IS) tendon to the posterior part of the greater tubercle of

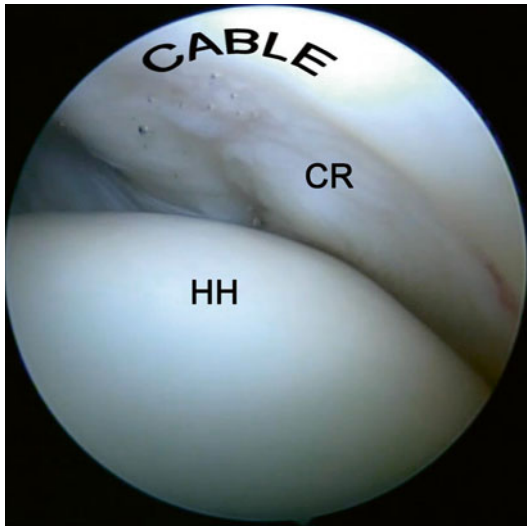


Fig. 33.11 Rotator cuff cable and crescent (*CR*), *HH* humeral head

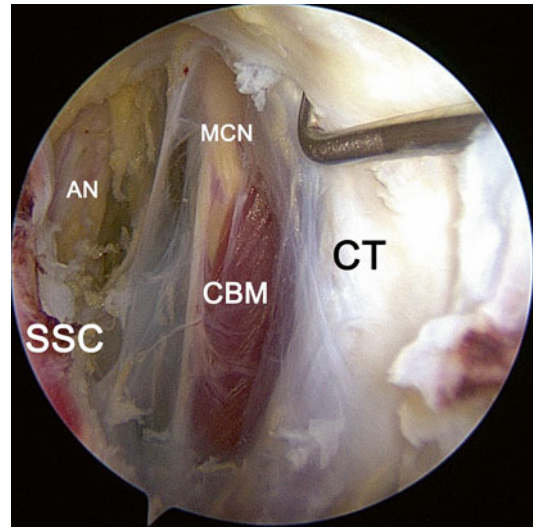


Fig. 33.12 Axillary nerve (*AN*) and musculocutaneous nerve (*MN*) entering the coracobrachialis muscle seen through the anterolateral portal. The hook inserted through the anterior portal. *CT* conjoined tendon, *SSC* subscapularis muscle

the humerus is separated from the humeral head cartilage by the "bare area." It is a region physiologically lacking cartilage and should not be considered as a cartilage damage. Regarding the anatomical findings of Mochizuki et al. and other authors, the IS insertion stretches to the superior part of the tubercle [14]. It is difficult to arthroscopically define the anatomic border between SS and IS insertion, but anatomically the posterior aspect of the greater tuberosity is covered only by the IS and teres minor insertion. The footprint of the IS is often incorporated with the teres minor muscle insertion. However, the teres minor insertion can appear as a round-shaped tendon, and it is possible to differentiate thin lower part of the IS from its thick superior margin.

33.6.4 Pectoralis Minor

The development of arthroscopic techniques, such as the arthroscopic Latarjet procedure, requires a vast knowledge of periarticular anatomy. When coracoid process region is considered, we need to take a closer look at variants of the pectoralis minor insertion and anatomic relations between the conjoined tendon and the nearest neurological structures.

Pectoralis minor muscle apart from the typical insertion at the medial plane of the coracoid process can present different variations. Whole tendon or a part of it can transverse the superior surface of the coracoid process and continue in the rotator interval or even supraspinatus muscle [15].

33.7 Musculocutaneous and Axillary Nerve

It is necessary to be aware of the path of the axillary and musculocutaneous nerve in the region between the anterior wall of the SSC and the conjoined tendon. We can expect the musculocutaneous nerve to appear at the level of the coracobrachialis muscle belly (Fig. 33.12). The branch to coracobrachialis muscle leaves as the first one above the bifurcation of sensory branch and the branch supplying the short head of the biceps. The axillary nerve runs from anteromedial to posterolateral direction crossing the inferior margin of the SSC belly at the level of the "three sisters" (anterior humeral circumflex artery and its venae comitantes) [16].

33.8 Subacromial Space

33.8.1 Subacromial Bursa

Subacromial bursa expands below the acromion and lubricates the motion of rotator cuff against the acromion, coracoacromial ligament, and deltoid fascia. It is crucial to know the borders of the subacromial bursa in order to perform an adequate bursectomy. The size of the subacromial bursa may vary. An investigation by DeFranco showed that "the mean distance from anterolateral corner of the acromion to the posterior bursal cavity is 2.8 ± 0.6 cm. The mean distance from the midpoint of the acromion to the subdeltoid bursal reflection of the subacromial bursa is 4.0 ± 1.0 cm" [17–19].

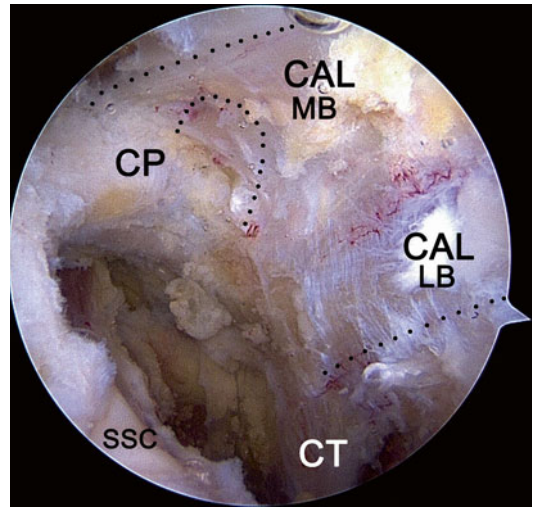


Fig. 33.13 The anatomy of the coracoacromial ligament (*CAL*), *MB* medial band, *LB* lateral band, *CP* coracoid process, *CT* conjoined tendon

33.8.2 Coracoacromial Ligament

Coracoacromial ligament forms the roof and the anterior wall of the subacromial space. It stretches from the coracoid process and inserts to the edge of the acromion with the inferior fibers covering lower plane of the acromion. Three predominant variants were observed by Holt and Allibone: quadrangular (48 %), Y shaped (42 %) (Fig. 33.13), or broadbanded (10 %) (Figs. 33.14 and 33.15). Kesmezacar distinguished another two types: V shaped and multiple banded. No statistical significance between the type of C-A ligament and rotator cuff degeneration was observed [20–23].

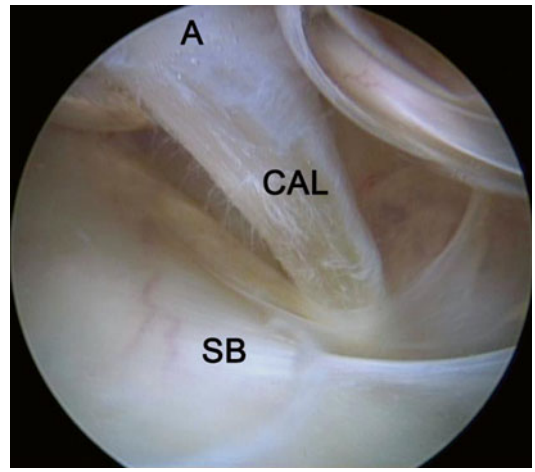


Fig. 33.14 Narrowband coracoacromial ligament (*CAL*) variation. *A* acromion, *SB* subacromial bursa

33.9 Coracoclavicular Ligaments

Arthroscopic assisted reconstruction of the acromioclavicular joint became a very popular procedure. Identification of anatomic insertions of coracoclavicular (CC) ligaments appears to be a crucial factor to successfully restore proper biomechanical relation between the scapula and the clavicle. CC ligaments consist of the trapezoid and the conoid ligament. From the direct anterior portal placed in front of the tip of the coracoid process (CP), trapezoid ligament is clearly visible arising from the medial aspect of the base of the CP. The conoid ligament originates from the coracoid behind the insertion of the trapezoid ligament and runs towards the conoid tubercle on the

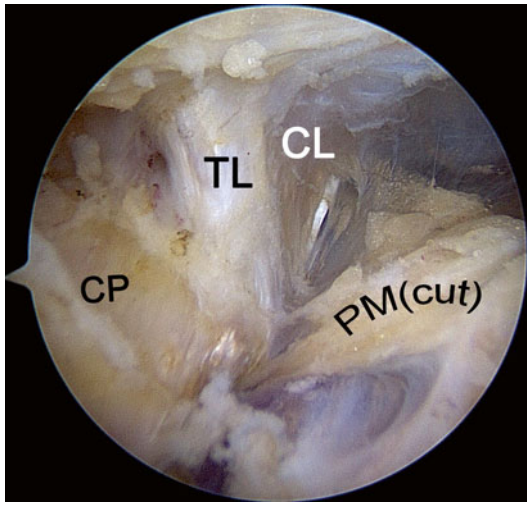
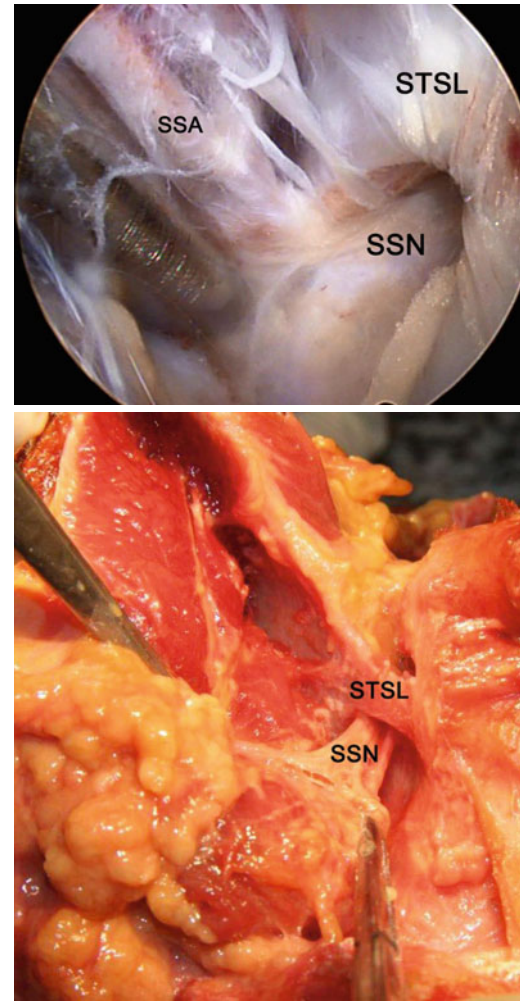


Fig. 33.15 The coracoclavicular ligaments: *TL* trapezoid ligament, *CL* conoid ligament, *PM* pectoralis minor cut from the coracoid process (*CP*)

posteroinferior plane of the clavicle (Fig. 33.14). The CC ligaments become visible after the debridement of aponeurotic tissue above the coracoid process and the pectoralis minor [17].

33.10 Suprascapular Notch Area

The suprascapular notch area is a region where the scapular nerve passes through the suprascapular fossa. It is necessary to visualize this area when treating suprascapular nerve pathologies (Figs. 33.16 and 33.17). Both superior transverse scapular ligament and scapular notch may present in many different variations. According to Rengachary there are six basic types of the suprascapular notch. Following the insertion of the conoid ligament at the base of the coracoid process in the medial direction, the superior transverse scapular ligament (STSL) can be seen [24]. In the most of the cases, the suprascapular artery passes above the STSL, but an anatomical variation can be encountered with the artery passing below the STSL accompanied by the suprascapular nerve.



Figs. 33.16 and 33.17 Arthroscopic and cadaver view of suprascapular nerve (*SSN*), superior transverse scapular ligament (*STSL*), and suprascapular artery (*SSA*)

33.11 Inferior Recess

Inferior recess or axillary pouch is limited by anterior and posteroinferior glenohumeral ligaments below the teres minor insertion. Its wall is composed of cross-linked fibers providing elasticity and durability (Fig. 33.18). High anatomical variability of the inferior recess is noted, from considerable volume accompanying joint laxity to a narrow pouch, arthroscopically impossible to access especially prior to the capsulitis [15].

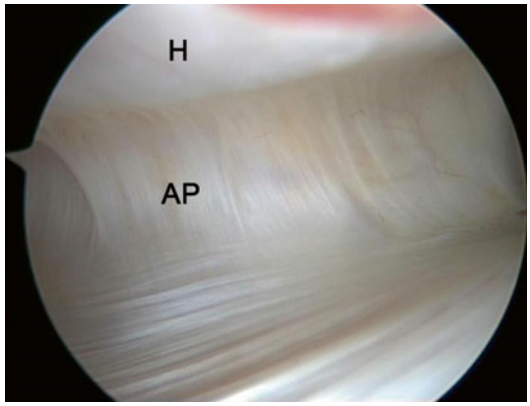


Fig. 33.18 Axillary pouch (*AP*) cross-linked fibers, *HH* humeral head

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Shoulder Instability: Traumatic and Atraumatic

34

Maristella F. Saccomanno and Giuseppe Milano

Glenohumeral instability has been described by Matsen et al. [1] as "a clinical condition in which unwanted translation of the head on the glenoid compromises the comfort and function of the shoulder." It can be the result of traumatic events causing structural damage to a previously intact and stable shoulder, called "traumatic instability," or it can be due to an inherent deficiency of passive and active shoulder stabilizers, thus occurring in the absence of relevant traumas, called "atraumatic instability."

Shoulder instability has a bimodal age distribution, with most affected patients in their late teens to mid-thirties, but with a second peak in older patients. In the latter case, shoulder instability often presents complex injury patterns including rotator cuff tears, fractures, and neurovascular injuries [2]. The overall incidence of shoulder dislocations ranges between 8 and 24 per 100,000 person per year in the general population [2, 3]. Dislocation rate among athletes and people involved in high-risk occupations has been reported to be higher than the general population with 0.12 episodes of glenohumeral instability occurring per 1,000 sporting exposures (defined as a practice session or competition session without reference to duration) [4–6]. Contact sports, such as American football, ice hockey, and rugby, are the most injurious, with the majority of dislocations occurring during contact with other athletes during competition [5]. A recent systematic review and meta-analysis of risk factors predisposing to traumatic shoulder instability showed that age equal or less than 40 years, male gender, presence of a greater tuberosity fracture, and hyperlaxity are the most significant variables [7]. Recurrence rate in these patients has been estimated to range between 60 and 100 % [4, 7–9]. On the other hand, the incidence and prevalence of atraumatic instability are difficult to estimate, given the spectrum of hyperlaxity and disease that might be present, albeit the constitutional trait of shoulder hyperlaxity and the pathological condition of instability representing distinct clinical entities. In shoulder hyperlaxity, range of motion and joint distractibility are increased without loss of function, and this condition may be essential to the athletic performance. In shoulder instability, the excessive translation of the humeral head on the glenoid is associated with a functional deficit, usually accompanied by symptoms of pain and apprehension. Instability and hyperlaxity may coexist, particularly in elite athletes who are often hyperlax and prone to injury through sport

M.F. Saccomanno, MD (✉)
Department of Orthopaedics, Catholic University, Rome, Italy
e-mail: maristellasaccomanno@hotmail.it

G. Milano, MD
Department of Orthopaedics, Catholic University, Rome, Italy

Service of Shoulder Surgery, "A. Gemelli" University Hospital, Rome, Italy
e-mail: giuseppe.milano@rm.unicatt.it

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[6, 10]. It is therefore clear that shoulder instability represents a broad spectrum of disease and a thorough understanding of the pathoanatomy is the key for a successful treatment algorithm of an unstable shoulder. The purpose of the following chapter is to provide an overview of current knowledge regarding diagnosis and classification of shoulder instability.

34.1 Clinical Diagnosis

A detailed history and a careful physical examination are paramount in understanding the underlying pathology of an unstable shoulder. From a clinical standpoint, instability can be described in terms of etiology (traumatic, atraumatic, or microtraumatic), direction (anterior, posterior, or multidirectional), degree (dislocation, subluxation), chronology (acute, recurrent, or chronic), and volition. Those five points are mandatory in the assessment of the pathology. Moreover, evaluation of local and generalized joint laxity is important to recognize the presence and the role of a preexisting joint laxity.

In case of acute (first episode) traumatic dislocations, patients usually refer falls on outstretched arm or secondary to motor or recreational vehicle accidents, or during sports events, particularly contact sports [11]. Although anterior shoulder instability is the most common event (up to 90–95 % of shoulder instability), posterior instability has been reported in approximately 4 % of all traumatic shoulder dislocations, and therefore, it must be carefully investigated [12]. Apart from sport injuries, posterior shoulder instability is common in patients affected by seizures. A good history can provide essential clues to the pathomechanics and then to the primary direction of instability. Especially in cases that required formal reduction by others, patients can usually clearly describe direction of dislocation. If reduction was not needed, feeling of instability is referred when the arm is placed in a particular at-risk position at the limit of glenohumeral joint excursion. Pain in the abducted and externally rotated position, such as the overhead serving position for volleyball or tennis, usually reminds to an anterior shoulder instability; pain with internal rotation and pushing forward such as during a bench press maneuver or pushing open a heavy door may lead to posterior shoulder instability. History of recurrent instability after a traumatic event or chronic (locked) dislocations can be indicative of glenoid or humeral head bone loss.

Atraumatic instability can be more insidious because there is no history of trauma and it is usually experienced in more than one direction. In the 1980s, Neer and Foster coined the term "multidirectional instability" [13], defined as symptomatic involuntary instability of the glenohumeral joint in more than one direction (anterior and/or posterior and inferior). The first challenge is to identify and classify patients with multidirectional instability (MDI): it can be found with or without hyperlaxity and it can also be voluntary. MDI without hyperlaxity is a very rare condition, and it is usually associated with a traumatic onset. MDI in patients with hyperlaxity can be atraumatic or due to repetitive microtrauma. Atraumatic MDI is usually characterized by pain and a sensation of instability even when the arm is in the middle of the glenohumeral range of motion. Symptoms develop gradually in these patients: at the beginning, pain during high-demand activities or provocative positions can be the only complaint; subsequently, instability symptoms may progress with subluxations and/or dislocations occurring during activities of daily living. Presence of numbness and tingling, secondary to traction on the brachial plexus, can be reported when carrying heavy objects, and it is associated to inferior subluxation [14]. Repetitive microtrauma is the most common etiology in patients involved in repetitive overhead activities, particularly in sports such as volleyball, swimming, and gymnastics. An accumulation of shear forces caused by persistent shoulder subluxation or microtrauma leads to a loss of chondrolabral containment with subsequent development of labral injuries [15–17]. The prevalence of generalized joint laxity in patients with MDI and shoulder laxity ranges between 40 and 70 % [13, 18, 19]. Generalized joint laxity can be congenital or acquired. Congenital hyperlaxity is usually caused

by connective tissue disorders, such as Ehlers-Danlos syndrome, Marfan syndrome, osteogenesis imperfecta, and benign hypermobility syndrome [20, 21]. Although congenital hyperlaxity is not necessarily related to a pathological condition, attention must be paid to rule out family history or presence of a connective tissue disorder, because it can change the treatment choice and prognosis. The prevalence of non-pathological hyperlaxity in the general population is between 5 and 15 % [22, 23]. It is slightly more prevalent in females than in males and becomes less common as individuals age [24, 25]. Acquired joint hyperlaxity is commonly observed in athletes (swimmers, gymnasts, pitchers, etc.) with no gender differences [10, 26–28]. Patients with MDI and hyperlaxity usually do not require reduction maneuvers to reduce their shoulder dislocations and do not develop bone loss.

Voluntary shoulder instability was first described by Rowe in 1973 [29] and is characterized by a patient's ability to subluxate or dislocate her/his shoulder using selective muscle contraction and relaxation. Most of the patients in the study by Rowe [29] had ligamentous laxity.

The physical examination of a patient in an acute setting is critical. The first step in approaching an acute traumatic shoulder dislocation is a meticulous neurovascular examination because an injury to the axillary nerve can occur in association with glenohumeral dislocation and should be recognized and documented before any intervention [30]. A patient with an acute dislocation will generally not tolerate attempted motion of the shoulder. At the inspection, subacromial defect or concavity may be visible in the soft tissue, with the humeral head palpable anteriorly, posteriorly, or inferiorly according to the direction of the dislocation.

In a chronic setting, a complete physical examination will be necessary not only to confirm the clinical suspicious but also to exclude other causes of shoulder pain, such as rotator cuff tears or cervical radiculopathy. Both shoulders should be evaluated, observing any asymmetry, abnormal motion, muscle atrophy, and scapular winging. Each patient should be asked for voluntary instability. Specific tests assessing the direction of instability and the degree of shoulder hyperlaxity and generalized joint laxity must be performed.

Clinical tests can be divided in two main groups: provocative tests, which are used to examine the shoulder's resistance to instability challenges, starting from positions at which the ligaments are normally under tension, and laxity tests, which are used to examine the degree of translation, starting from positions at which the ligaments are normally loose [10]. Basically, the replication of a patient's sense of instability distinguishes asymptomatic laxity from pathological laxity combined with instability.

Provocative tests (Fig. 34.1) evocate patient's symptoms to define a positive test. Most common tests are the following:

- *Anterior apprehension test*: it is diagnostic for an anterior instability and is performed with the patient supine. The shoulder is positioned at 90° of abduction and the elbow in 90° of flexion, with forced external rotation applied to the extremity as anterior stress is applied to the humerus to the end range of motion. The test is considered positive if the patient becomes apprehensive and either tightens up to prevent further movement or ask the examiner to stop as he/she feels his/her arm is about to dislocate [31].
- *Relocation test* (*or fulcrum test*): it is diagnostic for an anterior instability and is performed immediately right after the apprehension test when the patient is still in the position of apprehension. The examiner applies a posterior-directed force to relocate the humeral head. In a positive test, the patient's apprehension is reduced by this maneuver [32].
- *Anterior bony apprehension test*: it is diagnostic for an anterior instability and is performed identical to the standard apprehension test except that the arm is brought to only 45° of abduction and 45° of external rotation. A positive result should alert the examiner to the possibility of a bony lesion as the cause of symptomatic anterior shoulder instability [33].

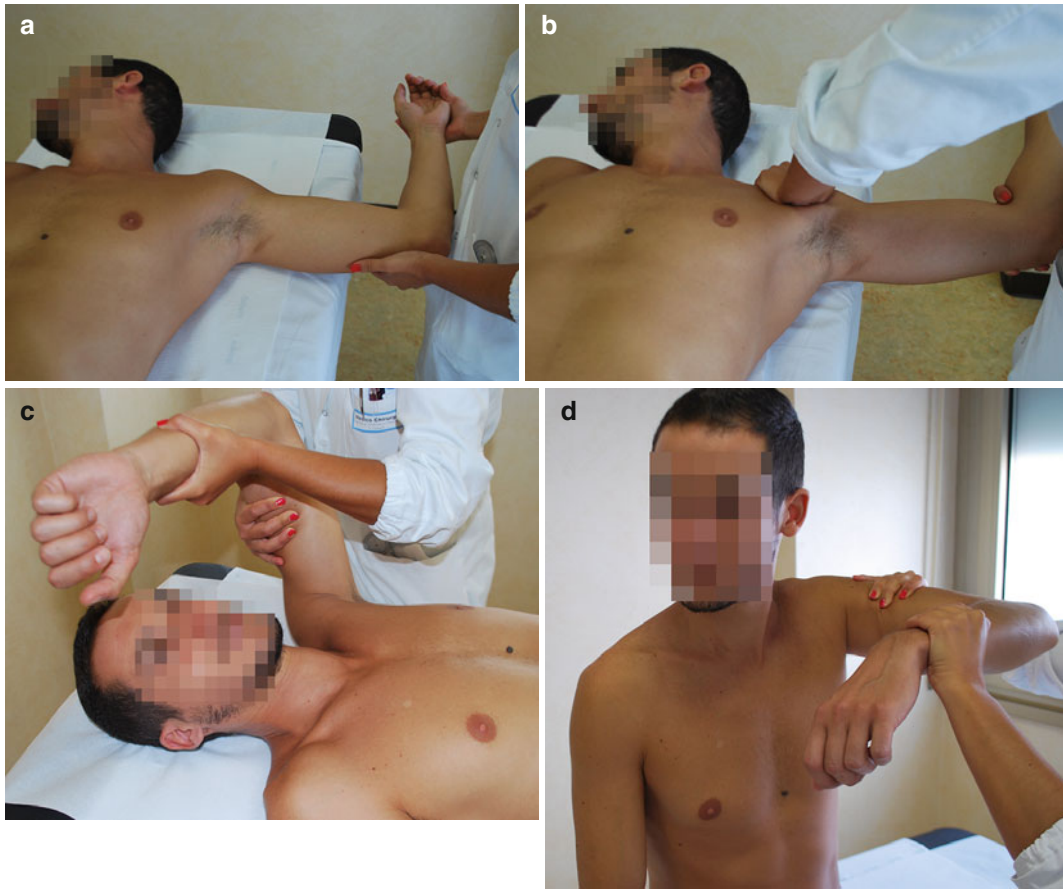

Fig. 34.1 Provocative instability tests: anterior apprehension test (**a**); relocation test (**b**); Kim's test (c); and jerk test (**d**)

- *Kim's test*: it is diagnostic for a posterior instability and is performed with patient in supine position. The affected arm is placed at 90° of abduction, when the examiner holds the arm and elbow and applies an axial loading force. The arm is then elevated 45° while maintaining axial force that pushes the humeral head posteriorly, and the result is considered positive if posterior pain or a palpable clunk is felt [34].
- *Jerk test*: it is diagnostic for a posterior instability and is performed with the patient in a sitting position. While the examiner holds the scapula with one hand, the patient's arm is abducted 90° and internally rotated 90°. An axial force is loaded with the examiner's other hand holding the patient's elbow, and a simultaneous horizontal adduction force is applied. A sharp pain with or without posterior clunk or click suggests a positive test result.

Although injuries of the superior glenoid labrum and/or biceps anchor, or SLAP (superior labrum from anterior to posterior) lesions, do not usually cause frank instability, those lesions sometimes occur in association with shoulder instability, especially in overhead athletes. Specific provocative tests for this type of lesions (Fig. 34.2) are:

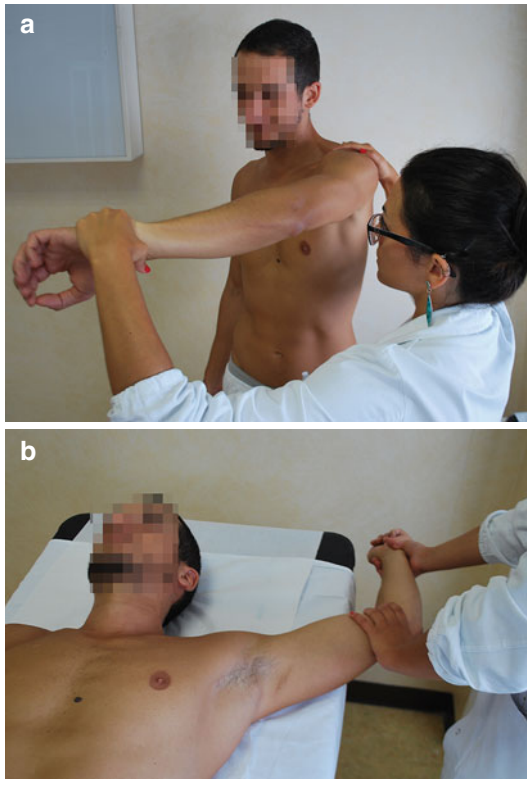

Fig. 34.2 Provocative tests for SLAP lesions: O'Brien test (**a**) and modified Jobe relocation test (**b**)

- *Active compression test* (*O'Brien test*): patient can be seated or upright. The affected arm is placed at 90° forward flexion, 10° adduction, and the thumb pointing down, while the examiner stands with one hand grasping the patient's wrist. Patient is asked to raise up the arm against examiner resistance. The test is then repeated with the patient's palm facing upward. A positive test is when pain is elicited in the internally rotated position and is reduced when retested in the externally rotated position [35].
- *Passive distraction test*: it is performed with the patient in supine position. The affected arm is elevated to 150° in the coronal plane with the elbow extended and with the forearm in supination. A positive test occurs if the patient experiences pain deep inside the glenohumeral joint either anteriorly or posteriorly when the forearm is pronated [36].

Laxity tests in the office require patient to be relaxed enough to allow translation of the humeral head on the glenoid.

Inferior shoulder laxity (Fig. 34.3) can be assessed as follows:

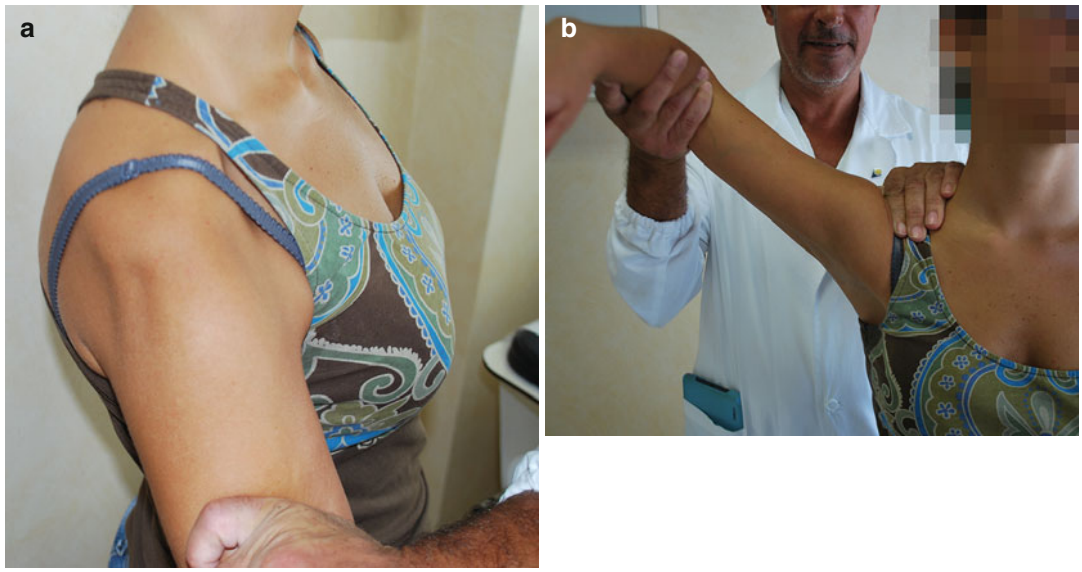

Fig. 34.3 Inferior shoulder laxity tests: Sulcus test (**a**) and Gagey test (**b**)

- *Sulcus sign*: it is performed by applying an inferior distraction to the patient's arm positioned in neutral rotation. Both arms should be evaluated. Patient can be upright or seated. The maneuver will produce a characteristic soft tissue indentation inferior to the acromion. The sulcus sign is graded according to the acromiohumeral distance on traction: a distance of <1 cm is graded as 1+, 1–2 cm as 2+, and >2 cm as 3+. The test can be repeated in external rotation to test the superior glenohumeral ligament and rotator cuff interval. A sulcus sign test is pathognomonic for inferior instability if it causes the typical symptoms of pain, dysesthesias, or apprehension [37].
- *Gagey test* (*hyperabduction test*): it is performed with the examiner standing behind the seated patient, with one hand pressing down firmly to stabilize the patient's scapula, while the patient's arm is abducted until the scapula is felt to be moving. The test is considered to be positive for laxity of the inferior glenohumeral ligament if the range of passive abduction is more than 105° in the affected arm [38] or if an asymmetrical hyperabduction of more than 20° is noted when compared with the abduction on the contralateral side [39].

Anterior shoulder laxity can be evaluated as follows:

- An external rotation greater than 85° with the arm at the side [40] denotes lax anterior capsule.
- *Anterior drawer test*: it is performed with the patient supine. The examiner holds the patient's arm in 80–120° of abduction, 0–20° of forward flexion, and 0–30° of external rotation and the hand of the extremity being evaluated in the examiner's axilla. One of the examiner's hands is placed on the humeral shaft to provide an anteriorly directed force. The other hand is used to stabilize the scapula by placing the fingers posteriorly along the scapular spine and the thumb anteriorly on the coracoid [41]. Test is graded as 0 when little to no movement is noted; 1+ in case of translation to the glenoid rim but not dislocation; 2+ if translation is consistent with dislocation over the glenoid rim, but with spontaneous reduction when the force is removed; or 3+ if translation is consistent with dislocation without spontaneous reduction [42].
- *Anterior load and shift test*: it is performed with the patient in the upright or supine position. The arm is placed in 20° of abduction, 20° of forward flexion, and in neutral rotation. The examiner stabilizes the scapula with one hand and grasps the proximal arm near the joint with the other hand. A slight axial load is then applied between the humeral head and glenoid, which facilitates the ability to feel the humeral head slide over the rim. As the head is loaded, anterior forces are applied to assess the translation of the humeral head on the glenoid [43]. Test is graded as previously described for the drawer test.

Posterior shoulder laxity can be assessed similarly to anterior laxity:

- *Posterior drawer test*: it is performed as previously described for the anterior drawer test, but a posteriorly directed force is applied to the patient's arm [41].
- *Posterior load and shift test*: as mentioned above for the anterior load and shift, as the head is loaded, a posteriorly directed force is applied to the patient's humerus [43].
- *Push-pull test*: it is performed with the patient supine and the shoulder in 90° of abduction and 30° of flexion. The examiner pulls up on the wrist with one hand while pushing down on the proximal humerus with the other hand [44].

Although there is no gold standard to evaluate generalized joint hyperlaxity, numerous clinical scoring systems have been proposed [45–47]. The Beighton scale [47] is the most popular, and it comprises five items: (1) passive dorsiflexion of the fifth finger beyond 90°, (2) passive thumb opposition to the forearm, (3) passive elbow hyperextension beyond 10°, (4) passive knee hyperextension beyond 10°, and (5) forward flexion of the trunk with knees fully extended so that the palms of the hands rest flat on the floor. Each item except for

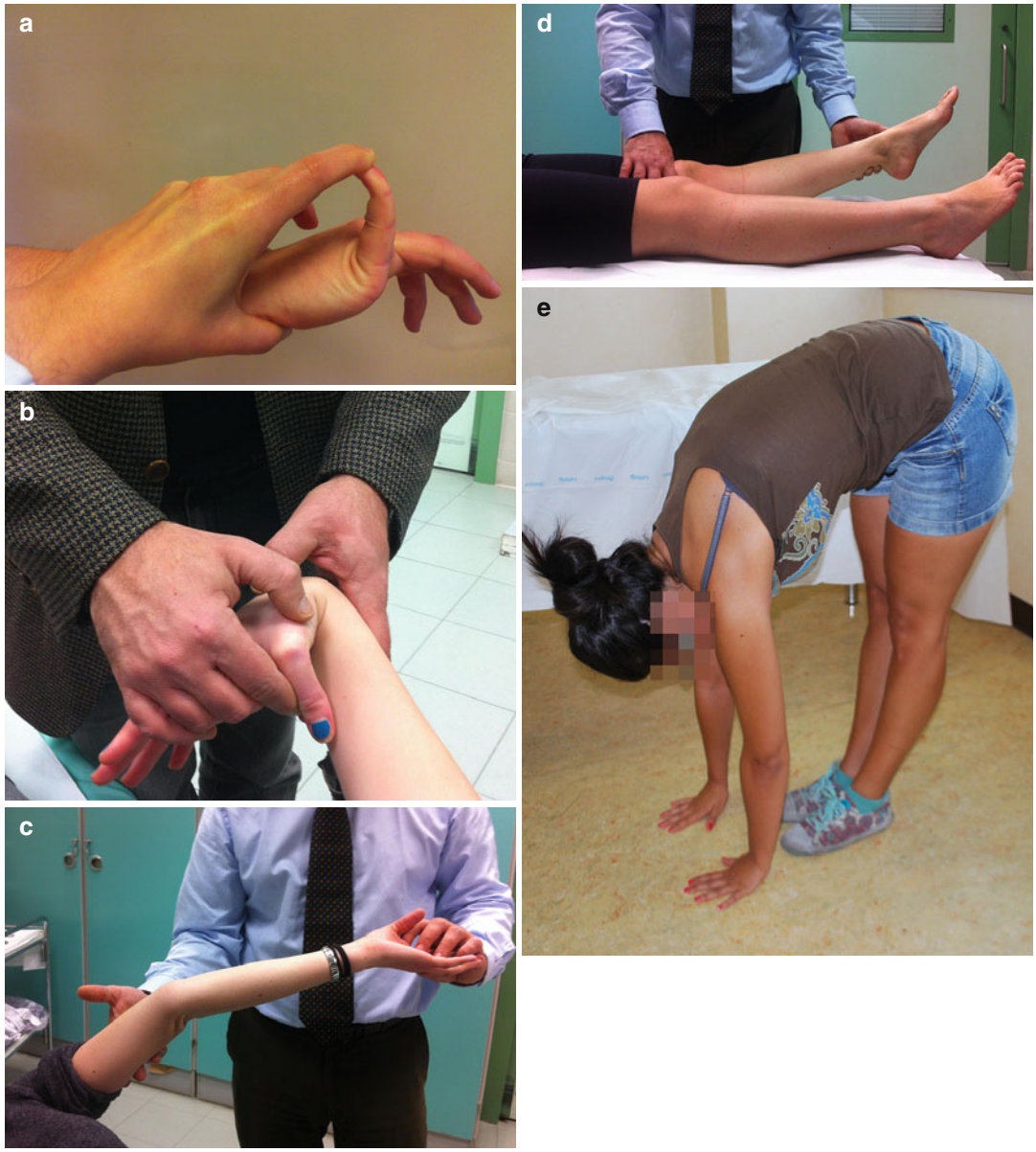

Fig. 34.4 Five items of the Beighton scale: passive dorsiflexion of the fifth metacarpophalangeal joint to ≥90° (**a**); passive apposition of the thumb to the flexor side of the forearm (**b**); passive hyperextension of the elbow ≥10° (**c**); passive hyperextension of the knee ≥10° (**d**); and forward flexion of the trunk with knees fully extended so that the palms of the hands rest flat on the floor (**e**)

trunk flexion is scored bilaterally, and the total score ranges from 0 to 9 (Fig. 34.4). Unfortunately its cutoff point remains arbitrary. Several studies [48, 49] applied Beighton criteria to show the association between generalized joint laxity and shoulder instability with cutoff values to define hyperlaxity ranging from 2 to 6 points out of 9.

Nevertheless, rotator cuff lesions can be sometimes associated to shoulder instability. Particularly, articular-side partial-thickness tears of the rotator cuff can be found in overhead athletes secondary to posterosuperior internal impingement, or full-thickness cuff tears must be investigated in patients over 40. Therefore,

specific tests, such as Yocum, Jobe, belly-press, lift-off, bear hug, and internal and external rotation lag sign tests, should be included in the physical examination.

Finally, even in a chronic setting, presence or absence of neurological symptoms must always be ascertained in order to rule out previous damage to the axillary nerve or cervical radiculopathy.

34.2 Imaging

34.2.1 Conventional Radiology

In an acute setting (emergency room), standard x-ray examination is mandatory to confirm the clinical suspicion of a dislocation or presence of fractures before and after the reduction maneuver. In a long-lasting history of instability, standard radiographs can reveal glenoid and/or humeral head bone loss and occasionally abnormal glenoid version, dysplasia, or hypoplasia that may contribute to instability [50].

Specific x-ray views have been reported in the literature to assess an unstable shoulder. A bony shadow or displaced osseous fragment (bony Bankart lesion) may be visualized on a standard anteroposterior (AP) view, in projections parallel to the glenoid face, such as axillary or the Bernageau view [51], or in some other angled projections relative to the glenoid face, such as the apical oblique [52], Didier [53], or West Point [54] views. The Stryker notch view and AP view with the humerus in internal rotation can be helpful for the evaluation of the Hill-Sachs lesion, a compression fracture of the posterosuperolateral humeral head that usually occurs in association with anterior instability [55].

34.2.2 Computed Tomography

Preoperative quantification of glenoid and humeral head bone loss is crucial for surgical decision-making. CT scan has been shown to be superior to plain radiography when evaluating the glenoid, as it provides an en face oblique view, which guarantees the opportunity to define

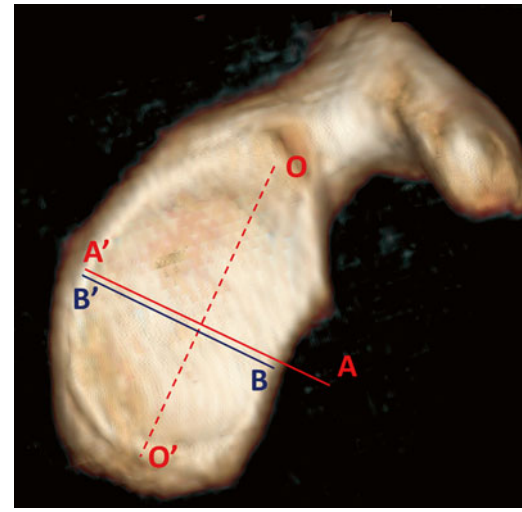

Fig. 34.5 CT measurement of glenoid bone defect on 3D CT scans based on the ratio between the maximum anteroposterior width of the affected glenoid (BB′) and that of the contralateral healthy glenoid (AA′) (OO′: maximum superoinferior length)

the size, location, and type (fracture or erosion) of glenoid defects associated with anterior shoulder instability [56]. According to the literature, the critical limit of bone loss over which the risk of recurrence after arthroscopic surgical repair becomes clinically relevant is reported to be about 20 % of the inferior glenoid area, which is equivalent to 25 % of the glenoid width [57–60]. Different studies suggested the use of three-dimensional (3D) volume rendering technique (VRT) [61–65] or two-dimensional (2D) multiplanar reconstruction (MPR) CT scans [66–71] with or without comparison with the contralateral shoulder [62, 65, 72–74]. Griffith et al. [68] and Chuang et al. [61] described a method for quantification of glenoid defects on 2D and 3D CT scans, respectively, based on the ratio between the maximum anteroposterior width of the affected glenoid and that of the contralateral healthy glenoid (Fig. 34.5). Both measurements were validated for accuracy using the arthroscopic measurement as reference standard [61, 68]; however, accuracy of arthroscopic measurement, based on the bare spot as center of the inferior glenoid, is rather controversial [75–77]. Sugaya et al. [65] first proposed the "circle method" to

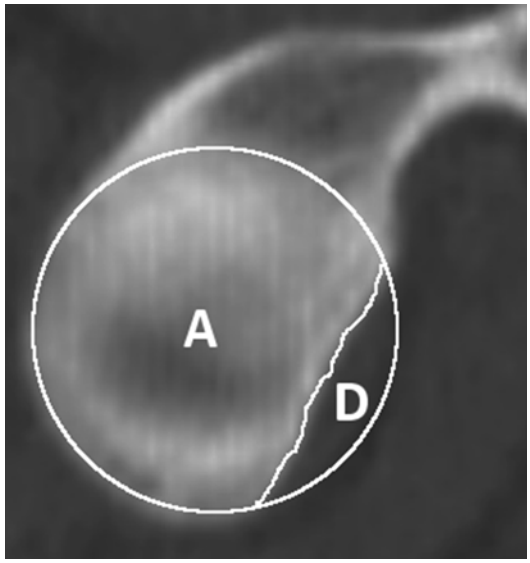

Fig. 34.6 "Pico" method for measurement of glenoid bone defect based on the use of the circle method on 2D CT scans by comparison with the contralateral healthy shoulder (*A* area of the inferior glenoid of the contralateral healthy shoulder. *D* area of the glenoid bone defect on the affected shoulder)

quantify glenoid bone defects on 3D CT scans. This method is based on the observation that the inferior part of the glenoid has the shape of a true circle [7, 73, 78], which can be drawn on the sagittal en face view of the glenoid. Later, Baudi et al. [66] described the "Pico" method, based on the use of the circle method on 2D CT scans by comparison with the contralateral healthy shoulder, which demonstrated very good intraobserver and interobserver reliability [71] (Fig. 34.6). Subsequently, Magarelli et al. [79] estimated agreement between 2D and 3D CT scans in quantifying glenoid bone defects with the circle method in anterior glenohumeral instability by comparison with the contralateral healthy shoulder and reported that mean difference between the two methods of measurement was negligible.

Classification of humeral-sided lesions has also been described. Most of these descriptions use CT scan quantification based on the humeral defect as a percentage of the circumference of the humeral head evaluated on axial 2D images, or direct visualization of the humeral-sided defect on 3D reconstruction [55]. Actually, the determination of the clinical significance of a Hill-Sachs lesion is still under debate. Historically, lesions less than 20% of the humeral head curvature were usually considered not clinically relevant and therefore left untreated; lesions greater than 40% directly correlated with the presence of recurrent instability, and therefore, they need to be fixed; defects between 20 and 40% represented a gray zone, as their clinical relevance can depend on the location, orientation, and engagement of the lesion with the anteroinferior glenoid [80, 81]. The concept of the "engaging Hill-Sachs" lesion was first described by Burkhart and De Beer [57] as a significant humeral bone defect oriented in such a way that it engaged the anterior glenoid with the shoulder in abduction and external rotation. Subsequently, several authors attempted to clarify the characteristics of Hill-Sachs lesion and its role in the setting of shoulder instability [82–88]. Yamamoto et al. [83] developed a novel approach. They based their description on the location and size of the humeral head defect and on the amount of glenoid bone loss. Using a cadaver model, they measured the contact area between the glenoid and humeral head at various degrees of abduction. At 60° of shoulder abduction, with an increase in arm elevation, the glenoid contact shifted from the inferomedial to the superolateral portion of the posterior aspect of the humeral head, creating a zone of contact, the so-called glenoid track. The medial margin of the glenoid track was located 84 ± 14% of the glenoid width. A Hill-Sachs lesion was considered at risk of engagement and dislocation if it extends medially over the medial margin of the glenoid track. If there is a glenoid bone defect, the width of the glenoid track decreases accordingly. In order to explain the geometric interplay of various sizes and various orientations of bipolar (humeral-sided plus glenoid-sided) lesions, Di Giacomo et al. [89] recently introduced the concept of "on-track/off-track" Hill-Sachs lesion on 3D CT scans. According to the authors, if the Hill-Sachs lesion is located within the glenoid track, it can be defined as an on-track lesion; if it extends more medially over the medial margin of the glenoid track, it is considered an off-track

lesion. However, to date, no consensus has been reached on the clinical utility of these classifications in guiding treatment.

34.2.3 Magnetic Resonance

Besides osseous defects, a wide spectrum of soft tissue lesions can be related to shoulder instability. The superiority of MRI compared to conventional radiology or CT in the detection of soft tissue lesions is beyond doubt. Furthermore, the addition of intra-articular gadolinium (MR arthrography, MRA), which allows for capsular distension, is supposed to improve the definition of the glenoid labrum, rotator interval, and glenohumeral ligaments. The use of provocative positioning maneuvers has also been advocated to further increase the sensitivity of the exam. Up to now, no differences have been found between conventional MRA and MRA in abduction and external rotation (ABER) position for detecting anteroinferior labroligamentous lesions (Bankart lesion, also known as "the essential lesion" of traumatic anterior instability. It consists of the detachment of the anteroinferior labrum with its attached inferior glenohumeral ligament complex) [90]. Tian et al. [91] recently found a significant improvement in ABER position only for the detection of Perthes lesions (variant of the Bankart lesion, where the scapula periosteum is stripped with the detached anterior labrum, but the labrum may appear to be in a normal position, albeit it is still unstable [92]). Only one study [93] showed that adduction internal rotation (ADIR) position is more accurate than neutral or ABER position for the diagnosis of anterior labroligamentous periosteal sleeve avulsion, or ALPSA lesion (variant of the Bankart lesion, where the anterior scapular periosteum ruptures, the inferior glenohumeral ligament complex, labrum, and periosteum are stripped and displaced in a sleeve-type fashion medial on the glenoid neck [94]). Finally, flexion-adduction and internal rotation (FADIR) position is supposed to improve the assessment of the posterior labrum and capsule in case of posterior instability [95], but further studies are needed.

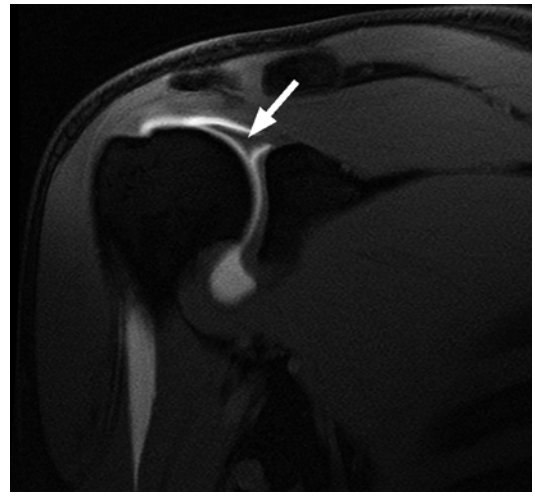

Fig. 34.7 MRA of a right shoulder. Coronal oblique T2-weighted image showing a SLAP lesion (*arrow*)

Nevertheless, advancing of arthroscopy over the last decades deeply changed both the way of assessing and treating shoulder soft tissue injuries; and arthroscopy was used as a reference standard to define MRI accuracy, with conflicting results [96–105]. Several studies reported a wide range of sensitivity in the detection of labral tears for conventional MRI ranging from 44 to 100 % compared with arthroscopy [96–102]. Hayes et al. [103] showed that the sensitivity and specificity of MRI in detecting Bankart lesions were 98.4 % and 95.2 %, respectively, with no differences between conventional MRI and MRA. Conversely, in a recent review [104] on the diagnostic test accuracy of MRA and MRI for the detection of glenoid labral injury, MRA appeared slightly more accurate than MRI for both sensitivity (88 % and 76 % for MRA and MRI, respectively) and specificity (93 % and 87 % for MRA and MRI, respectively), particularly for detecting anterior labral lesions and SLAP lesions (Fig. 34.7). Interestingly, a recent reliability study [105] conducted on 50 MR exams (25 conventional MRI and 25 MRA) from 50 patients who subsequently underwent shoulder arthroscopy showed poor to complete disagreement between radiologists and orthopedics in the assessment of Bankart lesions and ligamentous lesions using both MR and MRA. Moreover, cor-

relation with arthroscopy showed that none of the observers was able to correctly detect the presence of a ligamentous lesion.

MRI has also been claimed for the evaluation of osseous defects, reporting a high correlation between CT and MRI for the quantification of glenoid bone defect [106–109]. Definitely, considering mean age of patients usually affected by shoulder instability, it would be excellent if MRI enabled the assessment of glenoid bone loss and soft tissue injuries in a single examination without the risks related to radiation exposure. However, no definitive information on its superiority over CT has been provided by the current literature, and recent studies on the reliability of MRI and on its agreement with CT in estimating the presence, type, and size of glenoid bone defect reported results in favor of CT [110, 111].

34.3 Rating: International Classification

As already shown in this chapter, it is hard to classify the shoulder instability because many patients could exhibit overlapping traits. Therefore, it is not surprising that many attempts have been done over the last decades.

Historically, Rockwood's classification system consisted of four groups of instability [112]:

- *Type 1*: history of traumatic subluxation without a frank dislocation.
- *Type 2*: frank traumatic dislocation as a primary event.
- *Type 3*: voluntary subluxation with no history of a traumatic event. This group is subdivided into types 3a and 3b, with type 3a including a history of psychiatric problems and type 3b not.
- *Type 4*: atraumatic involuntary subluxation.

Subsequently, Kessel and Bayley have grouped voluntary and involuntary subluxation together and included both groups under the heading of "habitual instability" [113].

One of the most famous and worldwide used classification systems has been proposed by Thomas and Matsen in 1989 [114]. Two acronyms were used to describe shoulder instability and etiology:

- *TUBS* (Traumatic, Unilateral, Bankart lesion, Surgery): describes instability that is caused by a traumatic event, is typically unilateral, with a Bankart lesion and usually requiring surgical stabilization.
- *AMBRI* (Atraumatic, Multidirectional, Bilateral, Rehabilitation, Inferior capsular shift): describes instability that is atraumatic, multidirectional, commonly bilateral, and usually treated conservatively as a first option and inferior capsular shift in refractory patients. AMBRI patients typically develop instability insidiously and have underlying ligamentous laxity.

Unfortunately, although simple, as for previous classifications, these two groups represent only the extremes in this pathology.

Subsequently, Gerber and Nyffeler [115] described a classification system that distinguished among static, dynamic, and voluntary dislocation.

- *Static instabilities* (*class A*): are defined by the absence of classic symptoms of instability and are associated with rotator cuff tears and degenerative joint disease. The diagnosis of class A instability is radiological, not clinical.
  - Static superior migration (A1) is defined as an acromiohumeral distance of less than 7 mm on an AP radiograph.
  - Static anterior subluxation (A2) is a fixed anterior position of the humeral head on the glenoid.
  - Static posterior subluxation (A3) is a fixed posterior position of the humeral head.
  - Inferior subluxation (A4) is characterized by straight inferior translation.
- *Dynamic instabilities* (*class B*): are traumatic and patients present with the symptoms of instability.
  - Chronic, locked shoulder dislocation (B1). Depending on the direction, anterior or posterior bony Bankart or glenoid erosion and a Hill-Sachs or McLaughlin compression fracture may be present.

  - Unidirectional instability without hyperlaxity (B2). It accounts for 60 % of patients treated for traumatic shoulder instability.
  - Unidirectional instability with hyperlaxity (B3). It accounts for 30 % of patients treated for traumatic shoulder instability.
  - Multidirectional instability without hyperlaxity (B4). Rare.
  - Multidirectional instability with hyperlaxity (B5). It accounts for 5 % of shoulder instability.
  - Uni- or multidirectional instability, with voluntary reduction (B6).
- *Voluntary instability* (*class C*).

More recently, the Stanmore system has been proposed [116]. Basically, patients are assigned to one of three poles of a triangle:

- *Polar type 1*: patients have a defined history of a significant trauma, display unidirectional instability, and have a Bankart lesion.
- *Polar type 2*: patients have a less defined history of trauma, but are likely to have a structural lesion and do have an overlay of abnormal muscle recruitment (muscle patterning).
- *Polar type 3*: patients have no structural abnormality and may be habitual dislocators or have a significant muscle patterning abnormality.

This system allows patients to move around the triangle over time.

Finally, the FEDS (frequency, etiology, direction, and severity) classification recognizes four common used features of instability in existing classifications [117]:

- *Frequency*: describes how many episodes the patient sustained in the last year and is graded as "solitary" (1 episode), "occasional" (2–5 episodes), and "frequent" (>5 episodes)
- *Etiology*: describes the cause of injury as traumatic or atraumatic
- *Direction*: is defined as anterior, inferior, or posterior
- *Severity*: is defined as subluxation or dislocation

Unfortunately, shoulder instability represents a wide spectrum of disorders, and there is currently no satisfactory all-encompassing classification system that serves as a guide to the diagnostic treatment algorithm and facilitates easy communication between clinicians.

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Anterior Traumatic Instability Without Glenoid Bone Loss

35

Vivek M. Morey, Giuseppe Porcellini, Fabrizio Campi, Paolo Paladini, and Giovanni Merolla

35.1 Introduction

The glenohumeral joint is the most commonly dislocated joint in the body which can be attributed to its highly mobile articulation. Although glenohumeral instability can occur in any direction, anterior instability is by far the most common, which ranges from subtle increased laxity to recurrent dislocation. Traumatic injury is the most common cause of shoulder instability, accounting for approximately 95 % of anterior shoulder dislocations [1]. In the successful management of traumatic anterior shoulder instability, the importance of patient history and thorough clinical examination supplemented with the radiological workup cannot be overemphasized. As these issues are effectively elaborated in the previous chapters, in this chapter, we will discuss about the indications, techniques, complications, and results of surgical management of anterior shoulder instability without glenoid bone loss.

35.2 Indications

The primary indication for anterior surgical stabilization is the clear anterior unidirectional instability with persistent shoulder pain that has not responded to a minimum of 6 months of conservative management. Additionally, the ideal shoulder should have a Bankart lesion with robust labral tissue for repair.

However, there are several factors which should be given due consideration in the process of decision making and could be listed as patient age, the intensity of the trauma leading to dislocation, arm dominance, timing during a sports season, and patient's present and desired activity level. The typical patient with a high risk of developing recurrent instability is a male patient, either in his teenage years or early twenties, who suffers a primary dislocation while playing contact sports [2]. Although recurrent instability in the elderly patients is not that common, it has its own complications [3]. In old age patients and more sedentary individuals with occasional symptoms of instability, an initial trial of nonoperative treatment including strengthening of the rotator cuff may be more appropriate [2]. The instability symptoms at night have their own

V.M. Morey • F. Campi • P. Paladini • G. Porcellini
Unit of Shoulder and Elbow Surgery,
D. Cervesi Hospital, Via L.V. Beethoven 46,
Rimini, Italy

G. Merolla, MD (✉)
Unit of Shoulder and Elbow Surgery,
D. Cervesi Hospital, Via L.V. Beethoven 46,
Cattolica, Italy

"Marco Simoncelli" Biomechanics Laboratory,
D. Cervesi Hospital, Via L.V. Beethoven 46,
Cattolica, Italy

Unit of Shoulder and Elbow Surgery and "Marco Simoncelli" Biomechanics Laboratory, D. Cervesi Hospital, Via L.V. Beethoven 46, Cattolica, Italy
e-mail: giovannimerolla@hotmail.com; giovanni.merolla@auslrn.net

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importance. A patient who reports instability or a frank dislocation while sleeping most likely has severe instability and is more likely to fail conservative management compared with the patient who only experiences symptoms with activity.

There is a growing consensus toward early surgical stabilization in the management of acute first-time dislocations in young patients engaged in high-demand activities who are unwilling to modify their activities. A Cochrane Review evaluating the level 1 evidence of nonoperative versus operative treatment of acute first-time shoulder dislocations concluded that early surgical intervention was warranted in young adults (aged less than 26–30 years) engaged in highly demanding physical activities [4]. Boone et al. in their critical review concluded that the treatment of first-time anterior dislocation of the shoulder involves a consideration of not only the incidence of recurrent dislocation but should be influenced by the quality of life and an evaluation of outcomes [5]. They asserted that the treatment should be based on the method that results in the best outcome and hence recommended arthroscopic suture anchor repair especially in the at-risk group less than 25 years of age.

Although most of the anterior instability patients with abovementioned features can be successfully managed with arthroscopic stabilization, the authors have attempted to identify a subset of patients who can be recognized preoperatively solely on the basis of clinical criteria for high risk for redislocation following arthroscopic repair [6]. The distinguishing factors recognized are male sex, an age of 22 years or less, and an interval of more than 6 months between the first dislocation and surgery [6]. The authors recommend considering the option of open stabilization procedure (Laterjet) as a first intervention in these patients.

Nevertheless, the decision to operate is the patient's, and the role of the surgeon is to explain chance of recurrent instability in light of the patient's particular situation and let the patient and family decide on operative (arthroscopic or open) or nonoperative care. Not to forget, there are several contraindications for the arthroscopic management of anterior instability. Absolute contraindications include multidirectional instability, glenohumeral instability with volition, and emotional labiality. Patients able to selectively contract their muscles and demonstrate glenohumeral subluxation or dislocation have a poor prognosis after operative care. Relative contraindications include failed prior instability surgery, poor quality ligaments, HAGL lesion, and large bone defects of the glenoid or humeral head.

35.3 Techniques

Surgical stabilization for patients with anterior instability has evolved over the past century as our understanding of the pathology has improved. Early procedures focused on nonanatomic approaches to the problem. Reconstructions such as the Putti-Platt, Magnuson-Stack, and Bristow procedures were successful in preventing recurrent instability but resulted in limited external rotation, compromising the athlete's shoulder function [7].

Although open repair of anterior shoulder instability has been considered the gold standard, arthroscopic shoulder instability repair has become a key component in the diagnosis and management of shoulder instability. Arthroscopic surgery has changed the way surgeons think about and treat shoulder instability. Arthroscopic stabilization is done as day-care surgery offers attractive advantages over open repair such as improved cosmesis, less postoperative pain, reduced stiffness after operation, more rapid rehabilitation, the ability to accurately identify and treat the specific pathoanatomy, and less iatrogenic damage to normal tissues (subscapularis). However, the general surgical principles remain the same, that is, to restore the labrum to its anatomic attachment and to reestablish the appropriate tension in the inferior glenohumeral ligament complex and capsule. The widely used arthroscopic suture anchor technique can be elaborated as below.

35.4 Anesthesia and Positioning

Depending on the preference of the surgical team, anesthesiologist, and patient, the surgical procedure can be performed with general

anesthesia, interscalene block, or a combination of the two. The authors prefer general anesthesia with interscalene block of the brachial plexus. Patients can be placed in either the lateral decubitus or beach chair position. The beach chair position offers several advantages, including ease of access and ability to easily convert to an open procedure if indicated. However, the authors' choice is to use a lateral decubitus position as it allows ease of access and visualization of the entire capsulolabral complex. On account of the longitudinal and direct lateral suspension, it affords greater distension of the glenohumeral joint and better ability to make the necessary passes with instrumentation for optimal repair. One of the pitfalls of lateral decubitus positioning is the difficulty in achieving rotational control during instability repair. Furthermore, subscapularis repair in athletes with shoulder instability and rotator interval closure are ideally done in 30–45° of external rotation, which can be difficult to achieve in patients in the lateral position. For the lateral decubitus position, the patient is positioned on a long beanbag, and the arm is held in an arm traction device with approximately 30° of abduction and 15° of forward flexion and traction of 5 kg.

35.5 Examination Under Anesthesia

The examination under anesthesia (EUA) is usually performed to confirm preoperative clinical findings including direction of instability. Examination with the arm in various degrees of abduction and external rotation allows the examiner to assess the degree and direction of instability. Side-to-side comparisons can be particularly helpful in patients with subtle instability patterns or for those with global laxity and can serve to tailor specific operative planning, such as how much capsular plication to perform. Laxity is classified as grade 1+ (translation to the glenoid rim), grade 2+ (translation over the glenoid rim with spontaneous reduction), and grade 3+ (dislocation that does not spontaneously reduce). Grades 2+ and 3+ are always considered abnormal. By applying an inferior force to the adducted arm in internal and external rotation, the sulcus sign is elicited. The distance is measured between the lateral border of the acromion and humeral head. The distance greater than 1 cm indicates a significant inferior component to the instability pattern, and if it does not decrease when the arm is externally rotated, it implies a deficiency in the rotator interval region [8].

35.6 Portals

Before portal making, all bony landmarks including acromion, acromioclavicular joint, and the notch, formed by the scapular spine posteriorly and the clavicle anteriorly, are marked with a sterile marking pen. Proper portal placement plays a vital role in performing an accurate diagnostic arthroscopy and complete Bankart repair.

Usually three portals (two anterior and one posterior) are sufficient to perform arthroscopic anterior stabilization. A standard posterior portal is made approximately 2 cm inferior and 1–2 cm medial to the posterolateral corner of the acromion. The 30° arthroscope is introduced into the glenohumeral joint through this portal, and a brief diagnostic evaluation is performed to confirm the presence of an anterior labral lesion. Next, the anterosuperior portal is made by inside-out technique [9]. To do so, the arthroscope is advanced superior to the biceps tendon into the rotator interval. The arthroscope is then withdrawn from its sheath, and a Wissinger rod is advanced through the anterosuperior capsule of the rotator interval below the coracoacromial ligament indenting the subcutaneous tissue. A skin incision is made over the Wissinger rod to deliver it out after which the arthroscopic sheath is advanced over the rod. The Wissinger rod is removed, and the 6-mm anterosuperior cannula is pushed against the tip of the sheath into the joint by gentle screwing hand movements. The outflow tubing is attached to the anterosuperior cannula to establish directional flow of fluid. The arthroscope is reintroduced into the shoulder through the posterior cannula. The anterior cannula is moved anterior then inferior to the biceps tendon.

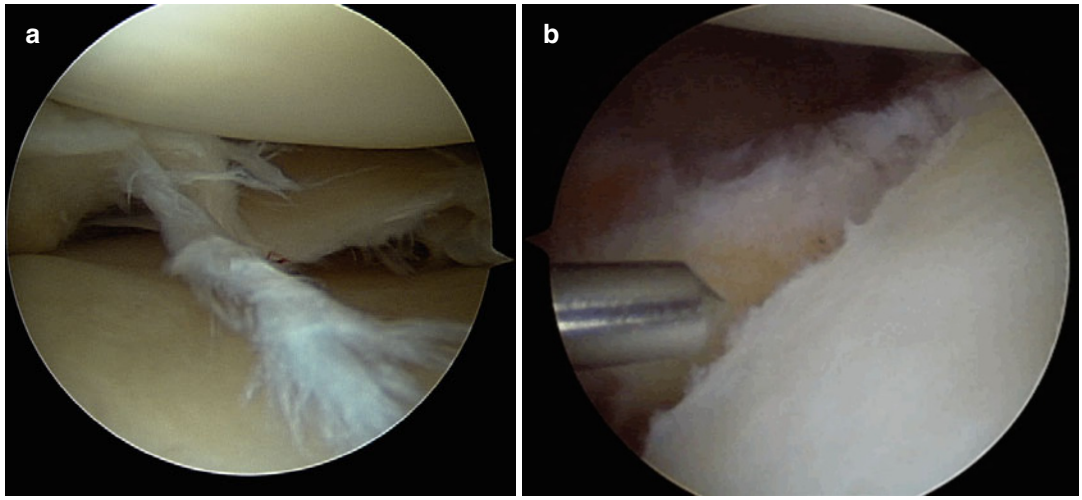

Fig. 35.1 (**a**, **b**) Anterior labral detachment (Bankart lesion). (**a**) View from the posterior portal, (**b**) view from the anterosuperior portal

A complete diagnostic examination of the glenohumeral joint is performed. Patients with a history of a traumatic anterior shoulder dislocation can have additional intra-articular injuries other than a Bankart lesion, such as a large Hill-Sachs lesion, a superior labral tear, a rotator cuff tear, or a bony Bankart lesion [10]. The diagnostic arthroscopy begins with the careful inspection of the biceps tendon and the biceps anchor [10]. The posterior glenoid and posterior band of the inferior glenohumeral ligament are examined, followed by the posterior aspect of the humeral head. The bare area of the humeral head and the insertion site of the infraspinatus tendon are examined as well as the posterolateral aspect of the humeral head to evaluate the frequently seen Hill-Sachs lesion. The arthroscope is then brought over the top of the humeral head to evaluate the supraspinatus tendon, the biceps tendon as it exits the shoulder, and the superior portion of the subscapularis tendon. The arthroscope is then drawn back medially into the glenohumeral joint, and the anterior structures are inspected. The Bankart lesion can generally be assessed while viewing from the posterior portal, but substantial medial displacement of the capsulolabral complex requires a view from the anterosuperior portal for a complete evaluation (Fig. 35.1a, b). Finally, a third anteroinferior portal, the working portal, is established above the subscapularis tendon, just lateral and distal to the coracoid, by the outside-in technique using an 18-gauge spinal needle, to introduce an additional 8.5-mm threaded cannula. Next, by using switching sticks, the arthroscope is switched from the posterior to the anterosuperior portal, and a 6.5-mm flexible cannula is passed through the posterior portal.

35.7 Glenolabral Preparation

It is imperative that the surgeon spends adequate time preparing and mobilizing the labrum-bone interface before anchor insertion and fixation [11]. Adequate mobilization ensures that the avulsed labrum and capsule will be reparable back to their anatomic insertion. An arthroscopic elevator is introduced into the joint through the anteroinferior portal while viewing from the anterosuperior portal. The elevator is positioned between the injured capsulolabral complex and the anterior glenoid. It is important to position the elevator parallel to the labrum to avoid transecting the labrum, which dramatically complicates the surgical repair [11]. The soft tissues are elevated beginning superiorly from the 3 o'clock position in a right shoulder and proceeding inferiorly to the 6 o'clock position. The dissection is continued medially along the anterior gle-

noid neck 1.5–2 cm [11]. A motorized shaver is used to remove soft tissue from the glenoid rim and neck.

35.8 Anchors and Repair

The standard arthroscopic Bankart repair typically uses three anchors placed below 3 o'clock with ideal anchor placement on the glenoid rim at a 45 angle relative to the glenoid surface 2–3 mm inside the anterior glenoid rim [11]. The authors' choice is to use either two double sutures (Lupine; DePuy Synthes, Warsaw, IN, USA) or three suture anchors (Bio Mini-Revo or Y-knot; ConMed, Largo, Fl, USA). The first anchor is placed at the 5 o'clock position in a right shoulder [10]. A targeting trochar within an anchor-specific cannula is placed through the anteroinferior portal to ensure proper anchor placement. Usually, a laser mark on the insertion device assists in determining the correct depth of insertion. The inserter is disengaged from the anchor by pulling the handle with longitudinal traction. The sutures are then passed through the inferior glenohumeral ligament and under the detached glenoid labrum with the use of a spectrum suture passer and Shuttle Relay (ConMed, Largo, Fl, USA) (Fig. 35.2). The suture limb that exits the anteroinferior cannula passing through the soft tissue will be the "post" suture down which the sliding arthroscopic knot will move. It is preferable to have the knot on the soft tissue capsulolabral side of the repair. Standard arthroscopic sliding knots are then tied to bring the detached capsulolabroligamentous complex in contact with the scapular neck and securing it to the edge of the articular surface of the glenoid to function as a bumper, thus restoring optimal conditions for concavity compression (Figs. 35.3 and 35.4). The knot is cut leaving a 3- to 4-mm

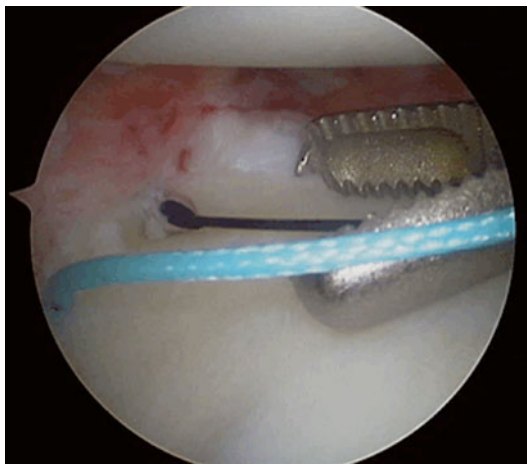

Fig. 35.2 Arthroscopic anterior Bankart repair. Surgical step showing the sutures passed through the inferior glenohumeral ligament and under the detached glenoid labrum with the use of a spectrum suture passer and Shuttle Relay (ConMed, Largo, Fl, USA)

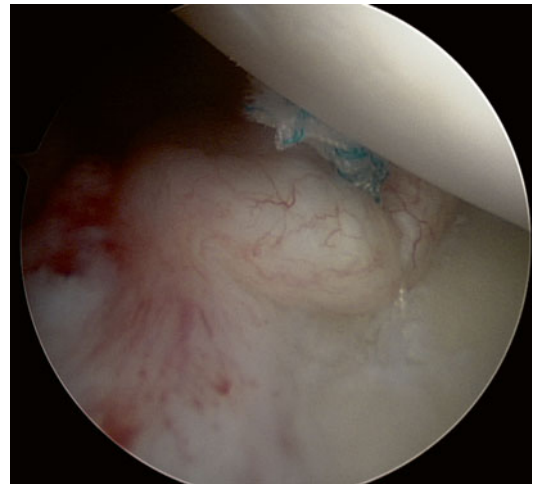

Fig. 35.3 Anterior Bankart repair: intraoperative findings showing a tied knot of a single loaded suture anchor

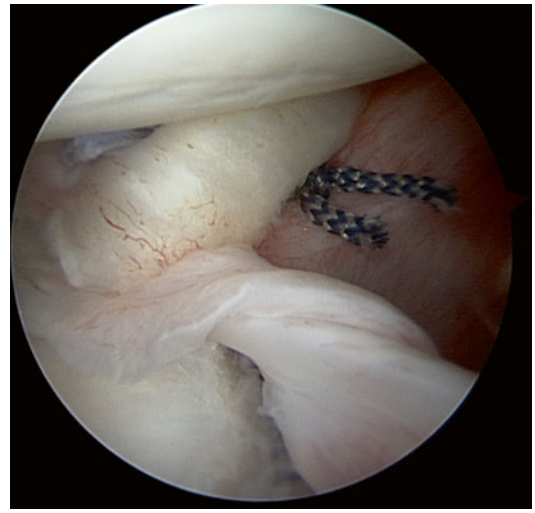

Fig. 35.4 Anterior Bankart repair: intraoperative findings showing a tied knot of a double loaded suture anchor

tail. However, if the suture does not slide easily, a reversed direction, switched-post, and multiple half-hitch knots (Revo knot) are also very effective and secure methods of tying the sutures [10]. Ligament tension is adjusted by grasping the ligament and placing it at different sites on the glenoid until the humeral head is centered on the glenoid. These steps are repeated for each subsequent anchor. Once the repair is completed, the probe is introduced through the anteroinferior cannula to evaluate the quality and tension of the repair.

35.9 Pearls and Pitfalls

- The anterosuperior portal should be made high in the rotator interval.
- The anterosuperior and anteroinferior portals should have enough skin bridge separation (2–3 cm) to avoid intra-articular crowding.
- The capsulolabral sleeve must be mobilized until it can be shifted superiorly and laterally onto the glenoid rim. The release should proceed until the muscle fibers of the underlying subscapularis are seen.
- The surgeon should be aware about the position of the axillary nerve which is closest at the 6 o'clock position on the glenoid (12.5–15 mm), which increases with abduction [11].
- A small bone cutting type of shaver (3.0–3.5 mm) is useful to prepare the anterior glenoid neck on a high-speed reverse setting, keeping in mind that this is a glenoid bone-preserving procedure [11].
- Accurate positioning of suture anchors on the glenoid with penetration at the margin of the articular surface allows recreation of the glenoid concavity during repair and avoids repairing the labrum complex too medially down the glenoid neck [11].
- Anchor placement should proceed from inferior to superior, and they should be at least 5–7 mm apart for a secure repair.
- The anchor should be assessed for security and the suture for slideability before proceeding further.
- Tension the capsulolabral structures with the arm in slight external rotation.
- The posterior labrum may not always be intact and may present as an extension of the anterior tear posteriorly. In this case, the balanced repair is performed in which suture anchors at 7 o'clock position are used to repair the labrum and plication of the capsule is done as necessary depending on the extent of posterior labral tear [11].
- Moreover, if there is significant posterior laxity and capsular volume, the balanced repair is done with either plication stitches (if posterior labrum intact) or suture anchor (if posterior labrum torn) repair after an anterior instability repair [12].

35.10 Postoperative Care and Rehabilitation [6]

Postoperatively, the shoulder is placed in a sling in 15° of abduction and neutral rotation for 3 weeks. Patients then begin assisted passive mobilization, avoiding external rotation until the fifth week. At this time, a proprioception recovery program is started. After the fifth week, patients begin active exercises in a pool and passive mobilization in external rotation, and at 8 weeks, they undergo strengthening exercises with a rubber band. Activities of daily living are permitted after 10 weeks, and general fitness training (including jogging and noncontact recreational activities) is permitted at 12 weeks. Patients are advised to avoid collision sports and high-risk activities until the sixth month.

35.11 Distinct Salient Scenarios

Although most of the patients with anterior instability without glenoid bone loss are managed optimally with abovementioned arthroscopic suture anchor stabilization technique, there are several conditions in which the associated lesions or the peculiarities of the indexed patient make the management either differ marginally or change completely.

35.12 Bankart Lesion with Hill-Sachs Fractures

Posterolateral humeral head compression fractures were first described by Hill and Sachs [13] as grooved defects and are found in 45–70 % of initial shoulder dislocations [14] and in nearly 100 % of patients with recurrent instability [15]. Defects involving less than 20 % of the humeral head have little clinical relevance, whereas larger lesions between 20 % and 40 % and especially ≥40 % are associated with significantly higher rates of recurrence [15]. Arthroscopic remplissage with anterior labrum fixation has provided good to satisfactory results in patients with anterior shoulder instability and limited glenoid bone loss [16, 17]. Most of the steps in this technique are common with abovementioned technique.

35.13 Pearls for Arthroscopic Hill-Sachs Remplissage and Anterior Bankart Repair

- The extent and location of the Hill-Sachs lesion is gauged through the anterior portal viewing from the posterior portal.
- After switching the arthroscope to the anterosuperior portal, the Hill-Sachs lesion is assessed again to establish whether it is confined to the articular surface or also involved subchondral bone [18, 19]; finally, a dynamic assessment with the arm in abduction, flexion, and external rotation allows establishing whether the humeral head engages the anterior glenoid rim [19, 20].
- The surface of the Hill-Sachs defect is prepared with a bur, removing a minimal amount of surface bone to obtain a bleeding bed.
- After precise identification of the edges and valley of the Hill-Sachs lesion, a double suture anchor (ConMed Super Revo) is placed in the defect valley to reduce the risk of joint stiffness associated with anchors placed close to the humeral head rim [19, 21].
- The cannula is withdrawn; the sutures are then passed through the lower portion of the infraspinatus tendon and the capsule and pulled out of the joint using a penetrating grasper.
- As an additional precaution against joint stiffness, the sutures are carefully passed through the capsule and the tendon close to the defect valley [19, 21].
- Finally, the posterior cannula is removed and the sutures are tied, thus filling the Hill-Sachs defect with the knots extra-articular in the subdeltoid space, fixing the infraspinatus tendon and posterior capsule to the bleeding and abraded humeral head defect [19].

35.14 Chronic Anterior Instability

In patients with chronic recurrent instability, it is very likely to get the bony lesions including glenoid erosions and Hill-Sachs defect as discussed before. With each episode of dislocation, there is ongoing plastic deformation and contracture of the capsule and labroligamentous complex, and in chronic cases, it may reach to the state of "no return" in which it would be very much difficult to bring it back to the glenoid neck. Also, the quality of this tissue would be very poor to sustain the anterior translation force even if one could secure it back to the glenoid. The authors recommend "Latarjet" surgery in this subset of patients, as there is a high risk of redislocation after arthroscopic stabilization. The decision to do so is favored by other factors like male sex, age less than 22 years, interval of more than 6 months after the first dislocation [5], associated anteroinferior glenoid bone loss, suboptimal patient compliance, and extreme sports participation. The salient steps in the technique can be briefly mentioned as below.

- Deltopectoral approach with approximately 5–6 cm anterior skin incision extending downward from the tip of the coracoid
- Lateral retraction of the cephalic vein with deltoid and developing the space between deltoid and the pectoralis major
- Identification of the coracoid and placing a Hohmann retractor above it
- Division of the clavipectoral fascia along the lateral border of the conjoined tendon
- Release of the coracoacromial ligament from the acromion and pectoralis minor from the

medial coracoid paying utmost attention not to damage the musculocutaneous nerve
- Coracoid osteotomy and decortication
- Drilling two holes in the coracoids with partial placement of lower screw (partially threaded)
- Subscapularis split and capsulotomy
- Scapular neck preparation
- Passage of the coracoid through the subscapularis split
- Precise coracoid placement on the anterior scapula and fixation with screws
- Capsular repair with the coracoacromial ligament (optional)
- Skin closure after ensuring hemostasis

35.15 Anterior Instability with Rotator Cuff Tears

Glenohumeral dislocation may cause a rotator cuff tear more commonly in older patients attributed to the changes that collagen undergoes with age [22, 23]. After a dislocation, if the shoulder is still painful and active abduction is reduced, a partial or complete rotator cuff tear should be sought. Recommended treatments in these cases are repair of the torn structures to restore shoulder stability [23], open repair of the torn subscapularis or transfer of the pectoralis major in case of complete disruption with irreparability of subscapularis [24], or a Trillat procedure without associated cuff procedures [25]. The authors have concluded in a study [26] that, although, it is impossible to establish whether a lesion of the capsulolabral complex or of the rotator cuff causes or follows a dislocation, patients with associated cuff and capsular lesions and a recent history of dislocation consistently had a lesion of the glenoid labrum or glenohumeral ligament that did not depend on their age or on the number of dislocations. Because the ligament lesion is always present, whereas lesions of the cuff are inconsistent, the capsulolabral lesion is to be considered as the main lesion in these patients and needs to be treated. The arthroscopic technique allows one to treat capsulolabral and cuff lesions in the same procedure using the posterior and anterior portals, plus a lateral portal 2 cm lateral to the lateral edge of the acromion and 1 cm anterior to the axis of the humeral bone.

35.16 SLAP Lesion with Anterior Instability

When the superior labrum separation is a normal variant, the superior glenoid is covered with smooth cartilage, and the labrum shows no evidence of trauma. However, tears within its substance, cartilage loss with exposed bone near labrum attachment, and an increase in superior labrum separation with abduction and external rotation of the arm suggest its traumatic separation which needs to be repaired anatomically after anterior stabilization. The superior glenoid bone is abraded with a power bur, and SLAP lesion is repaired with two suture anchors, one anterior and other posterior to the biceps anchor.

35.17 Humeral Avulsion of Glenohumeral Ligament (HAGL) with Anterior Instability

In HAGL lesion, the capsuloligamentous structures are avulsed and torn off the humeral head rather than at the glenoid. It's a contraindication for arthroscopic stabilization, and always an open repair should be performed.

35.18 Anterior Instability with Capsular Laxity

The shoulders with this type of instability usually don't have bony deformity in the form of Hill-Sachs defect or glenoid bone loss. However, the goal should be to achieve balanced repair with capsular plication as discussed before.

Finally, there are several more techniques for surgical stabilization of anterior instability which include open stabilization, arthroscopic stapling [27], transglenoid suture techniques [28], and Bristow-Helfet procedure of coracoid osteotomy and fixation to the anteroinferior rim of the

glenoid [29]. Although many of them have offered satisfactory results, in the contemporary practice, they either have only the historic importance or are rarely performed. Other adjunct procedures, which deserve a brief mentioning, are "thermal capsulorrhaphy" and "rotator interval closure." The former technique was performed as an adjunct to tighten the capsule for persistent capsular laxity. Unfortunately, peer-reviewed literature advocating its routine use is limited [8]. The latter procedure is performed if after repair of the labrum and inferior and middle glenohumeral ligaments, the shoulder shows persistent inferior or inferoposterior translation [8]. The authors don't find its usefulness in the management of anterior stability except in MDI or posterior instability.

35.18.1 Complications

Although arthroscopic labral repair is accepted as a safe procedure, in the literature, several complications have been ascribed to it [30]. The surgeon must be cognizant of these potential complications to avoid unsatisfactory outcomes and frustration on the patients' part. The important complications are discussed below.

35.19 Infection

It is intuitive to expect lower incidence of postoperative infection in arthroscopic anterior stabilization owing to its less invasive nature.

Bankart repair is reported to be 0.22 %, which is not substantially different compared with that in open procedures [31]. Though it is rare to find infection in deep tissues or intra-articular part, it has the potential to cause severe dysfunction of the joint. Hence, its prevention is of utmost importance, especially in patients at high risk, such as those with diabetes mellitus or atopic dermatitis [30]. Keeping low threshold of suspicion in mind, synovial fluid culture analysis should be done early. However, detecting the causative organism can be difficult sometimes. Hence, on suspicion, empiric therapy with intravenous or oral antibiotics should be started immediately. The penicillin-based or cephalosporin antibiotics should be used as the first choice because the major pathogens of infection are staphylococci including Staphylococcus aureus, coagulase-negative staphylococci, and Staphylococcus epidermidis [32]. Antibiotics can be changed according to the results of the culture and are continued until the CRP turns negative. For infections resistant to antibiotics, synovectomy and drainage are performed arthroscopically [30]. The sutures are removed, whereas the anchors are retained unless peri-anchor infection is apparent [30].

35.20 Nerve Injuries

Nerve injury is not an uncommon complication and has the potential of disabling outcomes. However, its incidence in arthroscopic Bankart repair (0.3 %) has been reported to be significantly lower than that in open procedures (2.2 %) [31].

The most commonly injured nerve is the axillary nerve [30]. Along this path, the nerve lies adjacent to the inferior capsule and is closest at the 6 o'clock position [33]. It can be injured while placing sutures at the anteroinferior and inferior positions [34] or when repairing capsular lesions, such as capsular tear or humeral avulsion of the glenohumeral ligament.

Electromyography (EMG) is performed once a patient is suspected to have iatrogenic nerve injury. The shoulder is closely monitored clinically to see any signs of reinnervation of the affected muscles. If after 6 months, there are no signs of recovery clinically or on EMG, exploration and repair is performed with or without nerve grafting.

35.21 Postoperative Stiffness

Postoperative loss of range of motion is a disabling and painful complication of arthroscopic anterior stabilization surgery, though the incidence and intensity is less as compared to the open stabilization. More often, there is a selective

loss of external rotation which can lead to functional disability [35]. This loss of motion may be the result of over tightening of the anteroinferior capsulolabral tissue or can be caused by interruption of transverse movement of the subscapularis tendon during arm rotation [35]. Ando et al. have proposed an arthroscopic treatment for this complication which is called the restoration of an anterior transverse sliding (RATS) and includes removal of scar tissue of the rotator interval and release of the subscapularis tendon from the anterior glenoid neck [35]. They reported an improvement of the external rotation ROM from 2.9° ± 4.9° to 47.9° ± 0.1° in seven patients with severe loss of external rotation after arthroscopic Bankart repair.

For the global stiffness, the treatment usually begins with physiotherapy. Local anesthetic and corticosteroid injections into the glenohumeral joint can be considered pain relief [30]. Most patients with stiffness respond to conservative treatment; however, a surgical treatment should be considered for patients who fail in a conservative treatment. In patients with severe stiffness of the shoulder even after a 6-month conservative treatment, arthroscopic capsular release can be performed [30].

35.22 Chondrolysis

Chondrolysis is characterized by rapid destruction of articular cartilage which leads to a progressive, severe, and refractory loss of shoulder comfort and function [30]. Several studies have reported association of thermal energy devices, such as radio-frequency or laser devices, in the development of chondrolysis [36–39]. Moreover, several recent articles have reported that postoperative infusion of intra-articular local anesthetic is strongly associated with chondrolysis of the glenohumeral joint [40–42]. Matsen and Papadonikolakis [42], in their analysis on all published cases of glenohumeral chondrolysis, concluded that there is a causal relationship between infusion of local anesthetic and development of glenohumeral chondrolysis. They also reported that the risk of chondrolysis in shoulders receiving intra-articular infusions via a pain pump was significantly greater with higher doses of local anesthetic. Thus, infusion of local anesthetic, especially bupivacaine, via an intra-articular pain pump should be avoided after arthroscopic surgery [30].

35.23 Osteoarthritis

It has been proven that osteoarthritis (OA) of the glenohumeral joint can develop after both conservative and surgical treatment for traumatic shoulder instability. In a long-term follow-up study, Kavaja et al. found that 50 out of 74 shoulders were diagnosed with radiographic arthrosis 13 years after arthroscopic Bankart repair [43]. However, 40 of them were classified as mild arthrosis, and their clinical and functional outcomes were relatively good. Franceschi et al. reported that the incidence of postoperative OA in patients who underwent arthroscopic Bankart repair was 21.8% (12 of 55 patients) in their study with an 8-year follow-up [44]. They also reported that the incidence of OA of the glenohumeral joint was associated with older age at first dislocation and at surgery, increased length of time from first episode to surgery, increased number of preoperative dislocations, increased length of time from initial dislocation until surgery, increased number of anchors used at surgery, and more degenerated labrum at surgery [44].

35.24 Complications Associated with Suture Anchors

The complication rate for arthroscopic labral repair surgeries in the early days using staples or bioabsorbable tacks was substantial, with a 30% rate of implant-related complications, including loosening, migration, and breakage [45, 46]. However, there is a falling trend in implant-related complication rates since the introduction of suture anchors as well as the development of various advanced arthroscopic instruments for secure insertion of the anchor in the glenoid. In

recent studies, the failure rate was reported to be 0.3 % [31]. Despite such developments, anchor failures may occur due to technical errors. In a cadaveric study, Lim et al. demonstrated that the most inferior anchors (the 5:30 and 6 o'clock positions in the right shoulder) had a high risk of perforating the inferior cortex of the glenoid when inserted via an anteroinferior portal in the lateral decubitus position [47]. Frank et al. evaluated the effect of portal placement and using a curved drill guide for the inferior suture anchor placement and found that transsubscapularis portal resulted in the lowest opposite cortex perforation compared to the straight and curved mid-glenoid portal [48]. However, there was no difference in the ultimate load to failure among the three different techniques of inferior anchor placement.

Another worrisome complication associated with suture anchors is related to the use of bioabsorbable materials, especially anchors made of poly-L-lactic acid (PLLA). Inflammatory reaction, osteolysis, and chondrolysis have been reported to be associated with the use of these anchors [30]. McCarty et al. macroscopically and microscopically investigated patients who underwent arthroscopic debridement after index surgery with PLLA anchors [49]. They found intra-articular anchor debris in >50 % of cases and chondral damage in 70 %. Microscopically, giant cell reaction, presence of polarizing crystalline material, and papillary synovitis were observed in most cases. Therefore, the use of PLLA anchors has decreased with the evolution of suture anchors, such as polyether-ether-ketone (PEEK) anchors and osteoconductive anchors. These anchors may have less influence on inflammatory reaction [50].

Symptomatic intra-articular migration of a suture anchor several weeks after placement with resultant pain and articular cartilage loss on the humeral head has been reported [51]. Rockwood et al. reported on three of eight patients with articular damage after complications from improper placement of metallic suture anchors [52]. The use of metallic hardware about the glenohumeral joint has been shown to have complications such as loosening, migration, and breakage leading to pain and arthrosis [53]. This problem led to the development of biodegradable implants for the shoulder.

Other rarely encountered complications include synovial fistula [54] and injury to the suprascapular nerve and pain due to the posterior knot after transglenoid repair [54].

35.24.1 Results and Review of Literature

The results of both the open and arthroscopic anterior stabilization procedures for anterior instability have been encouraging. Recently comparisons between open procedures and arthroscopic procedures have been reported in the literature. Green et al. reported that arthroscopic stabilization procedures decreased operating room time, blood loss, narcotic use, hospital stay, time lost from work, and complications when compared with open procedures [55]. Petrera et al. reported statistically insignificant difference between the recurrence rate with arthroscopic Bankart repair using suture anchors and that with open procedures, which were found to be 6 % and 6.7 %, respectively [56]. However, the difference was significant in studies conducted after 2002 (recurrence of 2.9 % in arthroscopic Bankart repair vs. 9.2 % in open procedures) [30]. Thus, it can be concluded that the rate of recurrent instability is decreasing with recent improvements in arthroscopic surgical techniques and devices.

Another feared issue concerning recurrent instability was the high recurrence rate in contact/collision athletes [30]. Petrera et al. compared outcomes after isolated arthroscopic Bankart repair between collision and noncollision athletes at a minimum follow-up of 24 months and reported that the rates of recurrent instability were 9 % and 0 %, respectively [57].

The results of arthroscopic anterior stabilization have been drastically improved with the innovation of the arthroscopic technique of Hill-Sachs "remplissage." This arthroscopic technique was first described by Wolf et al. [58], as a modification of the open procedure. Boileau et al.

performed this procedure in 47 of 459 shoulders and reported encouraging results with only one shoulder (2.1 %) showing recurrent instability [59]. Recent systematic reviews have described the overall recurrence rate after Hill-Sachs remplissage to be 3.4–5.4 %, without ROM restrictions [60, 61]. This technique may have a powerful stabilization effect and can be a useful augmentation with potential to reduce the rate of recurrent instability in high-risk patients; however, the recurrence rate currently varies among studies which may be attributed to differences in technique [30].

In the management of first time dislocators, Boone et al. have given their valuable inferences asserting ample evidence to consider primary stabilization as an option for treatment in the high-risk group, less than 25 years of age [5]. This is based not only on recurrences but improved quality of life outcome measures. They believed that the traditional treatment of reduction and a period of immobilization can be challenged. The authors advocated early surgical repair in young patients (15–25 years), because it has been shown to reduce their recurrence rate from 80–90 % to 3–15 % and improve overall quality of life. In patients who are aged 25–40 years, they recommended an initial trial of nonoperative management, because their risk of redislocation is much lower at 20–30 %. Their inference is supported by Owens et al. who, in their long-term follow-up study on 49 shoulders, concluded that treating young athletes with acute arthroscopic Bankart repair yields durable maintenance of shoulder function and stability and high subjective outcome scores and allows the return to a high level of activity [62].

Instability in the elderly often results from a combination of pathologies including soft tissue injury, rotator cuff tear (RCT), Bankart tear, capsular tear, glenoid fracture, and humeral fracture [63]. Failure to address all of the pathologies surgically leads to a higher incidence of recurrence. For a posterosuperior RCT and Bankart repair, an arthroscopic technique is a better option [63]. For a subscapularis avulsion and a Bankart lesion with a Hill-Sachs lesion, an open anterior approach is more suitable, depending on the degree of subscapularis tear and amount of the bony deficiency [63]. Overall, the appropriate treatment necessary in this population is likely more aggressive than the traditional teaching [26]. Addressing all of the issues surgically may lead to a higher incidence of stiffness. Therefore, there is likely no surgical procedure that works 100 % of the time in this difficult patient population. Rotator cuff repairs (RCRs) should be performed for large or massive acute or chronic RCT, specifically if there is persistent loss of function or there is an associated neuropraxic injury to the axillary nerve [63]. Often, these patients have an associated Hill-Sachs lesion, so posterosuperior cuff tears can be repaired into the lesion, which medializes the repair, accomplishing two goals: less tension on the repair and performing essentially a remplissage procedure (rendering the lesion extra-articular). In addition, early surgery should be considered when there is a reparable subscapularis tear. Neviaser at al. found in their series that 100 % of patients with recurrence had a subscapularis tear with disruption of the anterior capsule [64].

Finally, there are several factors that are associated with recurrent instability after surgical stabilization and can be classified into those caused by inappropriate patient selection and those attributable to surgical error [65]. However, athletes playing contact sports may often re-injure themselves with sufficient force to redislocate their shoulder irrespective of the quality of their previous repair [65]. The most common cause of recurrent instability is a failure to recognize a multidirectional or voluntary element in a patient thought to have anterior instability. The most common reason for surgical error is inadequate treatment of all the constituent components of the instability at the time of surgery [66]. Abnormalities commonly encountered at re-exploration after failed arthroscopic or open repair include an unhealed Bankart lesion [67], humeral avulsion of the glenohumeral ligaments [68, 69], extensive glenoid erosion or deficiency from a bony Bankart lesion [70, 71], excessive capsular laxity [67], a defect of the rotator interval [72], an engaging Hill-Sachs lesion, and reduced retroversion of the head of the humerus or excessive retroversion of the glenoid

cavity [73]. Several additional factors have been associated with recurrent instability after arthroscopic stabilization including a younger age at surgery [6, 74], male sex [6], an interval of more than 6 months between the first dislocation and surgery [6], noncompliance with postoperative immobilization [75], early return to contact sport [76], absence or deficiency of the capsulolabral complex and poor inferior glenohumeral ligaments [77], and multiple episodes of instability before stabilization [78].

Conclusion

The successful management of anterior shoulder instability without glenoid bone loss can be a significant challenge and is predicated on the accurate assessment and treatment of the offending pathologies. It is imperative for the surgeon to have an understanding of the pathoanatomy of recurrent anterior shoulder instability and must be prepared to address associated pathologies beyond the Bankart lesions, including Hill- Sachs defects, capsular laxity, rotator cuff lesions, and SLAP lesions. Keeping the importance of appropriate patient selection in mind, the thorough understanding of the principles of arthroscopic instability repair would aid in the comprehensive approach to patients with anterior shoulder instability with the optimism to have satisfactory results without complications.

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Anterior Traumatic Instability with Glenoid Bone Loss

36

Ettore Taverna and Riccardo D'Ambrosi

36.1 Indication

36.1.1 Decision Algorithm

The algorithm of treatment depends on many factors, but the size and type (fragment or erosion) of the glenoid bone deficit is the priority. If a mobile bone fragment is associated with a labral lesion, then there is a possibility to perform an arthroscopic repair, despite the size of the fragment. If there is a bone loss, there are no guidelines. If the bone deficit is greater than 20 % with respect to the healthy contralateral glenoid, a bone grafting procedure open or arthroscopic is recommended by most authors to fill the defect and to reconstruct the anatomic glenoid arch [1–4]. If the missing area of the glenoid is less than 10 % and there are no soft tissue alterations, an arthroscopic reconstruction of soft tissue is certainly a viable treatment option to restore the stability of the joint. If the bone loss is between 10 % and 20 %, other factors should be considered, such as the presence of a Hill-Sachs lesion that could represent an indication for a bone procedure (Table 36.1).

In addition to a classification of the possible presence of bone defects preoperatively, other risk factors should be considered that may preclude the arthroscopic stabilization. If the instability severity index score (ISIS) is higher than six points, a reconstruction of the soft tissues isolated may not be sufficient for the stability of the shoulder, especially in the long-term follow-up [5].

In conclusion, the preoperative evaluation of the bone loss, the ISIS scoring system, clinical examination, and medical history of the patient can help the surgeon to better select patients who may benefit more from an arthroscopic stabilization with soft tissue repair with anchors and sutures.

Table 36.1 Decision algorithm for the treatment of anterior traumatic instability with glenoid bone loss

Decision algorithm		
Glenoid bone loss	Surgical procedure	
>20 %	Bone graft	
<10 %	Capsulolabral repair	
>10 % <20 %	Hill-Sachs lesion	Bone graft
	ISIS score >6	Bone graft
	No Hill-Sachs – ISIS score <6	Capsulolabral repair

E. Taverna, MD
Upper Limb Unit, Department of Surgery, OBV Mendrisio, Mendrisio, Switzerland

U.O. Chirurgia della Spalla II, Istituto Ortopedico Galeazzi, Milan, Italy

R. D'Ambrosi, MD (✉)
U.O. Chirurgia della Spalla II, Istituto Ortopedico Galeazzi, Milan, Italy

Università degli Studi di Milano, Milan, Italy
e-mail: riccardo.dambrosi@hotmail.it

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36.1.2 Indications for Surgery

Patients who suffer a shoulder dislocation as a result of major trauma and who have no ligamentous laxity benefit most from surgical treatment [6, 7]. Recurrence of instability is the main complication after anterior stabilization. Currently, most of the surgeons perform arthroscopic stabilization of the soft tissue with anchors and suture due to more reproducible results. However, even after the recent technical developments, there is still a rate of recurrence of 5–20 % [8, 9]. The best way is to identify preoperative patients whose risk factors preclude arthroscopic stabilization. Literature reports numerous prognostic factors. Athletes who practice contact sports have a higher incidence of recurrence after a classic arthroscopic stabilization [10]. Eventually, patients with significant glenoid bone loss, due to the unacceptably high risk of recurrent dislocations and subluxations after arthroscopic repair of soft tissue, are candidates for arthroscopic procedures with bone graft.

36.2 Techniques

36.2.1 Arthroscopic Latarjet

The stabilization mechanism of this process is threefold:

- Increase in the glenoid surface
- Muscle tendinous hammock effect created by conjoined tendon passing on the bottom of the subscapularis with its tensioning, thus creating a dynamic tension in abduction and external rotation
- Suture of the inferior glenohumeral ligament to the coracoacromial ligament still attached on the coracoid, strengthening its stability

Due to the better arthroscopic vision of the joint, the positioning of the coracoid may have a perfect alignment on the glenoid surface and prevent the overlap of the graft in the joint and therefore a premature osteoarthritis [11].

36.2.2 Surgical Technique [11]

Patient is placed in a beach chair position. A diagnostic arthroscopy is initially performed to confirm the expected pathologic abnormalities and to identify any associated lesions. The anterior labrum, capsule, middle glenohumeral ligament, and anterior portion of the inferior glenohumeral ligament between the 2-o'clock and 5-o'clock positions are resected. The coracoacromial ligament and pectoralis minor are both detached. The coracoid is cleared of soft tissues circumferentially to its base while protecting the attachment of the conjoint tendon at the coracoid tip. Through a portal superior to the coracoid, two holes are drilled and tapped over guidewires. A "top-hat" washer is inserted into each hole, again over a guidewire. After a circumferential stress riser is created at the base of the coracoid, the osteotomy is completed by use of a curved osteotome. The surgeon splits the subscapularis at the junction of its inferior third and superior two-thirds. The split is completed medially via blunt dissection with a trocar and external rotation of the arm. The anterior glenoid face is then prepared. The coracoid is retrieved by use of the double-barrel cannula and long cannulated holding screws that engage the previously placed top hats. The inferior surface of the coracoid is decorticated with a bur, creating an even, flat surface to match the anterior glenoid. The coracoid is then manipulated via the double-barrel cannula, through the subscapularis split and onto the glenoid face between the 2-o'clock and 5-o'clock positions (previously marked). Long guidewires are inserted through the cannulated holding screws. Once graft positioning is verified and found to be acceptable, a 3.2-mm cannulated drill is used to predrill each hole before insertion of both 3.5-mm cannulated screws, beginning with the inferior screw. The long guidewires are removed posteriorly before removal of the double-barrel cannula anteriorly. Graft position is verified, and any prominence was addressed with a bur. The subscapularis sling effect could be observed immediately.

36.2.3 Indications

- Anterior glenoid bone loss
- Ligamentous tissues of poor quality
- Revision surgery
- Patients involved in extreme sports

36.2.4 Arthroscopic Bristow-Latarjet

The arthroscopic Bristow-Latarjet procedure was described for the first time by Boileau [12].

The effectiveness of the procedure is linked to a "triple lock":

- The effect of the bone block by the coracoid that increases the extension of the glenoid surface
- The sling effect caused by the passage of the conjoined tendon through the subscapularis
- The reproduction of the glenoid concavity that occurs due to labrum repair

36.2.5 Surgical Technique [12]

The patient is placed in a beach chair position. Shoulder arthroscopy is performed with a standard posterior and anterosuperior portal. The shoulder joint is visually assessed for lesions consistent with anterior instability. The scope is placed in the anterior subdeltoid space. An anterolateral portal located 2 cm lateral to the anterosuperior portal is established. The coracoid process and the conjoined tendon insertion are identified, and fibrous tissue just above the subscapularis tendon is removed. The coracoacromial ligament insertion and the pectoralis minor insertion are partially divided. A coracoid fragment measuring 15 mm in length is then removed. The bone fragment is then brought outside the incision for preparation. A resorbable suture is passed through a drill hole in the coracoid fragment and through the coracobiceps tendon. Once the coracoid fragment is prepared, an arthroscopic 8-mm cannula is inserted in the anterosuperior portal, passing above the subscapularis in the rotator interval. An arthroscopic Bankart repair is then performed. Under arthroscopy, the subscapularis tendon is retracted inferiorly, exposing the anterior glenoid neck, while the arm is internally rotated to relax the subscapularis. Socket placement is assessed, remaining above the 3-o'clock position on the glenoid and 10 mm medial to the glenoid articular surface. The glenoid neck is penetrated with a sharp-tipped awl, which prevents skiving or sliding of the guidewire along the cortical bone of the glenoid neck when drilling. A guidewire is then placed in the pilot hole and oriented parallel to the glenoid articular surface. A drill guide is used to perform this procedure safely and accurately. The guidewire is drilled until it just penetrates the posterior cortex of the glenoid. The guidewire is then overdrilled with a 10-mm cannulated reamer to a depth of 15 mm. The reamer and guidewire are then removed. A Beath pin pull-through technique is used for coracoid placement. The Beath pin is placed into the glenoid socket and the previous hole created by the guidewire and is recovered behind the shoulder. Both ends of the suture placed previously through the coracoid fragment and the coracobiceps tendon are passed through the eyelet of the Beath pin and then recovered behind the shoulder. Progressive traction on the suture makes it possible to pull the coracoid fragment into the glenoid socket. Before the entire coracoid fragment enters the glenoid socket, a flexible guidewire for the interference screw is inserted to prevent screw divergence. The coracoid graft is then pulled inside the glenoid socket by traction on the posterior suture. The graft is then fixed in the hole by use of a 7×15-mm bioabsorbable interference screw, inserted over the flexible guidewire.

36.2.6 Indications

- Anteroinferior glenoid bone loss
- Ligamentous tissues of poor quality
- Revision surgery

36.2.7 Arthroscopic Bone Graft Procedure

The arthroscopic bone block technique has been described originally by Taverna [13] and has been recently developed by Taverna et al. [14].

The new technique does not provide for the use of the screws, but the bone graft is fixed with EndoButton. The technique combines the Bankart repair with the transfer of the graft, harvested from the iliac crest, which is inserted through the cannula in the rotator interval and fixed on the glenoid surface. The effectiveness of this procedure is related to the effect of the bone block produced by the tricortical graft, which increases the area of the glenoid and the reproduction of the glenoid concavity produced by the capsule-labral plastic. Intraoperatively, despite a good selection of the patient, if we assess pathological soft tissue that contraindicates the bone block procedure, we can opt for an arthroscopically assisted Latarjet. The purpose of this procedure is to restore the normal anatomy in the unstable shoulder.

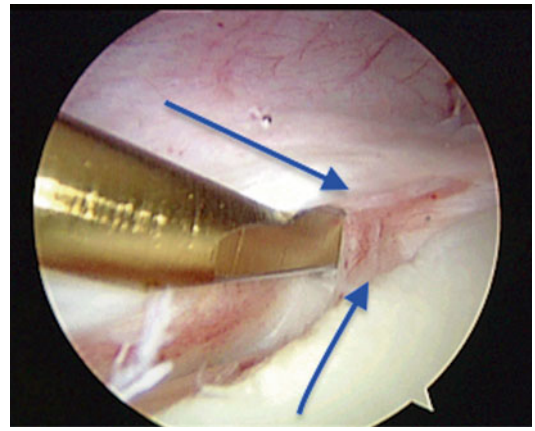

Fig. 36.1 Arthroscopic view from posterior portal. The labrum and capsule are elevated, and the anterior glenoid rim is decorticated to create a flat surface to accommodate the graft

36.2.8 Surgical Technique [14]

The patient is placed in the beach chair position. A standard posterior portal is created. Viewing from the posterior portal, an anterosuperior portal and midglenoid portal are created. The labrum is detached and all soft tissues are removed from the anterior glenoid neck. Then, the anterior glenoid rim is further decorticated and flattened with a motorized burr to create a flat and bleeding bony surface (Fig. 36.1). A spinal needle is inserted from posterior to anterior along, and perfectly parallel to, the face of the glenoid and centered on the anterior glenoid bone defect. A more posteromedial portal is made to provide access to the glenoid guide. The hook end of the glenoid guide is inserted through the specific portal. The hook is passed along the glenoid parallel to the glenoid face to avoid damaging the articular surface, and then, it is passed over the anterior edge. Then, the guide is rotated to capture the anterior edge of the glenoid under the hook. The hook should be placed at the center of the anterior glenoid defect. A bullet is placed in the inferior hole of the guide. A small skin incision is made, and the bullet is advanced until the ratchet teeth of the bullet is aligned with the screws adjacent to the guide handle. The process is repeated for the superior bullet. A 2.8-mm sleeved drill is placed in each bullet and advanced under power until exiting from the anterior aspect of the glenoid. The drills are placed 5 mm on the center below the cortical edge of the glenoid face, parallel to one another and 10 mm apart. The inner drill is removed, leaving the cannulated outer sleeve. Once drilling is completed, the bullets can be removed by rotating each bullet. The guide can be removed at this stage. Flexible looped guidewires are then introduced into the joint by passing one wire through each sleeve posterior to anterior. Each guidewire is retrieved using a loop grasper. The wires are separated and stored. The drill sleeves should be removed after this step is completed. The tricortical bone graft is harvested from the ipsilateral anterior iliac crest measuring 20 mm×8 mm×8 mm. Two 2.8-mm drill holes are made. The drill enters through the cortex and exits the cancellous side of the bone block. The holes created correspond to the distance of the cannulated drill sleeves previously placed in the glenoid neck (Fig. 36.2).

Each looped guidewire is passed through the prepared bone block and exits on the cortical side. The bone block is oriented so that the cancellous surface is facing the anterior neck of the glenoid. The anterior implant is passed with the preassembled suture through the end of the

looped guidewire with a classic sliding knot. This can be achieved by passing the lead suture through the looped guidewire and passing the implant through the lead suture. The bone block is slid toward the end of the guidewires to lodge the implants. Anterior round EndoButtons are advanced until they lie flat on the bone block. Sutures should be taut to allow smooth movement down the cannula. The bone block is tipped to be inserted into the 10-mm cannula, and care is taken to ensure that the superior end of the bone block enters the cannula first. The bone block is advanced by pulling the guidewires out posteriorly. Slight tension should be maintained on the sutures throughout this step. The sutures should advance the implant until the bone block sits flush on the anterior neck of the glenoid, with each implant's lead suture exiting the skin posteriorly. The posterior implants are placed on the transporter by advancing the instrument through the eyelet of a posterior round EndoButton. The suture is passed through the transporter. The transporter is retracted to allow the suture to pass through the eyelet of the posterior round EndoButton. The same steps must be performed for the second eyelet with the other side of the suture. The posterior round EndoButtons are advanced until they sit flush against the posterior face of the glenoid. The knot pusher is used to secure the posterior round EndoButtons. The knot pusher will provide tactile feedback when the posterior round EndoButtons are properly seated.

The side of the suture that was cut with the remaining lead suture tails will serve as a post. With the post in hand, we create a figure of four by placing the loop over the post. Then, we bring the loop underneath the post. The loop is opened at the end of the thread. Then, we place the post through the open loop created previously. Finally, we build the knot behind the posterior implant by pulling tight on the loop. Care must be taken to ensure that the knot is fully taut before pulling the post and advancing the posterior implant.

We advance the Nice knot to the face of the posterior round EndoButton. At this point, we use a suture tensioning device to secure the implant and to provide strong compression of the graft on the anterior glenoid neck. Once the implant has been tensioned, we secure the posterior knots with half hitches, and we cut the remaining sutures using a blind knot cutter (Fig. 36.3).

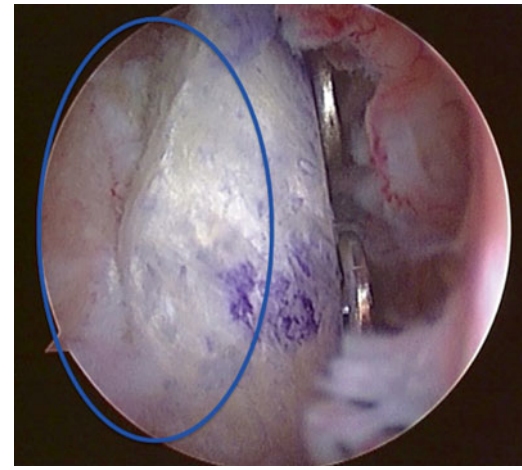

Fig. 36.2 The bone block is perfectly flush with the anterior glenoid rim

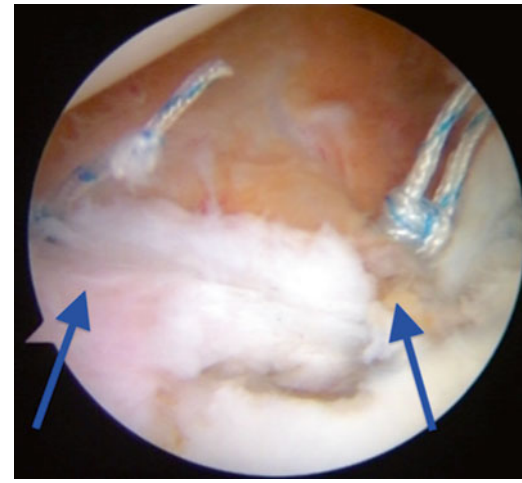

Fig. 36.3 The anterior labrum and capsule are repaired to the glenoid rim with suture anchors and a standard Bankart repair technique

The anterior labrum, capsule, and ligaments are repaired to the glenoid rim with suture anchors and a standard arthroscopic soft tissue repair technique (Fig. 36.4).

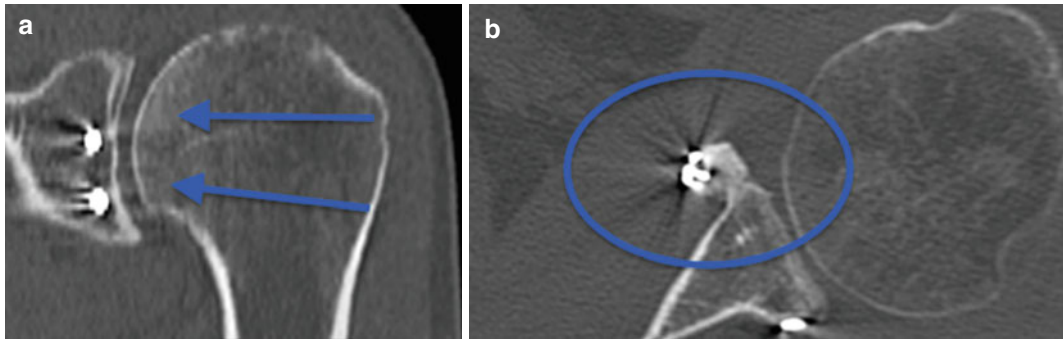

Fig. 36.4 Computed tomography images showing bone graft healing and remodeling after 6 months: (**a**) axial view and (**b**) coronal view

Table 36.2 Indications for arthroscopic bone graft procedure

Indications for arthroscopic bone block procedure
Isolated anterior glenoid bone loss >20 %
Anterior glenoid bone loss <20 % with associated Bankart lesion
Anterior glenoid bone loss >10 % <20 % with ISIS score 3–6 pts
First episode of dislocation is not more than 3 years before
Not more than 5 episodes of dislocation

36.2.9 Indications (Table 36.2)

- Anteroinferior glenoid bone defect
- Revision surgery
- Patients involved in extreme sports
- Bony augmentation of soft tissue repair in patients with ISIS score higher than 3

36.2.10 Rehabilitation Protocol

Rehabilitation protocol is the same in the three arthroscopic surgical procedures with bone graft. After surgery, the shoulder is immobilized in a 10° abduction brace for 4 weeks. There are no limitations regarding passive movement after immobilization, and patients are subsequently allowed to regain full elevation and external rotation. After complete healing of the wound, pool exercises and return to work activities are authorized. Progressive stretching exercises are started after 6–8 weeks. Return to contact sports and overhead mobility is generally allowed 4–6 months after surgery [15].

Table 36.3 Complications related to surgical procedure for anterior traumatic instability with glenoid bone loss

Complications	
Intraoperative	Postoperative
1. Graft-related complications	1. Immediate post-op
Malpositioning	
(a) Too high	(a) Hematoma
(b) Too low	(b) Subcutaneous swelling
(c) Too medial	2. Delayed postoperative
(d) Too lateral	(a) Infection
2. Graft fracture	(b) Neuropraxias
3. Nerve injury	(c) Brachial plexopathy
(a) Suprascapular nerve	3. Long-term complications
(b) Axillary nerve	(a) Nonunion
(c) Musculocutaneous nerve	(b) Osteolysis
(d) Vascular injury	(c) Recurrent instability
	(d) Arthritis

36.3 Complications

The three surgical techniques have some common complications, which can be divided into intra- or postoperative complications (Table 36.3).

36.4 Results Literature Review

36.4.1 Arthroscopic Latarjet

Lafosse, for first, in 2007 reports the preliminary results in 44 patients [11]. No complications from neurovascular injury or infection were found, reporting excellent clinical results. Subsequently, the same author shows clinical and radiographic results on 100 shoulders [16]. Eighty percent of patients described their result as excellent and 18 % as good, and only 2 % of patients were disappointed with their outcome. All patients returned to work at a mean of 2 months and returned to sport at 10 weeks. Radiographic evaluations show that 11 % progressed one stage only in osteoarthritis. The graft positioning, evaluated with CT scanning, was flush with the glenoid in 80 % of cases, medially placed in 8 %, and there was a lateral overhang in 12 % of patients. Vertical positioning was perfect (3–5 o'clock) in 78 % of cases, too high in 7 %, and too low in 5 %. Screw angle, in relation to the glenoid face, was on average 29°. Perioperative complications included two hematomas, one intraoperative fracture of the graft, and one transient musculocutaneous nerve palsy that fully recovered. Late complications included four cases of coracoid nonunion, and of these four cases, two had originally undergone coracoid fixation using just one screw. A further three shoulders were found to have lysis around the screws leading to prominence. In total, four patients required late arthroscopic screw removal. At 26 months, 35 patients were available for review, and on average, patients had lost 18° external rotation as compared with the opposite shoulder. There were no cases of recurrent dislocation. So the author concludes that the arthroscopic Latarjet technique has shown excellent results at short- to midterm follow-up, with minimal complications and good graft positioning. Recently Dumont evaluated the rate of recurrent instability and patient outcomes at minimum follow-up of 5 years after stabilization performed with the arthroscopic Latarjet procedure [17]. A total of 62 of 87 patients were contacted for follow-up. Mean follow-up time was 76.4 months. No patients reported a recurrent dislocation and only one patient reported a subluxations. Thus, one patient (1.59 %) had recurrent instability after the procedure. The study shows that the rate of recurrent instability after arthroscopic Latarjet procedure is low in this series of patients with a minimum 5-year follow-up and patient outcomes are good. Recently, a study has evaluated graft position and fusion rate in a patient who has undergone arthroscopic Latarjet procedure [18]. Nineteen consecutive patients were evaluated with CT scan performed 3 months postoperatively included an analysis of the fusion and the position of the coracoid bone graft using a validated method. 02:30–04:20 h was considered an ideal positioning in the sagittal view. In the axial view, the positioning was considered as flush, congruent, medial, too medial, or lateral. At the final follow-up, the fusion rate was 78 %. Coracoid grafts were positioned 01:52–4:04 H. In the axial view, 32 % of the grafts positioning were considered as flush, 38 % as congruent, 30 % as medial, and 6 % too medial. No lateral position was noted. Two complications occurred, one graft fracture during screwing requiring opening conversion and an early case of osteolysis in a medial-positioned graft.

36.4.2 Arthroscopic Bristow-Latarjet

In 2010 Boileau treated 47 patients with glenoid bone loss and capsular deficiency with arthroscopic Bristow-Latarjet technique [12]. The procedure was performed entirely arthroscopically in 41 of 47 patients (88 %); a conversion to open surgery was needed in 6 patients (12 %). The axillary nerve was identified in all cases, and no neurologic injuries were observed. No patient had any recurrence of instability at the most recent follow-up (mean, 16 months). The mean Rowe score was 88, and the mean Walch-Duplay score was 87.6. The subjective shoulder value was 87.5 %. The bone block was subequatorial in 98 % of the cases (46 of 47) and flush to the glenoid surface in 92 % (43 of 47); it was too lateral in one patient (2 %) and too medial (>5 mm) in three (6 %). There was

one bone block fracture and seven migrations. This study shows that arthroscopic Bristow-Latarjet-Bankart procedure is reproducible and safe and allows restoration of shoulder stability in patients with glenoid bone loss and capsular deficiency, as well as in the case of failed capsulolabral repair. The same author, in a recent study, evaluated 79 patients with recurrent anterior instability and bone loss of more than 20 % of the glenoid underwent arthroscopic Bristow-Latarjet-Bankart repair; 70 patients were available at a mean follow-up of 35 months [19]. At latest follow-up, 69 of 70 (98 %) patients had a stable shoulder, external rotation with arm at the side was on average 9° less than the nonoperated side, and 58 patients (83 %) returned to sports at preinjury level. On latest radiographs, 64 patients (91 %) had no osteoarthritis, and bone block positioning was accurate, with 63 grafts (90 %) place below the equator and 65 (93 %) flush to the glenoid surface. The coracoid graft healed in 51 cases (73 %), it failed to unite in 14 (20 %), and graft osteolysis was seen in five (7 %). Bone block nonunion/migration did not compromise shoulder stability but was associated with persistent apprehension and less return to sports. The authors concluded that the arthroscopic Bristow-Latarjet procedure combined with Bankart repair for anterior instability with severe glenoid bone loss restored shoulder stability, maintained ROM, allowed return to sports at preinjury level, and had a low likelihood of arthritis. Adequate healing of the transferred coracoid process to the glenoid neck is an important factor for avoiding persistent anterior apprehension.

36.4.3 Arthroscopic Bone Graft Procedure

The authors started to perform this technique approximately 18 months ago, which turns out to be the longer follow-up. Fifteen patients were treated, and none of them reported recurrence of instability, shoulder pain, or stiffness. Postoperative imaging does not show resorption of the bone block. The recovery of function and patient satisfaction were achieved in all cases treated. Of course we need a longer follow-up and a greater number of patients for a clinical evaluation of the procedure.

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Posterior Shoulder Instability

37

Ladislav Kovacic, Lennard Funk, and Pascal Gleyze

37.1 Introduction

Posterior shoulder instability has been shown more recently to be more common than previously thought [1, 2]. It can be challenging to diagnose and even more challenging to treat. Patients typically present with a variety of symptoms. The signs of instability are often nonspecific, and complete dislocation does not always occur. Classification and terminology are difficult as we have to distinct between unidirectional and multidirectional instability, instability and laxity, subluxation, or luxation caused by involuntary and voluntary muscle control. Recently, pathomechanics of shoulder instability is much better understood. Many structural abnormalities are recognized and can be properly addressed with surgical treatment. When conservative treatment fails, surgical treatment is valuable option if proper mechanical factors are modified with surgical procedure.

L. Kovacic, MD (✉)
Department of Traumatology,
University Medical Centre Ljubljana,
Zaloska cesta 2, Ljubljana 1000, Slovenija
e-mail: ladislav.kovacic@gmail.com

L. Funk, BSc, MSc, FRCSOrth, FFSEM
Wrightington Hospital, Lancashire, UK

University of Salford, Lancashire, UK
e-mail: lenfunk@shoulderdoc.co.uk

P. Gleyze, MD
Albert Schweitzer Hospital, Colmar F68000, France

French National Academy of Surgery,
Colmar, France
e-mail: pascal.gleyze@orange.fr

37.2 From the Concept to Reality

Hippocrates was the first who described reduction of posterior dislocation. Sir Astley Cooper described a posterior dislocation in a patient with seizure in the nineteenth century, and French surgeon Malgaigne was the first who described a series of 37 patients with posterior dislocation in 1855. This was before the advent of radiology.

Rowe and Yee were the first who described posterior shoulder instability [3]. During the twentieth century, the results of surgical treatment of posterior shoulder instability varied as the techniques designed to correct it. In 1984, Hawkins et al. reported a 50 % failure rate after a variety of different posterior stabilization procedures for recurrent posterior instability of the shoulder [4]. Tibone reported failure in 40 % of athletes treated with staple capsulorrhaphy [5]. The problem was that until recently, the pathomechanics and role of surgery for pure posterior shoulder instability have been poorly understood. In the first studies, the patient population was heterogeneous, including patients with multidirectional and inferior shoulder instability, as well as posterior instability [6].

Today we know that there is no single lesion responsible for posterior instability. In addition,

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many patients with multidirectional instability have a primary posterior component. Until recently, diagnosis and treatment of posterior shoulder instability was difficult because of the lack of differentiation between unidirectional and multidirectional conditions; traumatic, atraumatic, and microtraumatic causes; dislocations and subluxations; and voluntary and involuntary instability.

Posterior shoulder instability can have three different origins: traumatic, atraumatic, and cumulative microtrauma.

Repetitive microtrauma to the posterior shoulder complex is the most frequent cause of posterior shoulder instability. Patients are usually involved in sports activities with loading of the shoulder in front of the body. In these activities, the shoulder is placed in flexion, adduction, and internal rotation. Posterior load on the structures results in stretch of the posterior band of the IGHL and injury to the posterior labrum. The condition is often associated with a dynamic dysfunction of the shoulder kinematics or capsular laxity.

Traumatic instability typically follows a history of traumatic event causing dislocation or subluxation. As a consequence, patients after such an injury may develop recurrent episodes of posterior instability.

Atraumatic posterior dislocation is uncommon. Patients have no history of true dislocations. Condition is associated with generalized ligamentous laxity. Symptoms, which are pain and a sensation of instability in a young adult, are initially present only in higher demand activities and provocative positions. Over time, there is progression of symptoms leading to instability during activities of daily living.

It is important to recognize tears to the labrum after acute trauma or repetitive microtrauma. Patients with labral pathology yield good results with surgical treatment [7–10]. A Kim lesion may develop after cumulative microtrauma. In this model, there is cumulative posterior rim loading secondary to persistent shoulder subluxation or microtrauma. Pathologic process further leads to loss of chondrolabral containment and subsequent development of posterior labral marginal cracks or partial avulsions of the glenoid labrum [11].

37.3 Biomechanics

The unique balance between high mobility and low stability of the glenohumeral joint is achieved by numerous static and dynamic restraints that maintain the stability of the joint and allow large range of motion. There are some specific anatomical components of posterior shoulder stability.

37.3.1 Static Stabilizers

Glenoid Bony Abnormalities Abnormalities in glenoid shape and version were found in some patients with posterior shoulder instability. Glenoid hypoplasia, excessive glenoid retroversion, posterior glenoid rim deficiency, or loss of chondrolabral containment can all be a cause of posterior instability [12]. Excessive retroversion of the glenoid is defined as an angle of more than −7° in the sagittal plane [13]. In one study, average glenoid retroversion in patients with posterior shoulder instability (−10°) was compared to a control group (−4°) [14]. It was also shown that increased retroversion is mainly observed at the inferior part of the glenoid [15]. However, even with CT, it is difficult to accurately measure glenoid version. With rotation of the scapula, the axial plane varies and thus the glenoid version from these cuts [16]. In addition, it has not been shown whether changes in glenoid bony shape and version precede or follow the development of posterior instability.

Fracture of the posteroinferior rim of the glenoid, called reversed bony Bankart lesion, may occur after posterior glenohumeral dislocation, similar to anterior bony Bankart lesion after anterior dislocation (Fig. 37.1). Malunion of the bony fragment with medialization can be a cause for posttraumatic posterior shoulder instability [17].

After posterior humeral dislocation, impression fracture of the anteromedial humeral head, called reversed Hill-Sachs lesion, may occur. The size of reversed Hill-Sachs lesion may vary. It can be a cause of engaging and recurrent posterior instability.

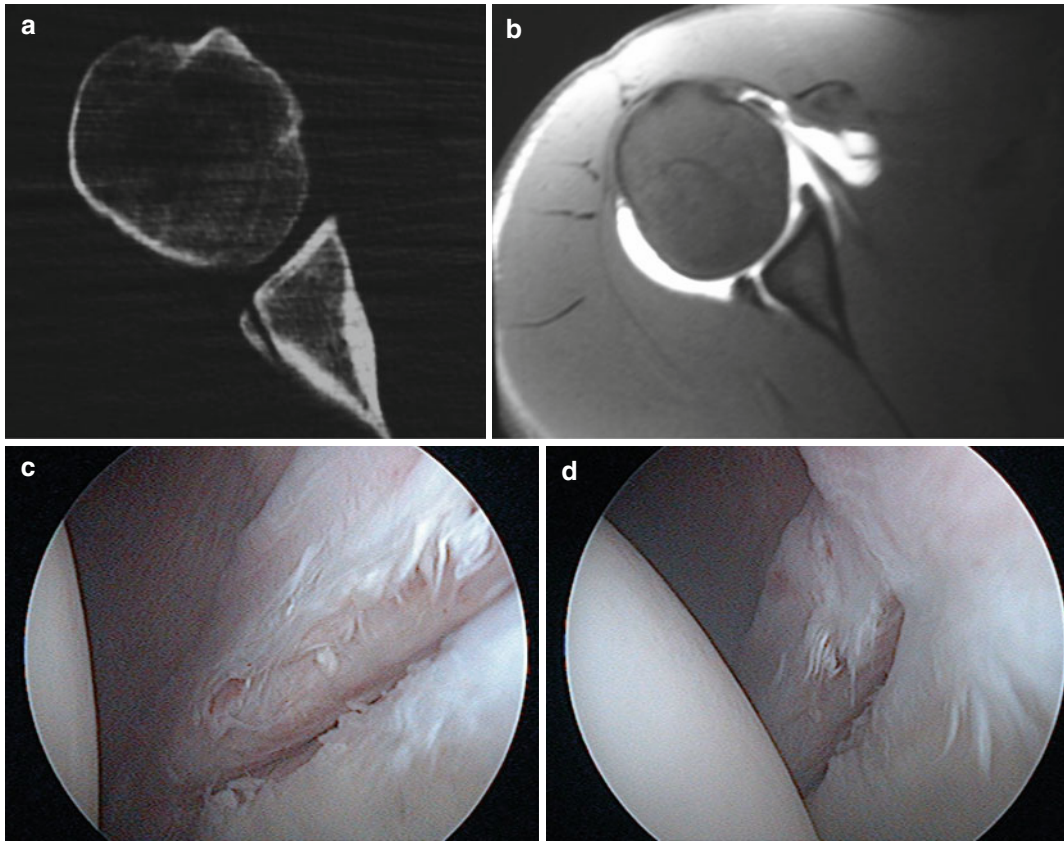

Fig. 37.1 Fracture of the posteroinferior rim of the glenoid – reversed bony Bankart lesion as seen on CT scan (**a**), MRI arthrogram (**b**), and arthroscopy (**c**, **d**)

Capsule and Rotator Interval Unlike the thicker ligamentous composition of the anterior structures, the posterior capsule is relatively thin (Fig. 37.2). Ligamentous components are less clearly defined [18]. Posterior thickening of the capsule contains the posterior band of the inferior glenohumeral ligament (PIGHL). It is the primary capsuloligamentous restraints to posterior translation at higher degrees of elevation and internal rotation. In this provocative posterior loading position, PIGHL is in anteroposterior orientation, providing resistance to posterior subluxation [19]. However, transection studies by Harryman et al. have demonstrated that if, in isolation, the posterior capsule was completely incised, the glenohumeral joint did not dislocate posteriorly. For dislocation to occur in the flexed, adducted, and internally rotated shoulder, the rotator cuff interval had to be incised in addition to the posterior capsule. Incision of the rotator interval capsule increases posterior translation by 50 % and inferior translation by 100 %. These findings suggest marked overlap in magnitude and direction of the various capsular regions to the overall instability pattern [20]. The posterior capsule may be torn in the midcapsule or at its humeral attachment. An avulsion of the posterior IGHL from its attachment on the humerus is called reverse humeral avulsion of the glenohumeral ligament (RHAGL) (Fig. 37.3).

Labrum The glenoid labrum acts as a static stabilizer by increasing concavity-compression mechanism of the glenohumeral joint. Labrum deepens the glenoid concavity, reduces glenohumeral translation, and serves as an anchor point for the capsuloligamentous structures. Labral excision decreases the depth of the glenoid by

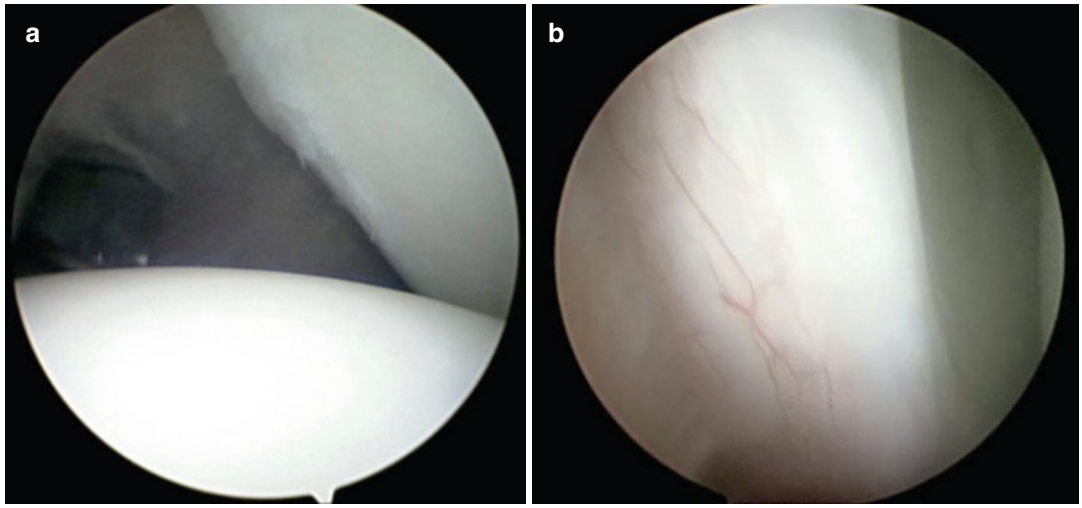

Fig. 37.2 Posterior capsule on arthroscopic view from anterior (**a**) and posterior (**b**) viewing portal

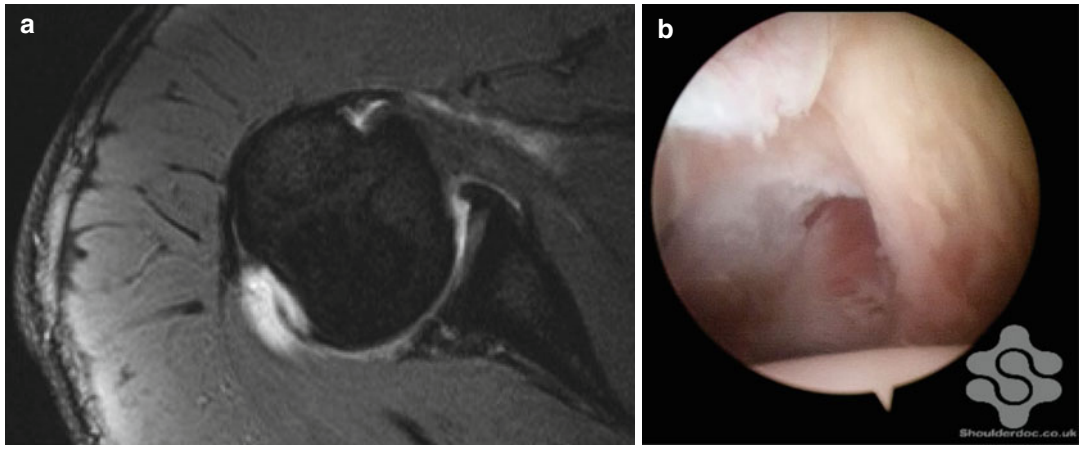

Fig. 37.3 Reverse humeral avulsion of the glenohumeral ligament (RHAGL) on MRI arthrogram (**a**) and arthroscopy (**b**)

50 % and reduces resistance by 20 % [21]. In patients with recurrent posterior instability, loss of chondrolabral containment has been demonstrated, which results in both an increase in glenoid retroversion and a loss of posteroinferior labral height [12]. Principle of posterior instability is much different from anterior instability because the posterior capsule and PIGHL are much less robust and are not able to sustain so much tensile force than the anterior capsule. The significance of reconstructing the glenolabral depth with a capsulolabral repair in establishing structural stability has been well described [22].

The importance of the posterior labrum in posterior instability has been neglected in the past. Since the advent of arthroscopy, posterior labral lesions have been more commonly identified and treated. Kim proposed to classify isolated posteroinferior labral lesions into four types [10]. Type I represents incomplete stripping; posteroinferior labrum is torned from the glenoid rim but not displaced medially. Type II is a marginal crack, also called Kim's lesion; it is superficial tear between posterior aspect of the labrum and glenoid cartilage. Posterior labrum losses its normal height and becomes flat and loosely attached. Type III

represents chondrolabral lesion. Type IV indicates a flap tear, which is of degenerative origin. Described labral lesions are frequently accompanied by stretching of the posteroinferior part of the capsule [23]. Recently, posterior labrocapsular periosteal sleeve avulsion (POLPSA) was described, in which posterior labrum and intact periosteum are stripped from the glenoid [24, 25].

37.3.2 Dynamic Stabilizers

Rotator Cuff Similar to their role in preventing anterior shoulder instability, rotator cuff muscles are the most important dynamic stabilizers in preventing posterior shoulder instability. Of the four muscles, subscapularis provides the greatest resistance to posterior subluxation [19, 26]. However, other rotator cuff muscles and scapular muscles are important also. Scapular rhythm and control are critical components. Scapulothoracic motion must be properly coordinated with glenohumeral motion resulting in appropriate position of the glenoid to provide stable platform beneath the humeral head.

37.4 Diagnosis

37.4.1 History

Athletes, such as weight lifters, throwers, racket sport athletes, rugby players, and swimmers, are at higher risk of posterior instability [27, 28]. Many of these athletes have inherently lax shoulders, which is an advantage for their sports but also makes them prone to instability. The repetitive trauma to their shoulders can lead to chronic instability.

A detailed history is essential to diagnose the patients with posterior shoulder instability. It is of outmost importance to determine the posterior instability in the patients as acute or chronic, traumatic or atraumatic, anterior, posterior, or multidirectional. Voluntary instability must be identified early (Fig. 37.4). These patients have poor results with surgical treatment. Voluntary instability can be found in two groups. One group represents patients with good muscle control who can subluxate and relocate their shoulder from an early age, which may

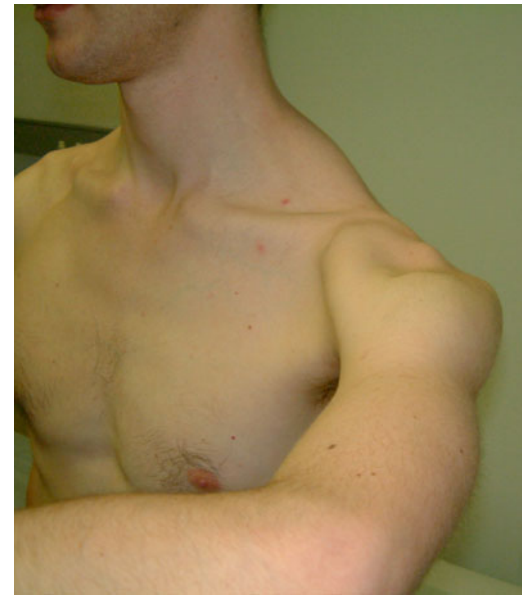

Fig. 37.4 Patient with voluntary posterior dislocation of the shoulder joint

lead to capsular laxity and subluxation that begins to occur at inopportune times producing symptoms. The other group represents true voluntary dislocators with psychiatric problems. Operative treatment for this population is rarely successful.

Patients with posterior shoulder instability usually don't present with a typical history of true dislocation. They often complain of mild, unspecific joint pain with sensation of clicking, looseness, or instability in certain positions. The exact position of the shoulder causing the symptoms should be noted. Symptoms mainly occur in the flexed, adducted, and internally rotated shoulder. Many patients associate the onset of symptoms to a specific event. History of trauma with the arm in provocative position should raise suspicion for posterior shoulder pathology.

37.5 Clinical Examination

The clinical examination is an important part of the diagnostic process. Throughout the clinical assessment, it is necessary to bear in mind the difference between laxity and instability. Lax patients can have the same degree of glenohumeral

translation as an unstable patient but report no symptoms or discomfort.

Scapulothoracic motion should be observed, looking for any excessive scapular protraction or dyskinesia. It is common for patients with posterior instability to protract their scapula on flexion, leading to a Kibler type 1 dysrhythmia, with inferomedial border prominence. Correction of the scapula position with posterior cuff activation may improve the discomfort and apprehension in patients with atraumatic instability. This denotes a propensity for good rehabilitation potential. It is important to differentiate a scapular dykinesis secondary to posterior instability in this way, as opposed to a primary serratus weakness [29]. Active and passive range of motion should be recorded, with and without scapula correction.

A number of clinical tests have been described for posterior instability. We find them useful in different situations, as described below [30].

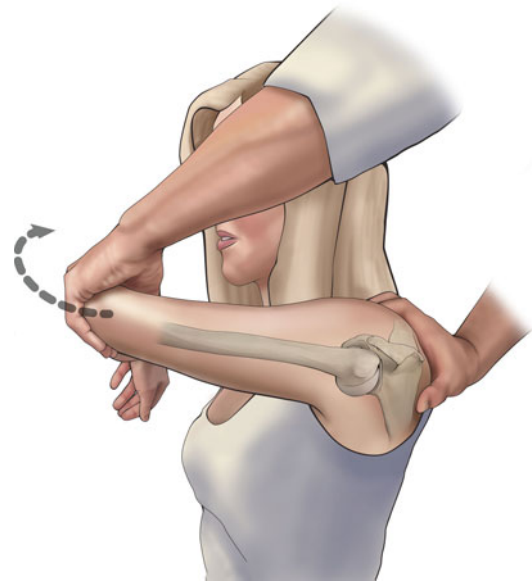

Fig. 37.5 Jerk test performed with affected arm in 90° of flexion and internal rotation. Posterior force on the elbow is applied, while the scapula is stabilized with another hand. Sudden jerk and pain indicate a positive result

37.5.1 Jerk and Kim Tests [31]

The Jerk test is performed with affected arm in 90° of flexion and internal rotation. The scapula is stabilized with one hand while providing posterior force on the elbow with the other hand causing posterior humeral head subluxation. Further abduction reproduces the patients' symptoms (Fig. 37.5). A sudden jerk and pain occur when subluxated humeral head relocates into the glenoid fossa [31]. Kim test is performed while the arm is abducted to 90°. The arm is then passively elevated to additional 45° of forward flexion while applying a downward and posterior force to the upper arm with an axial load to the elbow (Fig. 37.6). Pain and posterior subluxation indicate a positive result [32]. Combining the Kim and Jerk test has been shown to have 97% sensitivity for posterior instability.

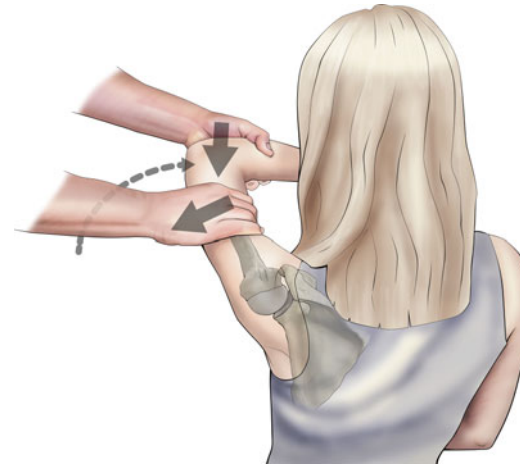

Fig. 37.6 Kim test performed with affected arm in 90° of abduction. The arm is passively elevated to additional 45° of forward flexion while applying a downward and posterior force to the upper arm with an axial load to the elbow. Pain and posterior subluxation indicate a positive result

37.5.2 Wrightington Posterior Instability Test (WPIT) [33]

In many cases of posterior instability, patients present with posterior pain and clicking instead of true dislocations. We have found this predominantly in muscular contact athletes. These patients have excess posterior laxity and translation and posterior glenohumeral joint pain in hyperabduction and external rotation. This is a form of subclinical instability. These patients will exhibit marked weakness and pain in resisted

Fig. 37.7 Wrightington posterior instability test (WPIT) is performed in patient with resisted flexion in full adduction and internal rotation. Weakness and pain indicate a positive result

flexion in full adduction and internal rotation at 90° – a similar position to the O'Brien's test (Fig. 37.7). This is probably due to posterior translation of the humeral head in the position of flexion and internal rotation, with resultant posterior cuff weakness. It is essential to correct and stabilize the scapula in performing the test. WPIT has a sensitivity of 83 % but low specificity.

When assessing the patients with posterior instability, it is important to also perform tests for anterior and inferior laxity and instability (apprehension). Posterior instability combined with inferior instability indicates bidirectional or multidirectional instability.

The patient should be assessed for generalized laxity using the Beighton Score [34]. A score of 6/9 or greater indicates hypermobility but not necessarily benign joint hypermobility syndrome.

37.6 Investigations

Investigations in patients with posterior shoulder instability usually initially include radiographs with AP and axillary views. This is to identify any bony abnormalities, such as reverse bony glenoid lesions, large reverse Hill-Sachs lesion, and possible developmental anomalies, such as a dysplastic glenoid (Fig. 37.8).

MR arthrogram is generally the gold standard nonsurgical diagnostic tool. It can identify both bony and soft tissue pathologies to the labrum, capsule, glenoid, and humeral head. It is important to include bone-enhancing T1 sequences to help identify any small bony glenoid lesions. Additional fat suppression sequences can enhance any associated paralabral cysts. Although this is the gold standard, even MR arthrogram is not 100 % accurate; therefore, a strong clinical suspicion for posterior instability should override the MR arthrogram and an arthroscopy be performed [35].

CT scan may be required for evaluating bony lesions, glenoid deficiency, and glenoid version. Functional EMG is also helpful for complex muscle patterning disorders. Examination under anesthesia and arthroscopy aids the diagnosis although one should have most of the information before.

37.7 Therapeutic Options

If the primary abnormality is muscle patterning and proprioceptive problems, then physiotherapy is the main treatment. It is essential that a therapist trained and experienced in dealing with shoulder instability undertakes this. There needs to be a close relationship between the therapist and the surgeon to ensure that if surgery is required, this is done as a part of the full rehabilitation program and done timely in accordance with the rehabilitation. If the primary abnormality is found to be structural such as posterior Bankart lesion, bony lesion, or capsular injury, then surgery is often required early, and the rehabilitation follows accordingly.

37.7.1 Nonoperative Treatment

All patients with posterior shoulder instability should be encouraged to start a comprehensive rehabilitation treatment program. Many patients with posterior shoulder instability can be well managed by education, muscle strengthening, and neuromuscular retraining. In approximately

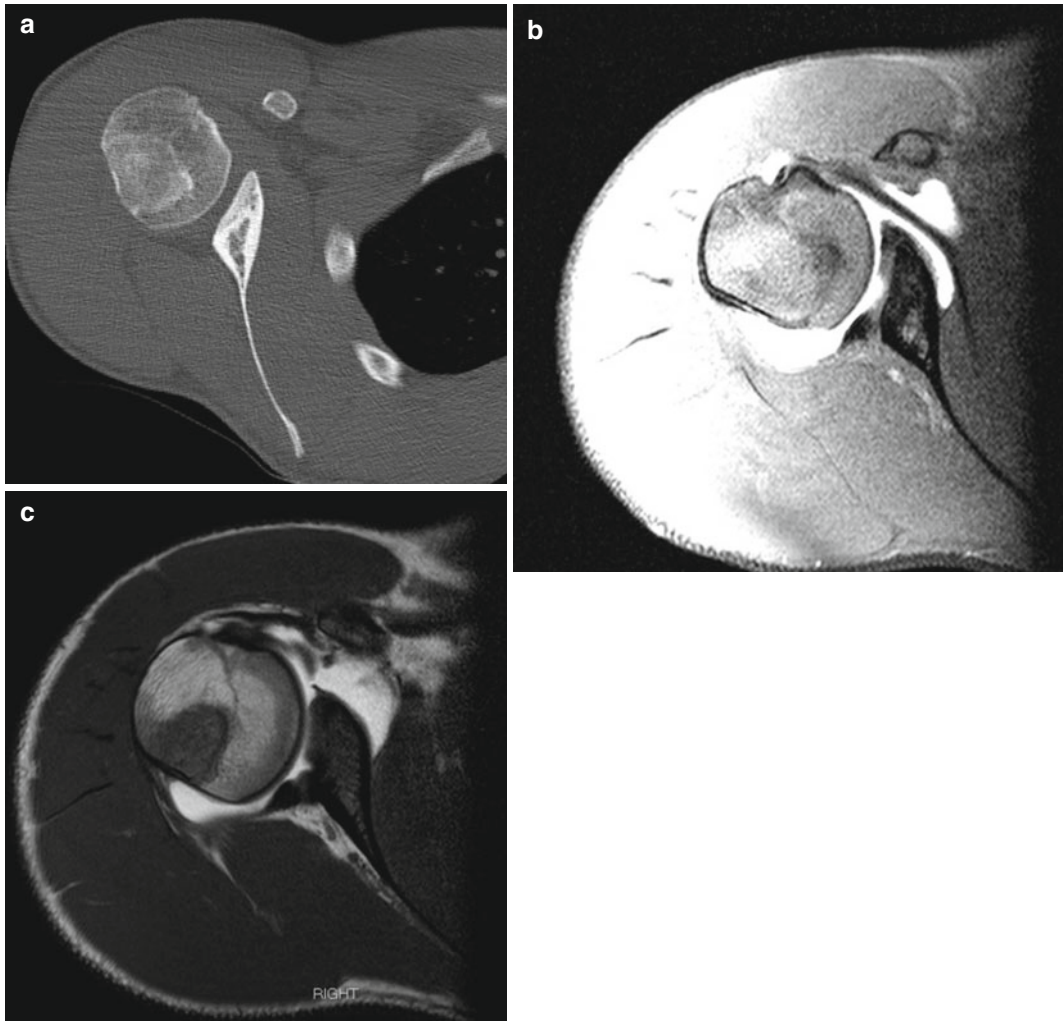

Fig. 37.8 Dysplastic glenoid on CT scan (**a**), MRI arthrogram T1 (**b**), MRI arthrogram T2 (**c**)

two-thirds of patients, appropriate strengthening and proprioception training programs diminish pain and improve stability [36, 37]. Rehabilitation may be particularly successful in patients with generalized ligamentous laxity and repetitive microtrauma of the shoulder joint [38]. Surgery is usually indicated when proprioceptive control cannot be achieved with rehabilitation due to excessive capsular redundancy or dysplasia. Surgery is not successful in patients with true voluntary instability and pure muscle patterning instability in the absence of hyperlaxity.

Nonoperative treatment is less successful in patients with traumatic instability [37, 38]. It has been shown that rehabilitation program has 70–89 % success in patients with atraumatic instability and only 16 % success in patients with traumatic instability [37]. Even in patients who are candidates for operative treatment, strengthening of dynamic stabilizers of scapula is crucial, and it is important in postoperative rehabilitation. In addition, as subscapularis muscle is important dynamic posterior shoulder stabilizer, strength of this muscle should be optimized.

37.7.2 Operative Treatment

Surgery is indicated for traumatic posterior instability with structural lesions. A period of nonoperative rehabilitation can be tried, but if this is not successful, surgery is indicated. Our indications are very similar to traumatic anterior instability. It is essential to identify direction of instability, possibility of accompanying multidirectional instability, and all anatomic factors that can contribute to the condition. Pathology needs to be identified, and treatment is directed accordingly. No single operative intervention applies to all patients with posterior shoulder instability.

The treatment of choice in posterior shoulder instability without significant bony injury is arthroscopic repair. Arthroscopic procedure yields less tissue dissection, easier access to the posterior capsulolabral complex, identification of the pathology, ability to address concomitant injury, and easier revision. It can be technically demanding. A clear understanding of the surgical anatomy and technique is crucial for success. The key element of successfully correcting posterior instability by arthroscopic means includes increasing the glenohumeral stability ratio by restoring the glenolabral concavity, reducing the capsular redundancy to reset capsular tension for proprioceptive feedback, and rehabilitating scapulohumeral and scapulothoracic musculature [22].

Recent meta-analysis of the clinical outcomes showed that arthroscopic procedures are effective and reliable treatment option for posterior shoulder instability with respect to outcome scores, patient satisfaction, and return to activities. Literature suggests that patients treated arthroscopically have superior outcomes compared to patients treated with open procedures with respect to stability, recurrence of instability, patient satisfaction, return to sport, and return to previous level to play [28, 39].

In patients with substantial amount of bone loss or other bony abnormality, open procedures may be used. Low incidence of recurrence is generally described [40]. There have been concerns that the results may deteriorate over time because of graft lysis and glenohumeral osteoarthritis; however, recent studies do not show this [41].

37.7.2.1 Treatment of Soft Tissue Injuries

Soft tissue injuries are much more common than bony pathology. Most of the procedures for posterior shoulder instability are soft tissue reconstructions. They can be effectively done with arthroscopic technique. Treatment consists of detachment, freshening, and repair of the labrum on the surface of the glenoid. Repair is often combined with capsular shift. Systematic review of the literature shows that arthroscopic stabilization for posterior shoulder instability has promising early and midterm results and acceptable recurrence rate, especially when compared with the first documented results of open shoulder stabilization for posterior instability [42].

Surgical Technique of Arthroscopic Posterior Capsulolabral Repair

We prefer the beach chair position, but the same technique can be used for lateral decubitus. An arm-holding device facilitates arm positioning for better access. For posterior repairs, viewing is done from the anterior portal and instrumentation via one or two posterior portals. Flexing the shoulder with the arm positioned improves visibility and access to the posterior capsule and labrum. A preoperative examination under anesthesia is routinely performed. We use the technique described by Cofield and modified by Copeland [43].

The initial posterior portal is made much more lateral than the standard posterior soft-spot portal, to allow for direct access to the posterior glenoid (Fig. 37.9). The anterior and superior structures are visualized from the posterior portal and probed from the anterior portal initially. The scope is then changed to the anterior portal and instrumentation introduced via the posterior portal. The extent of the labral injury is confirmed by probing.

The labrum is mobilized and the posterior glenoid rim prepared. Suture anchor repair is performed with suture anchors with high-strength sutures (Fig. 37.10). A mean of 2.3 (1–4) anchors is used, depending on the size of the tear. Capsular

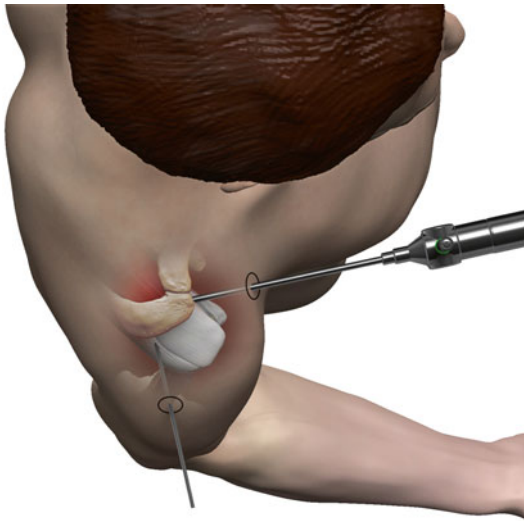

Fig. 37.9 Arthroscopic portals used for posterior capsulolabral repair

plication is added if depending on the amount of posteroinferior capsular laxity (Fig. 37.11).

37.7.2.2 Treatment of Bony Injuries

Bony abnormalities are less common than soft tissue injuries. They should be considered, especially in patients with failed soft tissue surgery and no muscle patterning or proprioceptive problems.

Posterior Bone Block

For a posterior bone block procedure, a bone graft from the iliac crest or from acromion can be used [44, 45] (Fig. 37.12). There is still some controversy about posterior bone-block positioning. Some authors suggested to position bone block on posterior glenoid extra-articular, with an overhang of approximately 5–10 mm [17]. Other authors recommend that a posterior enlargement of the glenoid cavity rather than a blocking effect should be obtained [44]. In a systematic review, it was shown that bone grafting is a reliable option [40]. Studies reported significant improvement in all outcome scores used. Generally, low incidence of recurrence is described. Traditionally, this has been performed with open surgery, but this is a large dissection, especially in muscular patients (Fig. 37.13). Arthroscopic bone grafting is becoming more common, with advances in the technique and instrumentation.

Subscapularis Transfer/Reverse Remplissage

There are many operative techniques described to solve the problem of large reverse Hill-Sachs lesions in posterior instability. Reverse Hill-Sachs lesions tend to involve more of the articular surface compared with their posterior counterparts [46]. Therefore, some authors hold that lesions involving as little as 10 % of the articular surface may be clinically significant and require direct intervention [46]. Reconstruction techniques include transposition of the subscapularis tendon, lesser tuberosity transposition into the defect, disimpaction with elevation, and bone grafting.

The original McLaughlin procedure involved transfer of the subscapularis tendon from the lesser tuberosity to the reverse Hill-Sachs lesion. However, Neer's modification has become more popular. This involves transfer of the lesser tuberosity along with subscapularis. Healing is improved, and the defect can be filled.

Arthroscopically, a reverse remplissage procedure can be performed with fixation of the subscapularis tendon into the Hill-Sachs defect with suture anchors [47, 48] (Fig. 37.14).

When the defect comprises more than 50 % of the humeral head, more extensive techniques are required, mainly rotational osteotomy of the proximal humerus or reconstruction with an osteochondral allograft. In chronic cases, there may be a need for arthroplasty.

In cases of excessive glenoid retroversion, that is 20°, glenoid osteotomy can be considered. This is demanding procedure, and the complication rate can be high [13]. Inadvertent penetration of the glenohumeral joint at the time of osteotomy can predispose the patient to glenohumeral osteoarthritis [49].

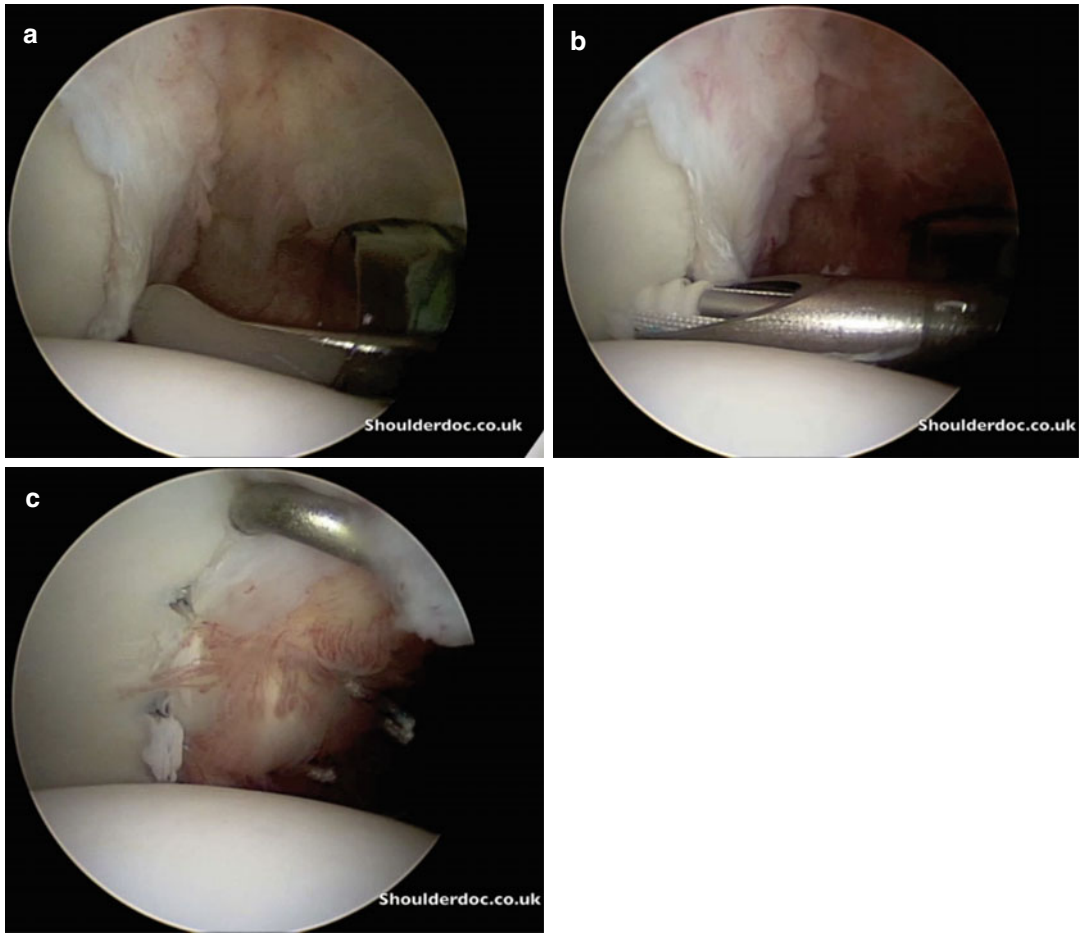

Fig. 37.10 Arthroscopic posterior capsulolabral repair starts with examination of extent of posterior labral injury, detachment of labrum, and refreshing of injury (**a**). Repair starts distally with suture anchor placed on posterior glenoid rim (**b**) and advanced proximally to complete repair (**c**)

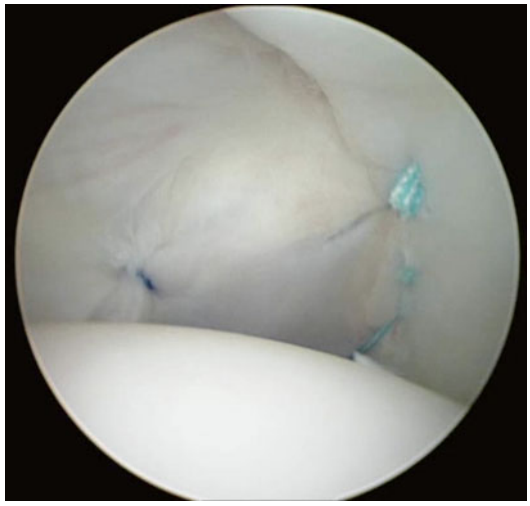

Fig. 37.11 Posterior capsule after plication

37.8 Postoperative Rehabilitation

Patients are placed in an external rotation sling postoperatively to limit stress on the posterior repairs. Current rehabilitation guidelines widely use between 3 and 5 weeks of shoulder immobilization following a Bankart repair [50]. We allow early mobilization as tolerated from day 3 postoperatively as supported by Kim [51]. The sling is worn for comfort between exercises. The key limitation is to avoid stretching and forcing motion, particularly in flexion and internal rotation [52].

Restoring normal scapula kinematics begins early, with maintenance of good posture with all exercises, maintenance of thoracic range of

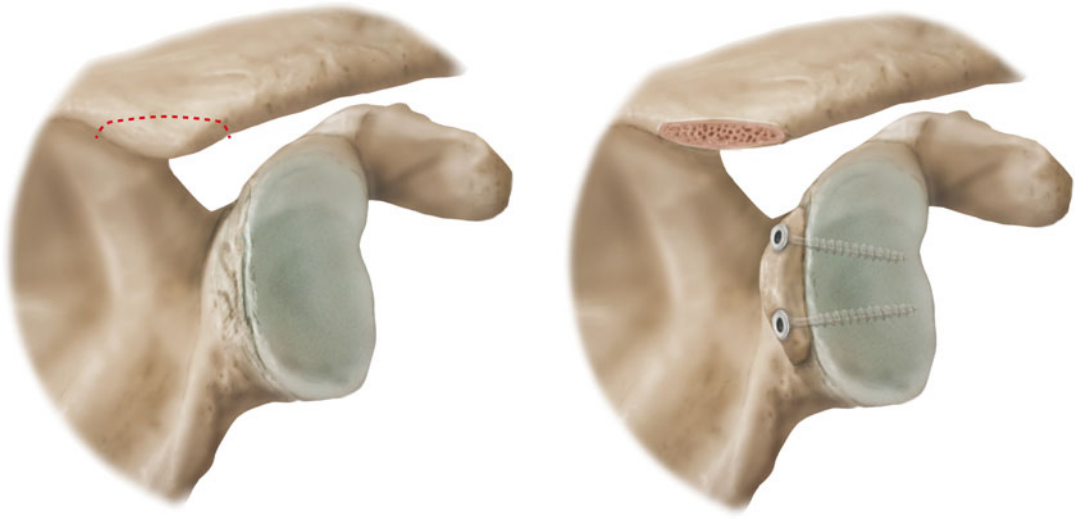

Fig. 37.12 Posterior bone-block procedure using bone graft from acromion

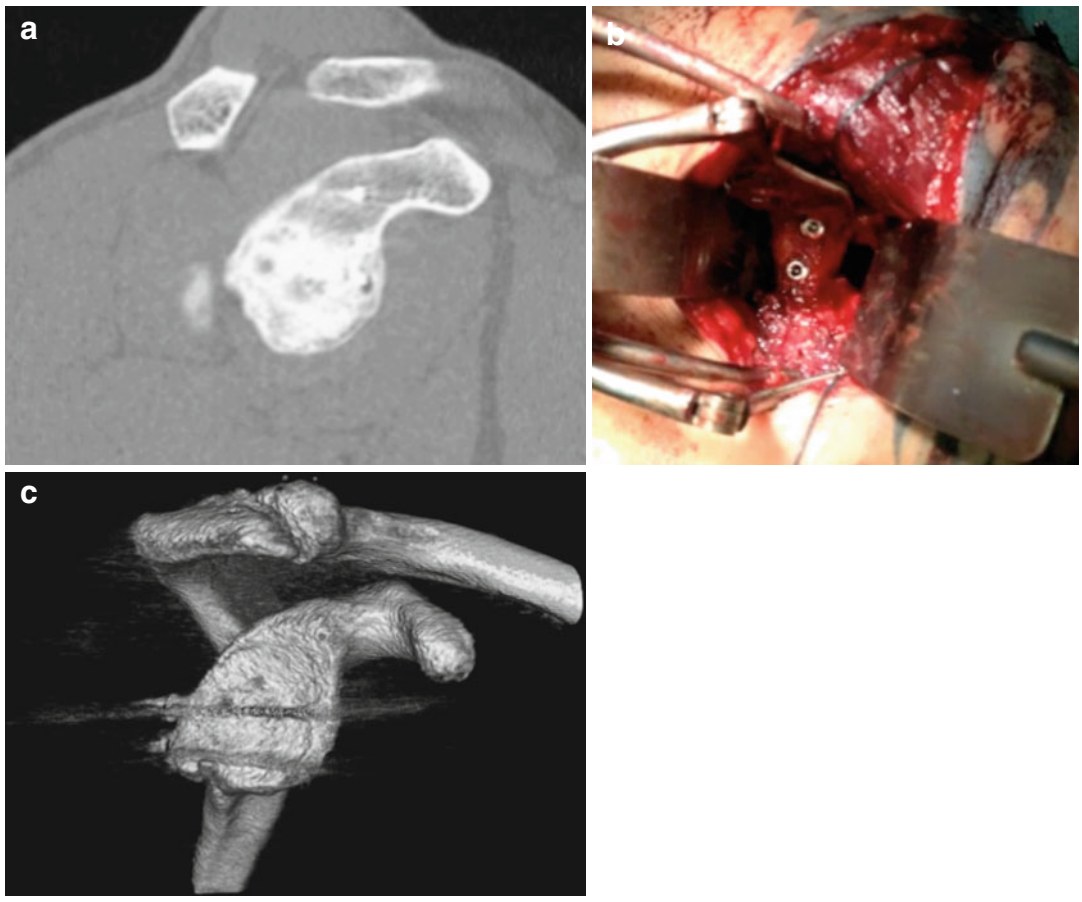

Fig. 37.13 Posterior bone-block procedure. Preoperative CT scan of glenoid in sagittal plane (**a**). Open posterior bone-block procedure through posterior approach to the shoulder (**b**). CT scan – 3D reconstruction image after the surgical procedure (**c**)

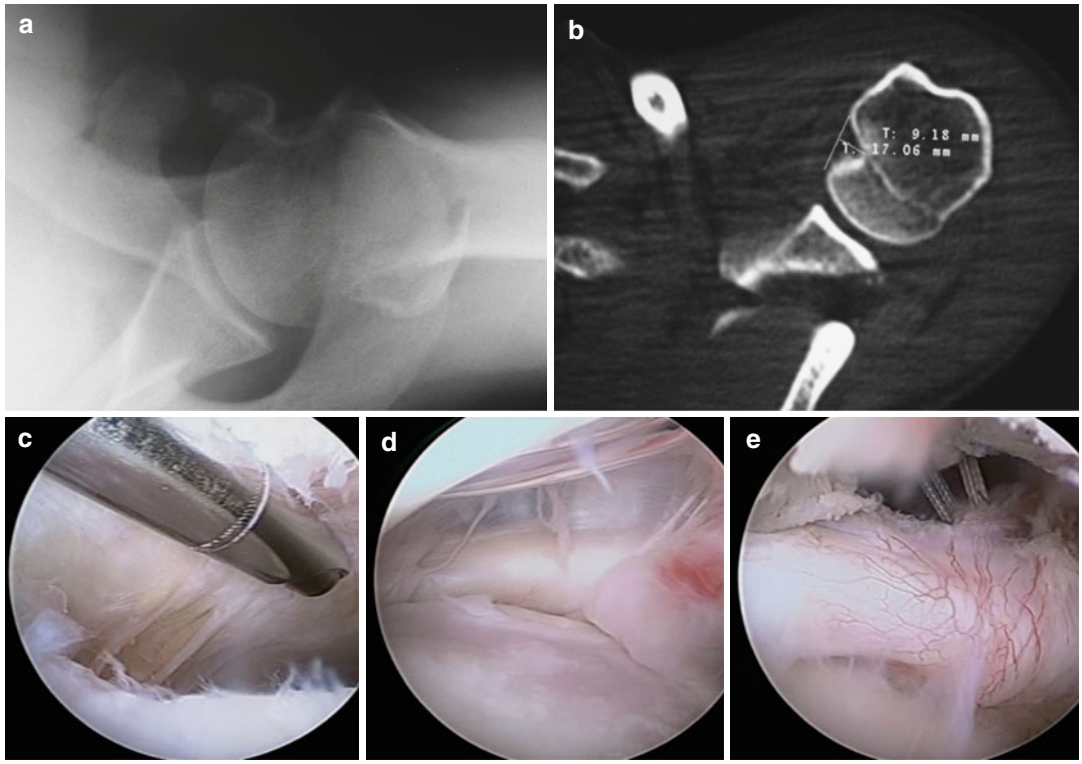

Fig. 37.14 Reverse Hill-Sachs lesion on x-ray (**a**), CT scan (**b**), and arthroscopic view (**c**, **d**). Arthroscopic reverse remplissage procedure (**e**)

motion, global kinetic chain exercises, and treatment of pectoralis minor and posterior cuff tightness [53].

In these early stages of rehabilitation, emphasis is placed on muscular coordination, control, and endurance [54]. Initially, isometric exercises are used to promote dynamic stabilization, proprioception, and neuromuscular control [55]. Exercises are rapidly progressed to isotonic exercise using elastic bands. Elastic band external rotation (ER) and internal rotation (IR), with the arm by the side, scaption and low rowing are all performed in the first week of rehabilitation. These exercises have been shown in electromyographic (EMG) studies to accurately target the rotator cuff muscles and supporting musculature of the shoulder girdle [54, 56].

As the patient progresses in strength and repetitions with elastic band training, ER and IR are performed at 90° abduction as well as by the side. These exercises utilize the principle of muscle training specificity by strengthening muscles in ranges used in practice to give the greatest carry over to performance [57].

Weight bearing or closed kinetic chain (CKC) exercises are incorporated early in rehabilitation to facilitate rotator cuff co-contraction and shoulder stability [58]. Elastic band resistance is progressed to cable weight resistance as tolerated. Weight training is incorporated last as a resistance method. In athletes, this is introduced at week 4 for pulling activities and from week 5 for pressing activities as symptoms allowed. Pressing activities place a greater load on the posterior labrum and are therefore introduced later to allow healing and appropriate joint stability [59].

The decision to allow manual work and contact training is based on isokinetic evaluations and/or free weight load lifted to pre-injury level. With close to normal rotator cuff strength, good shoulder proprioception and improving general upper body strength contact work can begin safely.

37.9 Summary and Conclusions

Posterior shoulder instability remains a diagnostic and therapeutic challenge in clinical practice. Patients present not only with true dislocation but also in many cases with posterior pain and clicking. The origin of posterior shoulder instability can be traumatic, atraumatic, or cumulative microtrauma. Updated knowledge of pathomechanics is necessary for successful approach to this patients and successful management. Patients with posterior instability should be differentiated from those with laxity, bidirectional, and multidirectional instability. Treatment of posterior shoulder instability depends on the underlying injury and pathomechanical changes to the shoulder joint (Table 37.1). It is essential to identify the pathology and treat accordingly. No single operation applies to all the patients with this condition.

Table 37.1 Treatment options for posterior shoulder instability

Treatment option	Condition
Rehabilitation program	Initial treatment for all patients Patients with muscle patterning and proprioceptive problems Patients with additional generalized laxity
Operative treatment	Patients with structural lesions Patients with traumatic posterior instability
Arthroscopic posterior capsulolabral repair	Patients with posterior shoulder instability and posterior labral lesion
Arthroscopic capsular plication	Patients with posterior shoulder instability without a labral lesion. In addition to capsulolabral repair in cases of posteroinferior capsular laxity
Lesser tuberosity transposition Subscapularis transfer Reverse remplissage	Patients with reverse Hill-Sachs lesion (25–50 % of humeral head) Usually in patients with acute locked posterior shoulder dislocation
Posterior bone-block procedure Posterior glenoid osteotomy	Patients with posterior fracture of glenoid cavity, increased glenoid retroversion, and glenoid hypoplasia and in patient with failed soft tissue surgery

Table represents general overview. Decision about treatment option must be made on individual basis

All patients with posterior shoulder instability should be encouraged to start a comprehensive rehabilitation program. Many patients can be well managed by education, muscle strengthening, and proprioception training program. Rehabilitation may be particularly successful in patients with additional generalized laxity and repetitive microtrauma of the shoulder joint. Nonoperative treatment is less successful in patients with traumatic instability. Surgical treatment is indicated when proprioceptive control cannot be achieved with rehabilitation, especially for traumatic posterior instability with structural lesions. Pathology needs to be identified and treatment directed accordingly. The treatment of choice in posterior shoulder instability without significant bony injury is arthroscopic posterior capsulolabral repair. This procedure is often combined with a capsular plication depending on the amount of posteroinferior capsular laxity. Soft tissue injuries are indeed more common than bony pathology. In patients with substantial amount of bone loss or other bony abnormality, open or arthroscopic procedures may be used to address underlying pathology. The lesser tuberosity transposition, subscapularis transfer, and reverse remplissage are used to solve the problem of reverse Hill-Sachs lesion in patients with posterior instability. Posterior bone block procedure or a posterior glenoid osteotomy is indicated in patients with posterior fracture of glenoid cavity, increased glenoid retroversion, and glenoid hypoplasia or in patients with failed soft tissue surgery.

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38 Humeral Avulsion of the Glenohumeral Ligament Lesion (aHAGL and pHAGL): Current Concepts in Treatment and Management

Philipp Proier, Stefan Buchmann, and Andreas Imhoff

Abbreviations

abHAGL	Anterior bony humeral avulsion of the glenohumeral ligament
AC	Acromioclavicular
aHAGL	Anterior humeral avulsion of the glenohumeral ligament
aIGHL	Anterior-inferior glenohumeral ligament
ALPSA	Anterior labral periosteal sleeve avulsion
faIGHL	Floating anterior-inferior glenohumeral ligament
fpIGHL	Floating posterior-inferior glenohumeral ligament
HAGL	Humeral avulsion of the glenohumeral ligament
IGHL	Inferior glenohumeral ligament
IGHLC	Inferior glenohumeral ligament complex
MR	Magnetic resonance
pbHAGL	Posterior bony humeral avulsion of the glenohumeral ligament
pHAGL	Posterior humeral avulsion of the glenohumeral ligament
pIGHL	Posterior-inferior glenohumeral ligament
ROM	Range of motion
SLAP	Superior labral tear from anterior to posterior

P. Proier • S. Buchmann • A. Imhoff (✉)
Department of Orthopaedic Sports Medicine, Klinikum rechts der Isar, Technical University of Munich, Ismaningerstr. 22, München 81675, Germany
e-mail: a.imhoff@sportortho.de

38.1 Instability and Capsular Tears

Traumatic glenohumeral instability is typically initiated by a specific traumatic event, followed by episodes of instability with a unidirectional pattern [1].

Sudden force at 90° of abduction and external rotation overwhelms the anterior capsular structures, while a fall onto an outstretched, internally rotated arm overwhelms the posterior structures of the inferior glenohumeral ligament (IGHL) in particular, which is according to the literature the most important passive stabilizer of the glenohumeral joint [2]. The term "IGHL complex" (IGHLC) [3] consists of an anterior and a posterior band, which represent thickening of the capsule and an interposed axillary pouch, reaching from the inferior glenoid to the humerus just below the anatomical neck (Fig. 38.1).

Two distinct configurations of the IGHLC insertion on the humeral side are described [4]. A collar-like attachment of the IGHLC inserts just below the articular margin of the humerus head.

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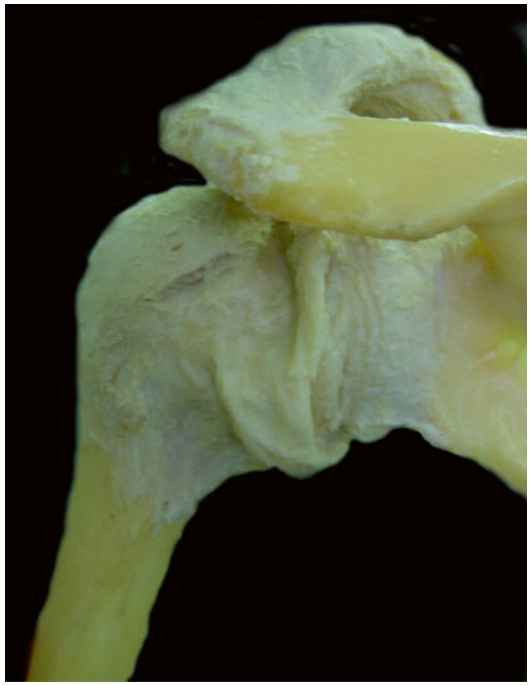

Fig. 38.1 Anatomic specimens, anterior view of the glenohumeral capsule illustrates the IGHL and axillary pouch

And a V-shaped configuration where the anterior and posterior band of the IGHLC attaches directly beyond the articular surface, whereas the interposed axillary pouch inserts distally with the center farthest away from the surgical neck, mimicking the shape of the letter "V" [5]. Identifying the type between the V-shaped and collar-like attachment in a clinical setting is not possible with a minimal invasive approach. That's why a clinical decision about anchor placements on the neck of the humerus [6] or on the inferior aspect of the humeral head (juxtachondral) [7] cannot be made anatomically. The best position of the suture anchors to obtain an optimal restoration of glenohumeral function was biomechanical tested in different average aHAGL repairs. And it has been shown that the anchor positioning on the humeral neck is more likely to restore the normal restraint to anterior translation than a juxtachondral repair [8].

Functionally, the IGHLC is acting as a hammock-like structure that rotates with respect the arm position. In external rotation, the complex tightens anteriorly, whereas in internal rotation, the complex tightens posteriorly [3].

The tear of the anterior-inferior and posterior-inferior capsulolabral complex are termed as Bankart and reversed Bankart lesion and are well known to be the main cause of shoulder instability [9, 10]. The abnormal laxity of the attached capsuloligamentous and the labral tear itself after traumatic shoulder subluxation or dislocation yields to increase the propensity for recurrent instability of the glenohumeral joint [11].

The humeral avulsion of the glenohumeral ligaments (HAGL) in contrast to the Bankart lesion represents an isolated tear of the inferior glenohumeral ligament at its humeral insertion after a high-impact shoulder dislocation [12]. The typical HAGL lesion is most commonly an avulsion of the anterior-inferior glenohumeral ligament (aIGHL) from its attachment on the humerus and leads to anterior-inferior instability. The posterior HAGL (pHAGL) lesions, being much more infrequent and described as an avulsion of the posterior-inferior glenohumeral (pIGHL) ligament, can cause posterior shoulder instability or pain [13, 14].

Biomechanical studies showed that failure of the aIGHL occurs mostly at the glenoid insertion, compared to the midsubstance or humeral insertion [15]. However, while more rare, HAGL can also occur and have been reported in 1–9 % as cause for recurrent instability [12, 16]. Just 7 % out of all HAGL lesions occur on the posterior humeral insertion [17].

HAGL lesions are generally seen in high-energy accidents or contact sports, such as ice hockey, American football, or rugby [18]. In countries where these kinds of sports are unpopular, this injury is seldom seen. Recently, repetitive microtrauma in throwing athletes has been reported as chronic cause for this specific pathology [19, 20]. Regarding the mechanism of injury that leads to a HAGL lesion, Nicola found in a cadaveric study that an anterior HAGL lesion resulted with the arm in 105° of hyperabduction and external rotation [21], whereas a forced cross-body adduction often in combination with a posteriorly directed force on the forward flexed, adducted arm with slight external rotation is the

most common mechanism for a posterior HAGL lesion [22]. Bankart lesions occurred when the arm was hyperabducted and compressed, without any significant associated rotation [21].

There exists no single physical examination that will assist the surgeon to diagnose a HAGL lesion versus more commonly found Bankart lesions or capsular laxity.

In particular, the posterior HAGL lesion presents with nonspecific symptoms like shoulder pain or posterior instability. Multiple potential etiologies lead to the same symptoms like labrum, capsule or rotator cuff tears, and multidirectional shoulder instability, leading to delay of diagnosis.

The only clinical sign that was found positive regularly was the presence of posterior shoulder pain during forward flexion and internal rotation [23].

There is a high incidence (68–95 %) of concomitant shoulder injuries associated with a HAGL lesion [24, 25]. Injuries like Hill-Sachs deformities, subscapularis tendon tears, supraspinatus tendon tears, SLAP lesion, labral tears, and partial- or full-thickness tear of the rotator cuff are seen regularly and should be confirmed and treated during surgery [23, 24].

Approximately 20 % of the HAGL lesions occur with avulsion of a bony fragment from the insertion zone of the IGHL at the neck of the humerus (bony HAGL) and can be diagnosed by X-ray [26]. MR is useful in the diagnosis of HAGL lesions. In subacute cases with the absence of joint effusion, the HAGL lesion can only be diagnosed with confidence if MR arthrography is used [27, 28]. The sensitivity for detection of HAGL lesions on MR arthrography compared with surgery is described with 70 % [24]. In the normal shoulder, the axillary pouch of the IGHL is presented as a distended U-shaped structure sitting below the articular edge of the humeral neck. With a lateral avulsion, the IGHL drops inferiorly and the U-shaped structure on coronal oblique arthrograms is converted as a J-shaped structure. Concurrent contrast extravasation can occur at its insertion of the torn humeral attachment [29].

According to imaging findings, Bui-Mansfield developed a West Point classification system for HAGL lesions distinguishing six distinct types characterized by involvement of the anterior or posterior band, the presence or absence of a bony avulsion, and the associated labral tear. When the anterior band failed at the medial insertion of the humerus, two entities of anterior HAGL are distinguished without (aHAGL) or with bony avulsion (abHAGL). An additional detachment of the ligamentous-labral complex (Bankart lesion) from the anterior-inferior glenoid is called "floating anterior IGHL" (faIGHL). Based on the anterior terms of lesion, posteriorly, they labeled the different entities similarly as pHAGL, pbHAGL, and fpIGHL [30], if a concurrent ligamentous-labral tear was seen [12]. Additionally, an isolated lesion of the axillary pouch as a form of the HAGL lesion (apHAGL) has been described recently in overhead athletes, such as volleyball [19] players and professional baseball pitchers [20].

To accurately diagnose HAGL lesions, it is essential to have a clear understanding of the anatomy of the normal glenohumeral ligament complex and its various forms of injury, for accurately describing the variations of HAGL lesions. Patients with anterior or posterior instability after a traumatic shoulder dislocation without a Bankart lesion must be highly assumed to have a HAGL lesion.

The HAGL lesion represents a diagnostic pitfall in open and arthroscopic surgery, since it can be easily overlooked if the area of the lateral IGHL insertion is not specifically searched for this injury [16, 31]. Therefore, preoperative diagnosis like a MR (Fig. 38.2) in acute and a MR arthrography in chronic cases is imperative.

38.2 Indication

Regarding the indication if a surgical reconstructive procedure should be performed or not is not well known yet. The combination of a demonstrable structural injury to the glenohumeral capsule with an unknown natural history and persistent instability led often to early surgery. Some biomechanical studies provide indications that small aHAGL lesions (≈18 mm) have no destabilizing effects compared to normal

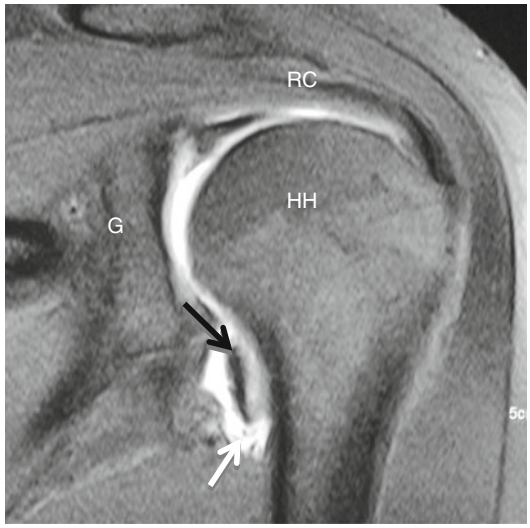

Fig. 38.2 Oblique coronal MR image demonstrating a tear at the humeral attachment of the anterior-inferior glenohumeral ligament (*black arrow*) with distal blood revealing (*white arrow*) "J-sign" (*RC* rotator cuff, *HH* humeral head, *G* glenoid)

shoulders in ROM and translation, since the superior and posterior portions of the capsule are still able to provide stability. Dislocation only occurs when three main capsular zones (cut from clockwise from 3 o'clock to 11 o'clock including the capsule from the pIGHL and aIGHL up to the bicipital groove) are violated [8, 32]; maximum external rotation and total rotational range of motion (ROM) in both the scapular plane and the coronal plane are increased with the large HAGL lesions and can be fully reversed after HAGL repair [33].

Treatment should always be based on clinical history and findings on physical examination; the presence of a HAGL on MR arthrogram alone does not mandate repair, especially when other concomitant lesions such as labrum, rotator cuff pathologies, or instability explain the patient's symptoms.

Another possible reason for a wait-and-see attitude with HAGL lesions may be the possibility of their healing. Reported cases of HAGL lesions were seen initially on MR arthrography and subsequently resolving on follow-up imaging or arthroscopic surgery [34, 35]. It suggests that the identification of HAGL from other abnormalities of the IGHLC with MR arthrography is difficult and is probably overdiagnosed, and the diagnosis should be reserved for arthroscopy. Despite its embarrassments in clinical diagnoses, a surgical repair should be mainly reserved for large HAGL lesions (≈36 mm) which have got an important effect on glenohumeral stability, and repair of the lesion can return these values to those of the intact joint [33].

38.3 Surgical Techniques

Surgery could be performed in both the beach-chair or lateral decubitus positions. Under general anesthesia, the type and direction of the instability is confirmed.

The lesion itself can be diagnosed on preoperative MR arthrography imaging or diagnostic arthroscopy. To diagnose concomitant injuries of the shoulder joint, a prior arthroscopy is always performed, independent if the surgeon is choosing an open or arthroscopic approach for HAGL repair.

Although a HAGL lesion is less common in recurrent shoulder instability, a high number of different surgical procedures have been published. Most repairs of HAGL lesions have been described by open or mini-open techniques [6, 18, 36, 37].

The limited exposure along the anterior-inferior pouch and humeral neck region makes the arthroscopic method difficult. The placement of suture anchors and the ability to reattach firmly the humeral ligament avulsion are technically demanding and probably restricted to advanced shoulder arthroscopists [30, 38, 39] (Fig. 38.3).

Wolf and colleagues [40] described the first arthroscopic repair.

They prepared the humerus by creating a trough of bleeding bone; the capsule was pulled into the trough. The suture was then brought through the subscapularis and was tied directly on top of it. Although the repair of the HAGL lesion was performed arthroscopically, this technique lacks the security of the previously described open suture anchor techniques, because the ligaments were not repaired directly to the bone [10].

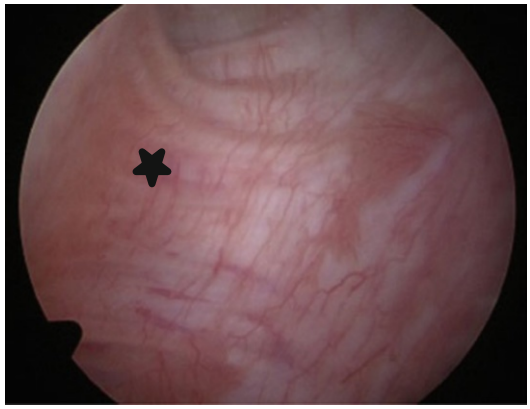

Fig. 38.3 Viewing from a posterior portal, with a direct visualization of the intact anterior-inferior humeral insertion of the capsule (*star*)

So Burkhart et al. described in 2004 a full arthroscopic anterior HAGL repair using suture anchor to achieve a secure capsule to bone fixation, which is known to be stronger than transtendon fixation [38].

Portal placement and portal adaption depending on the pathology are fundamental for an effective arthroscopic surgical management of aHAGL and pHAGL lesions.

Numerous portals have been described, including standard portals [13, 14, 22], modified portals such as an axillary pouch portal and an anterior-inferior portal [41], or standard anterior-superior portal with a more posterior-inferior portal [42].

To address both the medial- and lateral-sided pathologies, in case of a fpIGHL, the posterior portal is placed more lateral and superior to facilitate an eventual working portal that is at the appropriate angle for suture passage around the posterior labrum (similar to the inferior-medial portal in anterior arthroscopic labral repair). An anterolateral rotator interval portal is then made instead of the typical anterior-superior rotator interval portal. When the camera is placed in this more anterior and lateral portal, it facilitates viewing the posterior shoulder over the humeral head, rather than viewing "through" the glenohumeral joint. A full view of the posterior capsule and labrum should be able to be made from this portal with a 30° arthroscope [43].

38.4 Full Arthroscopic aHAGL Repair

A standard posterior portal is placed in the "soft spot" about 2 cm inferior and 2 cm medial to the posterior-lateral corner of the acromion, and a diagnostic arthroscopic examination is performed.

The anterior labrum is assessed for concomitant Bankart lesion or an ALPSA lesion. The glenohumeral ligaments are examined for a capsular redundancy and attachment to the humeral neck.

Under direct vision, the anterior-superior portal is placed anterior to the AC joint, slightly medial to the long biceps tendon and close to the glenoid. With the arthroscope in the anterior-superior portal, the humeral insertion of the glenohumeral ligaments is visualized.

Some authors recommend the alternated use of a 30° and 70° arthroscope to get a good view at the humeral bony insertion through the standard posterior portal [38].

It is important to repair the aHAGL lesion anatomically first and then to deal with the capsular and labral pathology to perform a capsular plication or shift if necessary.

For the aHAGL repair, a 5:30 o'clock low anterior-inferior portal [44] placed between 8 and 10 cm distally to the coracoid process and laterally to the axillary fold is essential to get a good approach to the proximal humerus and to the anterior-inferior glenoid as well.

This anterior-inferior portal penetrates the inferior third of the subscapularis, which was criticized, but no signs of negative long-term effect on the subscapularis muscle have been demonstrated [45].

The anchor insertion at an optimal position on the humerus neck is the most critical part of the surgery, and through the 5:30 o'clock portal, anchors can be introduced at an accurate angle.

To simulate the result of repair, a grasper is introduced through the anterior-superior portal, and the leading edge of the aIGHL is approximated upward to its original insertion site, to make sure that restoration of the appropriate tension of the aIGHL could be achieved [23]. Placing the arm in abduction and external rotation leads to a proper angle on the humeral defect and bone

bed, which is decorticated with a motorized shaver until a bleeding bony surface is created for capsule to bone healing.

Subsequently, suture anchors can be placed at the prepared bony bed through the 5:30 o'clock portal, and both suture limbs are retrieved through the posterior portal to improve the visualization of the operative field. The sutures are passed through the leading edge of the avulsed lateral capsule using a suture hook or lasso, taking care not to punch too deeply to risk injury to the axillary nerve. The ligaments must be visually confirmed to be reduced back to the proximal humerus and fastened by using a sliding knot and alternating half hitches to ensure knot security [7]. Dependent on the existing capsular laxity, the amount of capsule shift is determined by a dynamic shoulder examination with arthroscopic visual control.

Finally, the tension of the anterior band can be confirmed in abduction and external rotation. In case of a floating anterior IGHL, the capsulolabral complex can be repaired using the same 5:30 o'clock portal in combination with a capsule shift depending on the existing capsule laxity. Furthermore, in case of a large HAGL lesion that requires a repair of the axillary pouch, an additional posterior-inferior portal may offer a more favorable angle of anchor positioning.

38.5 Open aHGL Repair

A standard anterior deltopectoral approach is recommended to supply an aHAGL lesion.

The anatomical landmarks are the coracoid process and the proximal humeral shaft on the level of the axilla. A 10–12 cm long skin incision is necessary to expose the deltopectoral groove with the cephalic vein, which is retracted medially.

Incision of the clavipectoral fascia lateral to the conjoined tendon and inferior to the coracoacromial ligament is performed, and the proximal humerus is exposed.

The subscapularis tendon is identified, is carefully dissected from the underlying capsule, and is removed from the humeral insertion 1.5 cm lateral to the lesser tuberosity, the axillary nerve just distal to the subscapularis and medial to the proximal humerus. The anterior capsule is exposed and the humeral avulsion of the anterior-inferior capsule can be clearly identified. For a good visualization to the defect, an abducted to 60° and externally rotated arm by using a sterile articulated arm holder is necessary. This position also ensures that the capsule is not overtightened by the capsular shift repair.

Depending on the size of the defect, two to three suture anchors are placed at the anatomical preexisting capsular insertion below the articular margin of the humeral head. And the aIGHL is reapproximated to the humerus [10, 40].

38.6 Mini-Open Technique

The patient is positioned in the beach-chair position, and a routine diagnostic arthroscopy is performed using standard posterior portal and anterior-superior portals to verify the aHAGL lesion and exclude other potential concomitant injuries. Using air as the arthroscopy medium preserves a better tissue quality for later planed mini-open approach.

Mazzocca et al. described a "dual-window subscapularis-sparing" approach providing adequate exposure for combined reconstruction of the humeral and glenoid lesions.

A 4–5 cm incision is made from the coracoid process down to the axillary fold. Through a usual deltopectoral approach, the anterior portion of the subscapularis muscle is exposed, and an L-shaped incision is made in the lower half of the tendon 1.5 cm medial to the lesser tuberosity and is gently extended medially through spreading the muscle fibers horizontally. Before the horizontal part of the incision is made, the axillary nerve should be palpated to ensure it is medial and inferior of the planed incision. The aHAGL lesion is now exposed, and tag sutures can be placed at the reflected inferior portion of the incised subscapularis tendon.

According to the MR scans, an aHAGL is found at the anterior-inferior aspect of the shoulder joint. Suture anchors may be placed on the

proximal humeral neck, and the leading edge of the avulsed capsule is repaired.

At the end, a side-to-side repair closes the inferior portion of the subscapularis [6]. Although Mazzocca postulated excellent postoperative results, a subscapularis-sparing approach which avoids detachment or splitting of the subscapularis should be considered to prevent potential risk of subscapularis dysfunction and its negative influence on final long-term clinical outcome [46].

A new subscapularis-sparing approach permits adequate access to the humeral attachment of the IGHL without any detachment of the subscapularis tendon.

A 3 cm axillary incision is used to access the subscapularis tendon through a deltopectoral approach. The lower boarder of the subscapularis is identified, by inferior retraction of the pectoralis major, which overlaps the lower subscapularis boarder.

A further retractor is used to lift the entire inferolateral subscapularis superiorly to visualize the aHAGL lesion without detachment of any part of the subscapularis.

If exposure is inadequate, the approach can be easily converted to a conventional L-shaped tenotomy approach through the lower or upper region of the subscapularis as mentioned above.

Keep in mind this mini-open approach does not give excess to the glenoid, and any coexisting glenoid or labral pathologies cannot be visualized [47].

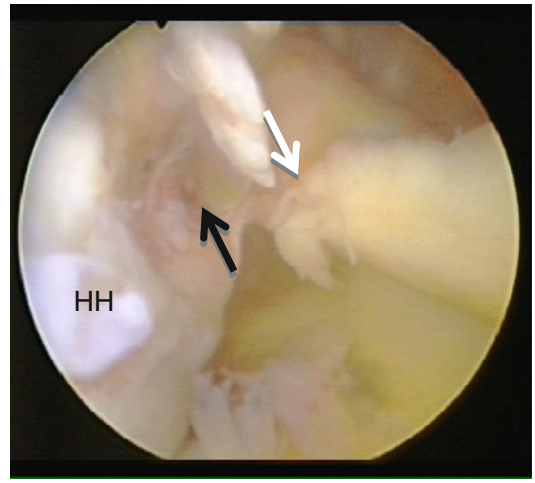

Fig. 38.4 Viewing from an anterior-superior portal, visualize a massive tear of the capsule and pIGHL (*black* and *white arrow*); (*HH* humeral head)

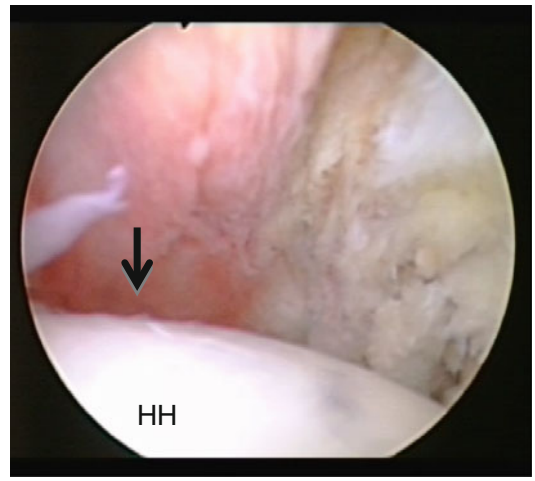

Fig. 38.5 Viewing from posterior superior portal after reattachment of the pIGHL (*black arrow*) and capsule; (*HH* humeral head)

38.7 Arthroscopic pHAGL Repair

Arthroscopic and open repair have been published in literature [14, 42, 48].

Arthroscopic repair of posterior lesions is generally more difficult as a result of poor visualization and access by the standard portals.

But technically, pHAGL repair is basically similar to the anterior repair.

Surgery can be performed in beach-chair or lateral decubitus position. With the use of a lateral decubitus position, more working space is gained posteriorly.

Diagnostic arthroscopy is performed by a standard posterior and anterior-superior portal to rule out concomitant injuries, like SLAP lesions and anterior or posterior Bankart lesions, which are present in 67 % of all pHAGL patients [23].

The arthroscope can be placed through the anterior-superior portal for visualization.

The detachment of the posterior band of the IGHL (Figs. 38.4 and 38.5) from its lateral insertion at the humerus is visualized easily with internal rotation and horizontal adduction of the arm, which does not tension up the posterior band.

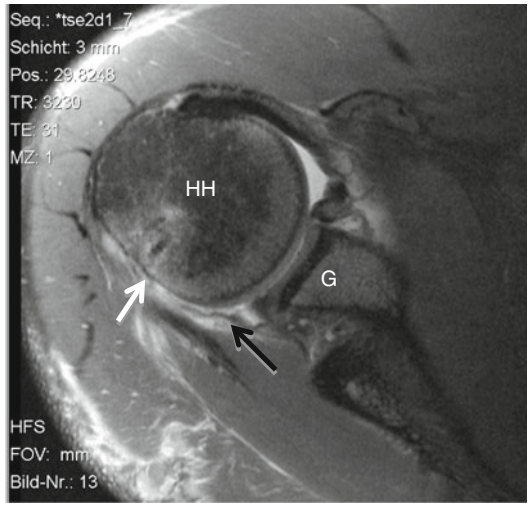

Fig. 38.6 Axial image of a full arthroscopic pHAGL repair with suture anchors (*white arrows*) (*HH* humeral head, *G* glenoid; *black arrow*, pIGHL)

The tissue of the posterior band drops inferiorly, because of humeral detachment.

Arthroscopic visualization of the posterior cuff muscle fibers through the avulsed joint capsule is highly suspicious for a pHAGL lesion.

Around 4–6 cm inferior and 2–4 cm lateral to the posterior-lateral acromion corner, an additional posterior-inferior or posterior-lateral working portal is created as equivalent to the anterior-inferior 5:30 o'clock portal, which is necessary for a pHAGL repair [42].

A motorized shaver is introduced through the posterior-inferior portal creating decortication on the humeral insertion. Using the posterior-inferior portal, the suture anchor can be placed right at the most inferior aspect of the capsular defect on the humeral neck (Fig. 38.6). Suture passing is managed through the standard posterior portal or an additional anterior portal. A sliding-locking knot is used to approximate the capsular to the prepared humeral bony bed.

38.8 Open pHAGL Repair

After a diagnostic arthroscopy through a standard posterior portal and an anterior-superior portal to assess the fully posterior capsule, the diagnosis of a pHAGL is verified and concomitant injuries are treated. The posterior portal is vertically enlarged to a length of 6–8 cm. The incision is placed between the acromion part and the spinal part of the deltoid muscle. A posterior deltoid-splitting approach with deep dissection in the interval between the infraspinatus and teres minor can be used, or alternatively the raphe between the superior and inferior bundles of the infraspinatus is identified and dissected laterally to its humeral attachment. The anterior motor branch of the axillary nerve crosses the humerus horizontally about 6 cm to the lateral boarder of the acromion. To protect the axillary nerve from uncontrolled distal dissection, a stay suture may be placed at the inferior boarder of the deltoid split.

The underlying capsule and the detachment zone of the posterior IGHL is prepared, and the underlying footprint is decorticated with a motorized shaver. Suture anchors a place at the footprint and the capsular is tied keeping the arm in internal rotation and horizontal flexion [22, 49].

38.9 Complications and Hints

The incidence of recurrent instability in patients with a HAGL lesion with operative or nonoperative treatment is unknown. While conservative treatment is neglected by the recent literature, surgical treatment may result in predictable outcomes.

HAGL lesions are often missed because of the lack of visualization during MR scans without contrast agent or diagnostic arthroscopy by using standard portals, which may lead to recurrent instability after surgery.

A high index of suspicion is necessary in cases of recurrent instability after surgery without trauma and missing injury of the capsulolabral complex during arthroscopy.

If a significant HAGL lesion is diagnosed as a concomitant injury during arthroscopy, a repair is recommended to minimize the risk of recurrence.

A diagnostic arthroscopy prior to arthroscopic and open surgery is essential, concerning concomitant injuries, bony lesions, and glenoid

dysplasia or HAGL lesion variations like a floating IGHL, which need to be repaired on humeral and glenoid side to prevent recurrent instability.

An overtightened aIGHL or pIGHL during the surgical procedure yields to a limitation of internal rotation in pHAGL lesions.

To prevent glenohumeral stiffness after surgery, it makes sense to keep the arm in abduction and rotation during the fixation process of the avulsed aIGHL and horizontal abduction and internal rotation of the arm during fixation of the pIGHL to the humeral neck. Finally, the tension of the torn capsule in full range of motion should be confirmed at the end of surgery under arthroscopic visualization.

A careful positioning particularly for the anterior-inferior 5:30 o'clock portal and posterior-inferior 7 o'clock portal is necessary to prevent injuries of the axillary nerve and medial circumflex artery anteriorly or suprascapular and axillary nerve posteriorly [44].

The use of a blunt Wissinger rod is favorable compared to a sharp 18 gauge spinal needle, which may compromise neurovascular structures.

38.10 Results of Literature Review

In 1942 Nicola et al. were the first that described in the broadest sense an avulsion of the anterior IGHL in context with anterior shoulder dislocation [21].

Five decades later, Wolf established the term humeral avulsion of the glenohumeral ligament and described treatment and outcome of the aHAGL lesion. They included six patients with aHAGL lesions, which were treated by open or arthroscopic repair. No recurrent instabilities have been described after repair, and all patients returned back to sports with full range of motion [40].

Bokor et al. described five combined HAGL and Bankart lesion repairs ("floating aIGHL") by an open deltopectoral approach and total release of the subscapularis tendon and led to excellent postoperative function in all of these patients, without recurrent instability. All were able to return to their previous level of function; four athletes were able to return to their respective sports within 1 year [37].

Arciero et al. published clinical results of eight patients after mini-open repair of an aHAGL lesion. None of these patients had a recurrence of anterior-inferior instability, and all returned to their previous activity levels. He discovered no weakness of the subscapularis muscle, after reinsertion [6].

Bokor et al. performed the largest retrospective treatment study identifying posterior instability cases associated with humeral avulsion of the posterior capsule.

Out of 140 patients with recurrent posterior instability, 19 cases were treated by open or arthroscopic pHAGL repair. The average age of pHAGL patients was 23 years; all of them were male and the injury was caused by a high-velocity mechanism in all patients such as rugby (18) and a skateboard fall (1). Just the half described a glenohumeral subluxation or dislocation at the time of injury, while the others had a "dead arm" sensation or just pain only, without any direct sensation of instability. The only consistent symptom in all patients was posterior pain and discomfort. The MR reports were accurate identifying the lesion in only 50 % of all cases. Associated injuries like labral tears, Bankart ("posterior floating band") or chondral lesions, and SLAP pathologies or rotator cuff tears were common.

While several reports describe satisfying results by using arthroscopic techniques for reattachment [13, 14, 42], Bokor used a deltoid-splitting approach, using the interval between infraspinatus and teres minor muscles but did not demonstrate clinical results during follow-up [22].

Current literature of the HAGL treatment leaks in outcome evaluation, back to sport rates or postoperative activity levels after nonoperative or surgical treatment. Just one prospective study showed the results of a series of patients with failed nonoperative treatment for a shoulder dysfunction with a confirmed HAGL tear on MR arthrogram (12 aHAGL, 8 pHAGL, 3 combined lesions) that were finally elected to undergo surgical treatment.

The authors performed 9 arthroscopic and 14 open procedures and demonstrated statistically and clinically significant improved outcomes and

a predictable return to activity (91 %) and patient satisfaction [50].

Extensive capsular-ligamentous lesions on the humeral side seem to be required before dislocation can occur. This may be a factor explaining the relative paucity of HAGL in clinical series [32].

Several surgical techniques have been described for repairing aHAGL and pHAGL lesions [6, 7, 38, 40]. Comparative reports on specific treatment of aHAGL or pHAGL lesions are not available in current literature.

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Multidirectional, Microinstability, and Acquired Instability

39

Alessandro Castagna, Mario Borroni, and Giacomo Delle Rose

39.1 Indication

The first choice should be a conservative treatment.

Usually, NSADs give temporary benefits, and rehab treatment is mandatory.

It usually consists of strengthening of rotator cuff, deltoid, scapulothoracic muscles, and proprioceptive activation [1–4].

In case of failure of rehab protocol after at least 8 months, surgery must be considered.

Many procedures have been proposed in the past, starting from Neer's inferior open capsular shift [5], but the advent of arthroscopy changed the surgical approach to these disabilities.

Several arthroscopic procedures were described with variable results.

For example, thermal capsulorrhaphy has been proposed as an easy procedure with good results, but further study reported catastrophic results [6, 7].

Even hamstring graft reconstruction, glenoid osteotomy, or bone-block procedures were proposed, but the results were unsatisfactory [8, 9].

Nowadays, the golden standard procedures seem to be arthroscopic plication [10, 11] in order to restore the adequate tension of the capsular ligamentous system also associated with suture anchors as suggested by some authors [12, 13].

39.2 Techniques

The procedure can be performed in both beach-chair and lateral decubitus position. Our preference is lateral decubitus that allows an easier approach for an eventual association of posterior or posteroinferior lesions.

The patient is positioned in modified lateral decubitus (rotate the patient approximately 15–20° posterior to match glenoid anteversion), arm in traction (4 kg) at 70° abduction and 10° of forward flexion.

Standard posterior and anterior portals are performed after drawing of anatomic landmarks.

Diagnostic evaluation according to SCOI 15-point exam [14]

The procedure starts evaluating of the labrum and the identification of associated lesions (SLAP, partial rotator cuff tears, SGHL or MGHL lesions, pulley lesion). The most complex part of the procedure is the exact evaluation of the anatomy in order to not overtreat physiological variations (Buford complex, sub-labral hole) and underestimate pathologies. Nevertheless, different variations such as MGHL hypoplasia or agenesia must be treated in specific cases.

In case of intact labrum, the capsule is abraded with shaver (no suction, to involve the synovial tissue only), and then plications are created with

A. Castagna (✉) • M. Borroni • G.D. Rose
Department of Shoulder and Elbow Unit, IRCCS Humanitas, Rozzano, Milan, Italy
e-mail: acastagna@me.com

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absorbable suture (PDS#1) in order to retain the MGHL and the IGHL complex. A common tool used for the plication is the Spectrum hook system® (Conmed, Tampa FL) as described by Snyder [14], but other choices are available.

Our technique starts from posterior to anterior for a progressive balancing of the humeral head and avoiding to unbalance the capsule tension.

Aim is not to reduce capsular volume but to increase the labrum bumper associated to a balanced retentioning of the entire inferior complex including the anterior and the posterior bands of the IGHL.

If a tear of the labrum is identified during the diagnostic phase (probe must be utilized very carefully to avoid the underestimation of subtle partial lesions that could be responsible of residual painful shoulder), it is repaired with absorbable suture anchors, preferably double loaded. The number and the position of the anchors are variable and related to the specific patient findings, but a good pattern could be to place them at 1-5-7 o'clock (in a right shoulder) that means strengthening the SGHL and the entire IGHL complex.

The difference with a standard Bankart repair is that the procedure is not performed to reduce the whole volume of the joint due to the capsular shift but to balance it with the final result in a "harmonic" movement. That is guaranteed by the whole balancing of the joint recreated, thanks to a reinforced inferior complex.

39.3 Complication

Complications from MDI repair (outside of recurrent instability) are infrequent. Superficial wound infections are reported so as musculocutaneous nerve injury that resolved with observation [11]. An author reported two patients, in whom persistent pain developed over the posterior suture knot, requiring removal.

Analyzing the recurrence rate and lower rate of recurrent instability in the studies using an open technique as compared with an arthroscopic technique was reported: 11.7 % (16 of 137) versus 20 % (11 of 55). Anyway, this difference was not statistically significant. Failure in patients treated by open means was equally associated with spontaneous (five patients) and traumatic (five patients) recurrent instability [15–17].

There was a trend toward increased return to preoperative level of sports participation for patients treated arthroscopically versus those treated with open capsular shift (86 % v 80 %) [11].

In case of open capsular shift, loss of external rotation is reported, but no difference in ROM is reported after arthroscopic procedure [11].

39.4 Result Literature Review

Many papers have been written reporting results of various techniques, but probably the most significative papers are two recent systematic reviews [10, 11].

According to the authors, it is clear that open capsular shift and arthroscopic plication techniques are the two more effective procedures to address multidirectional, micro-, and acquired instability of the shoulder.

Jacobson in his review [11] reported a non-statistically significant difference in recurrence rate after surgical procedures (11.7 % with open capsular shift and 20 % after arthroscopic plications), but the number of the patients in the two groups was unpaired (137 vs. 55).

Longo in a more recent review [10] confirmed the good results of these two procedures, but with a larger and more balanced number of patients, the differences in terms of recurrence rate were very similar: 7.5 % in open capsular shift (226 patients) vs. 7.8 % in arthroscopic plications (268 patients).

Finally, both the reviews concluded that actually arthroscopic plication technique has comparable results to those of open capsular shift.

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Shoulder Instability Associated to Humeral Head Defects

40

Grégoire Ciais and Philippe Hardy

40.1 Introduction

Humeral head defects are very frequent in case of shoulder instability, defined by recurrent dislocation or subluxations. Usually, it is an anterior instability with a posterosuperior lesion also known as Hill-Sachs lesion. In rare cases of posterior instability, an anterior bony lesion can be present, called reverse Hill-Sachs or McLaughlin lesion. Both anterior and posterior lesions, in specific conditions, can be responsible for glenohumeral instability, independently of any glenoid defect. In these cases, the lesion has to be considered for a proper surgical treatment.

40.2 Indications

The presence of Hill-Sachs lesion is frequent in case of anterior shoulder instability. In the literature, different authors report a rate of 40–90 % of patients presenting glenohumeral dislocation [1–4]. In some cases, the size of the defect can lead to an engaging lesion and induce recurrent instability. It depends also on the location of the defect. It is difficult to determine when a Hill-Sachs lesion has to be treated properly and independently of the glenoid aspect. Many authors have studied the parameters that could indicate if a lesion is engaging.

Burkhart and De Beer [5] defined the concept of engaging lesion, when the humeral bone defect is in front of the anterior glenoid rim with the arm in abduction and external rotation. In that position, the glenoid rim can engage in the humeral lesion and lead to recurrent dislocation (Fig. 40.1). Even if there is no universally accepted method to determine the critical defect size, different measuring techniques were described. Hardy and Conso [6] measured on anteroposterior and medial rotation radiograph

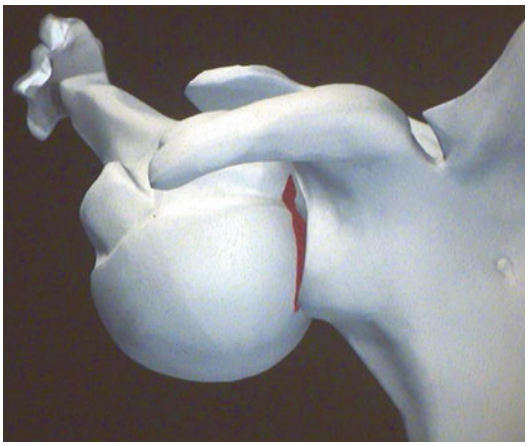

Fig. 40.1 Engaging lesion

G. Ciais, MD • P. Hardy, MD, PhD (✉)
UFR Paris Ile de France Ouest, Université de Versailles Saint-Quentin en Yvelines, Hopital Ambroise Paré, 9 Avenue Charles de Gaulle, Boulogne-Billancourt 92100, France
e-mail: philippe.hardy@apr.ap-hop-paris.fr

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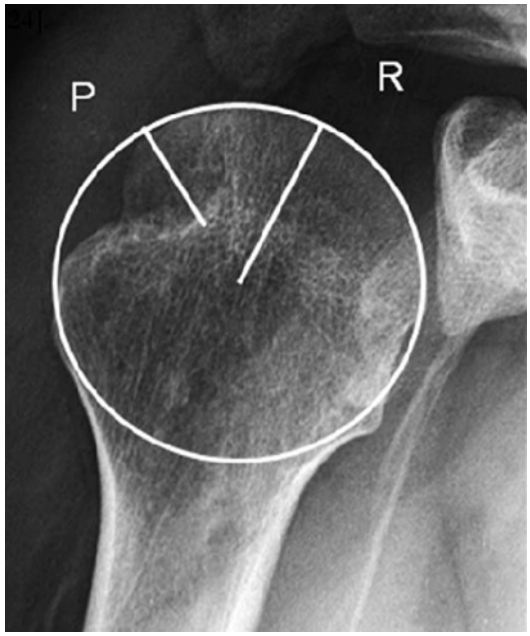

Fig. 40.2 P/R measuring method described by Hardy

the Hill-Sachs depth (D) and the humeral head radius (R) (Fig. 40.2).

The study concluded that there was a higher risk of recurrent dislocation if the ratio D/R was superior to 15 %. Itoi [7] proposed the measurement of the Hill-Sachs lesion with plain radiographs with the arm in 135° flexion and medial rotation 15°. The risk of recurrent dislocation is important if the lesion depth is superior to 3.9 mm. Burkhart [8] proposed an arthroscopic evaluation of the bone lesions and a preoperative testing to assess if it is engaging or not. But this technique is complicated to use for surgical procedures that need preoperative planning and decision (Fig. 40.3). Some authors [9, 10] used the computerized tomography (CT) scan and the magnetic resonance imaging (MRI) to evaluate the size, position, and depth of the lesion (Fig. 40.4). Kirkley [11] found a correlation between MRI and arthroscopic evaluation of the lesions. Boileau [12], in the ISIS score, considers that a humeral defect is significant if present on AP in lateral rotation radiographs. In case of ISI score >3 and no bony lesion on the glenoid, a remplissage is indicated in association with arthroscopic Bankart repair.

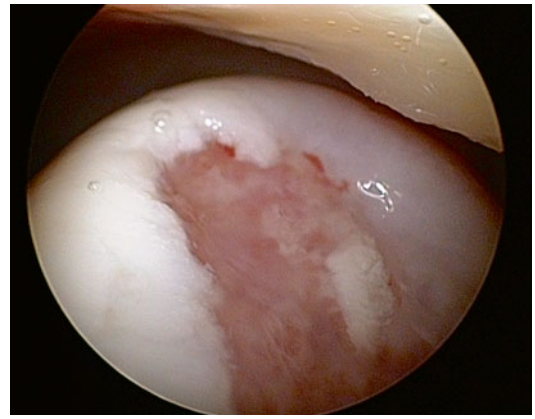

Fig. 40.3 Arthroscopic view of engaging lesion

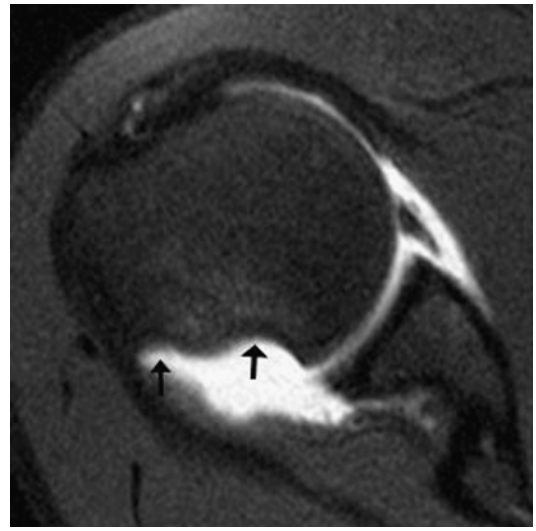

Fig. 40.4 Hill-Sachs lesion on MRI

In the literature, surgical indications for humeral lesions remain controversial. But usually authors consider that if it represents between 20 % and 40 % of the humeral head, a specific treatment has to be proposed. In case of lesion greater than 40 % of the humeral head or fracture dislocation with important bone block, a specific treatment is mandatory.

Most of Hill-Sachs lesions can be addressed with a remplissage technique, which is the most commonly used technique nowadays. This can be explained by the fact that it is an arthroscopic procedure that can be done in the same time of a

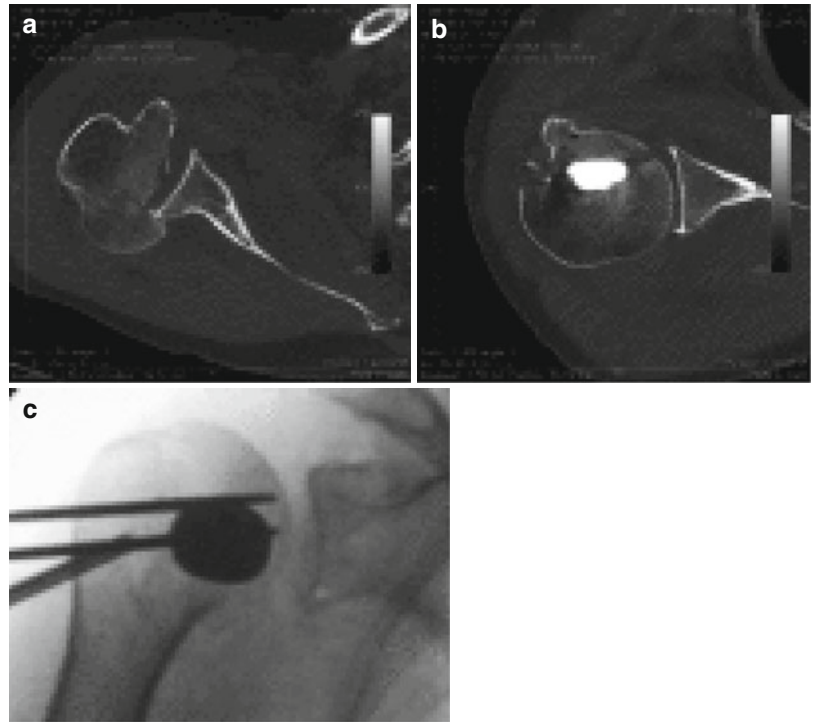

Fig. 40.5 Percutaneous humeroplasty. (**a**) Preoperative tomography. (**b**) Postoperative tomography. (**c**) Intra-operative X-ray control

Bankart repair. When a Latarjet procedure is indicated, a treatment of the humeral lesion is rarely indicated because the coracoid process transposition is sufficient to stabilize the glenohumeral joint.

If a remplissage is not indicated, another technique has to be elected depending on many criteria: the age of the patient, the size and location of the lesion, the quality of the bone, and the associated lesions.

For reverse Hill-Sachs lesions, the literature is poor. Moroder [13] in a cadaveric study found the same importance of size and location of the defect to predict the risk of chronic instability.

40.3 Techniques

Many procedures have been described, and the choice of the technique to address symptomatic Hill-Sachs lesion will be based on the delay from initial trauma, the size of head defect, and the patient age.

40.3.1 Humeroplasty

In case of acute lesion (<3 weeks), a humeroplasty with bone disimpaction can be performed with open surgery or percutaneously using a kyphoplasty balloon. It can be useful in case of bone loss inferior to 40 % of articular surface. Humeroplasty can be either used for posterior or anterior bone lesions, in case of posterior instability [14] (Fig. 40.5).

40.3.2 Remplissage

This technique was first described by Connoly [15], as a transfer of the infraspinatus tendon in the humeral defect with an open procedure. The technique which is used nowadays was described by Wolf [16], consisting in an arthroscopic tenodesis of the infraspinatus in the Hill-Sachs lesion associated with an anterior capsulolabral repair. By covering the humeral bone loss with soft tissues, the defect becomes extra-articular and prevents engagement with the anterior glenoid rim.

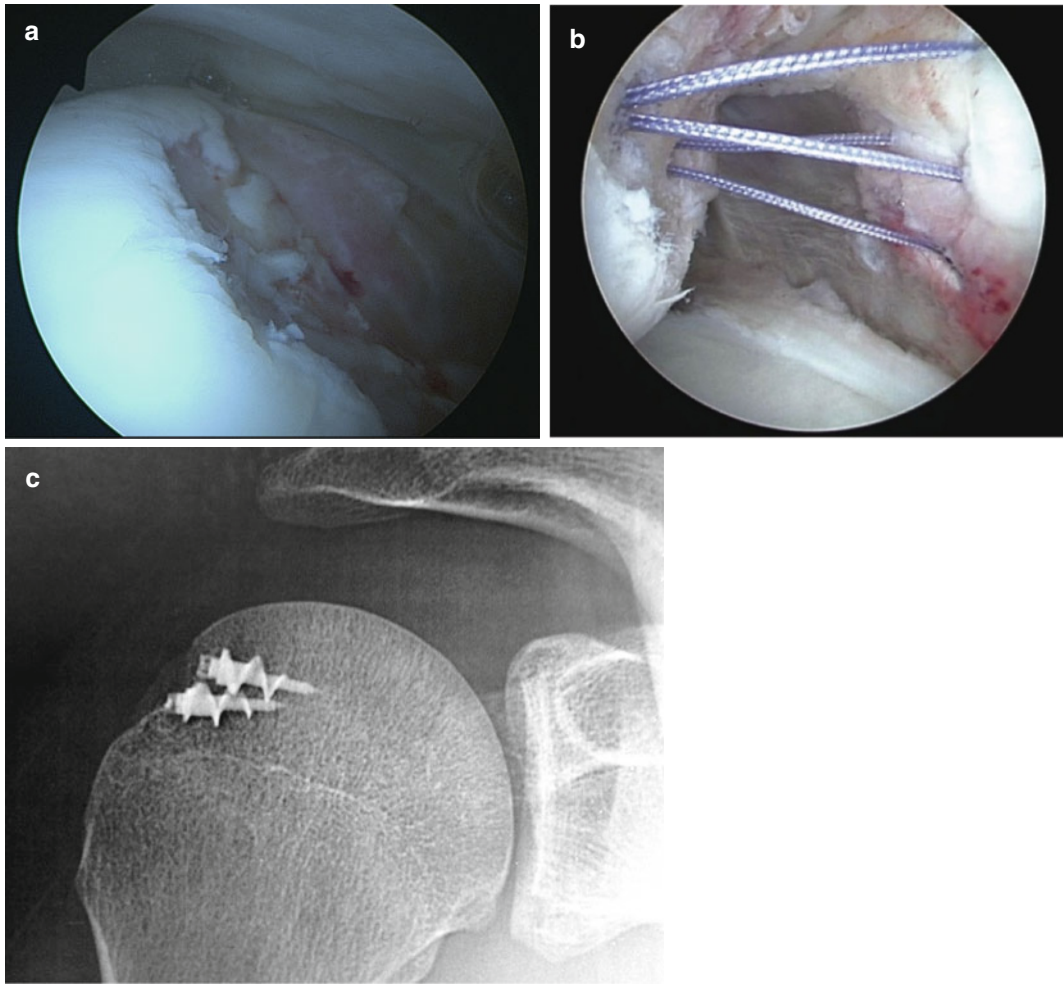

Fig. 40.6 Arthroscopic remplissage technique. (**a**) Hill-Sachs lesion preparation. (**b**) Double pulley with anchors. (**c**) Radiograph with two anchors fixing the infraspinatus tendon

The tenodesis is usually performed with two anchors inserted in the lesion, but in some case of large humeral defects, it can be useful to use more anchors in order to optimize the soft tissues coverage (Fig. 40.6).

40.3.3 Humeral Bone Loss Grafting

This technique can be used in young patients presenting bone loss inferior to 40 %. In most cases, the defect is filled with an osteochondral allograft, using a side and size-matching humeral head. The Hill-Sachs lesion is exposed with a deltopectoral approach, allowing if necessary to perform glenoid and/or capsulolabral repair in the same time. The Hill-Sachs lesion is osteotomized to prepare the allograft fitting. In some specific cases, a mosaicplasty can be used to address chondral defects (Fig. 40.7).

40.3.4 Partial Humeral Head Resurfacing

It can be used in the same indications of allograft in older patients. The operative technique is similar, but the defect is corrected by a round

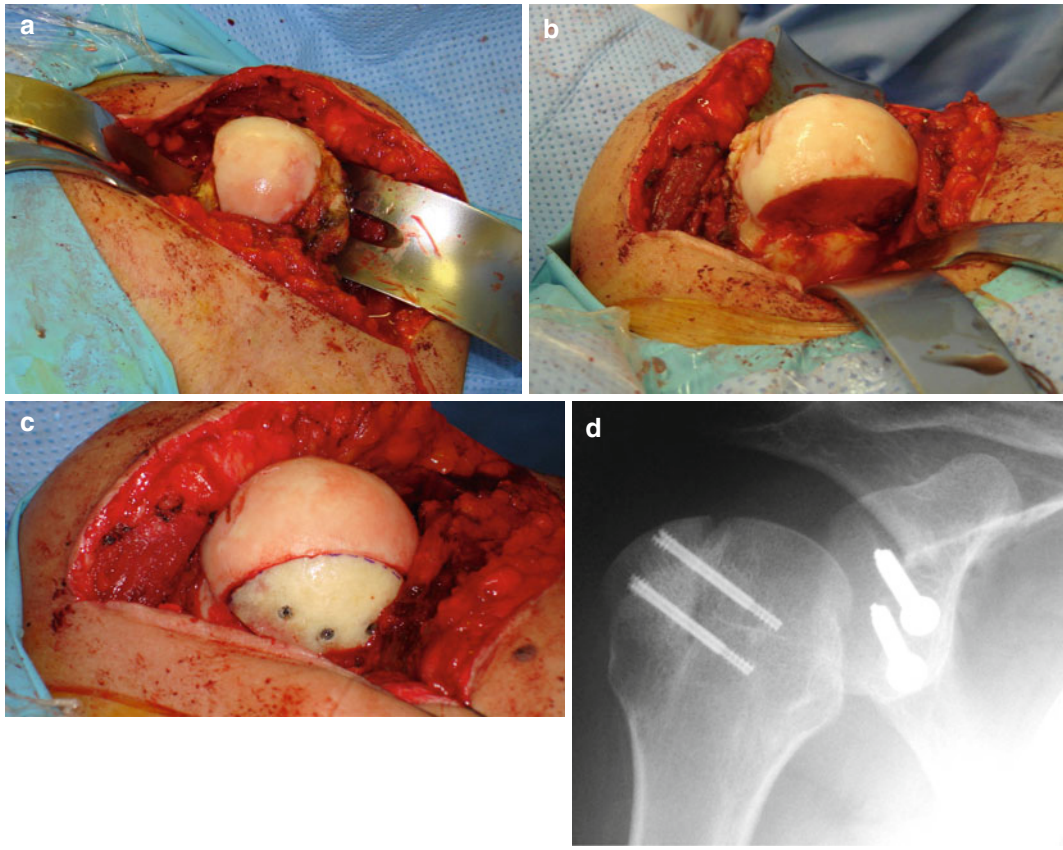

Fig. 40.7 Humeral bone allografting of Hill-Sachs defect. (**a**) Humeral head defect exposed. (**b**) Humeral head osteotomized. (**c**) Humeral head with allograft fixation with screws. (**d**) Radiograph showing humeral head graft associated with Latarjet procedure

cobalt-chrome articular component that is placed in the humeral head defect. This technique is not indicated in osteoporotic patients or with insufficient bone stock, because a good quality and density of bone are mandatory to obtain a good component fixation.

40.3.5 Hemiarthroplasty or Total Shoulder Arthroplasty

In case of bone loss superior to 40 % and preferably in elderly patients, a prosthesis is preferred, which type depends on humeral, glenoidal, and cuff lesion. In case of concomitant glenoid erosion, a total shoulder arthroplasty will be preferred.

40.4 Complications

Complications that are not specific to these techniques, like infectious, vascular, and nervous complications, will be not discussed in this chapter.

The specific complications depend on the kind of surgical procedure used to address the humeral lesion.

40.4.1 Humeroplasty

This technique is indicated in acute lesions; otherwise, the disimpaction of humeral defect by the balloon will be more difficult to obtain. If a

complementary fixation with cement is done, there is a risk of articular cement outflow.

40.4.2 Remplissage

Main complications are stiffness and posterior pain due to the over-tensioning of infraspinatus tendon tenodesis. If the suture pathway is too medial, it increases the risk of restriction in external rotation and less frequently in internal rotation.

40.4.3 Humeral Bone Loss Grafting

Main complications are those of allograft, infectious disease transmission, graft resorption, and nonunion. Usually, the bone block is fixed with screws that can be responsible of discomfort and lead to revision surgery to remove it.

40.4.4 Partial Humeral Head Resurfacing

This technique requires a sufficient bone stock and density; otherwise, a prosthesis loosening can occur. Depending on the defect location, it can also be responsible of glenoid erosion because of the contact between metallic hardware and glenoid cartilage.

40.4.5 Hemi or Total Shoulder Arthroplasty

The complications are similar to other indications, like infection, loosening, dislocation, and periprosthetic fracture.

40.5 Literature Review/Results

The most commonly used technique is remplissage. Merolla et al. [17] reported outcomes of Hill-Sachs remplissage on 61 patients. A significant decrease of external rotation and internal rotation was found compared to a control group without affecting quality of life. In their series, only one case of recurrent instability was observed. Cho [18] made a comparative study in patients with engaging Hill-Sachs lesion, with a group treated by isolated Bankart repair and another group treated by Bankart and remplissage. The mean deficit in external rotation was 3°±10° in the Bankart group versus 8°±23° in the remplissage group. There was no decrease in muscle strength in either group. But the recurrence rate was 25.7 % in the Bankart group and 5.4 % in the remplissage group. Buza [19], in a systematic review of patients who underwent remplissage procedure (6 studies, 167 patients), concludes to good to excellent functional results with low rate of complications and no significant restriction of motion.

Concerning percutaneous humeroplasty, two cadaveric studies report a good reduction of bone impaction. Stachowicz [20] regained 99.3 % of the volume of the initial defect, and Kazel [21] reduced the lesion from 1.755 to 50 mm^3. Jacquot [14] used a percutaneous technique for reverse Hill-Sachs lesion also known as McLaughlin lesion in three patients with posterior fracture dislocation. He reports good clinical and radiological results, with no recurrent dislocation.

Saltzman [22] made a systematic review of humeral osteochondral allograft. In his meta-analysis, 12 studies were included, representing 35 patients, with 33 patients treated for large Hill-Sachs lesion (mean size 3 ± 1.4 cm). Three patients received fresh grafts, and all others received frozen allografts (humeral, femoral, or osteochondral plugs). In most of cases, significant improvement of functional outcomes was obtained but with high rate of complications (20–30 %) and reoperation (26.67 %). Allograft resorption occurred in 36.2 %, necrosis in 8.7 %, and glenohumeral arthritic changes in 35.7 % of cases. Results seemed to be better in the three patients who received fresh grafts. Puskas [23] made a cadaveric biomechanical study to assess two types of humeral allograft fixation. He compared anterograde and retrograde screw fixation on eight pairs of fresh-frozen humeral heads. Both fixation types provide good results with mean displacement of 0.9 mm for anterograde

and 1.1 mm for retrograde fixation after 500 cycles at 10, 20, 30, and 40 N.

Very few data are available in the literature concerning partial head resurfacing. Grondin and Leith [24] report two cases with pretty good outcomes but with only 1-year follow-up. They used a HemiCAP implant on the humeral defect associated with a Latarjet procedure on the glenoid side. Moros and Ahmad [25] reported one case treated with the same method and obtained a good result at 10-year follow-up.

Giles et al. [26] made an in vitro biomechanical study to compare three different types of treatment for large Hill-Sachs lesions: remplissage procedure, allograft humeral head (AHH) reconstruction, and partial resurfacing arthroplasty (PRA). Stability was obtained in all specimens with AHH and remplissage but still engaged in 62 % of cases with PRA. Remplissage was the best technique to prevent engagement but caused reduction of range of motion in internal/external rotation and abduction.

In case of large humeral lesions, representing more than 30 % of the head surface or in situation of osteoporotic bone, a prosthetic treatment can be indicated. Depending on the type of lesion and the patient, it can be a humeral head resurfacing, a hemiarthroplasty, or a total shoulder arthroplasty (TSA). In the literature, authors [27, 28] suggest to avoid resurfacing if the defect is superior to 40 % or in case of insufficient bone stock. In osteoporotic patients, a stemmed prosthesis provides a better fixation and avoids the loosening of resurfacing implant. The decision between hemiarthroplasty and TSA will be oriented by the status of the glenoid and the age of the patient.

Conclusion

In specific conditions, the Hill-Sachs lesion can play an important role in shoulder instability and lead to recurrent dislocation regardless of glenoid lesion. The type of treatment remains controversial, but if the lesion is engaging and represents less than 30 % of the humeral head surface, the remplissage will provide satisfying functional outcomes with minor motion restriction. If the defect is wider, the decision will be oriented by the age of the patient and the quality of bone stock. The humeral allograft of resurfacing will be preferred in younger patients and the prosthetic treatment in elderly patient with osteoporotic bone. The literature is still lacking of important series of patient and follow-up to be sure of the best technique.

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Subacromial Impingement Syndrome

41

Giuseppe Sforza and Paolo Consigliere

41.1 Subacromial Impingement

Fifty percent of the general population experience shoulder pain every year [1]. Subacromial impingement syndrome (SAIS) is the most common disorder of the shoulder, accounting for 44–65 % of all complaints of shoulder pain [2].

In a Dutch study, the incidence of new cases of rotator cuff tendonitis in general practice was found to be around 3.2–4.2 per 1,000 person-years, and the corresponding incidence of shoulder pain (all causes) was 11.2 per 1,000 person-years [3]. Its prevalence is especially high in sports with overhead activity, such as swimming, volleyball, handball, and badminton. These overhead athletes have a high demand for optimal shoulder performance, and dynamic stability is required in order to prevent injury [4].

Shoulder impingement results from an "inflammation and degeneration of the anatomical structures in the region of the subacromial space" [5].

For many years, it has been thought that the anatomical basis was a mismatch between the structures in the subacromial space (Table 41.1).

Neer applied the phrase "impingement syndrome" in 1972 when he described the mechanism involved in this disorder [6]. It has been described as a chronic repetitive mechanical process in which the conjoint tendon of the rotator cuff undergoes repetitive compression and microtrauma as it passes under the coracoacromial arch [7]. As the arm is abducted or rotated, the subacromial space width changes and the cuff become increasingly compressed (Fig. 41.1a, b). The supraspinatus is in closest contact to the anterior inferior border of the acromion in 90° of abduction with 45° internal rotation [8].

In athletes where repetitive overhead activity is required, the act of throwing may subsequently lead to the pathological process outlined by Neer. Secondary impingement is usually associated with repetitive overhead activity resulting in glenohumeral instability [9, 10] (Table 41.2).

A recent study [13] focuses attention on the role of degeneration of the rotator cuff tendons, eventually giving rise to the development of tears.

A direct relationship between the anatomical substrate, functional load, and pain is not always explicitly present.

G. Sforza, MD, MCh (Orth) (✉)
Berkshire Independent Hospital and Ashford and St. Peter's Hospitals, Reading Shoulder Unit, Reading, UK
e-mail: gsforza99@yahoo.it

P. Consigliere, MD, MCh (Orth)
Berkshire Independent Hospital and Ashford and St. Peter's Hospitals, Surrey, UK
e-mail: paoloconsigliere@gmail.com

Table 41.1 Neer's classification: stages of subacromial impingement [33]

Stage 1: edema and hemorrhage, age <25, reversible
Stage 2: fibrosis and tendinitis, age 25–40, recurrent pain with activity
Stage 3: bone spurs and tendon rupture, age >40, progressive disability

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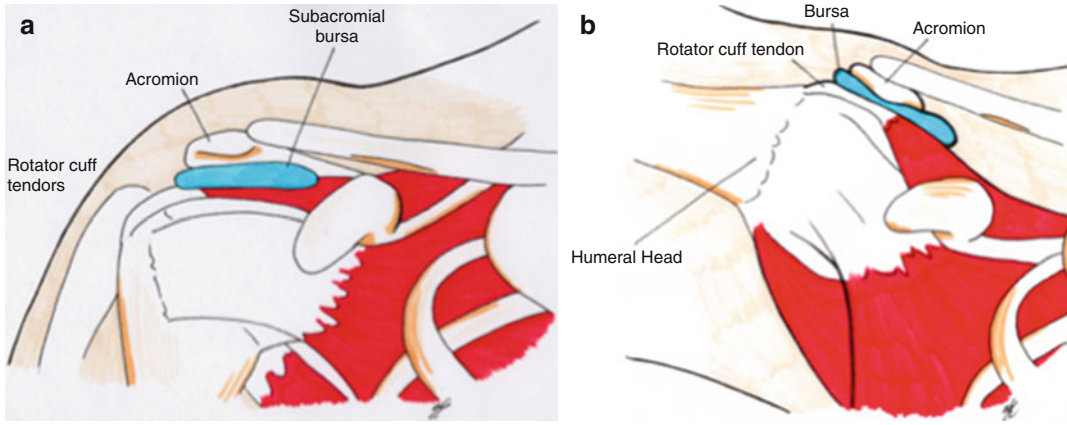

Fig. 41.1 Anatomy of the subacromial space. (**a**) Humeral head, rotator cuff, subacromial bursa, acromion. (**b**) Impingement mechanism during abduction of the humerus

Table 41.2 Jobe's classification (1989): stages of subacromial impingement in athletes

Stage 1: pure impingement with no instability
Stage 2: primary instability with capsular and labral injury with secondary impingement which can be internal impingement or subacromial
Stage 3: primary instability because of generalized ligamentous laxity with secondary impingement
Stage 4: pure instability and no impingement

The supraspinatus tendon is often the most involved tendon of the rotator cuff in shoulder impingement. It mainly derives its blood supply from the anterior circumflex humeral and suprascapular arteries. Within the supraspinatus tendon, near its insertion at the greater tuberosity, there is an avascular area also called "critical" zone. It is here that "impingement" usually occurs, and this zone has been found to increase in size with advancing age [14].

From the analysis of the recent literature [15], it seems likely that the imbalance and fatigue of the rotator cuff muscles (depressant action on the humeral head) lead to proximal migration of the humeral head during shoulder abduction/rotations.

Although this is probably the most accredited theory [21], other authors focused their attention also on the cinematic of the scapula in the last years. Ludewing et al. studied the role of the periscapular muscles during shoulder abduction. An imbalance/fatigue of periscapular muscles (scapular dyskinesia) may play a role in shoulder impingement. In patients with SAIS, a late activation of the lower trapezius (LT) and the serratus anterior (SA) and an early recruitment of the upper trapezius fibers (UT) lead to a narrowing of the subacromial space during shoulder abduction [16, 17]. A review of the literature on these topics (Struyf et al.) confirmed that patients with shoulder impingement have a decreased upward scapular rotation, a decreased posterior tilt, and a decreased external rotation [19, 20], due to an imbalance of the periscapular muscles. J. Lewis, instead, studied the role of the posture in patients with SAIS. "Forward head and shoulder posture" (increased thoracic kyphosis and forward shoulder posture) can't be considered the cause of subacromial impingement, but patients with an altered posture experienced pain at a reduced range of movement (ROM) during abduction/forward flexion of the shoulder [18].

Outcomes of arthroscopic decompression in these patients are not reported in the literature as most of these patients respond to an appropriate rehabilitation program focused on recovery of the scapulothoracic rhythm and correction of posture. However, good outcomes are observed in patients in which physiotherapy failed (minimum 6 months of physiotherapy) to regain a balance in periscapular muscles and improve symptoms. To explain these positive results, the authors conjectured that a deafferentation of the subacromial area allows a successful proprioceptive

reeducation of the shoulder movements with a modification of nociceptive stimuli (all the neurological causes of scapula dyskinesia must be excluded before arthroscopic subacromial decompression (ASD) is performed).

41.1.1 Diagnosis: Clinical

A recent systematic review concluded that several clinical shoulder tests have sufficient sensitivity but inadequate specificity [22]. Neer's sign and Hawkins' impingement tests, in particular, have been found useful in confirming SAIS but poor at ruling out pathology [23, 24]. Neer's and Hawkins' tests were found to have a sensitivity and specificity of 79 % and 53 % and 79 % and 59 %, respectively. No shoulder tests can by themselves confirm impingement [22].

A recent prospective study of patients admitted for surgery, however, found Neer's sign, the painful arc test, and the external rotation resistance test to be excellent screening tools to rule out SAIS [25].

The fundamental tests to rule out SAIS are:

Painful arc test: The patient is instructed to actively elevate the arm in the scapular plane and then slowly reverse the motion. The test is considered positive if the patient has pain between 60 and 120° of abduction.

Neer's sign: Subject is sitting. The scapula is fixed/stabilized in a depressed position, while the shoulder is maximally forwardly flexed.

Hawkins' test: Subject is sitting on the examination table. The shoulder is placed in 90° of forward flexion and passively internally rotated as far as possible (elbow flexed 90°).

Yocum test: The hand of the painful shoulder is placed on the opposite shoulder; the arm is flexed at 90° in the coronal plane. The elbow is pushed downward, while the patient is making active resistance. This is another test with high sensitivity but low specificity.

Jobe's sign: The examiner passively elevates the patient's shoulder to 90° of elevation with internal rotation. The examiner then applies a downward pressure against the arm. A positive test is the provocation of pain and abnormal weakness.

External rotation resistance test: Shoulder pain during forced external rotation of the shoulder against resistance (arm adducted, elbow flexed 90°). A modification of this test can also be used; the lack test is performed bringing the forearm of the patient to 60° of external rotation, asking the patient to hold the position. The test is positive if the patient can't hold the position. It reveals a weakness/tear of the posterosuperior RC.

Posterior impingement sign: Patient with the shoulder in 90° of abduction and elbow in 90° of flexion. Examiner stabilizes elbow and applies external rotation (ER) force to maximum ER.

Coracoid impingement test: Pain directly over the coracoid with arm passively adducted across chest (distinguish from acromioclavicular joint (ACJ) scarf test in which the pain is felt in the ACJ).

Visual assessment of the ROM is appropriate only for distinguishing between the affected and the contralateral side. Even when using a goniometer, which can increase the reliability of the measurements, the measurement error remains high; this is useful to detect capsular stiffness, particularly of the posteroinferior area, that might generate upward translation of the humeral head and secondary subacromial impingement.

In selecting an outcome instrument, it is important for the scale to have been validated in the language of the patients and the examiner. The simple shoulder test (SST) and the Oxford Shoulder Score (OSS) are instruments with relatively few questions and are easy to use. The Dutch Shoulder Disability Questionnaire (DSDQ) with 16 questions is a medium-length questionnaire and is also easy to use [13]. The Constant-Murley Shoulder Outcome Score (CS) is still probably the most commonly used outcome measure for assessing the outcomes of the treatment of shoulder disorders including subacromial impingement [26]. It has the benefits of including an objective measurement of strength, and in this it differs from other scores, in combination with pain score, functional assessment,

and range of motion. Several critics have been moved to this test about sensibility, interobserver reliability, etc. The Western Ontario Rotator Cuff Index (WORC) was developed for use as a primary outcome measure in clinical trials evaluating treatments and was comprehensively tested during development. The final set of questions was selected by determining the most important factors from a patient's perspective [27].

41.1.2 Investigation: Instrumental, Radiological

X-rays are the basis for investigating the painful shoulder and a shoulder impingement syndrome. They may demonstrate subacromial sclerosis or spurs (hooked acromion) and anomalies of the acromion (os acromiale), sclerosis of the greater tuberosity and undersurface of the acromion, and reduced subacromial space with a proximal migration of the humeral head if associated with a torn or dysfunctional rotator cuff. They are also important in the differential diagnosis of SAIS as could demonstrate calcifying tendinitis, fractures, and neoplasm. Both anteroposterior and axillary views should always be asked (Fig. 41.2).

Ultrasound (U/S) has been widely used for the evaluation of the shoulder, mainly for rotator cuff pathology. Ultrasonographic evaluation for rotator cuff tears were first described by Crass and Middleton in 1984 [28]. It has been shown to be a sensitive and accurate method of identifying patients with subacromial bursitis or full-thickness tears of the rotator cuff, and dynamic ultrasound can help confirm, but not exclude, a clinical diagnosis of impingement.

Although relatively inexpensive and noninvasive evaluation tool, the main issues regarding ultrasound relate to the interobserver variability in the demonstration of rotator cuff tears (Table 41.3).

Magnetic resonance (MR) arthrography is the most sensitive and specific technique for diagnosing both full- and partial-thickness rotator cuff tears that can be combined with subacromial impingement. U/S and MRI are comparable to each other in both sensitivity and specificity in

Table 41.3 Milgrom's ultrasound classification: grading of impingement changes

Stage 1: bursal thickness 1.5–2.0 mm
Stage 2: bursal thickness over 2.0 mm
Stage 3: partial- or full-thickness tear of the rotator cuff

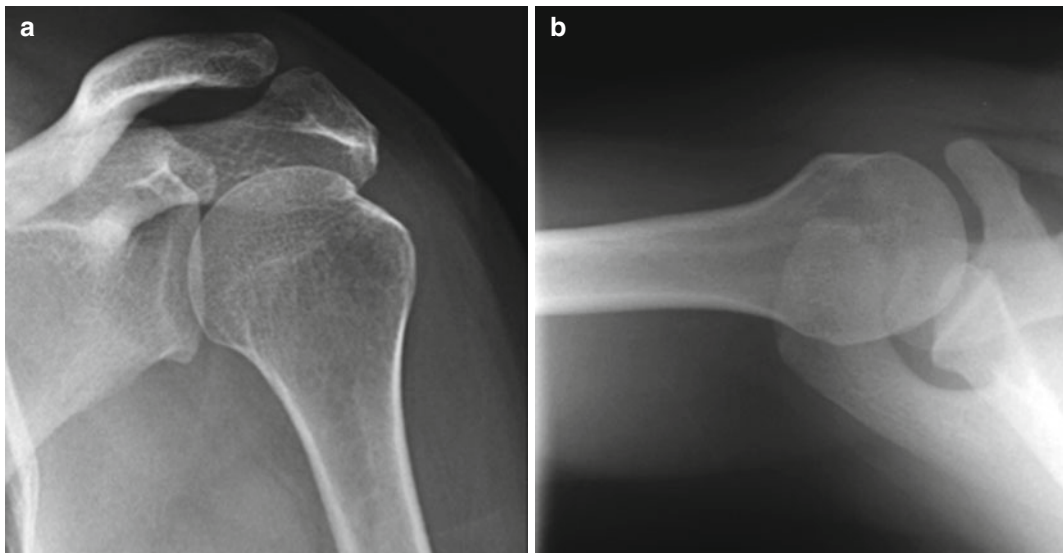

Fig. 41.2 Shoulder X-ray with signs of impingement. (**a**) Anteroposterior view, (**b**) axillary view

Table 41.4 Bigliani classification: grading of acromion deformities

Type 1: acromion is flat in shape
Type 2: more curved acromion, which lies parallel to the humeral head
Type 3: the edge of the acromion is hooked

the diagnosis of full-thickness rotator cuff tears but are rarely requested if just SAIS is suspected [13].

Although the indication for acromioplasty is based on clinical evaluation of the patient, it is generally supported by typical changes in acromial morphology on standard radiographs [6, 7, 96]. The most common classification is the one by Bigliani et al., but several attempts have been made to classify the acromial morphology (Table 41.4) [7].

Bigliani et al. [7] and Kitay et al. [97] described the *acromial slope* (AS; Fig. 41.3a), and Kitay et al. [97] and Aoki et al. [96] described the *acromial tilt* (AT; Fig. 41.3b). Other authors have focused on the lateral rather than the anterior extension of the acromion: Banas et al. [98] described the frontal plane slope of the acromion on MRI and found a lower *lateral acromial angle* (LAA; Fig. 41.3c) in patients with rotator cuff disease; Nyffeler et al. [99] observed that the acromion, of patients with a rotator cuff tear, appeared to have a more lateral extension than that of patients with an intact cuff and described the *acromion index* (AI; Fig. 41.3d) [29].

However, in the last years, this classification started to be discredited. Some authors [11, 12] reported that there are no close correlations between type III acromions and cuff ruptures and that spurs on the acromion deep surface, found mainly in old people, can't be related without any doubt with subacromial impingement.

41.1.3 Treatment Indications

Improved function can be obtained through reduction of inflammatory edema, strengthening of the muscles, which act as depressors and stabilizers of the humeral head, or by removing the inflamed and fibrotic tissue in the subacromial bursa and a part of the acromion itself. Treatment options, hence, can be conservative or surgical. Conservative management includes exercise therapy, ultrasound treatment, and subacromial injections.

Studies show that conservative management of shoulder impingement syndrome resolves the problem in 70–90 % of patients [32]. In symptomatic patients, a course of conservative management is widely accepted as first-line management, but the time frame for this is variable and a point of controversy. Furthermore, the condition is often treated conservatively in the primary healthcare sector by general practitioners or physiotherapists [33]. Most surgeons generally tend to observe patients for a 6-month period before considering surgery; however, based on individual patient factors, this can vary.

Exercise is seen to be an effective treatment for SAIS [34, 35]. Several authors reported in the past that physiotherapy aimed at strengthening the muscular motors and stabilizing the shoulder joint renders satisfactory results especially in patients aged under 60 and represents a cost-effective treatment. Different exercise regimens include supervised exercise, home exercise programs, and exercise associated with manual therapy.

Massage (myofascial trigger points in the shoulder muscles or soft tissue) appears to be more effective than placebo or no treatment in reducing pain and improving shoulder function in patients with shoulder pain. However, manual joint mobilizations have no added benefit to a program of active exercises in reducing pain and improving shoulder function.

Subacromial injections can be used to treat SAIS. A rotator cuff tear (RCT) showed that methylprednisolone conferred significant benefits on patients' symptoms and was effective in improving range of abduction at 6 weeks postinjection [36]. Literature reported that subacromial steroids were better than placebo in improving the range of abduction. The authors reported that the duration of benefit of subacromial corticosteroid injections appears to be from 3 to 38 weeks [37]. However, a RCT by Crawshaw et al. concluded that corticosteroid injections combined with exer-

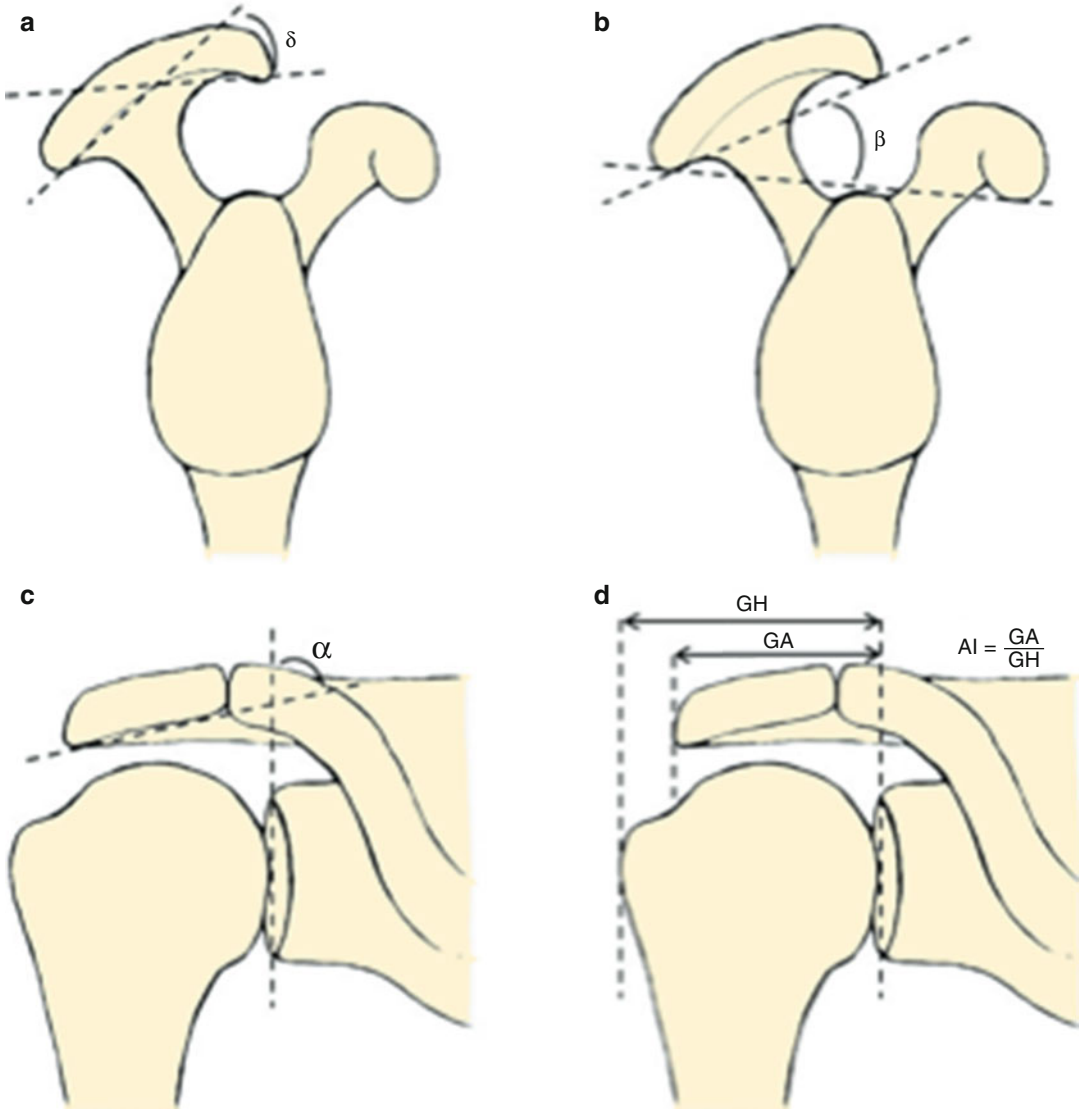

Fig. 41.3 Overview of parameters of acromial morphology. (**a**) Acromial slope AS (**d**) according to Bigliani et al. (1986) and Kitay et al. [97]; (**b**) acromial tilt AT (**b**) according to Kitay et al. [97] and Aoki et al. [96]; (**c**) lateral acromial angle LAA (**a**) according to Banas et al. [98]; (**d**) acromion index (AI) according to Nyffeler et al. [99], [12]

cise were only successful in achieving short-term benefit, and [2] long-term results (2-year follow-up) showed no differences with manipulation and physiotherapy (half of the patients experienced recurrent complaints). In a recent study, 232 participants were randomized and divided in two groups: injection plus exercise and exercise only groups resulted similarly effective at 12 weeks, with no differences at week 24 [37].

Oral NSAIDs appear to be more effective than placebo in reducing pain in the first 1–2 weeks, but don't control pain in a long term [13].

Laser treatment (of all types) appears to be more effective than placebo or ultrasound treatment in reducing pain after 2–4 weeks [13].

Acupuncture treatment appears to have a good effectiveness in pain management but not a long-term effectiveness [13].

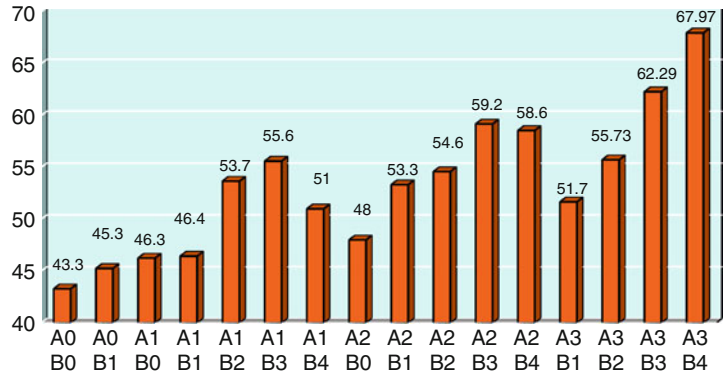

Fig. 41.4 Age – impingement lesions (Levy-Copeland classification)

When conservative treatments fail, surgical procedures are recommended. However, there isn't a consensus in the literature of the indications with regard to the age of the patient. Some authors say that patients, suffering from isolated subacromial impingement and resistant to conservative therapies, benefit substantially from surgical decompression if they are young (<60 years). In fact, although physical demands decrease notably in older population, it still remains unclear if surgery leads to better results in these patients [61]. Other authors had different results and reported that in elderly patients (>60 years), arthroscopic decompression leads to better outcomes than conservative treatment, while in young patients, it is possible to achieve equivalently good to excellent results for both treatment regimens [64].

Recently, Sforza et al. presented a study on 421 arthroscopic decompressions. They reported the correlation of the impingement symptoms and the age of the patients (Fig. 41.4).

They also reported the correlation of clinical results of subacromial decompression in different rotator cuff tear sizes. The results of their study showed worse outcomes in patients with RCT >3 cm (medium size) if compared with patients with RCT <3 cm that have undergone ASD alone. In these patients, an arthroscopic repair of the lesion would be recommended even in the older population [65].

In athletic or young individuals (<40 years), instead, especially with recent trauma and dysfunctional damaged rotator cuff, surgical intervention should be considered at an earlier stage as successful repairs allow this particular group to return to pre-injury level of function [87, 88].

Subacromial decompression doesn't seem to have an indication in frozen shoulder. A study presented in 2012 on 29 nondiabetic patients showed no further medium-term functional benefits in patients that underwent subacromial decompression in addition to a standard arthroscopic capsular release [94].

Regarding the need of performing an ASD in patients with a RC tear, recent literature reviews report that RC repair gives a new balance and strength to the RC muscles, which prevent superior migration of the humeral head and, thus, relieves the patient from impingement symptoms. However, some authors promote ASD as a source of growth/angiogenic factors (matrix metalloproteinases MMP-2 and MMP-9) that may improve the healing process of the tendons [89]. Moreover, ASD, increasing the subacromial space, allows a safer rehabilitation process avoiding conflicts between the acromial spur and the sutures applied to the rotator cuff.

In the past, patients with calcific tendonitis usually underwent to ASD, as literature reported that subacromial decompression was the primary procedure to perform in patients with subacromial impingement and calcific tendonitis. A study, dated 1998, reported good outcomes and a complete disappearance of the calcific deposits (postoperative shoulder X-rays) in 97 % of the patients treated with ASD alone (calcific deposits were left untouched) [66]. Anyway recent studies report that patients treated by debridement of the calcific deposit alone without a concomitant

subacromial decompression required a shorter time to return to unrestricted activity without pain and to the same function [67].

41.1.4 Surgical Techniques

With regard to surgery in shoulder impingement, the two structures that need to be addressed are the acromion and the rotator cuff itself. Neer was the first to popularize acromioplasty for the treatment of shoulder impingement (Fig. 41.5). He emphasized that resecting the anteroinferior portion of the acromion would increase the volume of the subacromial space and therefore decrease the degree of impingement of the supraspinatus tendon under the acromion. Neer, also, described the indications for acromioplasty as being long-term disability from chronic bursitis and either partial tears or complete tears of the supraspinatus [6–30].

Today, arthroscopic subacromial decompression (ASD) is the gold standard to surgically treat this pathology. The procedure includes debridement of the subacromial bursa, resection of the coracoacromial ligament, and the anteroinferior acromion, as well as any underhanging osteophytes from the acromioclavicular joint [39].

ASD nowadays is more spread and adopted because of less morbidity: the possibility to perform it through arthroscopic portals reduces infection rate and the risks of neurovascular damages; improvements gain in anesthesia play an important role in pain management and safety of the procedure. It can be performed in lateral or beach chair position. A standard glenohumeral arthroscopy is performed via the posterior portal. This enables assessment of the undersurface of the rotator cuff. The scope is then withdrawn and inserted into the subacromial bursa. The bursa itself is then carefully inspected. First, the bursal surface of the rotator cuff is inspected to confirm the presence of an impingement lesion of this area and subacromial surface ("kissing" lesion).

Many techniques were described to perform ASD. In 1994, Snyder presented the *cutting block technique* (Fig. 41.6) [40].

Through the posterior portal, a large full radius resector is passed for bursal resection,

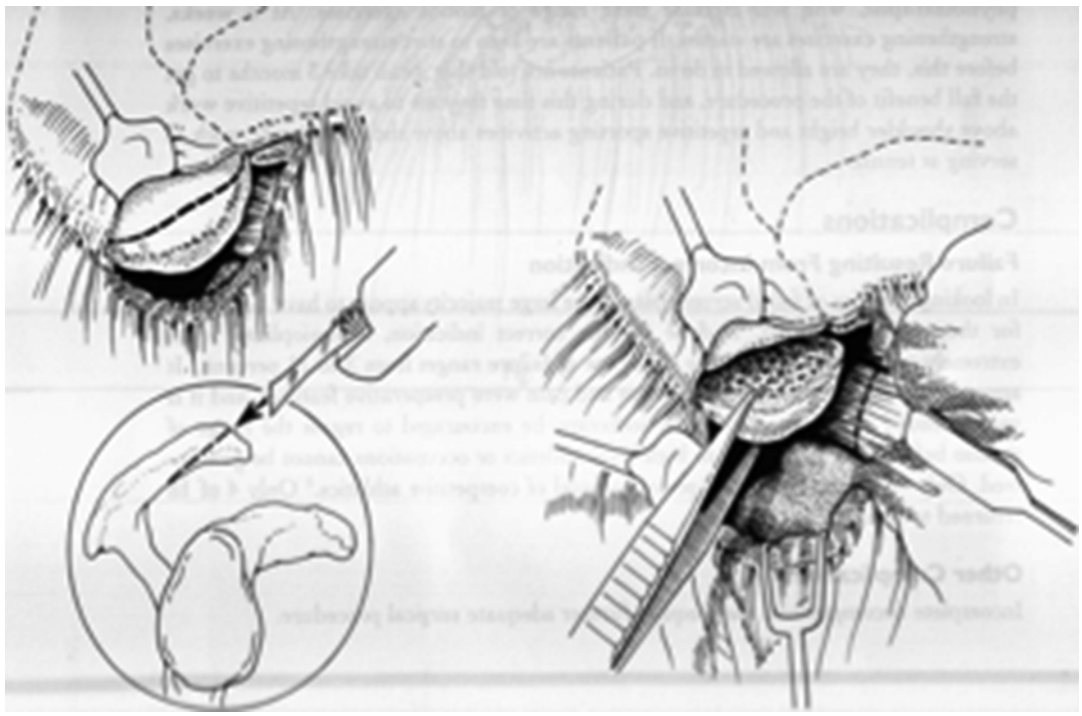

Fig. 41.5 Open subacromial decompression

while the subacromial space is distended and visualized using the arthroscope in the lateral portal. Once the bursal tissue and periosteum of the acromion have been adequately resected to allow identification of the anatomic landmarks, the coracoacromial ligament is resected. In this technique, the posterior aspect of the acromial undersurface will serve as a cutting block to guide the resection of the anterior acromion bone wedge. The burr sheath is firmly applied to the undersurface of the acromion so that medial-lateral sweeping of the burr tip creates a shallow groove just at the predetermined point. The burr is then slowly advanced anteriorly while maintaining the medial-lateral sweeping motion. The resection is completed when the anterior edge of the acromion is removed. Finally, the arthroscope may be switched to the posterior portal to better evaluate the most lateral edge of the acromion as this edge is often too close to the arthroscope lens, to allow safe burring when viewing from the lateral portal. Similar probe and burr technique may be used through the lateral portal if modification is necessary [41].

Fig. 41.6 Cutting block technique [29]

In 1995, Copeland [42] presented a different way of performing this procedure (Fig. 41.7).

The scope is kept through the posterior portal, while the resector works from the lateral portal throughout all the procedure. The starting point is the anterolateral edge of the acromion where the coracoacromial ligament is attached. After the ligament is resected, the exact bony margins of the acromion are visualized. By shaving medially,

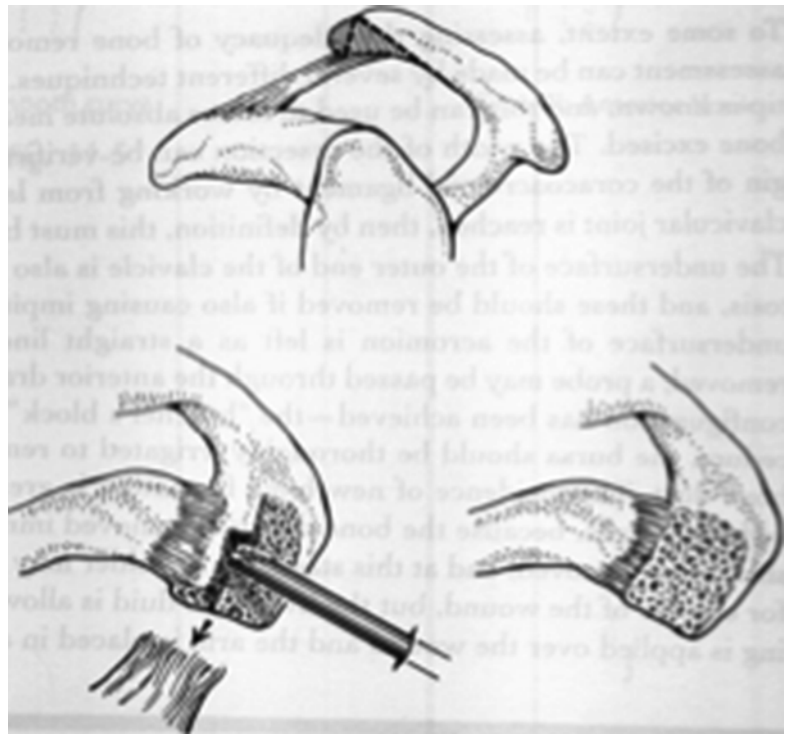

Fig. 41.7 Arthroscopic subacromial decompression [42]

Table 41.5 Levy-Copeland arthroscopic classification: grading of mechanical effects of impingement [31]

Acromial side
A0: normal – smooth surface
A1: minor scuffing, hemorrhage, or local injection and inflammation
A2: marked scuffing/damage of the undersurface of the acromion and CA ligament
A3: bare bone areas
Bursal side
B0: normal – smooth surface
B1: minor scuffing, hemorrhage, or local injection and inflammation
B2: major scuffing of cuff, partial-thickness tear
B3: full-thickness tear
B4: massive cuff tear

Table 41.6 Snyder classification of RCT

(A) Articular surface
A0. Normal
A1. Minimal superficial bursal or synovial irritation or slight capsular fraying over a small area
A2. Fraying and failure of some rotator cuff fibers in addition to synovial bursal or capsular injury. More severe rotator cuff injury fraying and fragmentation of tendon fibers often involving the whole of a cuff tendon, usually <3 cm
A4. Very severe partial rotator cuff tear that contains a sizeable flap tear and more than one tendon
(B) Bursal surface
B0. Normal
B1. Minimal superficial bursal or synovial irritation or slight capsular fraying over a small area
B2. Fraying and failure of some rotator cuff fibers in addition to synovial bursal or capsular injury. More severe rotator cuff injury fraying and fragmentation of tendon fibers often involving the whole of a cuff tendon, usually <3 cm
B4. Very severe partial rotator cuff tear that contains a sizeable flap tear and more than one tendon
(C) Complete tear
C1. Small complete tear, pinhole sized
C2. Moderate tear <2 cm of only one tendon without retraction
C3. Large complete tear with an entire tendon with minimal retraction usually 3–4 cm
C4. Massive rotator cuff tear involving 2 or more rotator cuff tendons with associated retraction and scarring of the remaining tendon

Comprehensive classification including the size position and quality of tendon [89]

the surgeon can visualize the acromioclavicular joint. All bone lying anterior to acromioclavicular joint is excised down to its full depth. This is best done starting laterally and then moving medially. After removal of the whole thickness of the anterior acromion, the anterior edge of the acromion is then shaped and angled posteriorly to leave the undersurface of the acromion as a straight surface, removing the bony hook. To assess the adequacy of bone removal, the thickness of the shaver can be used (4 mm). The width of the resection can be verified by exactly delineating the origin of the coracoacromial ligament by working from lateral to medial. Once the acromioclavicular joint is reached, the full width of the acromion has been reshaped. The inferior margin of the clavicle needs to be inspected to detach osteophytosis that might cause impingement. At the end of the procedure, the bursa should be irrigated to remove all possible traces of small bone dust [42].

The direct visualization of the kissing lesions (inferior surface on the acromion and bursal side of the cuff) through an arthroscopic procedure led to the development of a new classification (Table 41.5).

Concerning the classification of the rotator cuff lesions, Snyder's Classification needs to be mentioned (Table 41.6).

During revision of ASD procedures, some authors observed the regeneration of the coracoacromial ligament (CAL). This finding, therefore, started to be studied to aid the understanding of the successes and failures of ASD. In 2000 and 2001, Henderson et al. (Melbourne, AUS) and Levy et al. (Reading, UK) reported that coracoacromial ligament has an ability to reform or reattach, whether primarily resected or released, and that this might account for recurrent symptoms [43]. Electron micrograph studies (J. P. Henderson) [43] and histology (O. Levy) [44] revealed appearances indistinguishable from normal ligament, which was in continuity with the reformed periosteum of the acromion. In a following study, Levy et al. showed the results of mechanical testing on eight regenerated coracoacromial ligaments, which appeared to have the

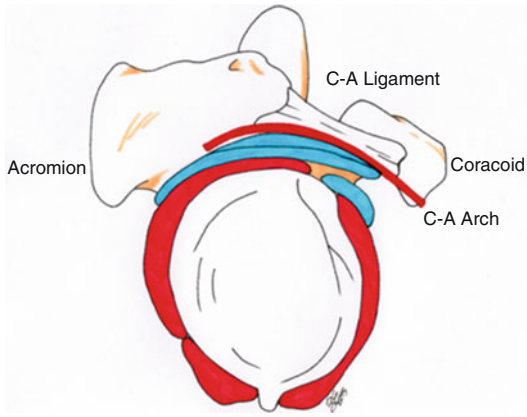

Fig. 41.8 Coracoacromial arch

ability to reform relatively quickly but took time to regain strength (3 years) [45]. Similar results were seen in a study performed on ACL of the knee. Well-organized parallel bundles of collagen fibers on hematoxylin-eosin and Van Gieson preparations were observed in the proximal one third of injured ACLs. Findings were consistent in all patients, and no scar or disorganized fibrous tissue was found. These characteristics are typical for a spontaneous healing process like it is known to happen in the medial collateral ligament (MCL) [46].

This regenerative process fails, instead, when a constant and repetitive strain is applied to the area of insertion of the CAL to the acromion. This happens in patients with a large or massive rotator cuff tear, where a consequent proximal migration of the humeral head is observed. This is a clinical condition in which subacromial interruption of the coracoacromial arch should be avoided, as proximal subluxation with anterosuperior escape of the humerus can occur as well described in previous reports (Fig. 41.8) [2, 13, 15–90].

41.1.5 Complications

Complications can be divided into general complications (generic to all shoulder procedures) and complications specific to the type of procedure performed. Complications related to general anesthesia (GA) and nerve blocks and general complications, such as infections, bleeding, and clots, continue to show low incidences. Shoulder arthroscopy presents increased risk of complications over knee arthroscopy in regard to vascular and neurologic injury, fluid extravasation, stiffness, iatrogenic tendon injury, and equipment failure. However, in all recent review studies, the rate of complications is still low (5.8–9.5 %) [92].

One of the most dreaded complications, after acromioplasty or arthroscopic decompression, is the fracture of the acromion process. In 1994 a study reported six cases of post ASD fracture of the acromion. Treatment of this complication ranged from total acromionectomy to conservative measures. Indifferently from the treatment, most results were poor. Risk factors include osteopenia and overzealous bone resection. An appropriate preoperative planning and meticulous surgical technique to minimize bony resection may decrease the risk of this complication and its resultant disability [47]. Postoperative heterotopic ossifications (HE) were observed in some patients after ASD or open acromioplasty. The authors reported that bone formation could not be correlated with the method of bone resection and that revision surgeries and HE prophylaxis for recurrence of symptoms are sometimes required [48]. Another rare complication is the recurrence of acromion spur. A case report showed as an anterolateral subacromial spur and clinical impingement signs can recur years after ASD [49].

41.1.6 Result Literature Review

Neer's initial results, as well as other follow-up studies, showed excellent outcomes, with success rates from 80 to 95 %. Ellman reported satisfactory results for ASD in 88 % of patients at 1–3 years of follow-up [39]. Many different techniques have been reported with similar results [50]. Since the initial reports, many authors [51–54] reported their results after ASD: 73–88 % good to excellent, approaching the results of the previously reported open subacromial decompressions. Other studies showed even better results. In a recent study, 45 female volleyball players underwent ASD for SAIS. Excellent results were reported in 62.3 %,

good in 30.7 %, satisfactory in 4.6 %, and bad in 2.4 %. The final results were 91 % included as good and excellent. Other authors had similar results: Paulos (85 %), Garstman (90 %), Godinho (90.8 %), and Altchech (92 %) [55].

Comparing arthroscopic ASD to open acromioplasty, literature confirms that open surgery doesn't allow better results. In a recent study in the group of patients that fail to benefit from the arthroscopic decompression, only a marginal improvement was noted after revision with open decompression [56].

However, despite the good results reported, literature is still divided. According to a Cochrane review, there is little evidence to support or refute the efficacy of common interventions for shoulder pain [57]. Moreover, evidence supporting the superiority of subacromial decompression relative to physiotherapy with training has been unconvincing [58, 59].

In a recent article in Orthopedics Today [60], doubts have been raised over the effectiveness of ASD. Health economists in Denmark have reported low and delayed return to work for patients treated for SAIS with ASD. Their argument is that there are no financial benefits for the government due to the poor rate of return to work. Surgeons argue that patients achieve good pain relief and a high standard of activities of daily living (ADLs) after ASD. A detailed review of the literature suggests that there is no clear benefit of surgery over conservative treatment.

Randomized controlled trials by Brox et al. [59] and Haahr et al. [61] comparing exercises with ASD found that, although individually they are successful treatments, ASD was not superior to specialized exercise programs. Also, systematic reviews by Dorrestijn et al. [34] and Gebremariam et al. [62] show similar results.

A long-term follow-up randomized study was performed in the Kanta-Häme Central Hospital, Hämeenlinna, Finland. The authors suggested [63] that treatment with ASD combined with structured exercise treatment did not provide better results at 5 years compared with structured exercise alone, when assessed by self-reported pain. The same pattern was seen in the secondary outcome measures of disability, pain at night, number of painful days, and the proportion of pain-free patients.

To confirm that the debate is still open, the findings of another study published in 2014 [2] have demonstrated significant improvement in outcome for patients with SAIS undergoing ASD, who have had previous failed conservative treatment with standard physiotherapy and at least one subacromial injection. The median Oxford Shoulder Score improved significantly at 6 months after ASD. This implies that patients have reported benefits in their activities of daily living. Furthermore, the improvements in the individual components of the constant score highlight excellent pain relief, objective benefits in ROM, and also increase in shoulder strength. The study showed that 75 % of patients achieved a minimum of 5-point benefit in OSS and 77 % of patients achieved a minimum of 10-point improvement in CS. This is a significant result and highlights the success of ASD for patients with SAIS [2].

Different impingements were documented more recently. Internal impingement refers to overhead athletes that experience shoulder pain during throwing sports. It can present as a constellation of pathological processes, including partial- or full-thickness rotator cuff tears, anterior or posterior capsular injury, labral tears, glenoid chondral erosion, chondromalacia of the posterosuperior humeral head, and biceps lesions. Moreover, the absence of these lesions does not exclude a diagnosis of internal impingement. Muscle fatigue can affect the mechanism of throwing leading to a humeral hyperextension in the late-cocking phase of throwing [69]. This can lead to a damage of the posterior capsulolabral structures. This condition is further permitted by the development of anterior capsular microinstability [70, 71] and posterior capsular stiffness (GIRD – glenohumeral internal rotation deficit), which lead to the translation of the humeral head (peel-back mechanism), which may "peel off" from the glenoid the labral biceps insertion (type II SLAP lesions) [72–93]. Stretching and physiotherapy give good results in patients with a mild symptomatology and no intrinsic lesions. When a lesion of the RC is found (Walch et al. 1991) [68],

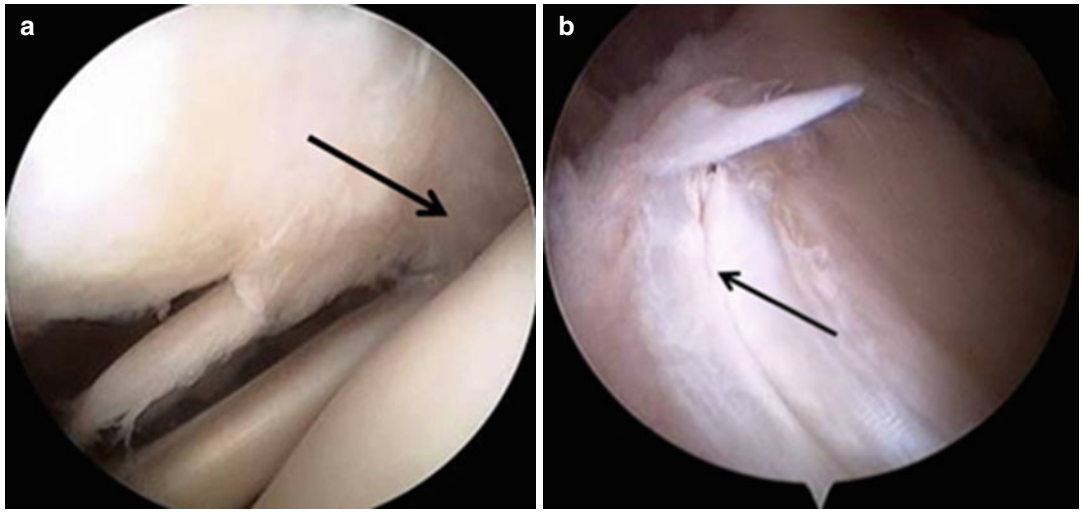

Fig. 41.9 (**a**) An arthroscopic view of the right shoulder shows an articular partial tear of the insertion of the supraspinatus tendon (*arrow*) with a tendinous flap, just posterior to the biceps. (**b**) An arthroscopic view shows posterior labrum delamination (*arrow*) [73]

however, a debridement of the tendon and of the labrum [68], followed by the shaving of the bone spur on the posterior edge of the glenoid [73], is recommended. Walch described this condition as the posterosuperior glenoid impingement (PSGI), in which a lesion occurs between the deep side of the supraspinatus tendon and the posterosuperior edge of the glenoid cavity (Fig. 41.9a, b).

Jobe [70] and Andrews [93], however, consider the anterior instability as the principal cause of intrinsic impingement and recommend treating anterior capsule laxity, in order to achieve good results.

The coracoid process can be another area of impingement, even if this is a less common cause of shoulder pain. Symptoms occur when the subscapularis tendon impinges between the coracoid and lesser tuberosity of the humerus. Coracoid impingement should be included in the differential diagnosis when evaluating a patient with activity-related anterior shoulder pain [74–76].

Palpation often elicits tenderness of the soft tissues around the coracoid process and between the coracoid process and the lesser tuberosity [77–79]. The coracoid impingement test is performed in a manner similar to that used to perform the Kennedy-Hawkins impingement sign, except that the patient's shoulder is placed in a position of cross-arm adduction, forward elevation, and internal rotation to bring the lesser tuberosity in contact with the coracoid [80]. Pain is elicited more consistently in the midrange of forward elevation than in the full elevation that is used to detect subacromial impingement [81, 82]. A lidocaine injection in the subcoracoid region may also be of utility in establishing a diagnosis [83]. MRI or CT examinations appear to be more precise in establishing the diagnosis than simple X-rays [84]. In most cases, axial sequences are used to measure the coracoid-humeral distance (CHD), defined as shortest distance between the humeral head and the coracoid process [85]. In addition to this, the coracoid index, defined as the lateral projection of the coracoid beyond the glenoid joint line in axial CT or MR images, is theorized to have an influence on developing coracoid impingement.

The first line of treatment for coracoid impingement should be a program of activity modification, with avoidance of the provocative positions of forward flexion and medial rotation, and physical therapy to strengthen rotator cuff muscles and scapular stabilizer musculature. Surgical decompression of the subcoracoid space may be undertaken if the above conservative measures fail (Fig. 41.10a, b) [77]. The options

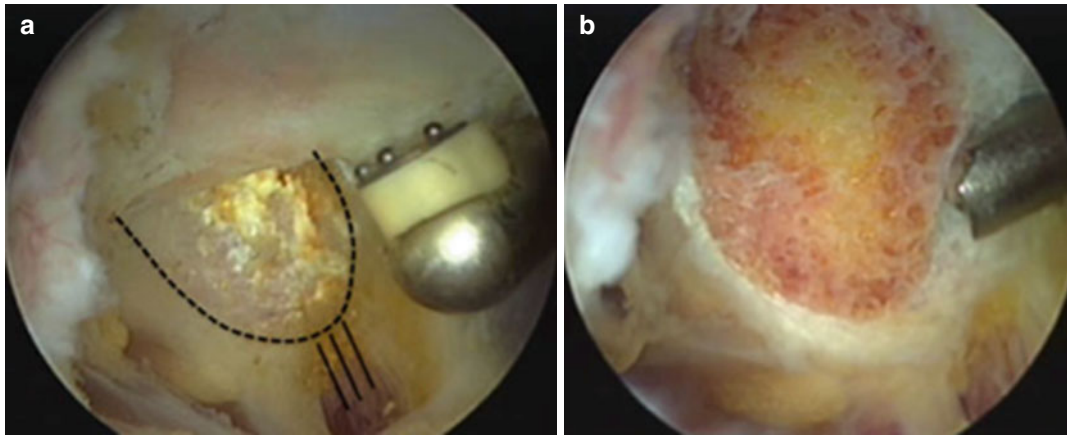

Fig. 41.10 (**a**) Preparation of coracoid process (*dotted black line*) with electrocautery through the open joint capsule and (**b**) completed coracoplasty [95]

include open or arthroscopic coracoplasty, a combination of coracoacromial ligament resection and acromioplasty, or anterior shoulder stabilization [81, 86].

Partial-thickness tears of the subscapularis muscle are usually found in these patients. Most of them are undersurface tears, but it is possible to find linear longitudinal subscapular tears, which indicate a tensile undersurface fiber failure (TUFF lesion). The "roller-wringer effect" was described by Burkhart to explain the pathomechanism of TUFF lesion (increased tensile forces on undersurface of subscapularis insertion) and is common in this kind of impingement [93].

Conclusion

When we look at shoulder impingement, we can't consider only subacromial impingement. In the last years, the authors described different typologies of impingement. The shoulder is a complex joint that needs to be balanced to work properly. Mechanical forces have to be counteracted by muscle action and capsular ligament structures.

When at least one of these anatomical structures loses its function (due to injuries, overload, age, dyskinesia, etc.), movements of the humeral head are not controlled, anymore. Therefore, during the range of motion of the joint, humeral head loses the natural rapports with the socket and hits the surrounding structures (bone structures, labrum, and tendons) leading to an inflammatory process and, eventually, to a structural damage.

Arthroscopic decompression is a quick and safe procedure that gives good results with a low rate of complication and failures. However, it is very important that the surgeon has a clear idea of the pathogenic mechanism that leads to the symptoms, before surgical procedure is offered to the patient.

Failure to improve patient symptoms, therefore, can be expected if the procedure is proposed with an incorrect indication. The shoulder is a high-demanding joint that hardly forgives diagnostic errors.

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Calcifying Tendonitis of the Rotator Cuff

42

Olaf Lorbach and Romain Seil

42.1 Introduction

Calcifying tendonitis of the rotator cuff is described as a frequent cause of shoulder pain [1] which is characterized by the presence of carbonate hydroxyapatite deposits mainly located in the supraspinatus tendon [2]. Women aged between 30 and 60 years are most frequently affected [3, 4]. However, the presence of a calcific deposit does not necessarily mean a significant impact on shoulder pain [5]. Louwerens et al. [6] could find a prevalence of approximately 8 % in asymptomatic patients, whereas a prevalence of 42.5 % was found in patients suffering from a subacromial pain syndrome.

Although the etiology is not clearly understood, various etiologies including tendon hypoxia, genetics, or an endocrine disorder have been proposed [7].

Three distinct phases were described [7]:

I. *Pre-calcification phase*:
   The tendon undergoes fibrocartilaginous transformation with metaplasia of tenocytes in chondrocytes.
II. *Calcific phase*:
   The calcific stage is broken down further into a formative phase during which calcium crystals are deposited in matrix vesicles that coalesce to form large deposits.
III. *Post-calcific phase*:
   After a resting phase during which the deposits ceases, a resorptive phase arises during which spontaneous resorption of the calcific deposit may be seen. During the resorptive phase, the expected amount of shoulder impairment as well as shoulder pain is usually the most.

42.2 Diagnosis

42.2.1 Clinical Evaluation

Patients with a symptomatic calcifying tendonitis usually suffer from a subacromial pain syndrome which may be explained by the secondary mechanical outlet impingement and subacromial bursitis caused by swelling and inflammation of the affected tendon.

In patients with a chronic subacromial pain syndrome, range of motion is merely slightly limited due to pain. Patients often present with

O. Lorbach, MD, PhD (✉)
Department of Orthopaedic Surgery,
Saarland University, Kirrberger Str., Geb. 37/38,
Homburg, Saar 66421, Germany
e-mail: olaf.lorbach@gmx.de

R. Seil
Department of Orthopaedic Surgery,
Centre Hospitalier de Luxembourg,
78, rue d'Eich, Luxembourg 1460, Luxembourg

Sports Medicine Research Laboratory, Luxembourg
Institute of Health, Centre Médical Norbert Metz,
78, rue d'Eich, Luxembourg 1460, Luxembourg

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rest and night pain with a variable intensity. Typically, a painful arc [8] between 60 and 120° of abduction exists, and impingement tests like the NEER test [9] or the Hawkins-Kennedy test [10] are positive as well. Clinical tests concerning the supraspinatus tendon or the biceps tendon are often painful, too. However, a weakness of strength is usually not found.

42.2.2 Radiological Evaluation

Radiologic evaluation consists of a true AP, an axial, as well an outlet view X-ray. This series is able to clearly identify the shape as well as the size of the deposit. Moreover, a clear localization of the calcific deposit can be reached, which becomes of high importance if the deposits require further surgical treatment. According to the size and the radiographic appearance, the deposits can be classified. The size of the deposit can be categorized according to the Bosworth [5] classification in three categories of small (<0.5 cm), medium (<1.5 cm), and large (>1.5 cm). Gärtner [2] classified the calcific deposit according to their radiological appearance (Fig. 42.1).

42.2.3 Ultrasound Evaluation

Ultrasound evaluation is also described as a very valuable tool in order to localize the calcific deposit preoperatively. According to the quadrant technique, with the patient's arms placed in a neutral position [11], it may also help to identify the deposit during surgery. Moreover, it offers a fast and cost-effective method to assess the disappearance of the calcific deposit as well as to evaluate the integrity of the rotator cuff after percutaneous needling or arthroscopic/open removal of the deposit.

42.3 Treatment Options

42.3.1 Conservative Treatment

Most authors recommend conservative treatment including nonsteroidal anti-inflammatories, pain medication, physical therapy, subacromial injections of local anesthetics with or without cortisone, needling and lavage (barbotage) of the deposit, or extracorporeal shock wave therapy (ESWT) [12].

42.3.2 Operative Treatment

In patients with persistent symptoms of more than 6 months and failed conservative treatment, surgical treatment may be indicated which can be performed in an open or all arthroscopic technique.

In the arthroscopic procedure, the arthroscopy is typically performed through a standard posterior portal. After the diagnostic round to rule out concomitant pathologies, a 20 gauge needle is used to identify and mark the deposit under arthroscopic control (Fig. 42.2). A suture may be passed through the needle, or the needle can alternatively be left in place while the arthroscope

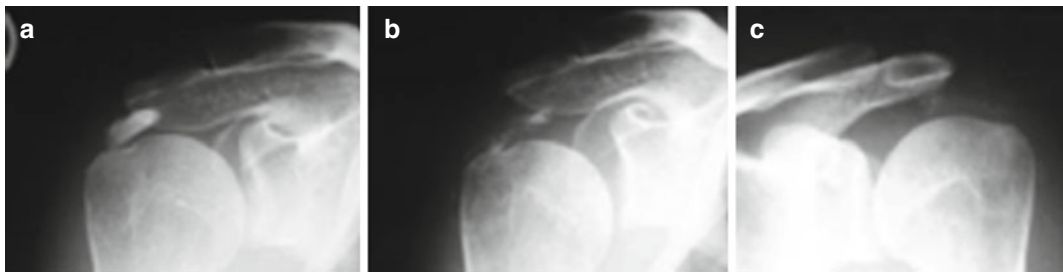

Fig. 42.1 (**a**–**c**) Classification according to Gärtner [2, 43]. (**a**) Sharp/dense contours. (**b**) Poorly defined dense or sharp contours. (**c**) Poorly defined/transparent

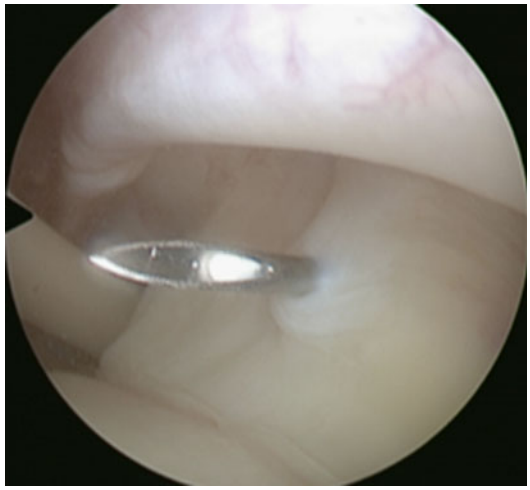

Fig. 42.2 Arthroscopic view intra-articular from the posterior portal. Marking of the calcific deposit using a spinal needle

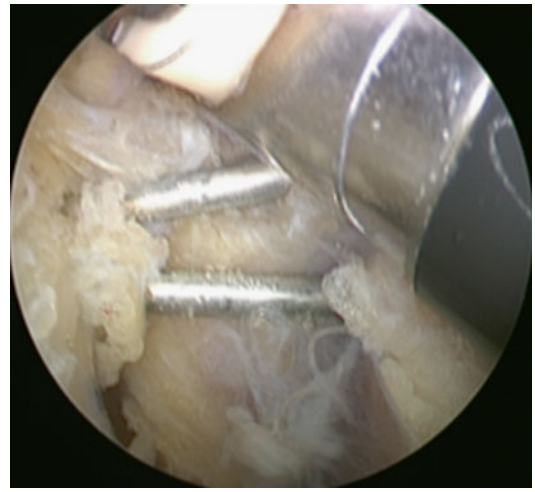

Fig. 42.3 Identification of the spinal needle from the subacromial space

is introduced in the subacromial space through the posterior portal. A subacromial bursectomy is performed to ensure a complete visualization of the rotator cuff tendon using a standard shaver and a radiofrequency device. The needle or, respectively, the suture is identified with special care not to damage it (Fig. 42.3).

After clear localization of the deposit, the tendon is opened with an arthroscopic knife longitudinally and parallel to its direction. The deposit is pressed out with blunt instruments; the typical snowstorm pattern that occurs is removed with the synovial shaver which may also be used to remove loose parts of the deposit within the tendon without damaging the tendon extensively (Fig. 42.4a, b).

Dependent on the size and the shape of the deposit, a minor or a major damage may occur in the rotator cuff tendon (Fig. 42.5). In the authors' clinical practice, minor defects are left in situ, whereas more substantially defects like bursa-sided partial rotator cuff tears or subtotal rotator cuff tears were treated with surgical repair of the rotator cuff (Fig. 42.6). A subacromial decompression is only added if signs of subacromial irritation are apparent on the undersurface of the acromion.

The postoperative regimen included passive and active mobilization of the arm as tolerated under physiotherapeutic control during the first 6 weeks. In patients with a more substantive rotator cuff tear that require a rotator cuff repair using bone anchors, patients were treated with an abduction pillow for 6 weeks. Passive range of motion is allowed to 90° of flexion and abduction as well as 30° of external rotation.

42.4 Complications

Subacromial injections and needling may carry the risk of infection, injuries of blood vessels or nerves, as well as allergic reaction mainly caused by the concomitant local anesthetic medication. The needling procedure is associated with slight to moderate pain. Moreover, concomitant damage of the tendon as well as the underlying cartilage cannot be ruled out. However, severe complications are rare in the literature.

Serafini et al. [13] reported a few mild vagal reactions during treatment in their needling group and a painful bursitis in 13.2 % of their patients within the first 3 months. De Witte et al. [12] did not find a similar incidence of posttreatment bursitis but reported two frozen shoulders after needling.

If extracorporeal shockwave therapy (ESWT) is used, the described complications are also rare,

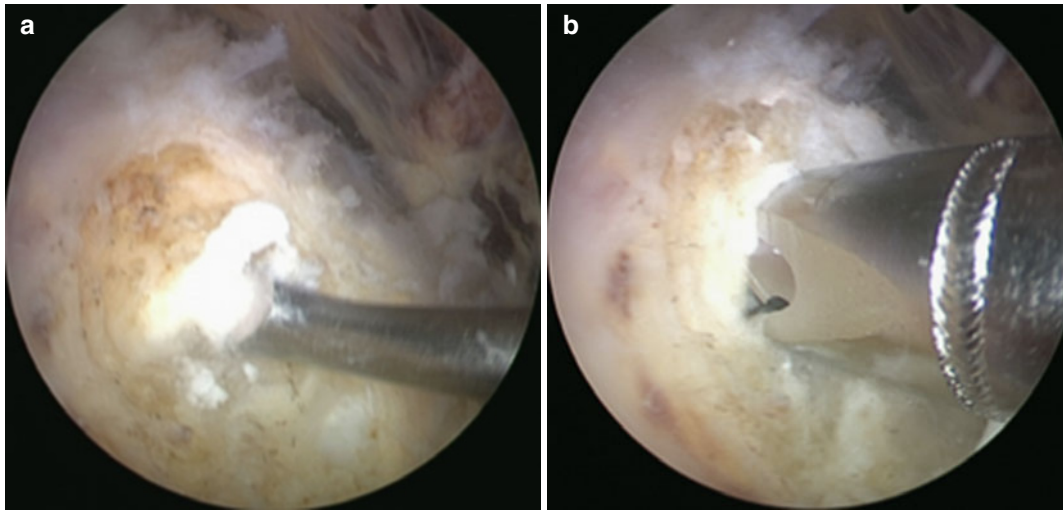

Fig. 42.4 (**a**, **b**) Removal of deposit using arthroscopic instruments with special care not to extensively violate the rotator cuff

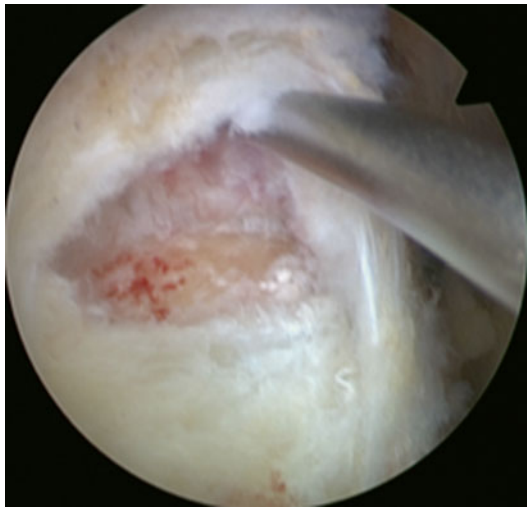

Fig. 42.5 After removal of the deposit, a bursa-sided tear of the rotator cuff is evident

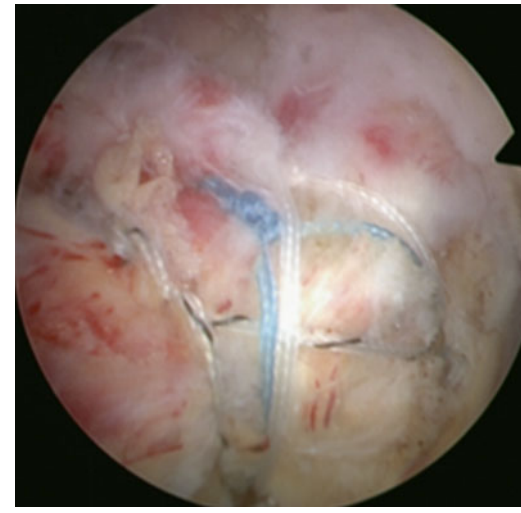

Fig. 42.6 Arthroscopic repair of the bursa-sided partial rotator cuff tear using a triple-loaded suture anchor (5.5 mm Bio-Composite Corkscrew, Arthrex, Naples, USA) medial performing a triple-mattress repair as well as two press-fit anchors (4.5 mm Bio-PushLock, Arthrex, Naples, USA) to realize a double-row suture bridge repair

mainly less severe such as reddening of the skin, pain, as well as the development of small hematomas.

In a systematic review by Louwerens et al. [4] concerning the evidence of minimally invasive therapies in the management of chronic calcific tendonitis of the rotator cuff, the most reported side effects were pain during treatment [14–16], soreness [17], local subcutaneous hematomas [18, 19], and small petechial hemorrhages [15, 20]. All of these affected only a small number of the treated participants, and all of the adverse side effects resolved within a few days.

However, also more severe complications were described in the literature. Liu et al. [21] presented a patient developing a humeral head osteonecrosis 3 months after ESWT treatment

without any predisposing factors in clinical history such as injury, use of steroid medication, blood disorders such as sickle cell anemia, excessive alcohol abuse, Gaucher's disease, radiation treatment, chemotherapy or others, connective tissue diseases, or dyslipoproteinemia. Durst et al. [22] also reported on the development of an osteonecrosis of the humeral head after ESWT. Therefore, even if rare, the possibility of such a complication should be considered if ESWT is used.

The reported complications after arthroscopic removal of the deposit are low.

Seil et al. [23] reported in their study group one patient with a subcutaneous hematoma which resolved spontaneously and two patients who suffered from shoulder stiffness which was treated with intra-articular cortisone injections. Both complications did not have a significant impact on the postoperative results. However, two patients showed a persistence of pain requiring additional subacromial decompression [23].

Similar findings were reported by others [24].

42.5 Results

Wang et al. [25] reported on the clinical results of 37 patients with calcific tendonitis that were treated with shock wave therapy. Patients were observed 24 and 30 months after initial treatment. In the study group, 20 shoulders (60 %) were complaint-free, 10 were significantly better (30 %), and 2 patients were unchanged (6 %). Radiological evaluation revealed a significant reduction in deposit size with a complete elimination in 57 % of the patients. The authors concluded that ESWT in the treatment of calcific tendonitis of the shoulder is a safe and effective treatment option.

The reported results may be dose dependent as Albert et al. [26] performed a prospective randomized trial of 40 patients in each group who underwent high-energy versus low-energy ESWT for calcifying tendonitis of the shoulder. In their results at a mean of 112 days after initial treatment, patients treated with high-energy ESWT showed significantly higher Constant scores, more improvement from the baseline level, as well as significantly more total or subtotal resorption of the calcification. However, even in the high-energy group, only 15 % of the calcific deposits were changed in appearance on X-rays.

Castillo-Gonzalez et al. [27] reported on a 2-year longitudinal prospective study of 121 patients suffering from calcific tendonitis of the shoulder. All patients were treated with US-guided needling and lavage. In the results significant reduction of pain as well as of the size of the deposit was observed at 3 months, 6 months, as well as 2-year follow-up. In conclusion of their results, the authors considered this technique as a valid alternative as a first-choice treatment of calcific tendonitis of the shoulder.

Gatt and Charambolus [28] performed a systematic review on the outcomes and complications of US-guided barbotage for calcific tendonitis of the shoulder. Based on their findings, they concluded that ultrasound-guided barbotage is a safe technique, with a high success rate and low complication rate. However, they did not find evidence assessing its effectiveness compared with other major treatment modalities.

In a randomized controlled trial, De Witte et al. [12] compared two groups of patients with calcifying tendonitis of the shoulder that were either treated with US-guided needling and lavage or subacromial steroids alone. At final follow-up after 1 year, both treatment groups showed an improvement in the clinical scores with no significant differences at 3 and 6 months follow-up. However, at final follow-up, clinical and radiological results were significantly better in the barbotage group.

Kim et al. [29] compared the clinical results of US-guided needing and additional cortisone injection to a group of patients who received ESWT three times a week. At 1-year follow-up, the US-needling group had significantly better clinical scores evaluated by the ASES score, simple shoulder test, as well as visual analog scales for pain compared to the group treated with ESWT.

However, another recently published systemic review [4] concerning the evidence of minimally invasive therapies for calcifying tendonitis of the

shoulder options pointed out that there is only a moderate quality of studies supporting the effect of ESWT on pain relief and functional status compared to other interventions. Moreover, needling has not been proven to be more effective than US-guided subacromial corticosteroid injections; therefore, further research may be necessary to prove its effectiveness.

Hence, US-guided needling with barbotage as well as ESWT both seem to be a safe and effective treatment option in patients with symptomatic calcifying tendonitis of the shoulder. However, a randomized trial comparing ultrasound-guided barbotage and extracorporeal shock wave therapy would be of great value, as current literature cannot support a clear trend toward one of the treatment options.

If conservative treatment fails, arthroscopic removal has been reported with excellent midterm to long-term results [23, 24, 30–32]. However, the question if the damage to the rotator cuff needs to be repaired or not as well as the question if a complete removal of the deposit is necessary or an additional acromioplasty needs to be performed is still a matter of discussion.

Seil et al. [23] investigated the clinical and radiological results of 54 patients after arthroscopic removal of calcific deposits of the shoulder without repair of the rotator cuff. In their results, the Constant score could be significantly improved from 33 to 91 points after 2 years, and 92 % were satisfied with their clinical outcome. However, only 31 % of the patients reached their minimum pain level after 3 months and 17 % after 6 months whereas another 20 % needed 9 months and 28 % 12 months for their minimum pain level. Although this study could reveal the previously reported excellent clinical results, a prolonged postoperative phase until a complete pain-free recovery was achieved could be seen. Moreover, 66 % of the patients showed irregularities within the rotator cuff on postoperative ultrasound examination even if this did not have any significant influence on the reported short-term results.

The prolonged postoperative period, until pain relief is reached, is supported by other studies as well [24, 30, 31, 33, 34]. Balke and coworkers [30] reported on the midterm results of 62 patients after arthroscopic treatment of calcifying tendonitis of the shoulder. Comparable to the work of Seil et al. [23], they tried to minimize the damage to the rotator cuff tendon and did not perform a rotator cuff repair in their patients. After a mean follow-up of 6 years, patients showed a significantly lower Constant as well as ASES scores compared to their healthy contralateral shoulder. Ultrasound examination at final follow-up revealed a partial rotator cuff tear in 11 patients whereas only 3 contralateral shoulders showed a partial tear. The authors concluded that even if good midterm results were achieved, the clinical scores were lower than the scores of the healthy contralateral shoulder. Furthermore, the amount of partial rotator cuff tears seemed to be higher in the operated shoulders. Comparable to the study of Seil et al. [23], the minor changes on the rotator cuff did not seem to have a clinical impact on the results. However, Porcellini et al. [31] did not find any partial rotator cuff tears on postoperative ultrasound examination in their patients at 2 years follow-up and recommended repair of the tendon after resection of bigger calcific deposits.

Especially in large deficits, the damage on the rotator cuff may be underestimated if the defect is not carefully inspected.

The impact on the amount of removal is also discussed controversially in the literature. Seil et al. [23] did not find any correlation of postoperative shoulder function and the amount of remaining calcific deposit on postoperative X-ray controls. Moreover, they could find a progressive resorption of the deposits even if they had not been completely removed during surgery. This is in conclusion with the findings of other authors who did not find evidence that a complete removal of the deposit is necessary to achieve good clinical results [23, 24, 33, 35].

In contrast to that, Porcellini et al. [31] found in their study a strong correlation of the presence of residual calcific depots after surgery with an inferior clinical outcome. These findings were confirmed by other authors as well [32, 36, 37].

Therefore, it seems reasonable to remove as much of the deposit as possible without extensively damaging the tendon in order to achieve a sufficient decompression and clinical result.

Several authors do recommend an acromioplasty only in patients' signs of mechanical irritation on the undersurface of the acromion [23, 30, 31] as they could not find any significant benefit in their clinical results compared to patients without additional acromioplasty.

However, others have reported a significant benefit in their patients when performing acromioplasty even without removal of the calcific deposit [38–40] with disappearance of the deposit in the majority of patients.

As the results of patients with acromioplasty and an additional removal of the deposit did not show any significant differences compared to an isolated acromioplasty [41, 42], some authors concluded that additional removal of the calcific deposit does not further improve the clinical outcome.

Balke et al. [30] performed an additional acromioplasty compared to isolated removal of the deposit in 44 of their 62 patients. Although additional acromioplasty did not have a significant influence of the total Constant and ASES scores, the "subitem" pain was significantly lower in the acromioplasty group.

Acromioplasty as well as partial or complete removal of the calcific deposit seems to have a significant benefit on the clinical results in patients with calcifying tendonitis of the shoulder. Therefore, reduction of subacromial irritation by decompression seems to be the major step in order to reduce shoulder pain as well as to induce dissolution of the calcific deposit. A combination of both treatment options, however, does not seem to add additional benefit on the clinical results.

42.6 Summary

Calcifying tendonitis of the shoulder is a common cause of shoulder pain mainly affecting women between the age of 30–60 years. In patients with a symptomatic calcifying tendonitis of the shoulder, conservative treatment using needling of the deposits with barbotage or ESWT has shown to achieve satisfactory results in a significant amount of patients. If conservative treatment fails, arthroscopic treatment is recommended. Based on the current literature, arthroscopic complete or subtotal removal of the deposit is recommended without making substantial damage to the rotator cuff. In patients where a more substantial defect is found after removal, arthroscopic repair of the rotator cuff is indicated. Subacromial decompression is recommended in patients with additional signs of subacromial impingement such as of fraying on the undersurface of the acromion. Moreover, it may be added in patients with insufficient removal of the persistent calcific deposits.

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Rotator Cuff Tears

43

Mark Tauber

43.1 Clinical Diagnostics

The spectrum of the clinical image of rotator cuff tears (RCT) is broad. Usually, patients suffering from rotator cuff tears present with pain. Typically, they complain pain at night or under physical load. Furthermore, loss of strength or function in dependence from the tear extent is responsible for the patient's limitation during daily or sports activities. An important role plays the long head of the biceps tendon, which often is involved in RCT and may contribute a meaningful part to clinical symptoms.

Before starting the clinical examination, the patient's history should be checked for trauma or some kind of chronic professional or sports activity-related shoulder overuse. Traumatic RCT are characterized by a sharp pain in the shoulder with immediate loss of function for a variable period of time ranging from hours to several days depending from the underlying cuff tear extension. Usually, pain relieves within some days with full recovery of shoulder function if tear compensation is possible.

A thorough clinical examination is of utmost importance and often allows an exact diagnosis of the RCT. Inspection of the shoulder may reveal muscle atrophies, especially at the posterior aspect involving the infraspinatus and teres minor muscle (Fig. 43.1). A gross neurological check should exclude peripheral nerve lesions or complaints deriving from the cervical spine. The sensory branch of the axillary nerve should be evaluated, especially in patients with a history of trauma. The range of motion in all planes including forward elevation, abduction and external and internal rotation has to be evaluated in comparison to the uninvolved side. Also the amount of passive motion has to be proven in order to detect shoulder stiffness which sometimes can evolve

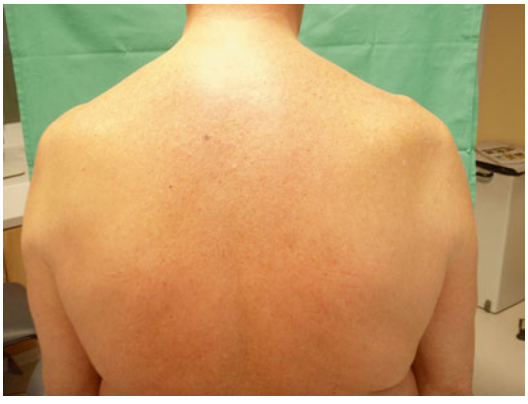

Fig. 43.1 Patient suffering from chronic posterosuperior RCT at the right shoulder. Note the evident hollow at the fossa infraspinata due to atrophy of the underlying muscle belly

M. Tauber, MD, PhD (✉)
Shoulder and Elbow Unit, ATOS Clinic Munich, Munich, Germany

Department of Traumatology and Sports Injury, Paracelsus Medical University Salzburg, Salzburg, Austria
e-mail: tauber@atos-muenchen.de

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secondary to RCT. Capsular stiffness is characterized by a hard stop which usually is painful in active capsulitis. Muscle strength should be rated according to the Medical Research Council (MRC) [26]. To evaluate strength for forward elevation and abduction, the arm is in 90° at the horizontal level. Rotational force is evaluated with the arm at the side and in neutral rotation position. Thus, gross estimation of muscle function and functional shoulder compensation is possible. However, full range of motion with good muscle strength cannot exclude RCT due to full functional compensation. Already in 1971 Neviaser et al. reported this observation and showed that the active range of motion does not correspond to tear size [31].

43.1.1 Specific Clinical Tests

43.1.1.1 Impingement

A frequent accompanying pathology in RCT is subacromial bursitis due to a mechanical outlet impingement. A series of clinical tests can provoke subacromial pain caused by compression of the inflamed bursa. The Neer test is the most frequently used test for clinical diagnosis of subacromial impingement [30]. The examiner is behind the patient and fixes with one hand his scapula, whilst the other hand lifts the arm into a forced elevation (between flexion and abduction). Pain is validated as a positive sign indicating subacromial impingement of every grade. Table 43.1 shows involved structures, sensitivity, specificity and positive predictive value (PPV) for all clinical relevant tests handling with RCT.

43.1.2 Supraspinatus Tendon

With the empty-can and full-can tests, the integrity of the supraspinatus tendon can be proved. With the empty-can test (Fig. 43.2a), the posterior aspect of the supraspinatus can be tested, whereas the full-can test (Fig. 43.2b) involves more the anterior insertional parts. The arm is brought in a position of 90° abduction, 30° horizontal flexion and full internal rotation for the empty can and 45° of external rotation for the full-can test, respectively [23].

The drop-arm sign is positive if the patient is not able to actively start the abduction. Furthermore, if the arm is brought passively in 90° of abduction, the patient cannot hold it in this position, or at least only under highest effort. Under minimal resistance the arm drops down.

43.1.3 Infraspinatus Tendon

Tests detecting isolated lesions of the infraspinatus were not described yet. Usually, if an infraspinatus tendon tear is present, external rotation is compensated by the teres minor muscle with a certain loss of strength. Once the teres minor shows fatty infiltration grade 3 or 4, external rotation insufficiency is present resulting in a positive hornblower sign. For this test the patient is asked to bring his hand to the mouth. Due to complete loss of external rotation, the arm deviates in internal rotation. The patient tries to compensate this by glenohumeral abduction. Hereby, often the elbow is higher than the hand itself.

For evaluation of the external rotation lag sign, the arm is positioned in 20° of abduction and in maximum external rotation with the elbow flexed in 90°. If the patient is not able to keep the arm in this position with the elbow supported by the examiner and the arm returns in an internal position, the test is positive. With this test the supraspinatus, infraspinatus and teres minor muscles are evaluated. It has been shown that the extent of the lag sign correlates with the tear size [7].

43.1.4 Subscapularis Tendon

The standard test for subscapularis function evaluation is the belly-press test (Fig. 43.3). In this test, the patient presses the abdomen with the hand flat and attempts to keep the arm in maximum internal rotation. If active internal rotation is strong, the elbow does not drop backward, meaning that it remains in front of the trunk. If the strength of the subscapularis is

Table 43.1 Shows involved structures, sensitivity, specificity and positive predictive value (*PPV*) for all clinical relevant tests handling with RCT

Author	Structure	Sensitivity (%)	Specificity (%)	PPV (%)
Impingement				
Park et al. [36]	Tendinitis/bursitis	85.7		20.9
	Partial RCT	75.4	48	18.1
Silva et al. [41]		88.7	68.4	30
Calis et al. [6]		88.7	Low	Low
Supraspinatus	*Empty can*			
Noel et al. [32]	Muscle weakness	95	65	
Itoi et al. [22]	Muscle weakness and/or pain	89	50	
	Only muscle weakness	77	68	
	Full can			
Itoi et al. [22]	Muscle weakness and/or pain	86	57	
	Only muscle weakness	77	74	
Drop-arm sign				
Park et al. [36]	Complete RCT	34.9	87.5	69.1
	Bursitis/tendinitis	13.6		8.0
Calis et al. [6]	Subacromial with involvement of RC	7.8	97.2	87.5
Infraspinatus	*Hornblower sign*			
Walch et al. [49]	ISP and TM insufficiency	100	93	
	ER lag sign			
Hertel et al. [21]	SSP	70	100	
Castoldi et al. [7]	SSP	56	98	
Subscapularis	*Belly press*			
Bartsch et al. [3]	SSC	80	88	
Barth et al. [2]	SSC	40	97.9	
	Belly off			
Bartsch et al. [3]	SSC±SSP, ISP	86	91	
	Bear hug			
Barth et al. [2]	SSC±SSP, ISP	60	91.7	
	Lift off			
Scheibel et al. [39]	Complete SSC	100		100
	IR lag sign			
Hertel et al. [21]	SSC	95	96	97

SSC subscapularis, *SSP* supraspinatus, *ISP* infraspinatus, *TM* teres minor, *ER* external rotation, *IR* internal rotation

impaired, maximum internal rotation cannot be maintained, the patient feels weakness, and the elbow drops back behind the trunk. According to Scheibel et al., the test can be modified with measurement of the wrist flexion angle in maximum internal rotation (elbow brought in front) during the belly-press manoeuvre [40]. A wrist flexion angle of 90° (positive result) indicates a complete tear, whereas with an angle of 30–60°, a partial tear of the upper two-thirds has to be assumed. An electromyography study could show that the belly-press test activates more the superior aspects of the subscapularis and the lift-off test more the inferior aspects, respectively [47].

Another test for evaluation of subscapularis integrity is the belly-off sign (Fig. 43.4). It represents the inability of the patient to maintain the palm of the hand attached to the abdomen with the arm passively brought into flexion and internal rotation. It is likely that the patient is unable to keep this position due to predominant external

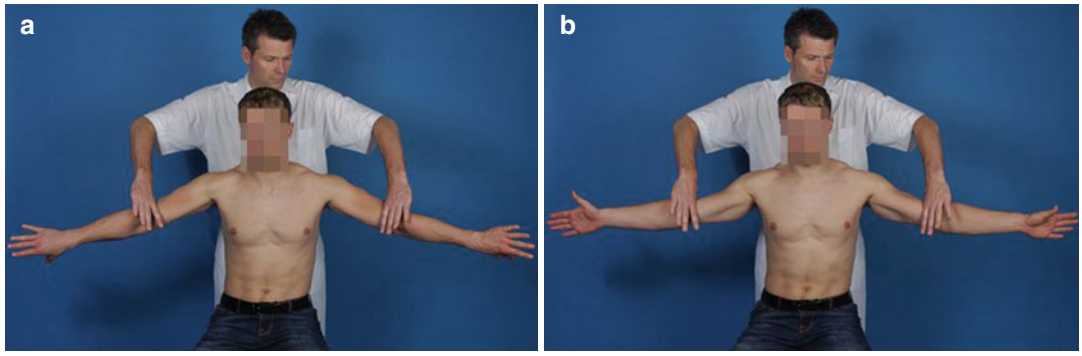

Fig. 43.2 (**a**) The empty-can test is performed with the arm in 90° of abduction in the scapular plane and internal rotation. (**b**) The full-can test is performed with the arm in 90° of abduction in the scapular plane and external rotation

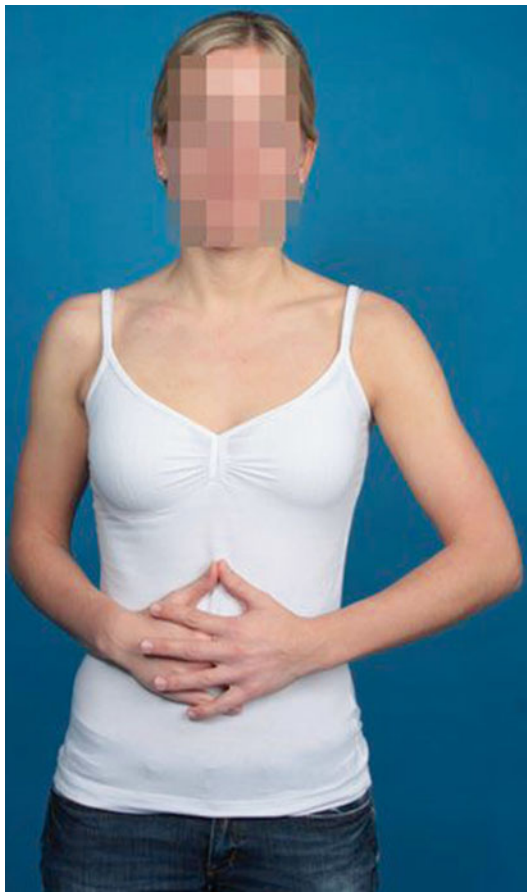

Fig. 43.3 Positive belly-press test on the right side. Note that the hand must be kept flat in contact with the abdomen

rotator muscles in terms of an unbalanced transverse force couple [5].

As an alternative the bear-hug test can be used [2]. The palm of the involved side is placed on the opposite shoulder with the fingers extended, and the elbow is positioned anterior to the body. The patient tries to hold the starting position by means of resisted internal rotation as the examiner tries to pull the patient's hand from the shoulder with an external rotation force applied perpendicular to the forearm. A positive bear-hug test results when the patient cannot hold the hand against the shoulder as the examiner applies an external rotation force. Hereby, a 90° flexion position addresses more the inferior subscapularis, whereas a 45° flexion position involves both, the superior and inferior aspects. Thus, the latter is recommended for routine clinical use.

A positive lift-off test indicates a complete subscapularis tear. The arm is in internal rotation positioned with the backhand to the middle part of the lumbar spine. The patient is asked to lift off the hand from the back. Inability indicates subscapularis insufficiency. Elbow extension and/or deviation of the hand from the mid-part of the lumbar spine render the test positive, as well.

Finally, using the internal rotation lag sign, the function of the subscapularis can be tested in maximal internal rotation. The arm is brought in maximal internal position with the elbow flexed and the backhand with a submaximal distance from the lower lumbar spine. The patient is asked to keep this position. The extent of the lag correlates to the tear size, and especially partial tears

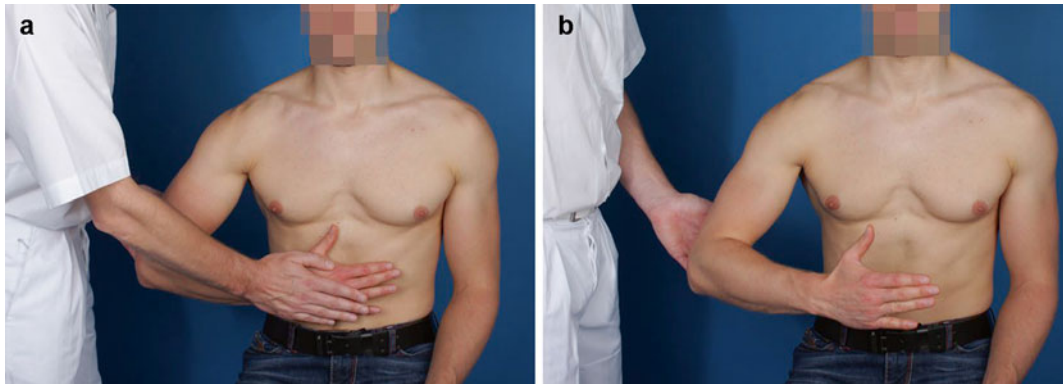

Fig. 43.4 Positive belly-off sign. The patient with subscapularis deficiency is not able to hold his hand at the abdomen due to rotational imbalance in favour of external rotators

of the upper subscapularis tendon can be diagnosed in the presence of a subtle lag. Be aware that passive restrictions of the shoulder can falsify this test.

43.2 Exploration: Instrumented and Radiological

To evaluate a suspected RCT, various imaging modalities can be used. Routinely, plain radiographs in three planes should be performed including a true AP view, an outlet and an axillary view. Even though conventional radiography does not visualize soft tissues, several associated and prognostic relevant factors can be seen allowing for further therapeutic decisions. Concomitant radiologic changes as glenohumeral or acromioclavicular osteoarthritis, calcifying tendinitis or osteolysis can be detected. Several radiologic parameters have been described as risk factors for development of RCT including a lateral acromion angle below 70°, a large lateral extension of the acromion in terms of the acromiohumeral index and the critical shoulder angle [1, 27, 34, 35]. The configuration of the acromion in the parasagittal plane according to Bigliani does not show any significant correlation [28]. Another important information which can be got from the native X-ray relates to humeral head centering. Superior migration of the humeral head indicates loss of function of the RC and appears with a long-standing two-tendon tear. The normal acromiohumeral distance (AHD) measures from 9 to 10 mm with a range from 7 to 14 mm [38]. It has been suggested that an AHD <7 mm is consistent with an RCT [8, 11] and fatty degeneration [33, 48, 51] and that a space <5 mm indicates a massive RCT [15, 50]. Another way to determine superior head migration is the assessment of the normal "Gothic arch" [24] or so called Maloney's line which is interrupted in patients with RC failure or dysfunction.

In cuff tear arthropathies based on chronic massive RCT characteristic radiologic changes can be observed with joint space narrowing, superior migration of the head, rounding of the greater tuberosity, concave erosion of the acromial undersurface (acetabularization), superomedial glenoid wear and finally humeral head collapse [20].

43.2.1 Ultrasound

Ultrasound examination allows for accurate diagnosis of RCT. Every shoulder surgeon should be familiar with this everywhere and cost-efficient imaging tool. It allows quick and reliable diagnostics focusing on RC tendon integrity [44]. With high-resolution probes up to 12.5 MHz, even partial RCT can be detected. In addition, pathologic changes of the long head of the biceps

tendon (LHBT), including peritendinitis or subluxation/gross instability, can be diagnosed. Furthermore, intratendinous calcium deposits and perihumeral fluid accumulation in terms of subcoracoid, subacromial or subdeltoid bursitis can be seen. Compared to MRI, dynamic testing is a clear advantage when RCT are evaluated. However, the grade of tendon retraction and secondary alterations as muscle atrophy and fatty infiltration cannot be determined. Also intraarticular structural pathologies as labral tears, SLAP lesions or cartilage lesions cannot be detected by ultrasound [45]. Obviously, the reliability is strongly dependent from the observer's experience. Another advantage of ultrasound is offered during the postoperative course evaluating RC integrity after repair or the presence of intra- or periarticular effusion due to postoperative inflammatory processes.

43.2.2 Magnetic Resonance Imaging (MRI)

MRI represents the most accurate imaging tool to evaluate RCT. In addition to the structural lesion itself, prognostic and therapeutic decision influencing factors including muscle atrophy [46], tendon retraction [37] and fatty infiltration [13, 17] can precisely diagnosed. The classification system of muscle atrophy, tendon retraction and fatty infiltration are presented in Chap. 1.3. Certain principles have to be respected, i.e. that parasagittal slices are extended beyond the coracoid process in order to assess adequately the grade of muscle atrophy and slice thickness should not exceed 3 mm.

43.3 Rating: International Classification

The classification of RCT is of utmost importance within the setting of the preoperative staging for surgical planning. In order to achieve an excellent surgical result, a preoperative pathology-related therapeutic planning has to be performed. This includes the functional demands of the patient and his motivation and compliance regarding the long-lasting rehabilitation period, as well. Parameters providing all required information include tendon tear size and retraction, muscle atrophy and fatty infiltration.

43.3.1 Articular-Sided Partial Tears

The first established classification of articular-sided partial tears was described by Ellman [9].

Classification of partial tears according to Ellman [9]	
Grade 1	Diameter <¼ or >3 mm
Grade 2	Diameter <½ or 3–6 mm
Grade 3	Diameter >6 mm

However, due to its mono-dimensional approach considering the medial-to-lateral extension alone, it does not fulfil the criteria required for a complete classification.

Habermeyer et al. introduced in 2008 a new classification for partial supraspinatus tendon tears considering two dimensions [18]. In the parasagittal plane, three zones are defined:

- Zone A includes the lateral pulley sling.
- Zone B includes the crescent zone.
- Zone C is a combination of both.

In the paracoronal plane, another three zones are distinguished similar to the classification according to Ellman:

- Type 1 refers to the articular-sided area directly close to the osteochondral transition zone.
- Type 2 extends to the middle third of the footprint.
- Type 3 involves the lateral third in terms of a subtotal lesion.

43.3.2 Bursal-Sided Partial Tears

The classification according to Ellman for partial tears can be applied for bursal-sided tendon lesions as well. However, the more detailed classification according to Snyder [42] is preferred by the author.

Classification of bursal-sided partial tears according to Snyder [42]	
Grade 0	Normal
Grade 1	Minimal superficial bursal or synovial irritation or slight capsular fraying over a small area
Grade 2	Fraying and failure of some rotator cuff fibres in addition to synovial bursal or capsular injury. More severe rotator cuff injury fraying and fragmentation of tendon fibres often involving the whole of a cuff tendon, usually <3 cm
Grade 3	Very severe partial rotator cuff tear that contains a sizeable flap tear and more than one tendon

A special kind of partial RCT is represented by intratendinous tears located between both tendon sheets: the bursal- and articular-sided layers are intact [14]. The diagnosis is difficult and is possible by MRI.

43.3.3 Partial Subscapularis Tendon Tears

Subscapularis tendon tears can be either of traumatic or atraumatic origin. The pathomorphological mechanism for atraumatic lesion is caused by pulley lesions in terms of instability of the long head of the biceps tendon. Chronic antero-medial subluxation out of the bicipital groove leads to tendon damage at its insertion area at the lesser tuberosity and stepwise tendon avulsion. Two classification systems are established for tears of the subscapularis tendon, whereas that according to Lafosse [25] takes imaging-verified muscle atrophy into account, as well.

Classification of SSC tendon tears according to Fox and Romeo [12]	
Type 1	Partial thickness tear
Type 2	Complete tear of upper 25 % of SSC tendon
Type 3	Complete tear of upper 50 % of SSC tendon
Type 4	Complete rupture of SSC tendon

Classification of SSC tendon tears according to Lafosse [25]	
Type 1	Partial lesion of superior one-third
Type 2	Complete lesion of superior one-third
Type 3	Complete lesion of superior two-thirds
Type 4	Complete lesion of tendon but head centred and fatty degeneration classified as less than or equal to Goutallier stage III
Type 5	Complete lesion of tendon but eccentric head with coracoid impingement and fatty degeneration classified as more than or equal to Goutallier stage III

43.3.4 Tear Size

Before sizing an RCT, the two-dimensional character of RCT has to be taken into account. This means that the size has to be related to the parasagittal extension from anterior to posterior and to the paracoronal extension from lateral to medial which corresponds to the grade of retraction. Obviously, depending from the number of tendons involved, the tear size increases. An internationally well-accepted classification system for full-thickness tears was introduced by Bateman et al. in 1984 [4].

Complete cuff tears: Bateman classification	
Grade 1	Tear <1 cm after debridement
Grade 2	Tear 1–3 cm after debridement
Grade 3	3–5 cm
Grade 4	Global tear, no cuff left

In combination with the topographic classification of rotator cuff tears in the sagittal plane according to Habermeyer [19], the RCT can be sized precisely in the parasagittal plane regarding tear extension as distance measurement and the region with the according tendons involved.

- Sector A: Anterior lesions – subscapularis tendon, rotator interval and LHB tendon
- Sector B: Central superior lesions – supraspinatus tendon
- Sector C: Posterior lesions – infraspinatus and teres minor lesions

For example, a posterosuperior RCT tear involving the infra- and supraspinatus tendons is classified as Bateman 3 BC.

43.3.5 Tear Configuration

Depending from the direction of retraction, different tear configurations can evolve. For reconstruction purposes it is important to analyse the tear pattern in order to achieve anatomical reduction of the RC and a tension-free refixation of the tendon at the footprint. A widely accepted classification was presented by Ellman in 1993, which covers most of the cases [10].

Tear configuration according to Ellman and Gartsman [10]	
Transverse	Tear at the insertion site
Crescent cable	Transverse tears with deformation due to SSC/ISP tension
L shaped	Transverse tear with extension into the interval between SSP and ISP
Reversed L shaped	Transverse tears with extension into the rotator interval
Trapezoidal	L shaped + reversed L shaped
Massive RCT	Extension into TM or anterior SSC

43.3.6 Tendon Retraction

Once the tendon shows a complete tear, a certain trend towards retraction of the stump following the muscle tension in a medial direction is present. The course over time is unpredictable. However, the grade of retraction is of prognostic value in regards to RC repair feasibility and success [16]. The classification according to Patte has been established to grade tendon retraction [37]. Note that the grade of tendon retraction does not provide any information regarding tendon's elasticity and thus the feasibility of tendon reconstruction.

Classification of tendon retraction according to Patte [37]	
Grade 1	Proximal stump close to bony insertion
Grade 2	Proximal stump at level of humeral head
Grade 3	Proximal stump at glenoid level

43.3.7 Muscle Atrophy

In chronic RCT degenerative changes evolve over time and lead to functional impairment. A nonworking muscle due to the interruption of its myo-tendino-osseous function chain loses its contractility and atrophies. This means that muscle volume reduces, and the surrounding perimuscular space is replaced by fibrous and/or fat tissue. For classification purposes the occupational ratio between the entire space of the fossa supraspinata and the SSP muscle belly itself is calculated [46]. Measurements are performed on the scapular cut in the parasagittal plane at level of the medial border of spine of scapula (first cut of scapular Y shape, Fig. 43.5).

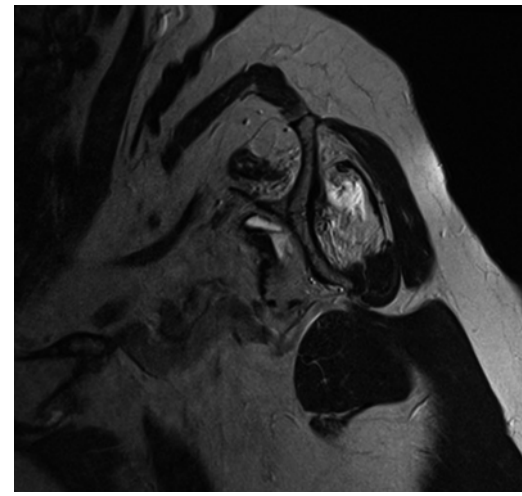

Fig. 43.5 Parasagittal plane of a left shoulder showing advanced muscle atrophy and fatty infiltration in a massive global cuff tear. Only the teres minor is at least in part viable

Classification of muscle atrophy according to Thomazeau [46]	
Stage 1	Normal/slight atrophy occupation ratio (1.00–0.60)
Stage 2	Moderate atrophy occupation ratio (0.60–0.40)
Stage 3	Severe atrophy occupation ratio (<0.40)

Basically, degenerative changes are reversible until a certain critical "point of no return". For SSP muscle atrophy this critical point is achieved when the muscle belly is below a tangent line drawn from the top of the coracoid base to the scapular spine (= tangent sign according to Zanetti [52]). The risk for RC irreparability or RC retear is directly correlated to the grade of muscle atrophy. Again, speed of atrophy progression varies, but is directly correlated to the number of tendons torn. The subscapularis as the strongest RC muscle tends to atrophy more quickly. It could be shown that over a 4-year follow-up period in patients with massive RCT refusing surgery, both muscle atrophy and fatty infiltration together with osteoarthritic changes increased [53]. Whereas shoulder function was stable, four out of eight patients with a primary reconstructable RCT showed an irreparable situation at the final follow-up.

Moosmayer et al. [29] observed clinical deterioration of 36 % of initially asymptomatic full-thickness tears within 3 years. Progression of tear size, muscle atrophy and fatty infiltration were correlated directly with the presence of symptoms.

43.3.8 Fatty Infiltration

Over time, muscle atrophy is accompanied by fatty infiltration of the muscle tissue. It could be shown that the localization of the fatty infiltration is not the muscle cell itself, but the intercellular space [43]. The first description and classification of fatty infiltration of the RC was performed on CT scans by Goutallier et al. in 1994 [17]. Fuchs adapted this classification to MRI, which nowadays represents the primary imaging modality in evaluation of the RC [13]. However, fatty infiltration is a negative prognostic value and irreversible when stage 3 or 4 according to Goutallier is achieved.

Classification of fatty infiltration		
Goutallier [17] stage (CT)	Degree of fatty change	Fuchs [13] stage (MRI)
0	Normal muscle	1
1	Some fatty streaks present	
2	More muscle than fat	2
3	Equal muscle and fat	3
4	More fat than muscle	

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Treatment of Partial Cuff Tears

44

Klaus Bak

44.1 Introduction

The treatment of partial-thickness tears of the rotator cuff tendons (PTRCT) involves a thorough clinical examination, tracing the history of symptom development as well as diagnostic imaging. This chapter elaborates on the current knowledge concerning treatment options, arthroscopic techniques and the expected outcome. The developments in diagnostic criteria, diagnostic measures and overall clinical assessment have led to the constant evolution in the treatment of PTRCT. Over the last decade, advances in rehabilitation programmes seem to have improved outcomes too and in some cases reduced the need for surgical intervention. However, the evidence is still lacking [1, 2]. Despite a rapid improvement in arthroscopic techniques, the outcomes may still be unpredictable, particularly in overhead athletes [3].

In the general population, PTRCT is regarded to be a result of a slow degenerative process of the enthesis occurring mainly in individuals over 50 years of age. On the other hand, degeneration of the tendon insertion seems to occur at a younger age in the case of overhead athletes. Furthermore, the presence of a PTRCT may be unrelated to symptoms and decreased function as earlier records have shown it to be frequently prevalent in asymptomatic throwers [4]. Connor et al. found that the MRI showed a prevalence of 40 % of mainly partial rotator cuff tears and that the presence of this pathology required no intervention during the subsequent 5 years of follow-up [4]. There appears to be no clear correlation between the symptoms and the presence of a partial tear, but larger tears are more likely to become symptomatic [5]. In addition, no correlation is evident between the occurrence and the size of the tear and the choice of primary treatment. Some of the crucial points to be raised here are: When does a PTRCT become symptomatic? What is responsible for the pain? And at what tear size can nonoperative treatment be expected to have no effect?

In throwers, it has been shown that compressive as well as increased tensile loads due to forceful overhead motions from the abducted and externally rotated position during the deceleration phase expose the entheses of the supra- and infraspinatus tendons to shear stress and early degeneration predisposing them to gradual avulsion [6–9]. Changes in the humeral head rotation as well as the decreased internal rotation, kinetic chain dysfunction and scapular dyskinesis place the enthesis further at risk [10]. All these factors need to be considered when planning a treatment programme (Table 44.1). There are a number of uncontrolled series that have reported favourable results with arthroscopic treatment of partial rotator cuff tears [11–21]. Recently, however,

K. Bak, MD
Division of Arthroscopic Shoulder Surgery, Aleris-Hamlet Parken, Teres Hospital Parken, Copenhagen, Denmark
e-mail: skulderbak@gmail.com

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Table 44.1 Factors associated with partial cuff tears in throwers

Dysfunction of the kinetic chain (unstable ankle, back, core)
Scapular dysfunction
GIRD (adaptive changes in the humeral version, pericapsular contracture)
Technical or training errors

randomised controlled trials and level 2 prospective comparative studies have been published [22, 23] as well as two meta-analyses and one systematic review [24–26]. This is in great contrast to the lack of studies on the conservative treatment specifically addressing the PTRCT. Currently, there are no comparative studies showing any benefit of nonoperative treatment over surgical repair, or vice versa. Due to the lack of high-level evidence in this field, the present chapter is based on a combination of current knowledge and ideas about future treatment and necessary studies.

44.2 Primary Treatment

When a partial-thickness rotator cuff tear (PTRCT) is diagnosed, a number of factors have to be considered before initiating a treatment plan: the size of the tear, the tendon or tendons involved, associated pathology of the glenoid labrum or the long head of biceps, as well as the aetiology and biomechanical factors responsible for the development of symptoms. Based on the aetiology, PTRCT should be divided into either traumatic tears or degenerative tears, although in some cases it may be difficult to make a clear distinction because some of the supposedly traumatic PTRCT originally may have been degenerative in nature. In young throwers, a PTRCT may be seen at an early age, whereas most other tears are a result of age and factors that provoke degeneration such as repetitive loading and smoking [27].

The following PTRCT should be considered mainly for nonoperative treatment when first diagnosed:

- Small tears involving less than 50 % of the footprint [11–26]
- Non-traumatic tears seen in overhead athletes [10, 33]

Table 44.2 Nonoperative treatment of PTRCT

Analysis of aetiology
Correction of technique or work load
Pain relief (NSAID, cortisone injection)
Correction of kinetic chain dysfunctions
Correction of scapular dysfunction
With a stable scapula – strengthening of the rotator cuff
Regular evaluation of progress in treatment and outcome

The following PTRCT should be considered for primary operative treatment:

- Traumatic tears involving over 50 % of the footprint [11–26]
- Bursal-side tears involving more than 50 % of the tendon thickness
- PTRCT of more than one rotator cuff tendon or associated long head of biceps pathology

Nonoperative treatment consists of a number of corrective measures depending on the pathology and dysfunctions found after clinical assessment [10]. This treatment should involve an analysis of aetiology (trauma or overuse), the biomechanics, core dysfunction, scapula dysfunction and disturbances of the kinetic chain [10]. Corrections of the kinetic chain can decrease the load on the shoulder girdle [28–31]. Many throwers have disabilities of the back or core, or even from an unstable ankle that increases the demands for force generated in a different part of the chain, often the shoulder joint, which puts extra load and shearing stress on the rotator cuff tendons [10]. Technical or training errors while performing the sport should be analysed and corrected. Adaptive changes in humeral head version and tightness of pericapsular structures may also be responsible for rotator cuff pathology.

Apart from addressing the aetiology, nonoperative treatment also consists of interventions to relieve pain, improving range of movement, improving scapular and cuff strength and endurance (Table 44.2). In most cases, it seems that the pain associated with a rotator cuff tear comes

mainly from a bursal inflammation [32] and a short course of NSAIDs and/or a cortisone injection can relieve pain. However, none of these treatment modalities can stand alone. Nonetheless, with effective pain relief, the patient could undergo a rehabilitation programme in order to regain mobility, strength and function. There is no clear evidence of the effect of nonoperative treatment, and outcome studies are lacking in literature. In a current concept paper, Matthewson et al. referred to a study where 50 % of the patients with a diagnosis of PTRCT underwent nonoperative treatment and had a 91 % successful outcome after a 4-year follow-up [1]. Additionally, there is a lack of knowledge regarding the duration of nonoperative treatment. Most references recommend 3 months of nonoperative treatment but rarely discuss what stage the patient is expected to be at after this time. Would it be acceptable if there were no progression at all over 3 months? Would a 50 % improvement be sufficient? Would surgery be indicated if there was no progression or the symptoms worsened after 6 weeks of nonoperative treatment? Moore-Reed et al. showed that more than half of the throwers with shoulder pain were able to improve their shoulder function significantly after a 6-week structured rehabilitation programme [33]. The author suggests that 3 months of nonoperative treatment is advisable if the therapist and the patient experience continuous improvement and that 6–8 weeks of resultless nonoperative treatment leads to a decision about arthroscopic repair.

44.3 Surgical Treatment

Almost all shoulder surgeons prefer arthroscopic treatment than open surgery due to the better overview and direct vision by handling anchors and sutures. There are a number of surgical treatment possibilities among which debridement, decompression and repair are the most common. The type of treatment depends on the size of the tear and the aetiology. The most widely used classification is the one by Snyder et al. [17] which uses the thickness of the tendon as a guide

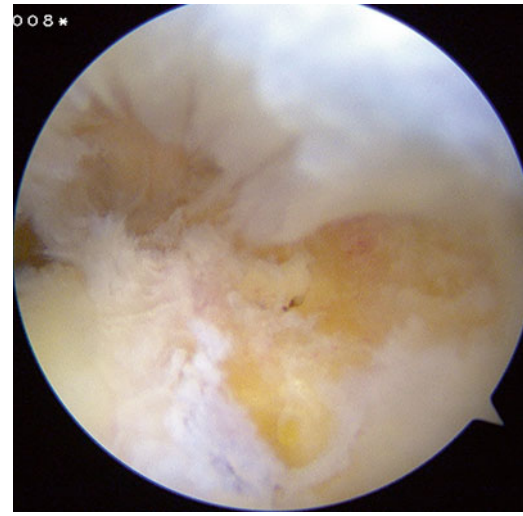

Fig. 44.1 The supraspinatus footprint after debridement

to ascertain severity while also noting the degree of footprint exposure. To use this classification, the arthroscopic surgeon has to perform a debridement and an assessment of the percentage of the tendon and footprint involved (Fig. 44.1 – footprint after debridement).

The indications to opt for surgical treatment are painful, restricted shoulder movement, weakness and decreased function despite relevant nonoperative intervention. The purpose of intervention is to improve function and reduce symptoms as well as to reduce the risk of tear propagation with time. It is generally accepted that minor articular side tears (A1) can be treated with simple debridement without any need for repair. Often these tears are seen in conjunction with posterior-superior labral pathology in overhead athletes. These patients often have a combination of microtraumatic anterior instability, GIRD, PASTA tear and labral pathology [10] where addressing the PTRCT itself is just a minor part of the treatment. In young overhead athletes, a subacromial stenosis is not a part of the pathology, and, therefore, arthroscopic subacromial decompression (ASD) is rarely a viable option in these patients [21, 34]. Conversely, degenerative PTRCT seen in manual workers is more often associated with subacromial stenosis, and in these cases ASD may be considered a relevant intervention. In some cases, subacromial stenosis

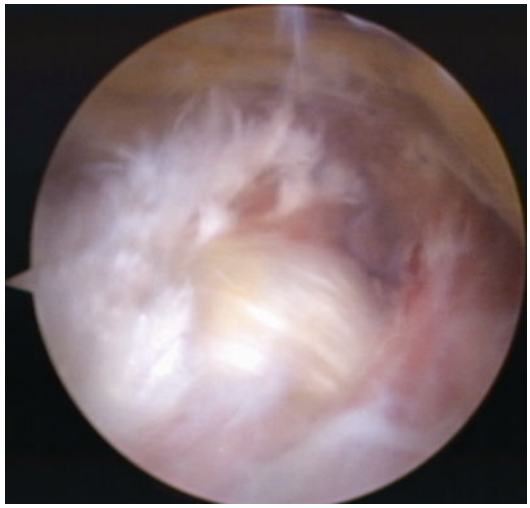

Fig. 44.2 A bursal-side supraspinatus tear

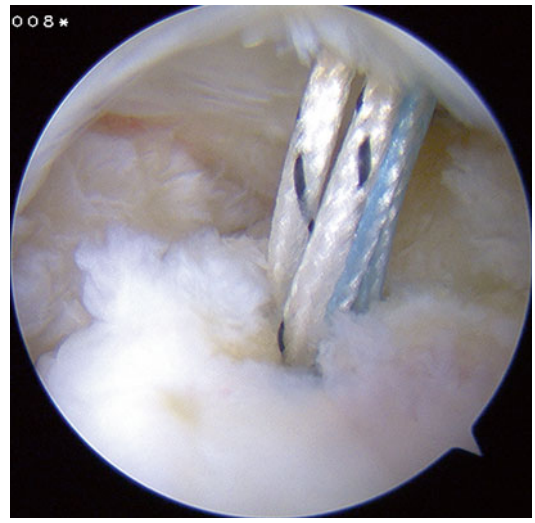

Fig. 44.3 Shows sutures after transtendon introduction of an anchor

is associated with partial bursal-side tears of the supraspinatus tendon (Fig. 44.2). ASD has been shown to increase healing factors in the subacromial space [35] and to improve the posterior tilt by creating more space under the anterior acromion. In contrast to this, Kartus et al. found that ASD and debridement of the PTRCT did not protect the tear from propagation with time [36]. In full-thickness cuff tears, there seems to be a higher reoperation rate when acromioplasty is not performed [37].

The effect of a simple debridement remains unclear. In many cases, this simple method can be used to treat small, delaminated tears without footprint involvement. Andrews reported short-term good or excellent results in 85 % of overhead athletes after debridement [38], and Reynolds et al. found the same outcome without using ASD [39]. It is likely that the removal of scar tissue (caused by failed healing response) related to the tear can improve healing. In rare large laminated tears without footprint involvement, Ellatrache et al. suggested a suture repair technique.

In A2 and A3 tears where repair is indicated, more techniques have been described among which the transtendon technique and the conversion to full-thickness tear are the two most common. Before repairing the tendon to the footprint, there appears to be a good rationale behind removing the scar tissue and the remnants of the results of the enthesopathy in order to promote healing. Recently, trephination has been suggested to facilitate release of healing factors like the one contained in the bone marrow, embedding in the repaired tendon and possibly enhancing healing, but so far no studies have been published. The transtendon technique, first described by Lo and Burkhart [14], involves placing one or two anchors in the footprint directly through the tendon under arthroscopic vision (Fig. 44.3). Sutures can be retrieved during the articular view, and knots can be tied using a bursal view. A single or a double-row repair is possible, and knotless anchors are available for this procedure. Figure 44.4 shows the final appearance after double-row repair. One anchor is recommended for tears less than 1.5 cm, while two anchors are suggested for tears larger than 1.5 cm [14]. Tear conversion technique has been shown to provide good functional results as well. The advantage of this technique over the transtendon seems to be that the remaining attached tendon tissue, which may comprise affected tissue with failed healing response, can be freed from the enthesis and the tendon can subsequently be reinserted to a footprint completely debrided of scar tissue. Figure 44.5 shows a scalpel initiating the conversion technique by releasing the tendon off the tip of the major tubercle. A number of randomised studies and meta-analyses show no significant differences in

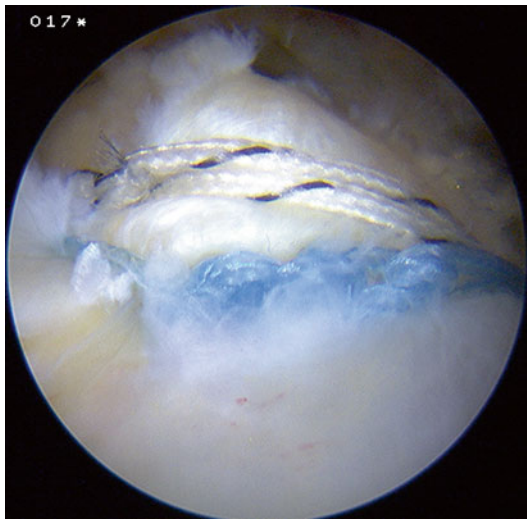

Fig. 44.4 Final look after double-row repair

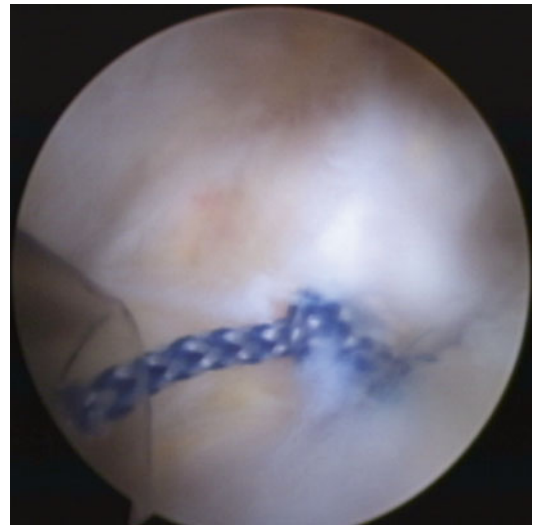

Fig. 44.6 Bursal-side tear after repair

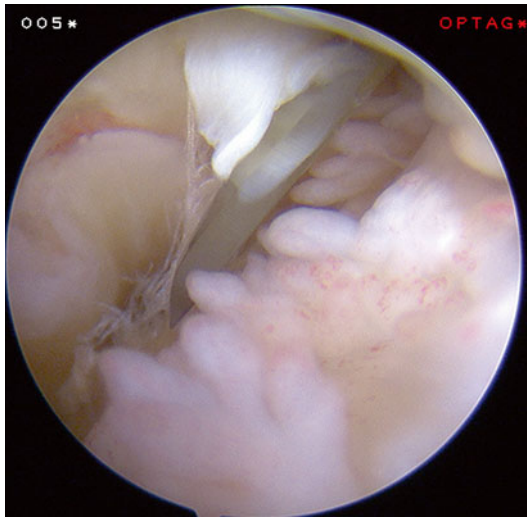

Fig. 44.5 A scalpel is introduced to release the tendon off the tip of the major tubercle

outcome between the two techniques [22–26]. The transtendon technique seems to result in a slower recovery but also in lesser gapping and lower retear rate, whereas the conversion technique results in a faster recovery but entails a higher risk of retear or gapping. Shin et al. showed that repair after conversion to a full-thickness tear showed less postoperative morbidity but also reduced tendon integrity, whereas the transtendon repair technique resulted in complete tendon integrity but slower functional recovery [24]. In a meta-analysis Sun et al. showed that while there was no difference in functional outcome between the two techniques, the retear rate was significantly higher in the tear conversion technique [25]. In a systematic review, Strauss et al. concluded that there is a significant variation in the outcome of treatment of PTRCT, and they did not find any differences in outcome between transtendon technique and the conversion to full tear technique [26]. In a biomechanical study, Gonzalez-Lomas et al. compared in situ transtendon repair (two anchors) with tear completion and double-row repair (four anchors) and found significant less gapping and higher mean ultimate failure strength with the transtendon technique [40]. Tauber et al. used a transosseous-equivalent technique and found preliminary good results with significant pain relief and functional improvement [19]. Recently, an arthroscopic transtendon double-row transosseous-equivalent technique for repair of PASTA lesions has been published [41]. There have been concerns about possible medial failure after transtendon repair, which analogous to double-row repair of full-thickness tears is a challenge if revision is needed [42]. Large bursal-side tears may need end-to-end repair or in some cases conversion to full-thickness tears (Fig. 44.6). The use of stem cells, platelet-rich plasma (PRP) and other biologic healing factors is not well

investigated in PTRCT. In a randomised controlled study with a 1-year follow-up, Kesikburun et al. evaluated the effect of PRP in patients with chronic rotator cuff tendinopathy including those with PTRCT and found no difference to placebo injection [43].

44.4 Complications

Complications to arthroscopic repair of PTRCT are relatively rare according to the literature. The most common complication is failure of the repair, followed by stiffness and infection. Strauss et al. reported that the complication rate in their systematic review ranged from 2.5 to 11.9 % [26].

Conclusion

The aetiology of a PTRCT may be more complex in overhead athletes than in nonathletes. This affects the primary treatment approach. The size of the PTRCT and the degree of pre-tear tendinosis seem related to the symptoms. Large-size tears seem to do better with repair; however, no controlled studies exist. Transtendon repair and conversion to full-size repair seem to result in a comparable outcome. The author suggests a treatment algorithm (Fig. 44.7) that takes into consideration the tear size and the aetiology. Below is a list of some issues with PTRCT that is not clearly known and that need to be further investigated:

(a) There are no studies in the literature on the outcome of nonoperative treatment of PTRCT.
(b) There are no controlled studies in literature comparing nonoperative treatment and arthroscopic repair or documenting the timing of arthroscopic treatment. Only a few controlled studies comparing different arthroscopic techniques exist.
(c) In overhead athletes, there is a lack of studies showing any relation between outcome and changes in tear size.
(d) There may be a difference between "normal" degenerative age-related tears and early degenerative tears in younger individuals in overhead athletes.

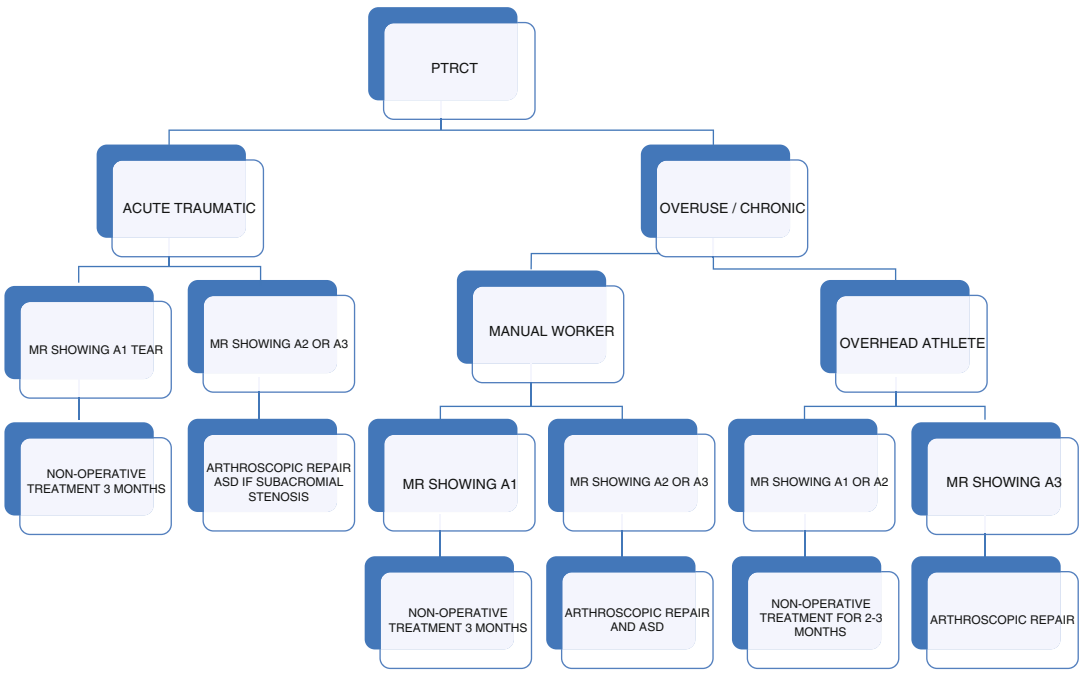

Fig. 44.7 Suggestion of a treatment algorithm for PTRCT

(e) Studies on the effect of biological intervention (growth factors, stem cells, etc.) are lacking.

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Subscapularis Tears

45

Maristella F. Saccomanno and Giuseppe Milano

The subscapularis (SSC) muscle is the largest and strongest muscle of the rotator cuff. It allows active internal rotation of the humerus, provides anterior stability of the shoulder, and is involved in maintaining balanced force couples of the glenohumeral joint in the transverse plane [1, 2]. Anatomic studies reported different shapes for its insertion on the lesser tuberosity: comma, Nevada state, ear, and trapezoid [3–8]. It has been shown that the superior two-thirds of the SSC insertion are tendinous, while the inferior third is muscular and directly attached to the humerus through a thin membranous structure. The upper part of its insertion extends in a thin tendinous slip, which is attached to the fovea capitis of the humerus [3]. The size of its footprint widely varies between 25 and 51 mm in mean length and 9.5 and 18.1 mm in mean width [3–8].

The prevalence of isolated SSC tears range between 4 and 7 % [9–14], whereas anterosuperior cuff tears, involving the SSC and the supraspinatus (SS) tendon, are quite more common ranging from 2 to 49 % [10, 12, 14–17]. The most common finding is represented by a partial-thickness tear of the upper third of the SSC tendon in combination with a full-thickness tear of the anterior part of the SS tendon and a lesion of the biceps pulley, which unequivocally leads to instability of the long head of the biceps (LHB) tendon.

The etiology of SSC tendon tears can be divided into degenerative, traumatic, and microtraumatic. Degenerative tears can be caused by intrinsic and extrinsic factors. Intrinsic factors are linked to metabolic and vascular changes strictly related to the aging process, while extrinsic factors can be mainly related to the development of an external impingement [18]. Several mechanisms have been reported for trauma: forced hyperextension and external rotation [19, 20], external rotation with the arm at the side [21] or at 60° of abduction [22], and an anterior traumatic dislocation [23–25]. Microtraumatic tears are common in throwing athletes and are mainly due to the development of an internal impingement [26, 27].

From a clinical standpoint, patients usually complain pain in the anterior part of the shoulder, frequently associated with biceps symptoms as well, and loss of strength in internal rotation. At the clinical examination, tenderness at palpation over the lesser tuberosity is a common finding. Moreover, an increase in passive external rotation can be noticed in case of a large lesion. A recent paper showed that an anterosuperior cuff lesion

M.F. Saccomanno, MD (✉)
Department of Orthopaedics,
Catholic University, Rome, Italy
e-mail: maristellasaccomanno@hotmail.it

G. Milano, MD
Department of Orthopaedics,
Catholic University, Rome, Italy

Service of Shoulder Surgery,
"A. Gemelli" University Hospital, Rome, Italy
e-mail: giuseppe.milano@rm.unicatt.it

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involving the entire SSC and the SS tendons is a risk factor for pseudoparalysis [28].

Specific tests have been described for the evaluation of the SSC tendon. The most commonly used are lift-off test, belly-press test, Napoleon test, bear-hug test, and internal rotation lag sign (IRLS). The internal rotation resistance test at 0° (IRRT0°) of abduction and external rotation and at 90° of abduction and external rotation (IRRTM) has been recently described [29]. Compared to the previous tests, the IRRTM test showed the greatest sensitivity (76.5 %) and the highest accuracy (79 %), while the IRLS (31.6 %) test showed the lowest sensitivity and the lift-off the lowest accuracy (65.3 %). Moreover, the authors showed that positive IRRTM and IRRT0° and bear-hug and belly-press tests indicate a lesion of the upper third of the tendon, while a positive lift-off and IRLS tests predict a bigger lesion of at least two-thirds of the tendon [29].

Plain radiographs are routinely asked for the evaluation of shoulder disease, albeit only indirect signs of a SSC tear can be noticed in case of a massive cuff tear, when an anterosuperior migration of the humeral head has occurred. A recent systematic review and meta-analysis on diagnostic accuracy of ultrasounds (US), magnetic resonance imaging (MRI), and magnetic resonance arthrography (MRA) showed similar performance of the three imaging modalities for overall estimates of sensitivity (0.90–0.91) and specificity (0.93–0.95) in the characterization of full-thickness cuff tears. Moreover, in case of partial-thickness tears, equivalent specificity (0.93–0.94) between the three imaging modalities was also reported, while MRA showed the highest sensitivity (0.83) [30]. Few data specifically regarding the SSC tendon tears are available. Particularly, reported sensitivity of MR in the diagnosis of SSC tears range from 25 to 94.7 % [31–36]. As already mentioned, subluxation or dislocation of the LHB tendon is frequently associated with a SSC tendon tear. Shi et al. [37] recently showed that subluxation of the LHB on MR as a predictor for full-thickness SSC tears had a sensitivity of 82 %, specificity of 80 %, positive predictive value of 35 %, and negative predictive value of 97 %. By the way, although over the last decades, diagnostic accuracy of clinical tests and imaging modalities sensibly increased, arthroscopy still remains the gold reference.

45.1 Indications

From a clinical standpoint, symptomatic lesions must be repaired. Apart from this, a common finding during arthroscopy is a minor fraying of the upper part of the SSC tendon, which usually does not require any surgical treatment, especially in elderly patients and if the biceps pulley is intact. Conversely, partial-thickness and full-thickness tears always need to be repaired to ensure the force couple balancing. In case of retracted and irreparable SSC lesions, a pectoralis major transfer can be proposed in young active patients, although functional outcomes are still debatable. Up to now, although literature is lacking on this topic, isolated irreparable SSC tendon tears seem to be the best indication in order to achieve pain relief, partial recovery of strength, and slight reduction of external rotation [38–40].

Differently from posterosuperior cuff tears, isolated SSC tendinopathy has never been described, and, as already mentioned, partial-thickness tears can be easily missed at clinical and imaging evaluation. Therefore, since diagnosis of SSC tears is mainly arthroscopic, there is no real indication for conservative management.

45.2 Surgical Technique

Surgery can be performed in general or regional anesthesia with an interscalenic block or in general or blended anesthesia. The patient can lie in lateral decubitus or beach chair position, according to surgeon's preference. It is authors' preference to perform rotator cuff surgery in regional anesthesia and beach chair position with the affected arm in 50–60° of forward flexion and 20–30° of abduction. A traction (2–3 kg) is also applied to the affected arm. Regional anesthesia should allow the patient to collaborate in his

positioning and provide a better control of postoperative pain.

Before starting the surgical procedure, it is very useful to mark bony landmarks with a marking pen: the spine of the scapula, the acromion, the clavicle, and the coracoid process. These landmarks will guide the portal placement during surgical procedure when soft tissues are swollen. Three portals are usually enough to repair the SSC tendon. In some cases, additional portals might be necessary for the optimal positioning of the suture anchors.

Portals used by the authors are:

- Posterior portal: it is used as viewing portal. It allows an en face view of the intra-articular side of the SSC tendon.
- Anterosuperior portal placed with the outside-in technique: it allows to approach the joint passing through the rotator interval. In rotator cuff surgery, it is usually used for controlling the outflow and as secondary operative portal for suture management and powered or radiofrequency instruments. In case of combined anterosuperior tears, it can be performed slightly more anterior than the usual one, so it can be also used for the correct placement of suture anchors for SSC repair with no need for an additional anterior mid-glenoid portal.
- Anterior mid-glenoid portal: it is necessary for suture anchor placement in case of isolated SSC tears. In this case, the anterosuperior portal is used for suture management.
- Standard lateral portal: it is used as operative portal for suture management in case of combined anterosuperior cuff tears. Moreover, it can be used as viewing portal for the evaluation and dissection of the subcoracoid space, when needed.

All the arthroscopic procedures start with a diagnostic evaluation on air. If lesions of the subscapularis tendon and/or the long head of the biceps are present, they should be addressed from the intra-articular side before passing the scope into the subacromial space. There are two main reasons that justify this approach. First, working area is very limited compared to the subacromial space for a posterosuperior cuff repair, and soft tissue swelling during arthroscopy can further limit the working space. Second, it is almost impossible to reestablish the anatomic tendon attachment if the repair is performed from the bursal side, because the lesser tuberosity footprint as well as the upper margin of the tendon cannot be visualized unless the rotator interval is completely open.

A 30° or a 70° scope can be used for the management of SSC tears. It is authors' preference to use a 30° scope. As most tears begin as a partial-thickness tear of the upper articular surface, a good inspection of the lesser tuberosity footprint is mandatory. In order to achieve a good visualization, a "shank maneuver" (forward flexion, abduction, and internal rotation of the arm) or a "posterior lever push" maneuver (posterior subluxation of the humeral head to increase the anterior working space) should be performed [41].

Once the inspection on air is complete, portals should be placed and irrigation fluid can start. As most of the tears are associated with a pulley lesion and therefore the LHB is usually unstable or anteriorly dislocated, biceps treatment is the first step of the procedure. A tenotomy or a tenodesis can be performed, according to patient's age and functional request or surgeon's preference. Tenotomy is usually performed in elderly patient. If a tenodesis is chosen, it can be done open or arthroscopically. It is authors' preference to perform an arthroscopic tenodesis by using one or two suture anchors in the upper part of the bicipital groove. Main advantage of arthroscopic tenodesis is that tenotomy can be performed after the tendon is fixed, so length and anatomic position of the tendon are perfectly maintained.

Once the biceps pathology has been treated, the second step is the SSC repair. Several arthroscopic classifications have been described, although there is no universally accepted system [12, 17, 31, 42]. The most commonly used is the Lafosse classification [12], which actually is a mix of arthroscopic and imaging classification. It is a five-stage classification: (1) upper one-third partial-thickness tear; (2) upper one-third full-thickness tear; (3) upper two-third full-thickness tear; (4) full-thickness tear, centered humeral

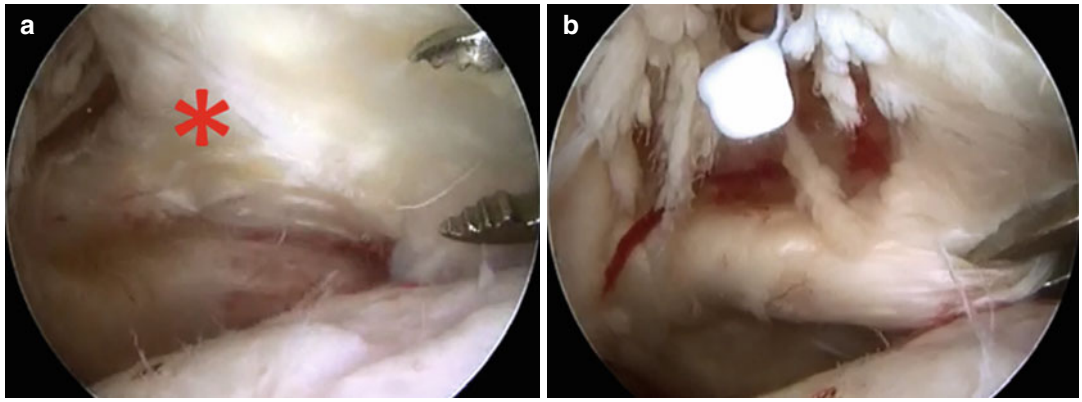

Fig. 45.1 Right shoulder, the scope is placed in the posterior portal. (**a**) Arthroscopic view of the "comma sign" (*asterisk*). (**b**). The comma sign disappears when the subscapularis is reduced to the humeral head

head, and fatty infiltration less than grade 3, according to the Goutallier classification [43]; and (5) full-thickness tear, anterosuperior subluxation of the humeral head, and fatty infiltration higher than grade 3, according to Goutallier [43].

Principles of SSC repair are almost the same of posterosuperior cuff repair. After identification of the lesion, mobilization and reduction must be first obtained in order to understand the size and the shape of the tear and to perform a tension-free repair. An aggressive release is not a routinary procedure, but it is sometimes required in chronic or traumatic retracted lesions. Single-row, double-row, and suture-bridge techniques with different types of anchors can be used for tendon repair. It is author's preference to use double-loaded metal anchors placed in a single-row configuration.

As mentioned in the previous section, minor fraying or articular-sided partial-thickness tears without involvement of the biceps pulley usually do not require any treatment, especially in elderly patients, or in alternatives, a slight debridement can be performed. On the contrary, lesions described by Lafosse's classification always need to be repaired.

The first step is to recognize the upper border of the tendon. The key to understand the lesion, especially in case of full-thickness tear, is the "comma sign" [44] (Fig. 45.1). The comma sign, as described by Lo and Burkhart in 2003 [44], is a lesion typically located in the region where the fibers of the humeral insertions of the SSC tendon merge with those of the superior glenohumeral ligament/coracohumeral ligament complex. When the SSC tendon is torn off the lesser tuberosity, this composite forms a comma-shaped arc, which can be used as a marker for identification of superior and lateral margin of the SSC tendon. The continuity of these fibers should not be interrupted, so in case of combined anterosuperior lesions, the SSC repair will also reduce the superior cuff retraction and tension [45].

If the SSC tear is retracted to the glenoid, a release can be necessary to mobilize and reduce the lesion. This situation is frequent in case of chronic degenerative tears in elderly or in case of traumatic tears. A stepwise three-sided release of the SSC tendon, avoiding inferior dissection which risks to damage the axillary nerve, has been described [46]. A traction suture can be applied at the comma, and a superior release is first performed through a radiofrequency instrument or a shaver by excising the rotator interval, paying attention not to interrupt the fibers' continuity at the comma sign. The release continues anteriorly by cleaning the subcoracoid space, so soft tissues (scar tissue/adherence) between the tendon and the undersurface of the coracoid are removed. In case of subcoracoid space reduction less than 6 mm, a coracoidplasty has also been suggested [18]. Finally, a posterior release can be performed between the posterior SSC and anterior glenoid neck, by using an elevator to release

the capsule and the middle glenohumeral ligament. Once tendon excursion is free of tension up to the lesser tuberosity footprint, a tension-free repair to the bone can be attempted. The footprint is prepared in a standard fashion by electrocauterization to remove residual soft tissue and a shaver to abrade the cortical surface in order to have a bleeding bone bed, and the anchors are then placed. Microfractures of the lesser tuberosity can be performed before knot tying rather than performing a cortical abrasion, especially in osteoporotic bone (Fig. 45.2). If a single-row repair is performed, one anchor can be enough for grade 1–2 tears, according to the Lafosse classification [12]; two anchors can be necessary for grades 3–4, as well as for grade 5, if repairable. If more than one anchor is needed, the first anchor will be the lower one. The anchor must be placed closed to the articular margin, and an important tip for the correct placement is to follow the rule of the "hand-on-jaw" position [47] (Fig. 45.3).

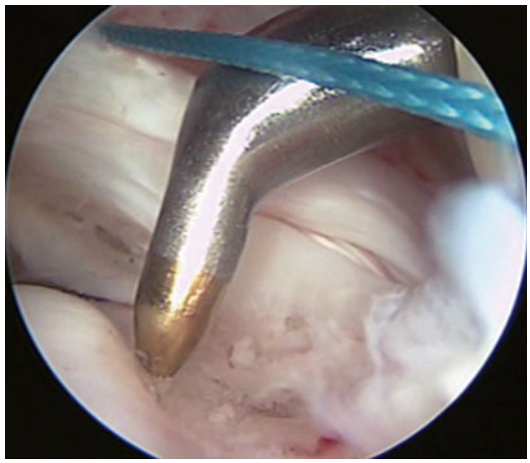

Fig. 45.2 Right shoulder, the scope is placed in the posterior portal. Footprint preparation: microfractures of the lesser tuberosity are performed by a dedicated arthroscopic awl

Several stitch configurations have been described for SSC repair, but the key is to respect the direction of the force vector. According to the author's preferences, sutures from the inferior anchor are passed in a horizontal mattress configuration. For the superior anchor, one suture is usually passed in a horizontal mattress configuration, while the second suture is passed in a simple suture configuration at the intra-articular side of the comma (Fig. 45.4). Knot tying follows the same order. While tying the first suture, a slight traction on the second suture can be applied, if necessary, in order to reduce the tension.

Once the SSC tendon is repaired, the scope can be moved to the subacromial space, and a repair of posterosuperior cuff can be performed, if needed.

Postoperatively, patients are immobilized in a sling for 4 weeks. Free movement of the hand and wrist is immediately allowed, while any kind of load is totally forbidden for the first 2 months. Rehabilitation protocol is the same used for

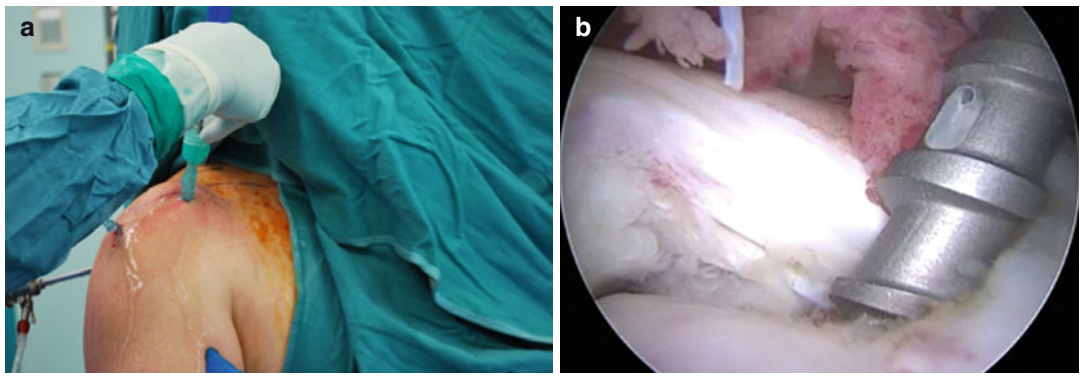

Fig. 45.3 Right shoulder, anchor placement for SSC repair. (**a**) External view. Because of the retroversion of the humeral neck, the angle of approach for the correct placement of the anchor requires that the surgeon directs his/her hand toward the patient's jaw ("hand-on-jaw" position). (**b**) Intra-articular view from the posterior portal. The anchor should be placed on the lesser tuberosity footprint between the articular margin of the humeral head and the biceps groove

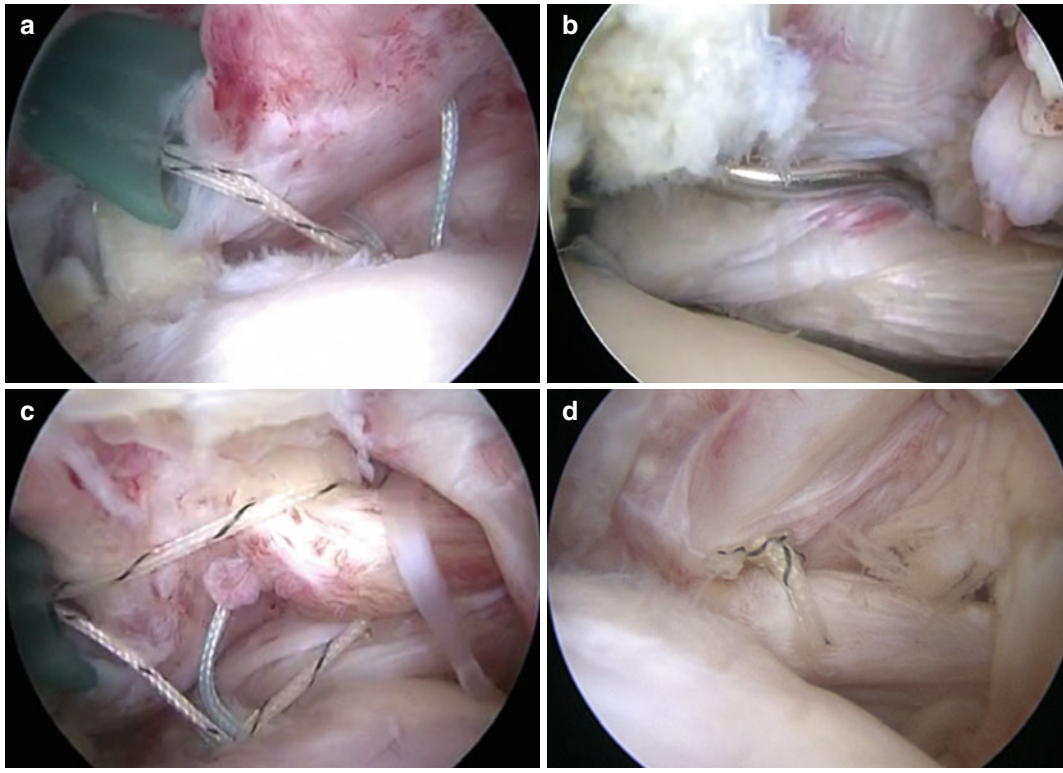

Fig. 45.4 Left shoulder, the scope is placed in the posterior portal. (**a**) The distal suture (*blue*) is passed in a horizontal mattress configuration. (**b**) The suture hook for the proximal stitch is passed at the confluence between the SSC tendon and the CHL ligament. (**c**) The proximal suture (tiger) is passed in a simple suture configuration at the intra-articular side of the comma. (**d**) Anatomic and in-continuity repair

posterosuperior cuff repair: recovery of passive range of motion starts after sling removal and it usually lasts for 4 weeks. Besides passive and active assisted exercises, massage and electrotherapy are also suggested in order to control pain and facilitate the rehabilitation. Usually starting from weeks 9 to 12 after surgery, active range of motion, strengthening, and proprioceptive exercises are prescribed. Return to sports activities and heavy manual work is allowed 6 months after surgery.

45.3 Complications

Subscapularis tendon repair is usually considered more challenging than a standard posterosuperior cuff repair and surely requires a longer learning curve and larger experience. This is the reason why, differently from rotator cuff repair, some surgeons still prefer an open SSC repair rather than an arthroscopic one. What makes subscapularis repair so challenging is first the anatomic location, as it is very closed to important neurovascular structures, such as the axillary artery, the axillary and musculocutaneous nerves, and the lateral cord of the plexus. Particularly, the axillary artery and nerve lie close to the inferior border of the SSC tendon, and therefore an inferior release of the tendon is never considered. The musculocutaneous nerve arises from the lateral cord of the brachial plexus, which is medial to the coracoid and penetrates the coracobrachialis muscle. Although it has been shown that all these structures are greater than 2.5 cm away from the coracoid tip [48], caution must be paid in case of SSC tendon retraction and presence of scar adhesions because a neural damage can be induced both by

tendon traction and by a direct injury of these structures by using a radiofrequency device or a shaver during an aggressive anterior release.

Moreover, the working area is very limited when compared to the subacromial space for a posterosuperior cuff repair. Either way, if the posterior portal or the lateral portal is used as a viewing portal, management of arthroscopic instruments during suture passage can be difficult, and most of the time, during knot tying, the surgeon cannot clearly visualize at the same time the knot and tendon reduction. Furthermore, the shoulder can become swollen during arthroscopy, and this further reduces the working space; therefore it is strongly recommended to perform the SSC repair at the beginning of the procedure. Anyways, if the shoulder becomes too swollen, switching from arthroscopic to open subscapularis repair can become an option.

Besides, general intra- and postoperative complications, such as anchor pullout, due to an incorrect surgical technique or to bone quality, as well as instrumentation breakage and postoperative infections are also possible, albeit there are no specific data in the literature.

45.4 Results

Despite its importance as a major muscle of the rotator cuff, the SSC muscle tendon unit has relatively received less attention in the published literature, compared with the posterosuperior rotator cuff. However, the importance of SSC tendon repair relates to its intrinsic biomechanical and functional properties, which include active internal rotation of the shoulder, force coupling in the transverse plane, and a contribution to the dynamic anterior stability of the glenohumeral joint [2]. Since the first description of an arthroscopic technique by Burkhart in 2002 [11], a gradual switch from open to arthroscopic techniques has been reported.

A recent systematic review [49] on repair of isolated SSC tears reported significantly enhanced function and pain relief with no differences between open and arthroscopic approach. Moreover, tendon healing, evaluated by ultrasound or MR, was reported as high as 95 % of the shoulders. A significant strength deficit compared to the healthy contralateral shoulder still remains after repairing full-thickness tears compared to partial-thickness tears, despite radiologically confirmed tendon healing [13, 50, 51].

Re-tear rate after anterosuperior cuff repair ranges from 8 to 35 %, and the SS tendon is always involved in the re-tear pattern [52–58], whereas some studies reported subscapularis re-tear rate as low as 0 % [55–57]. Nevertheless, it must be noticed that no differences in functional outcomes have been reported between isolated and combined lesions [50, 52, 59].

Several configurations and surgical techniques have been described [60–65]. Recently, differences between in-continuity repair technique and disruption of the comma fibers were investigated [66]. Although the authors did not report any clinical or structural difference, it must be highlighted that the study has some important limitations in the design; therefore, further studies are needed to clarify this issue. Similarly, only one recent level III retrospective study compared single-row and double-row suture-bridge technique [67]. Once again, no differences could be found in structural and functional outcome, except for a higher abduction strength in the double-row group.

Several factors have been claimed as prognostic factor on the functional and structural outcome, but no prognostic studies in design are available. Based on the available data, the role of age seems to be controversial [13, 53]. Ide et al. [53] in a small case series of 17 patients affected by traumatic anterosuperior tears showed that the patients with a failed repair had a significantly higher mean age; on the opposite, Lanz et al. [13] recently showed no correlation between age and tendon re-tear in 46 patients affected by large to massive isolated and combined anterosuperior lesions at 2–4 years of follow-up. Tendon retraction [53], tear size [68, 69], presence of degenerative changes of the glenohumeral joint [69], and late repair of traumatic lesions [16, 52, 70] have also been advocated as negative prognostic factors on the functional outcome. The role of advanced fatty infiltration has also been

questioned. Recent studies showed that fatty infiltration can probably influence the re-tear rate [71], but it also can progress over time even when tendon healing has occurred [72]. Moreover, it seems to have no influence on the functional outcome [71–73].

Based on the paucity of studies and small sample size, no definitive conclusions can be drawn neither on surgical techniques and suture configurations nor on prognostic factors on structural and functional outcome.

In summary, although less common than posterosuperior cuff tears, isolated anterior or combined anterosuperior cuff tears must be recognized and carefully repaired in order to prevent further extension of the lesion and to reestablish the force couple balancing.

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Arthroscopic Repair of Full-Thickness Rotator Cuff Tears

46

Pietro Randelli, Paolo Capitani,
Liborio Ingala Martini, and Vincenza Ragone

46.1 Indications

When treating rotator cuff pathology, many treatments are possible, depending on symptoms, type of lesion, and patient's expectations.

Nonoperative therapy is recommended for the initial stage of the majority of rotator cuff lesions, but in full-thickness tears, it may provide satisfactory results only in inactive patients, with reduced functional requests.

Unfortunately full-thickness rotator cuff tears do not heal spontaneously because of tendon retraction and a difficult biological environment (poor tendon vascularity, interference from synovial fluid, and reduced cellularity) [1, 2]; thus a surgical treatment has to be considered to improve pain and function in full-thickness rotator cuff tears [3].

Many surgical repair techniques have been reported since the first descriptions by Müller and Von Perthes in Europe (1898, 1906) and by Codman in the United States in 1911 [4]. In particular, during the past decade, the surgical management of rotator cuff tears (RCTs) has evolved from open and minimally open repairs to all-arthroscopic techniques. Arthroscopic rotator cuff repair (ARCR) can provide a strong biomechanical construct, while at the same time providing improved patient satisfaction and a decrease in postoperative complications [5]. In addition to this, ARCR produces smaller skin incisions, deltoid detachment is not necessary, and there is less soft tissue dissection [6]. For these reasons, arthroscopic techniques have become the "gold standard" in the operative treatment of symptomatic rotator cuff pathology, and large-scale reports with increasingly longer follow-up studies on ARCR outcomes are now available [7].

Surgical indications for rotator cuff repair are evolving due to technical improvements and patient's requests and expectations [8].

There are various studies in literature with a great number of rotator cuff repair, but only a few of them face indications for surgery with an evidence-based method [9]. Even among surgeons there is no consistency in surgical indications [10].

Actual indications to arthroscopic rotator cuff repair can be related to pain, timing (acute vs delayed repair), loss of strength, and finally age.

Pain is the principal contributor to indicate surgery in a full-thickness rotator cuff tears. On the other hand, asymptomatic full-thickness rotator cuff tears are many. We don't know what might trigger pain in some patients and not in others. It is not defined the period of time that

P. Randelli (✉) • P. Capitani • L.I. Martini
V. Ragone
2nd Orthopaedic Department, IRCCS Policlinico San Donato, Via Morandi 30, San Donato Milanese, Milan 20097, Italy

Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Via Mangiagalli 31, Milan 20133, Italy
e-mail: pietro.randelli@unimi.it

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must elapse with symptoms before suggesting surgery. A longer duration of symptoms is correlated with larger tears, but it is not related to the outcomes after repair.

Timing is also important, because full-thickness rotator cuff tears will continue in retraction of tendon even to become irreparable [9, 12]. Thus it is important to avoid a delayed surgery; after a conservative treatment of 3–6 months, if symptoms are not reduced, authors suggest an operative treatment. Some other cuff tears need an early treatment like in the case of true acute tears, which are reported to make up 8 % of all RCTs and are usually related to a traumatic event such as a fall or shoulder dislocation. The real incidence of acute tears is not really known due to the difficulty to define it. Differentiating between acute and chronic tears is complex and often requires additional tests to determine (e.g., MRI to evaluate fatty degeneration, atrophy, and retraction). Bassett and Cofield, in a retrospective series, reported that tears that were repaired within the first 3 weeks of an acute injury had a greater recovery of motion (abduction) than those repaired from 3 to 6 weeks and those repaired from 6 to 12 weeks. Time from injury to surgery is not significant for the final outcome [9, 13].

Another important criterion to indicate early surgery is a relevant *strength reduction*. Preoperative clinical tests that show weakness are related to worse result after surgery repair. Loss of range of motion with or without an adhesive capsulitis could be present, and, when the loss is dramatic, surgery should have the aim to restore the functionality rather than repairing the tear.

Age must be evaluated carefully regarding indication to surgery in rotator cuff tears. Mostly, in literature, 70 years of age is considered a limit to surgery, but in every decision the physiological age needs to be considered [11]. A patient more than 60 years old, presenting a positive impingement signs and weakness in abduction, is most likely to have a full-thickness rotator cuff tear [9, 12].

Some authors suggest a more aggressive approach in patients less than 50 years old or more than 50 years old but still active. Daily activities, sports played, and the health status can help to define the physiological age. Clinical results after ARCR are good also in elderly patients even if the tendon may not heal completely [9, 14].

Finally there are some contraindications for surgical cuff repair like uncontrolled diabetes mellitus, body mass index >30, osteoporosis, age, history of infection, smoking, multiple corticosteroid injections, therapy with immunosuppressive drugs or prednisone, and parkinsonian disorder. All this conditions could adversely affect healing [15].

Another important factor to be clarified and discuss with patients, prior to schedule for surgery, is a severe preoperative fatty degeneration because it has been correlated with a worst surgical outcome and a high rate of retear [16].

46.2 Techniques

The goal of rotator cuff repair surgery is to reduce pain and improve function with an anatomic restoration of the cuff footprint respecting biomechanics, thus enabling attachment of the cuff tendons to the bone [11]. Arthroscopic operative alternatives include debridement of the tear, subacromial decompression with or without acromioplasty, and repair of the torn tendons, all done with many different techniques available. Different repairs are available depending on configuration of the anchors and sutures: single row, double row, suture bridge, and transosseous [9].

A successful rotator cuff repair is related to the structure of the tendon, the bone density at the greater tuberosity, the anchor/suture material, and the procedure itself [8]. Few studies evaluated the integrity of the cuff after surgery over time, but failure rate seems to achieve high rates [9].

The footprint reconstruction recently entered in the surgical knowledge; it was demonstrated that the larger the interface, the better is the potential for tendon-bone healing and the strength of the repaired tendon. Many different surgical techniques have been developed to provide greater holding power, larger interface area, and high contact pressure, and the arthroscopic

suture-bridge technique (transosseous equivalent) is one of them [8, 16, 17].

The outcome of the rotator cuff repair depends on several surgical choices: at first the choice between transosseous sutures or suture anchors and resorbable suture anchors or metal ones; second, between the different ways of technique (open, mini open, arthroscopic). Lately anchors have acquired an important role in rotator cuff repair [8]. Size and localization of the tear represent important elements that influence surgical decisions [11].

Suture breakage represented a failure reason in the past, but has been nowadays overcome by newer, extremely strong ultrahigh molecular weight polyethylene (UHMWPE)-containing sutures. Therefore, now, the weakest point of a repair is the suture-tendon interface. Titanium anchors have limitations such as problems in the case of revision surgery or the interference created in MRI. On the other hand, compared to resorbable anchors, the titanium one gives the radiological proof of anchor dislocation and cut costs. In addition to this, inserting bioresorbable anchors need more steps than inserting metal suture: a predrilling of the bone is necessary because they are not able to drill the bone on their own. Both anchors lead to good results; therefore the choice of the material plays a key role [8, 18].

Osteopenic and normal bone had similar pull-out strength both for anchors and for transosseous sutures. This latter technique improves the contact area of the tendon on the humeral footprint compared to the double-row repair [8, 16].

Single row is made by placing a single row of anchors (with two or three sutures) with a longitudinal suture configuration (Fig. 46.1). Instead, a double row consists in a medial and lateral row of two anchors (with two sutures) with the same suture configuration. A suture-bridge technique (transosseous equivalent) starts like the single row, with the placement of two anchors. Then one strand of suture from each anchor is removed and the remaining strands are passed through the tendon. Finally, one strand from each anchor, in pairs of two, is fixed to the greater tuberosity lateral to the medial row with two knotless anchors. A true transosseous is nowadays arthroscopically possible, with a refined surgical technique, using a transosseous guide and one to three sutures per hole.

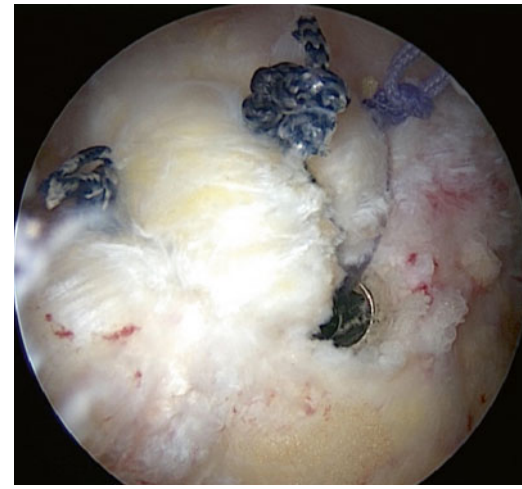


Fig. 46.1 Shoulder arthroscopy: single-row repair of the supraspinatus, final result

Many modifications to the original techniques have been proposed in the literature with good results. Castagna et al. showed reliable results of a different suture configuration, with a horizontal loop and a two vertical stitch (Mason-Allen modified) to repair the rotator cuff [20].

The goal of the treatment of RCTs is to shift from the simple treatment of the injury to the improvements in healing rates [16].

Full-thickness tears, which develop in massive tears, cannot enable the full repair of the lesion because of the retraction of the tendon and its low-quality tissue. In these situations a partial repair can be carried out leading to similar results to tears entirely repaired [21]. Authors suggest as gold standard the single-row repair with titanium anchors avoiding repair of tissue with overtensioning.

Acromioplasty, described by Neer in 1972, is one of the most frequent procedures in shoulder surgery. That's because Neer postulated that the coracoacromial arch could mechanically damage the rotator cuff. After acromioplasty, in the subacromial space, there is an increased concentration of growth factors [22]. There is no statistically significant difference in outcome after ARCR

with or without acromioplasty, even if it has been reported a higher reoperation rate in the group without it [23, 24].

The authors use the lateral decubitus position to perform shoulder arthroscopy: once the mobility of the tendon is assessed, a surgery plan is chosen. Generally, two types of sutures can be done, related to the morphology of the lesion and mobility and quality of the structures and not to the configuration and fixation device: they are tendon to bone and side to side. In the first case, the structures are reinserted at the site of origin or insertion, respectively; in the second the tendons are sutured on their lateral side, to cover the area of injury and reestablish the balance of force vectors on the rotator cuff. In some situations the techniques may be associated [25].

C-shaped (crescent) tears can be reattached to the bone directly, by using anchors loaded with non-reabsorbable sutures. You should remove 1–2 mm of bone to make visible the underlying cancellous bone on the footprint preparation (Fig. 46.2a). The bleeding that results promotes healing of the tendon-to-bone interface [26].

The anchors will be stuck or screwed into the greater tuberosity, through a mini-access on the skin, in order to insert them in 45° angle direction (the deadman angle, Fig. 46.2b) [27]. It has been shown that this inclination reduces the risk of the pullout under the traction exerted by the tendon. Anchor shaft should be positioned 4–5 mm lateral to the articular surface and spaced 5–8 mm between them in a row (authors' preferred) or two.

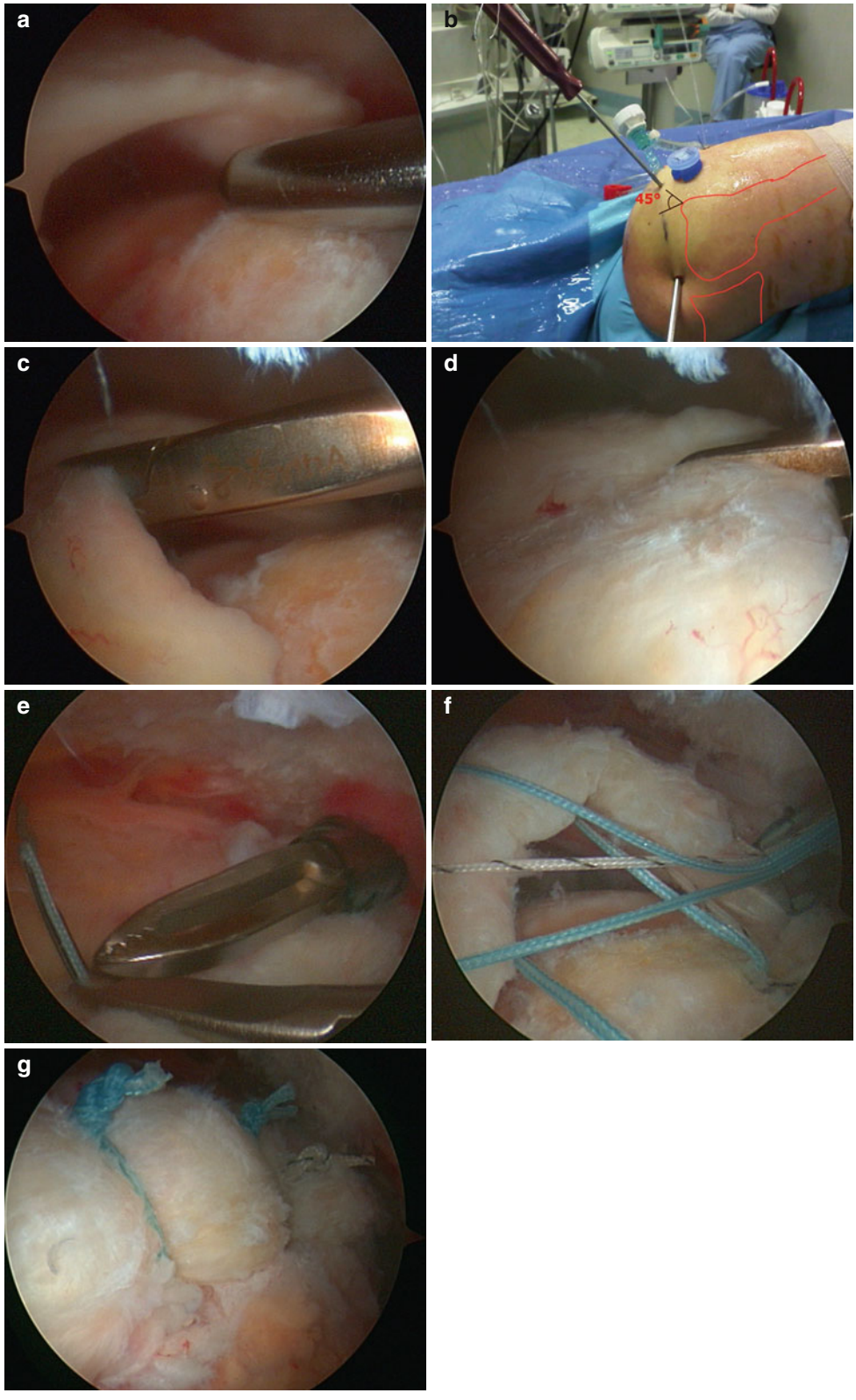
The authors prefer to use 5 mm titanium anchors, loaded with two, or three, sutures (FiberWire, Arthrex, Naples, Fla). It is advisable to practice, after insertion, a pullout test by pulling sutures on the anchor to ensure an optimal grip. A grasper is introduced to test cuff possibility to be repaired to bone without tension (Fig. 46.2c, d).

Then one suture at a time, with a suture-passer device, is passed through the full-thickness tendon. Alternatively, the suture can be recovered by a suture-retriever-type or Arthropierce instrument through the tendon-free margin (Fig. 46.2e). This technique, despite being more laborious, allows the surgeon to decide what amount of tendon tissue to use.

Once all the sutures are passed through the tendon (Fig. 46.2f), the knots are the next step. The thread post should be identified as the one on which we want the knot to run through; we evaluate with a pusher that there are no twists, and the knot is free to slide. We repeat the maneuver on the suture in which the loop is made on. The sliding knot commonly used by the authors is the Tennessee slider or, alternatively, the Duncan loop. The knot is slipped so that it pushes the tendon to the insertion area, previously prepared thereby contributing to healing. Keeping tension on the suture while two half hitches are performed and reversing the suture post with loops, two other half hitches are done. Finally loops should be closed from front to rear (Fig. 46.2g). By moving the scope to the lateral portal, an evaluation of the result can be made. The same kind of tendon-to-bone repair can be performed by transosseous repair and, even if technically demanding, can provide the advantage of a huge footprint coverage and a hardware-free repair (Fig. 46.3).

If the injury had a U-shaped or L-shaped configuration, the surgeon may begin the repair with a side-to-side suture [28]. To perform this type of suture, you prepare with the arthroscope from the lateral portal. The preferred technique by the authors consists in trespassing the first flap of the tendon with a hook-shaped instru-

Fig. 46.2 Shoulder arthroscopy single-row repair in a full-thickness rotator cuff tear: preparation of the footprint on the humerus (**a**). The anchor is inserted with a 45° angle direction (**b**), a grasper is introduced to test the cuff tension (**c**), the cuff is easily tractioned laterally (**d**), the sutures are passed through the cuff with a needled device (**e**), all sutures are passed and put in clear view (**f**), and final result once all knots are tied (**g**)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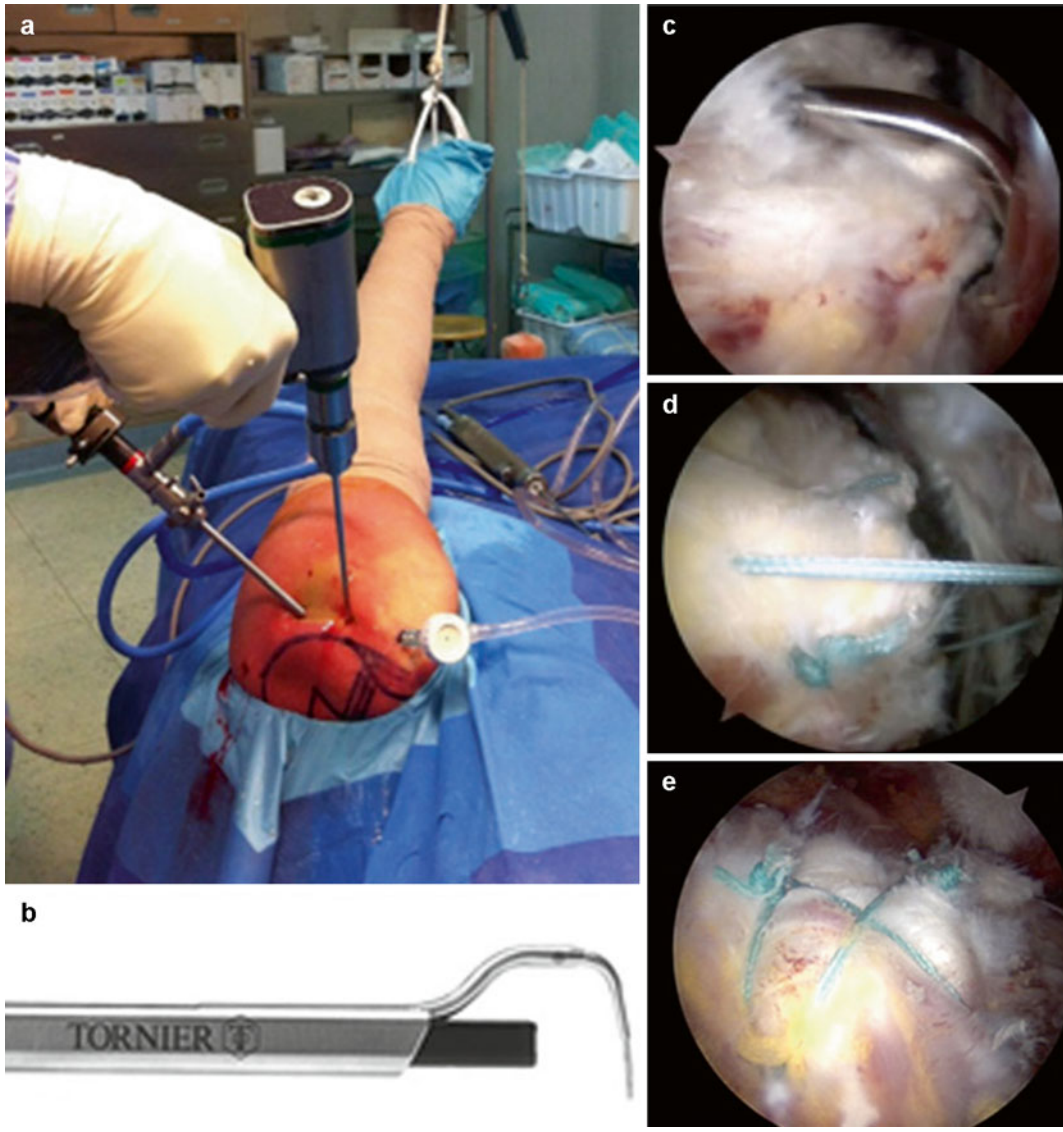

Fig. 46.3 Arthroscopic transosseous repair. The transosseous tunnels are drilled (**a**) with the help of an aiming device (**b**, **c**) (ArthroTunnelerTM, Tornier N.V., Amsterdam, The Netherlands); sutures are then passed through the tunnels and through the free margin of the lesion (**d**) and tied in a X-box modified suture that maximizes the tendon-bone contact surface (**e**)

ment, inserted from the anterior portal and loaded with a monofilament suture, which is then released inside the lesion. The suture is recovered with a suture retriever, which crosses the tendon from the portal opposite to the previous. Once the monofilament is passed through, it is used as a carrier for a nonabsorbable suture with which the authors perform the suture (Fig. 46.4). If after the side-to-side repair there is still movement in between tendon and bone, movements of internal and external rotation will be necessary to support with one or more anchors placed in margin convergence zone, so counteracting strong front and rear forces [29]. With L-shaped tears, first you have to treat longitudinal interval lesion by side-to-side knots and then repair the horizontal lesion with suture-charged anchors [28].

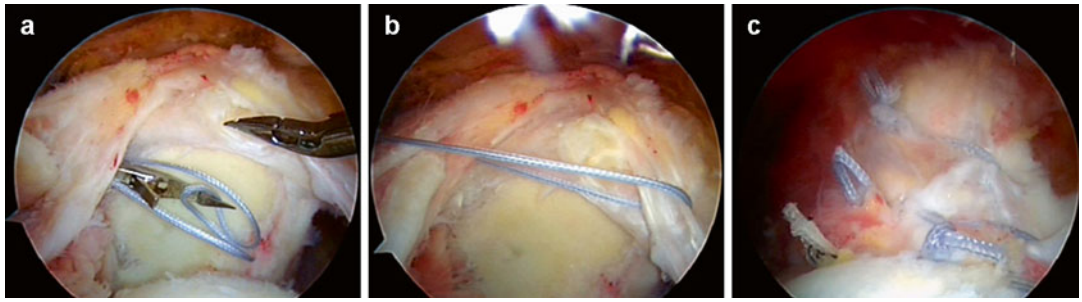

Fig 46.4 Side-to-side suture: UHMWP wires are passed from the anterior to the posterior border of the lesion (**a**). Once the knots are tied, the free margin of the lesion advances (**b**); thus permitting to repair the tendon to the bone without excessive tension (**c**)

46.3 Complications

Complications related to arthroscopic rotator cuff repair are divided in general (anesthesiological, neurovascular, thromboembolic events, septic) and specific (re-rupture, hardware related like implant failure or intolerance, stiffness) [6].

After ARCR the most common complication is stiffness. It ranges from 1.5 to 11.1 %. Many risk factors have been suggested, like age under 50 years and coexisting diagnosis of adhesive capsulitis or calcified tendinitis [6]. Different rehabilitation programs are available, and they are composed of a balance between exercises that on one hand should let the tendon to bone heal and on the other should reduce the risk of stiffness. A universal rehabilitation protocol that reaches both of these goals has not yet been found. An overly conservative approach can result in stiffness, while a too aggressive can lead to retear [19].

Another complication is retear, which leads to poor clinical outcomes. In literature case series with rate of retears from 11 to 94 % are reported. After repair of isolated supraspinatus, retears ranged from 24.5 to 40 %. In ARCR done on tears >2 cm or in the presence of rotator cuff muscle atrophy, the retear rate after 2 years is very high, up to 94 % [6, 19, 20].

In the first 12 months after retear, patients could have an improvement in functional score; however it will then worsen but for most without compromising satisfaction [9, 20]. Larger size of cuff tear is related to high rate of retear at 6 months after surgery, more than the tissue quality or simultaneous injuries [20, 30]. In Table 46.1 the retear rates for different suture techniques and the radiological methods for evaluating are reported.

Migration of the anchor from the implant site is rare (Fig. 46.5), with an incidence rate lower than 2.6 %. Noteworthy is the very low incidence of adverse reactions to the biodegradable anchors [6]. Thromboembolic and septic events are rare, leaving open the debate on prophylactic use of antibiotics. Neurovascular complications are reported from 0.4 to 3.4 %: surgeons, firstly, must be very careful to patient's position on the operating table [6].

46.4 Results (Literature Review)

The preoperative tear size affects the outcome more than the surgical technique [16]. Tendon-to-bone healing is influenced by acute inflammatory response after surgery, and the management of NSAIDs (nonselective or COX-2 specific) can affect healing adversely. Nevertheless more than half of patients admit to use NSAIDs to control pain after surgery [11]. Some authors have reported the difficulties to find a relationship between the function of the shoulder and cuff integrity: more studies are needed [16].

The suture-bridge technique leads to similar good results in the presence of both small and

Table 46.1 Retear rates (radiological diagnostic methods)

	Single row	Double row	Suture bridge
Sugaya et al. [31]		17 % (MRI)	
Lafosse et al. [32]		11 % (CT/Arthro-MRI)	
Huijsmans et al. [33]		17 % (US)	
McCormick et a. [34]	22 % (MRI)	18 % (MRI)	11 % (MRI)
Ma et al. [35]	37 % (MRI)	23 % (MRI)	
Gartsman et al. [36]	25 % (US)		7 % (US)
Charousset et al. [37]	40 % Arthro-CT	22.58 % Arthro-CT	
Frank et al. [38]			12 % (MRI)
Sethi et al. [39]			17 % (MRI)
Kim et al. [19]		24 % (US/MRI)	20 % (US/MRI)
Park et al. [40]			9 % (US)
Voigt et al. [41]			29 % (MRI)

MRI magnetic resonance imaging, *CT* computed tomography, *US* ultrasonography, *Arthro* arthrography

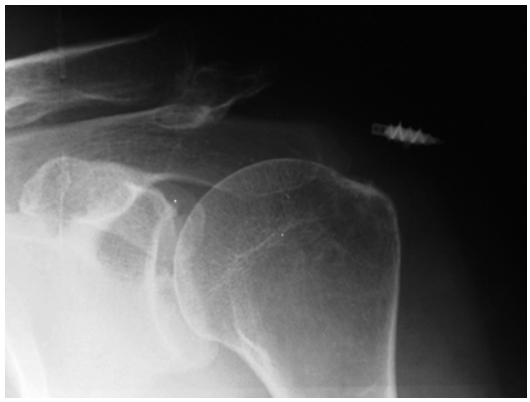

Fig. 46.5 Migration of a titanium anchor detected by X-ray

large tears (pain reduction, ROM recovery), and both groups have similar recurrence rates [16].

Full-thickness rotator cuff tears that underwent ARCR with the double-row or the suture-bridge technique have similar patient satisfaction, functional outcome, and retear rates [19].

With a diagnostic ultrasound evaluation, the suture bridge of an isolated supraspinatus rotator cuff tear has a significantly higher tendon healing rate, when compared to arthroscopic single-row repair [36].

New studies with a larger population, long-term follow-up, and comparisons between different techniques should be done in the future to help us better understand outcomes [16, 19]. In a meta-analysis ARCR have similar shoulder function, muscle strength, forward flexion, internal rotation, patient satisfaction, or return to work with double-row or single-row repair [42]. For this reason and because of time saving, cost saving, and less complexity, single-row repair is considered the gold standard in RCR.

In irreparable RCTs, both arthroscopic debridement associated with acromioplasty and bursectomy or partial ARCR can be performed with a reduction of symptoms and higher functional outcome for partial repair (functional repair) after years. However, the choice of surgical procedure must take account of the subacromial space and functional requirements of the patient [43].

Full-thickness rotator cuff tears in athletes generally occur from either high-energy contact or repetitive overhead activity. Surgical management of these injuries with a technique that maximizes footprint contact while providing a gap-resistant repair may enhance an optimal healing environment. The elite overhead athlete with a full-thickness tear has a relatively poor prognosis and requires special consideration [44]. RCTs in young patients are rare and usually related to trauma. Results after ARCR range from very good to poor outcomes, but in young patients early surgery is advocated to avoid losing working days and be able to support high-demand activities. Immediate arthroscopic repair of full-thickness RCTs in patients aged under 40–50 years old leads to good results in most of the cases [9]. Workers' compensation affects negatively the

outcome of ARCR. The interdependence between work-related injuries and outcomes is not yet clear [45]. In these young patients, there is still no management agreement to prevent tear progression and the development of glenohumeral osteoarthritis [11]. After ARCR young and older patients had similar outcome with the exception of the strength that in young patient had a better restoration [45]. Despite the failure of many ARCRs is reported in the literature, most of patients, after surgery, have an enhanced functionality and reduction of pain [9].

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47 Biological Augments in Rotator Cuff Repair

Christophe Charousset and Amine Zaoui

47.1 Indication

Improvements in arthroscopic repair of rotator cuff (RC) tears and suture anchor technology have concurred to the development of stronger constructs with multiple suture configurations, allowing repair of large and massive tears through minimally invasive means. However, although repair instrumentation and techniques have improved, healing rates have not [1]. A recent meta-analysis has shown that the development and introduction of novel surgical techniques are not related to an improvement of clinical and anatomical results over the investigated period (1980–2012) [2]. In fact, there is a high incidence of failure ranging from 30 to 94 % [3]. Arthroscopic repair of massive RC tears is associated with less favorable clinical results and the highest retear rate when compared with the repair of smaller tears with structural failure in up to 90 % at 1 and 2 years postoperatively [4–8]. Retearing correlates with decreased functional outcome after RC repair [9]. In order to reduce the failure rate after surgery, several experimental in vitro and in vivo biologically based strategies to augment RC repair were developed.

C. Charousset, MD (✉) • A. Zaoui, MD
Paris Orthopaedic Shoulder and Knee Surgery,
Institut Ostéo Articulaire Paris Courcelles,
60 rue de Courcelles, Paris 75008, France
e-mail: dr.charousset@ioapc.fr; aminezaoui@yahoo.fr

47.2 Techniques

47.2.1 Platelet-Rich Plasma (PRP)

The biological study of tendon healing revealed that growth factors are one of the most important molecular families for tissue healing [10]. The use of platelet-rich plasma in the treatment of tendon lesions over several years led to a significant improvement in healing [11–13], thanks to the numerous growth factors that it releases. Indeed, activated platelets release α-granules that contain growth factors and act as messengers by traveling to cell receptors and promoting cell proliferation (these factors act as signaling agents to promote and accelerate tissue healing) [14, 15]. Autologous PRP is usually prepared from venous puncture; the blood is activated or not and then centrifuged to obtain the concentrated plasma rich in platelet. The PRP contains a large number of platelets (four to eight times the circulating levels). It also contains significant concentrations of the growth factors (PDGF, bFGF, TGF-β, VEGF, and IGF-1) that are essential for healing. A variety of blood sample kits with different types of centrifugation, in terms of speed and time, are currently available. The resulting growth factor concentration obtained is variable [16]. Furthermore, we can also differentiate PRP (in liquid or gel form after activation) (Fig. 47.1) and platelet-rich fibrin matrix (PRFM), which becomes solid after two centrifugations through the formation of a fibrin matrix.

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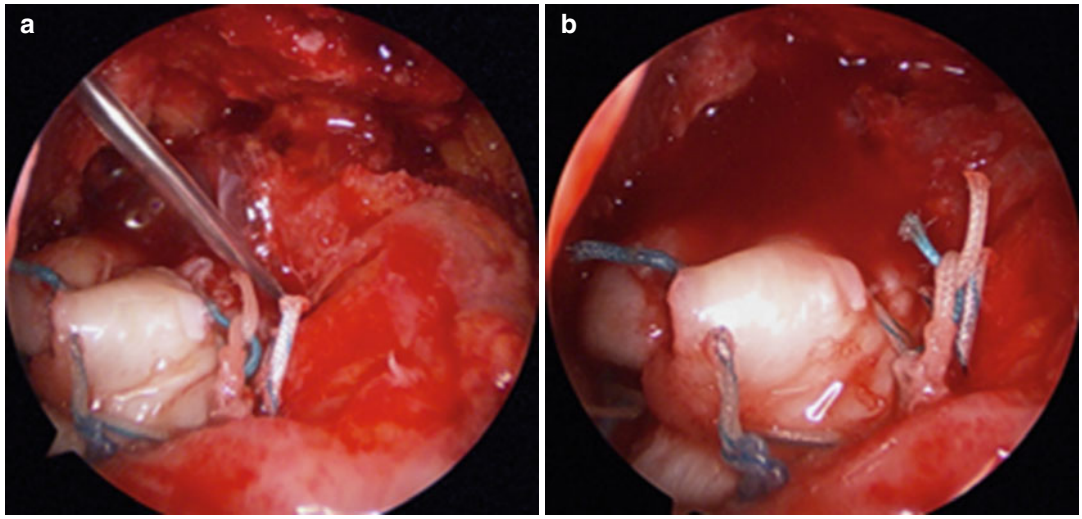

Fig. 47.1 (**a**) Leuco-PRP system (Biomet) and rotator cuff repair. Arthroscopic view of position of applicator through repair site. (**b**) Checking of clot formation

Leukocytes may or may not be present, depending on the kit used. Castillo et al. (2011) found significantly higher levels of VEGF and PDGF in L-PRP (Biomet system) than PRFM without leukocytes (cascade system).

47.2.2 Extracellular Matrix Augmentation

In the repair site, the extracellular matrix (ECM) acts as a scaffold for aligned cellular growth and collagen assembly [17]. These biological augmentations are available in two forms: xenograft and allograft. Extracellular matrices (ECMs) formed from xenogeneic (Fig. 47.2) or allogenic tissues after multiple processes of decellularization to avoid immune reaction and rapid rejection. Allogenic extracellular matrices are obtained after decellularization of cadaveric material. Two commercially available allogenic ECMs have been studied to date: Allopatch® (Musculoskeletal Tissue Foundation, Edison, NJ), an allogenic ECM made from harvested human fascia lata, and GraftJacket® (Wright Medical Technology, Arlington, TN), made from human dermal tissue. Cadaveric studies comparing allogenic-augmented rotator cuff repairs (GraftJacket®) to rotator cuff repairs without augmentation demonstrated that the use of human dermal allograft increased the strength of the repaired tendon [18]. Despite differences between allogenic ECM and autogenic cellular tendon, equivalence has been proved between autografts and allogenic ECM. Adams et al. [17] compared cellular autografts to an allogenic ECM (GraftJacket®) in a canine rotator cuff repair model. During the first 6 weeks, rotator cuffs repaired with cellular autograft augmentation

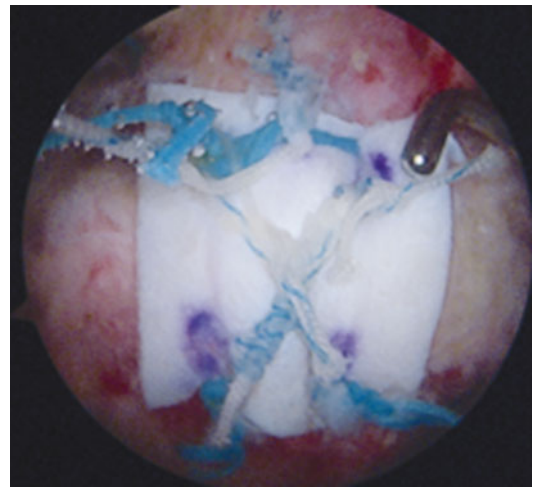

Fig. 47.2 Double-row rotator cuff reparation with xenograft ECM

showed better recovery and repair than those repaired with allogenic ECM. After 3 months, the rotator cuffs repaired with allogenic ECM and the rotator cuffs repaired with autogenic tendon were equivalent in strength and histologic measurement. At 6 months, control and graft specimens mimicked normal tendon structure grossly and histologically.

47.2.3 Stem Cells

Mesenchymal stem cells (MSCs) can differentiate into several mesenchymal tissues, including the muscle, bone, and tendon. Thus, MSCs can theoretically be stimulated to undergo differentiation into a tenogenic lineage and produce tendon tissue [19, 20]. The iliac crest is the most common site for MSC harvesting, although a number of other sources have been recently identified. Recent research performed by Mazzocca et al. [21] demonstrated that MSCs can be successfully and safely harvested from the proximal humerus during arthroscopic rotator cuff repair in humans, these MSCs treated with a single physiologic dose of insulin differentiated into cells with characteristics consistent with tendon. Beitzel et al. [22] showed that arthroscopic bone marrow aspiration from the proximal humerus is a reproducible technique and yields reliable concentrations of MSCs. In 2013, Randelli et al. [23] confirmed the existence of new stem cell populations in shoulder tissues; samples from human supraspinatus tendon and human long head of the biceps tendon were collected during arthroscopic rotator cuff repairs from 26 patients. Morphology, self-renewal capacity, immunophenotype, gene and protein expression profiles, and differentiation capacity were evaluated and resulted in characterization of two new types of human stem cells. Subacromial bursa is another potential source of MSCs. In fact, Utsunomiya et al. [24] isolated MSCs from four shoulder tissues: synovium of glenohumeral joint, subacromial bursa, rotator cuff tendon, and enthesis at greater tuberosity, obtained from the shoulder joint of 19 patients undergoing arthroscopic rotator cuff repair.

47.3 Complications Related to Biological Augments

47.3.1 PRP

Bergeson et al. [25] showed an infection rate of 12 % among patients treated with fibrin matrix rich in platelets without leukocytes compared to 0 % in the control group. This difference did not reach statistical significance. To date, except this study, there are no complications reported from the use of PRP.

47.3.2 Extracellular Matrix Augmentations

One xenograft ECM, Restore® (DePuy Orthopaedics, Richmond, VA), is a collagen-based material made from porcine small intestine mucosa. It was found to contain a relatively high level of DNA within its matrix and has also resulted in an inflammatory in 20 % of patients whose rotator cuff tears were repaired with Restore® augmentation [26, 27]. A retrospective study [28] reported that patients whose rotator cuffs had been repaired with the Restore® had decreased post-repair strength, increased shoulder impingement, slower pain resolution after activity, and no decrease in retear rate when compared to patients whose rotator cuff tears had been repaired using standard surgical techniques. With the unsatisfactorily high proportion of patients with a severe inflammatory reaction to the xenograft, the authors from the study did not recommend the use of this implant. Zimmer® Collagen Repair Patch, known as Permacol® (Tissue Science Laboratories PLC, Aldershot, Hampshire, UK), is a porcine dermal graft. TissueMend® (TEI Biosciences, Boston, MA) and CuffPatch® (Arthrotek, Warsaw, IN) are two other commercially available xenografts. A study comparing rotator cuff repairs augmented with Restore ®, CuffPatch®, TissueMend®, and Permacol® demonstrated rotator cuff repairs augmented with CuffPatch® experienced substantial inflammation when compared to the other grafts [29]. Another similar study demonstrated

TissueMend® had higher levels of DNA embedded in the ECM when compared to other xenograft materials [30]. To date, no complications were associated to allograft augmentation RC repair. A histologic assessment of one patient's allogenically augmented rotator cuff repair (GraftJacket®) demonstrated no calcification, infection, or inflammatory response at 3 months. Collagen was well aligned, and little blood vessel ingrowth was observed, demonstrating improved bone-to-tendon healing with allograft ECM augmentation [31].

47.4 Results (Literature Review)

47.4.1 PRP

In a prospective randomized study, Randelli et al. [32] found that patients treated with L-PRP had accelerated functional recovery and particularly pain reduction, although no difference in tendon healing could be observed. Barber et al. [33] found a significant improvement in tendon healing for tears of various sizes, but functional results were identical in all patients. However, Rodeo et al. [34] and Castricini et al. [35] could not observe any improvement in terms of function or healing. In fact, Rodeo et al. [34] even showed that PRFM could have a negative effect on healing, by modifying the biological interface between the tendon and the bone. Gumina et al. [36], who used another form of PRFM that included leukocytes (L-PRFM), compared two groups with large tears and noted a significant improvement in healing in patients treated with L-PRP, but no difference in functional recovery. In our study [37], the use of autologous L-PRP improved the quality of the tendon healing in patients undergoing arthroscopic repair for a large or massive rotator cuff tears based on postoperative MRI evaluation. However, the functional outcome was similar in the two groups of patients. This should probably state similar failure rate. These studies have reported controversial results on the effectiveness of the use of PRP injection in chronic rotator cuff tendon diseases. The systems of PRP preparation were not similar among trials, and different treatment protocols were used (single or double PRP injections). Besides, we do know the levels in vitro obtained with different techniques (PRP/PRFM), but the levels in vivo at the time of the injection and a few hours or days later are still missing.

47.4.2 Extracellular Matrix Augmentations

In a randomized control trial of the xenograft Restore®, Iannotti et al. [38] demonstrated no improvement in patients with Restore® augmentation when compared with patients who underwent the same procedure without augmentation. One retrospective analysis of rotator cuff repair using Permacol® showed improved functional scores by 50 % at 4.5 years [39]. Another study investigated the use of Permacol® in bridging gaps in massive rotator cuff tears and found no significant efficacy [40]. Bond et al. [41] showed repairing massive rotator cuff tears with allogenic augmentation (GraftJacket®) yielded a failure rate of 19 %. A prospective randomized controlled trial, comparing 22 allografts (GraftJacket®) augmented to 20 non-augmented large cuff tear repairs [42], reported intact cuffs in 85 % of repairs in allograft-augmented group and 40 % in non-augmented group 2 ($P < .01$) at a mean of 14.5 months.

47.4.3 Stem Cell

There is a lack of literature that looks specifically at stem cell augmentation in RC repair. Up to date, only one cohort study has evaluated the safety of clinical application of MSCs in shoulder surgery. In this study Ellera Gomes et al. [43] investigated the effects of bone marrow mononuclear cells (BMMCs) in 14 patients with complete rotator cuff tears. Autologous BMMCs were harvested from the posterior iliac crest prior to the surgical repair and subsequently injected in tendon borders after being fixed down by transosseous sutures through mini-open incision. Overall rates of failure during the first postoperative year

range from 25 to 65 %, depending on lesion diameter. This suggests that implantation of BMMC in rotator cuff sutures appears to be a safe and promising biological approaches to enhance tissue quality in affected tendons. Further investigations are needed to better assess the efficacy of this interesting biological approach.

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Massive Cuff Tears

48

António Cartucho

48.1 Indication

Massive rotator cuff tears (MRCTs) have been defined according to the number of tendons involved (two or more) [1] and according to the size of the tear (more than 5 cm) [2]. If the tendons involved are considered, these tears may be classified as (A) superior subscapularis (major) and supraspinatus; (B) supraspinatus and subscapularis (major and minor); (C) infraspinatus, supraspinatus and superior subscapularis; (D) infraspinatus and supraspinatus; and (E) teres minor, infraspinatus and supraspinatus [3]. In terms of onset, massive tears may be acute, associated to a traumatic event on a young patient and, rare comparatively, to chronic and acute on chronic tears. If function is considered, massive tears may also be classified as functional or compensated and dysfunctional or non-compensated [4]. Some of the patients with a balanced chronic massive rotator cuff may turn out to have, after a traumatic event, an unbalanced acute or chronic tear due to a structural aggravation of the chronic tear.

MRCTs may also be considered repairable, partially repairable or irreparable. The limits for these concepts have been changing as arthroscopic techniques progress and analysis of the results have been published. Classically, tears with a fatty degeneration greater than two according to Goutalier [5] and a retraction greater than two according to Patte [6] have been considered irreparable. Nevertheless, more recently, authors [7, 8] have reported good results for the treatment of massive rotator cuff tears with grade 3 and even 4 fatty degeneration using "margin convergence" and "interval slide" arthroscopic techniques.

Management of MRCTs has to take into consideration patient age, motivation and expectations, pain, the clinical exam, the type and onset of the lesion, the static upward migration and arthritic changes of the humeral head, the presence of muscle atrophy and fatty degeneration of the muscles involved and, if tendon transfer is considered, for a posterosuperior rupture, the fatty degeneration of the teres minor as it is considered to influence the final result [9].

Patient expectation management must consider the most common outcome to the specific type of tear presented and the degree of pain. This last may benefit with surgical approach if there is no response to conservative treatment. As an example, a long head of the biceps tenotomy or tenodesis, in a patient with a compensated massive rotator cuff with resilient pain, may produce an excellent result. On the other hand, a patient whose main complaint is weakness of the shoulder and has also a compensated MRCT is not a good candidate for surgical management.

A. Cartucho
Shoulder and Elbow Department,
Hospital Cuf Descobertas-José de Mello Saúde,
R.Mario Botas – Parque das Nações- Piso 0,
Lisbon 1998-018, Portugal
e-mail: a.cartucho@gmail.com

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A good clinical exam is mandatory. The presence of pseudoparalysis, defined as a forward flexion equal or inferior to 90° with full passive forward flexion and loss of a stable glenohumeral fulcrum, is determinant to the decision algorithm. A positive bear hug or press belly sign will indicate a superior subscapularis tear, and a positive "lift-off" test will point to a more extensive tear of this tendon [10]. On the other hand, a positive "empty-can" sign associated to an external rotation weakness indicates a failure of the posterosuperior cuff. In this case, a repair may not be a good option but, in a motivated patient with a teres minor without fatty degeneration and a healthy or repairable subscapularis, a latissimus dorsi transfer may be the best option.

An acromio-humeral distance shorter than 7 mm is considered to indicate a non-repairable rotator cuff tear [11]. For many authors [12–14], this fact is associated with fatty degeneration greater than two, and even if it was possible to "cover the hole", the functional results obtained are not satisfactory. Despite this fact, in a relatively young, painful patient, even with pseudoparalysis, some authors [15–19] propose a partial repair according to the principles of "suspension bridge" using techniques as "margin convergence" and "interval slide" in order to obtain a balanced shoulder without pain with good range of motion and more strength.

48.2 Techniques and Results

MRCT surgical treatment may have different goals and there are different arthroscopic approaches to the problem. Long head of the biceps tenotomy and tenodesis associated with cuff debridement may be used to control resilient pain. Subacromial decompression, reversed subacromial decompression and "interposition techniques" aim to give pain relief and ameliorate function by facilitating the slide of the humeral head under the acromion and, in the last, lower the humeral head. Arthroscopic repair, or partial repair, may ameliorate function and control pain. The use of grow factors, stem cells and tendon augmentation aims to enhance tendon resistance and healing capacity. Finally, tendon transfer may restore power and function in non-repairable and dysfunctional tears.

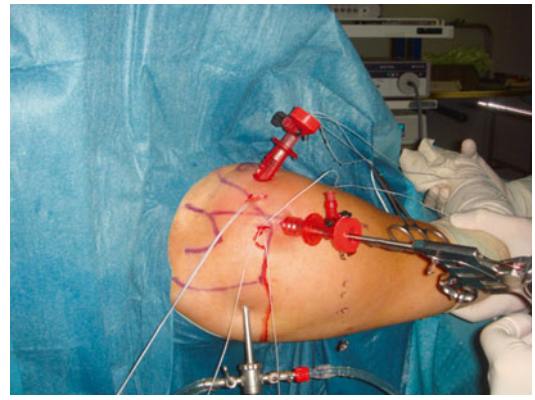

Fig. 48.1 Accessory portals are produced according to the need of the surgeon

We routinely use the beach chair position, initially produce a posterior viewing portal and establish an external and anterosuperior working portals. The assessment, debridement and repair of the rotator cuff are most of the time done using the external portal as a viewing portal. Accessory portals are produced according to the need of the surgeon taking into consideration the type of tear and the technique to apply (Fig. 48.1).

48.2.1 Debridement and Long Head of the Biceps Tenotomy or Tenodesis

Debridement and long head of the biceps tenotomy or tenodesis have been indicated in low-demanding patients whose pain is the major complain and shoulder function is sufficient to fulfil their daily living activities [20]. Authors [21] have reported good results in this population with a mean ASES score from 24.0 points preoperatively to 68.8 at a mean follow-up of 47 months and a pain reduction from an average value of 7.8–2.9 on a visual analogue scale. Debridement is not indicated if the acromio-humeral distance is inferior to 6 mm. Patients with severely impaired shoulder function without reaching the mouth with the hand do not benefit

from this procedure. At surgery, the degenerated tendon edges may be debrided and a bursectomy should be performed. Acromioplasty and/or acromio-clavicular ligament detachment should not be performed in order to maintain the coracoacromial arch.

Biceps tendon lesions should determine the type of action to be performed. This can go from "no touch" in a tendon without synovitis, no subluxation and no degenerative changes to tenodesis or tenotomy if those pathologies are present.

Isolated tenotomy or tenodesis of the long head of the biceps (LHB) is indicated for pain management of MRCT with a fair function in low-demanding patients [22, 23]. Tenotomy is a very simple procedure with no associated costs. The described complication is loss of 17 % of supination strength and a "Popeye sign". In a recent review of the literature, this complication was only present in 7 % of the cases [24]. This is due to the fact that an autotenodesis may occur on the bicipital groove.

Tenodesis can be performed at different places and in different ways. For these patients, our preferred method is to perform the tenodesis in the superior groove with a suture anchor. Other locations like subpectoral [25] and other methods as with an interference screw have been described, but they are seldom necessary for this patient population [26].

The main concerns with those procedures were the duration of the pain relief, the progression of arthritic changes of the glenohumeral joint and the upward migration of the humeral head.

Walch et al. [21] reported the results for biceps tenotomy as symptomatic treatment of RCTs at a mean follow-up of 57 months. Patient satisfaction was 87 % and the post-operative constant score was 67.6 compared to 48 pre-operatively. With a follow-up of approximately 5 years, there was no aggravation of the clinical results.

As a result of symptomatic treatment and no repair, muscles and cuff tendons continue to degenerate and tendon retraction and fatty degeneration tend to increase. This fact is to be taken into consideration. In the presence of a repairable, partial or complete, rotator cuff lesion, those mentioned palliative measures should not be taken alone.

Another worrisome fact is the upward migration of the head. According to Boileau [23], there is a decrease of the acromio-humeral distance in patients with LHB tenotomy, but only if the patients progress to a full cuff arthropathy.

As a conclusion, for low-demanding patients, with a confirmed non-repairable cuff RCT, preferably balanced, debridement and LHB tenotomy or tenodesis may lead to patient satisfaction in more than 80 % of the cases for a period of at least 5 years.

48.2.2 Reversed Arthroscopic Subacromial Decompression

In order to maintain the coracoacromial arch and facilitate the excursion of the humeral head under the acromion, Fenlin [27] described an open debridement and concomitant tuberoplasty. The authors obtained good pain relief and better function in 90 % of the patients. Scheibel et al. [28] described an arthroscopic tuberoplasty, which consists in removing, with a burr through the lateral portal, any remaining prominence of the greater tuberosity and the remains of the torn tendons, associated with cuff debridement and a tenotomy of the long head of the biceps depending of the pathologic findings. The authors report less pain, a significant increase of range of motion and daily living activities and no major complications. Nevertheless, there was a shortening of the acromio-humeral distance by 0.6 mm, a progression of pre-existing osteoarthritic changes and an onset of arthritic changes in 25 % of the patients. More recently, in a 38-patient series with tuberoplasty and tenotomy in all patients regardless of the status of the long head of the biceps, the authors describe similar clinical and radiological results but state that patients with pseudoparalysis do not benefit from the procedure [29].

In conclusion, tuberoplasty or reversed arthroscopic subacromial decompression especially if associated with biceps tenotomy is a minimal invasive procedure that will ameliorate pain and function of low-demanding patients

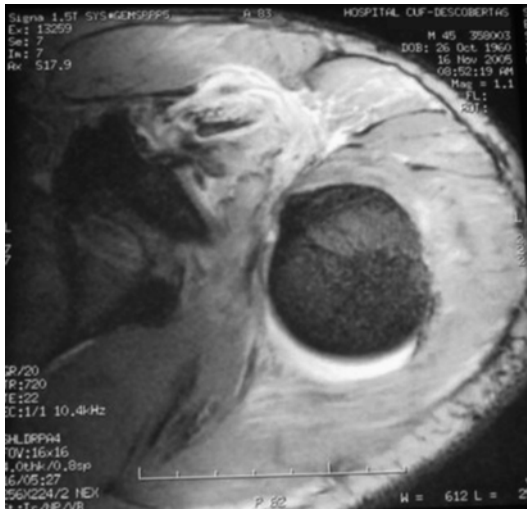

Fig. 48.2 Acute massive rupture

with a massive and irreparable RCT. A shortening of the acromio-humeral distance and an aggravation of the osteoarthritic changes should be expected, but these facts did not influence the follow-up final results. Reassuring is the fact that the acromial arch is preserved and that this procedure does not interfere with a prosthetic replacement in the future.

48.2.3 Repair and Partial Repair

Acute MRCTs are very rare. These entities are more common in the younger population after a high-energy traumatic event (Fig. 48.2). In these cases, full repair is possible and the quality of the tendons involved permits the use of techniques with high primary stability and prone to reproduce the footprint like double row or suture bridge.

In a recent paper using "Suture Bridge" technique to repair medium, large and massive tears, the authors [30] found a greater incidence of retear on massive tears with fatty degeneration. Retear was also higher in older patients and in heavy workers, but those results were not statistically significant. Nevertheless, there was an improvement in clinical outcome measures and a relatively high patient satisfaction despite of retear incidence.

Chronic MRCTs with tendon retraction and delamination associated to muscle atrophy and fatty degeneration are more common. According to Gerber [13, 31] and Goutalier [5, 14], fatty degeneration greater than two was considered a predictive factor of clinical bad result. Patients in those series were treated by open surgery using the technique described by Debeyre [32] in approximately two thirds of the patients. This technique consists in massive mobilization of the tendon and muscle from the scapular fossa, in order to achieve a medial to lateral repair with footprint coverage. This technique could damage the vascular supply of the mobilized tendon muscle unit, and a tension-free lateral repair would be difficult to achieve. It has been described by Goutalier [5] that the more retracted and bigger the tears are, the more likely to have a greater degree of fatty degeneration, and at the same time, greater difficulty to a repair without an "aggressive" mobilization is to be expected. This fact could be an important bias when analysing clinical results on fatty degenerated muscle tendon units.

The anatomic repair of massive tears may not be possible, but partial repair may produce good clinical results in selected patients. Converting a three-tendon tear in a two- or one-tendon tear may enhance active elevation, and when fatty infiltration of fewer than three tendons is present, a partial repair may prevent extension of the tear [3].

According to principle of "suspension bridge" described by Burkhart [7], it is possible to transform a non-functional cuff tear into a functional cuff tear without fully repairing the cuff to the bone or "closing the hole" [4].

According to this author, a functional rotator cuff tear must fulfil the following criteria: force couples must be intact in the coronal and transverse planes, a stable-fulcrum kinematic pattern must exist, the shoulder "suspension bridge" must be intact, the tear must occur through a minimal surface area and finally the tear must possess edge stability.

The techniques described allow repair of the "margins" of the rotator cuff, namely, the inferior half of the infraspinatus and all the subscapularis, in order to maintain the force couple between the

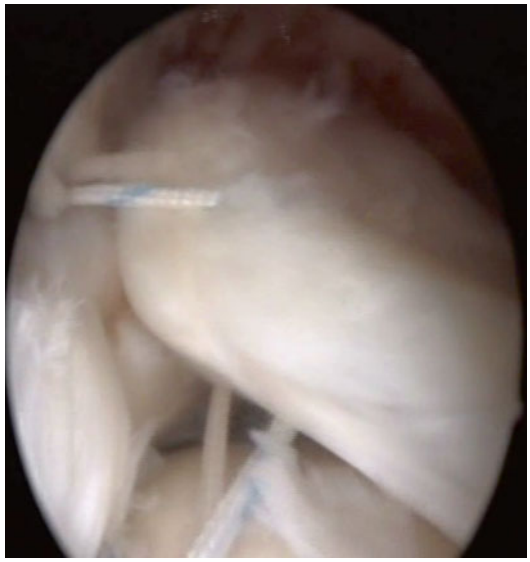

Fig. 48.3 "L" type rupture

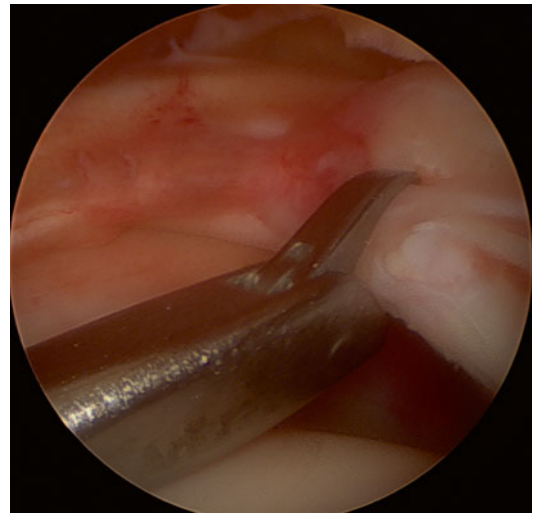

Fig. 48.4 Determine the corner of the "L"

rotator cuff and the deltoid, achieving a functional repair. Under no circumstances, an intact subscapularis or infraspinatus should be transferred superiorly to "cover a hole" in the cuff because, doing so, the centroid of the transferred tendon passes superior to the centre of rotation of the humeral head destroying the force couple.

In order to achieve a functional repair, the concepts of "margin convergence" and "interval slide" were introduced [15, 33]. Retracted RCTs may have several configurations like "U", "V", "L" and inverted "L" (Fig. 48.3). Most of the time, it is impossible to bring the edge of the tendon to bone with an adequate tension, and so according to the principle of margin convergence, the author proposes to reduce tension by using side-by-side repair that produces a shift of the free margin of the cuff toward the greater tuberosity. Even without fixation of the free margin, there is a centring effect on the humeral head, and the strain reduction achieved by this technique protects the side-by-side reconstruction and diminishes the strain on an eventual fixation to the bone. This technique is used in "U" shape tears that have poor medial to lateral mobility and in "L" shape tears. These tears have a leaf more mobile than other, and it is very important to determine were the corner of the "L" shape tear must be restored (Fig. 48.4). Then a side-by-side suture is performed along the longitudinal split, bringing the free margin to the bone edge.

Some tears, although less than 10%, are not repairable by the margin convergence technique and require the use of interval slide [15]. Massive contracted immobile rotator cuff tears are classified according to this author in longitudinal tears and crescent tears. The last are usually larger in an anteroposterior direction and so more difficult to repair. The identification of the landmark for the anterior interval slide is of utmost importance and sometimes difficult, especially in revision cases. It should start at the leading edge of the biceps root and progress toward the base of the coracoid (Fig. 48.5). While performing the interval slide, the surgeon should apply tension on a previously passed traction suture placed on the anterior portal while using the lateral portal as a viewing portal. This way, a mobile supraspinatus is obtained and can be more easily brought to the bone bed (Fig. 48.6).

If a posterior interval slide is needed, usually in crescent retracted tears, the scapular spine should be clearly identified by removing all the bursa, fatty and scar tissue from the subacromial space just behind the acromio-clavicular joint (Fig. 48.7). The base of the scapular spine separates the supraspinatus from the infraspinatus. In

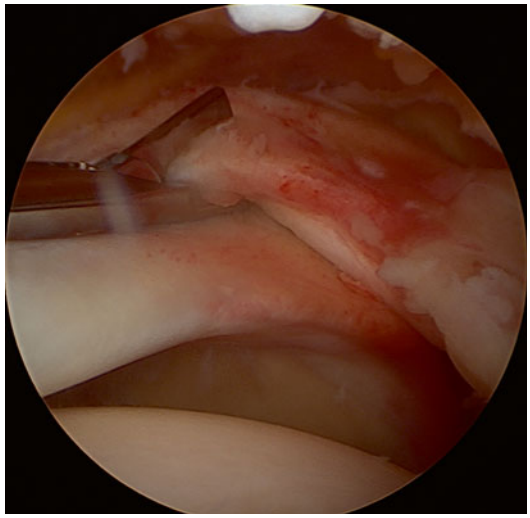

Fig. 48.5 Landmark for the anterior interval

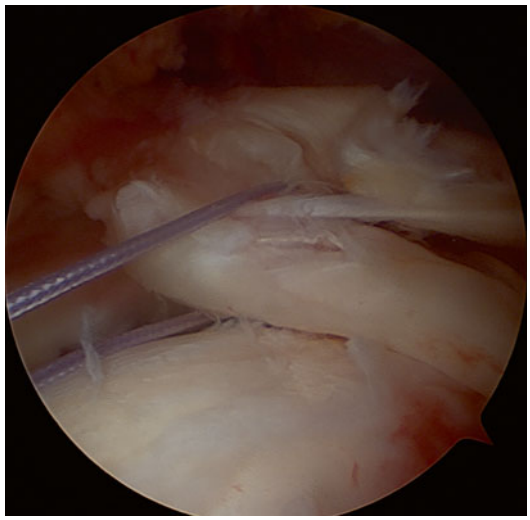

Fig. 48.6 Traction sutures for anterior interval slide

order to perform a posterior interval slide, both the posterior margin of the supraspinatus and the anterior margin of the infraspinatus should be provided with traction sutures. The release is performed between these two sutures. It is essential to protect the suprascapular nerve at the superior glenoid. In order to do so, the view portal must be changed to the lateral portal, with the suture of the supraspinatus on the anterior portal and the suture of the infraspinatus on the posterolateral portal. With the sutures under traction, a scissor

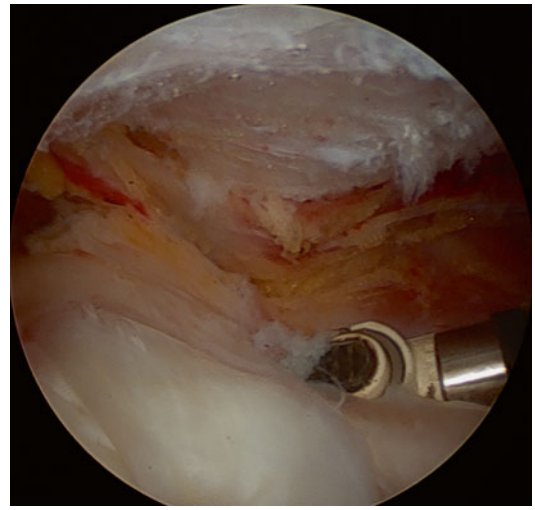

Fig. 48.7 Scapular spine should be clearly identified

is introduced by the posterolateral portal and progressively advanced internally, till the superior glenoid. Scissor blades should be managed in order to avoid a lesion of the suprascapular nerve.

A combined anterior and posterior interval slide provides around 3–4 cm of lateral mobility permitting a tension-free insertion of the lateral margin of the supra- and infraspinatus. After this, the interval between the two tendons may be closed by side-to-side sutures protecting the tendon-to-bone interface according to the "margin convergence" principle.

If even with those techniques a tension-free insertion in the bone cannot be achieved, the rotator cuff footprint may be medialized 0.5 cm in order to achieve this purpose.

Burkhart [16] published a series of 22 patients with MRCTs with grade 3 and 4 fatty degeneration that underwent an arthroscopic rotator cuff repair using a combination of side-to-side sutures and tendon-to-bone repair with suture anchors. The clinical results improved in 86 % of the cases although there was a statistical significant difference between the results of patients with grade 3 to the worse results of patients with grade 4.

Following the same principles to obtain a functional repair, Porcellini (and all 2011) [19] reported a series of 67 patients with MRCTs treated with partial repair. All the patients had a non-repairable supraspinatus tear, a repairable

infraspinatus tear and a healthy subscapularis tear. They report a mean follow-up constant score of 73 for a pre-op score of 44 and conclude that as long as the couple forces of the cuff may be restored trough the infraspinatus and the subscapularis, even leaving the greater tuberosity uncovered by the supraspinatus, the mean results are good.

Other authors [34] present a series of 23 MRCTs repaired with less than 50 % of the original footprint coverage. Repair was performed with a single-row technique with an anchor inserted laterally on the greater tuberosity and coverage of the footprint was attempted as allowed by tension. A high retear rate was found (45.5 %), but there was also a significant clinical improvement with no statistical difference between the retear and no retear group.

Recently, a side-by-side technique named "shoestring bridge technique" (Fig. 48.8) has been described for arthroscopic treatment of retracted supra- and infraspinatus tears [8]. Two thirds of the patient had Goutallier stage 3 fatty degeneration. The technique consists in using a FiberTape suture (Arthrex, Naples, FL) passed through the anterior limb of the tear using a SutureLasso starting at the apex of the tear from the bursal side to the articular side at least 1 cm away from the tendon edge. The same suture is passed from the articular to the bursal side in the posterior limb of the tear. This suture tread is then passed to the anterior limb more laterally and from articular to bursal. The same goes for the anterior tread. These steps are repeated bringing the edges together and the FiberTape can be secured at the level of the footprint with a sutureless anchor. The authors report a significant improvement of pain and function with high patient satisfaction and a low retear rate, although 17 out of 25 patients had a partial coverage of the footprint at follow-up indicating that the final result may be due to restoration of the rotator cable principle [7].

The results of arthroscopic rotator cuff functional repair using margin convergence and interval slide techniques have also been described in the treatment of pseudoparalysis. This impairment is more frequent if the entire subscapularis and supraspinatus is involved (type B) or if three tendons are involved (types C and E) [3]. The authors report 90 % of reversion of pseudoparalysis among primary repairs, with an average gain in forward flexion of 106° and 43 % in revision cases [18]. Accordingly, another group report 76 % rate of reversal of pseudoparalysis and consider arthroscopic rotator cuff repair, first line of treatment for RCTs independently of acromiohumeral distance and fatty degeneration [17].

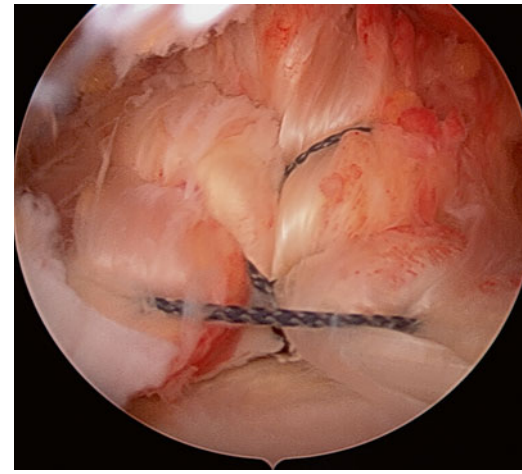

Fig. 48.8 Shoestring bridge technique

In summary, muscle atrophy, tendon retraction and fatty degeneration may influence the clinical results of tendon repair. The understanding of mechanical principles like "suspension bridge" and "force couple" applied to rotator cuff repair, allied with arthroscopic possibility of a better understanding of tear patterns and mobility, associated with techniques of complete and partial reconstruction, that aim for a functional repair, is expanding the indication for massive symptomatic rotator cuff repair in selected patients with grade 3 and even 4 fatty degeneration.

48.2.4 Interposition Techniques

With the purpose to prevent impingement during abduction and to produce a painless activation of the scapulohumeral musculature, authors [35, 36] propose interposing of tissue or a device that lowering the humeral head may provide an improved

balance between the subscapularis anteriorly and the infraspinatus posteriorly, permitting better deltoid activation and compensation through the arc of motion. A biodegradable balloon meant for arthroscopic insertion into the subacromial space following bursa excision may be used to achieve improvement in daily and nightly pain as well as range of motion and ultimately power in this preliminary prospective pilot study with 22 patients with symptomatic MRCT and a mean 3 years follow-up [35]. The pre-shaped balloon is comprised of a copolymer in a 70:30 ratio which biodegrades over a period of 12 months. Insertion of the balloon is performed arthroscopically by the lateral portal viewing from the posterior portal, and pressure inside the balloon may be adjusted by the surgeon. Once positioned in the subacromial space, the balloon permits frictionless gliding of the humeral head against the acromion. The authors state that it is unclear exactly how long the balloon remains inflated, nor is it understood why pain and functional scores continue to improve beyond the period of balloon disintegration. It is conceivable that new soft tissue forms in the balloon area and continues to act as a barrier between the humeral head and the acromion providing continued pain relief despite balloon deflation.

With the same objective, Mihata et al. [36] propose a superior capsule reconstruction with fascia lata, associated with side-to-side sutures between the graft and infraspinatus tendon and between the graft and residual anterior supraspinatus/subscapularis tendons to improve force coupling. Suture anchors to attach the graft medially to the glenoid superior tubercle and laterally to the greater tuberosity were used. Results reported, at an average follow-up of 34.1 months, were very promising with a pre-operative mean flexion of 148° for a pre-op value of 84° and a 4.6 mm increase of acromio-humeral distance.

48.2.5 Regenerative Techniques

MRCTs have a poor biologic environment. Regenerative techniques using scaffolds, stem cells and grow factor are prone to enhance local biology and consequently healing rate and clinical results.

48.2.5.1 Grow Factors and Platelet-Rich Plasma (PRP)

The roles of growth factors are cell proliferation, collagen deposition and improved gene expression for matrix-degrading enzymes and endogenous growth factors. They also stimulate tendon healing, enhancing angiogenesis. However, the understanding of administration timing and dosage is not clear. Even if autologous PRP is safe and there is some evidence that it may improve pain after arthroscopic small RCT repair at short term follow-up [37], PRP has not been shown to improve healing rates in RCTs and the data do not support routine use of PRP in rotator cuff [38].

48.2.5.2 Stem Cells

Bone marrow-derived stem cells (BMMCs) can be harvested from bone marrow and differentiate into tenocytes that may be able to repair tendon defects.

Despite the lack of basic studies in animal models, when compared to "in vitro" investigation, a pilot study was able to enrol 14 patients with complete RCTs. Prior to cuff repairs, autologous BMMCs were harvested from the iliac crest and subsequently injected into the repaired tendon borders [39]. These patients were monitored for a minimum of 12 months, and UCLA scores improved on average from 123.0 to 313.2, and tendon integrity was demonstrated by magnetic resonance imaging in all 14 patients. No control group was included in this study, but historically for this procedure, overall rates of rerupture during the first post-operative year range from 25 % to 65 %, depending on lesion extent. The small number of patients in this study, and the fact that the patients were treated using a mini open approach, turns difficult to determine the efficacy of BMMCs as an adjunct to arthroscopic rotator cuff repair. However, implantation of BMMCs in rotator cuff tendon borders appears to be a safe and promising approach to enhance the healing of tendon repairs. Further research will be critical to better investigate the use of this biologic approach [40].

48.2.5.3 Tendon Augmentation Graft

Grafts may be used to improve stability to the repaired tendon and enhance healing or as a substitute of part of the missing lateral tendon. They may be derived from allografts, xenografts and synthetic materials.

The commercially available tendon augmentation grafts are from human dermis, porcine small intestinal submucosa, bovine dermis and porcine dermis, may or may not be cross-linked, have different processing methods and differ also on the number of layers and thickness.

The selection depends on the tissue of origin, graft processing, cross-linking of the material, physical properties of the tissue and the experience of the surgeon [41]. Grafts may act as a scaffold providing primary resistance to the repair and also provide a collagen reservoir to fibroblasts. The strength increase derived from the graft varies from the type of tissue and processing. A concern with the use of grafts is the host tissue response. It is important to keep in mind, in the act of choice, that a balance between the biomechanical and biocompatibility properties of the graft is desirable.

Porcine submucosa subintestinal grafts were found to increase pain and lead to poorer tendon healing and may not be suitable for human rotator cuff repair. These results are in contrast to the animal preclinical studies [42].

On the other hand, human dermis-derived grafts, used as scaffold augmentation or as a bridging construct for irreparable rotator cuff RCTs, were reported to improve clinical outcomes at follow-up, with low incidence of complications and no cases of graft rejection [43, 44].

The graft may also be used in a bridging construct. After assessing irreparability of the tear, bursa and cuff are debrided. A knotted suture technique is used to measure four aspects of the cuff defect in order to tailor it. A suture construct, including lateral suture anchors at the footprint, is then passed in the cuff edges and in the graft, permitting its guidance trough a lateral 8 mm cannula with a push-pull technique into the subacromial space. After fixation of the graft to the remaining cuff, the anchored sutures are then passed through the lateral edge of the graft using standard arthroscopic rotator cuff repair techniques. At final examination, the authors recommend that the pump is turned off, in order to permit the escape of the bone marrow elements from the decorticated tuberosity. The mean constant score improved from 53.8 pre-operatively to 84 post-operatively, and regarding the simple shoulder test, the patients had a consistent increased ability to perform each task [45].

In a recent paper, Barber et al. [46] compared the clinical and retear rates in patients with fatty degeneration grade 1 and 2 of the infraspinatus and grade 3 or 4 of the supraspinatus. In one group, partial repair was performed, and in the other group, partial repair and fascia lata augmentation as a bridging construct of the defect was performed. Clinical results were better on the graft group with a constant score of 81.1 compared to 69.9 of the partial repair alone, and the retear rate of the infraspinatus was 4.7 % in the graft group compared to 41.7 in the no graft group.

Synthetic scaffolds have the theoretical advantage of being well tolerated and being suitable as a scaffold for cellular ingrowth and were shown to provide satisfactory clinical results and function despite the high retear rate of 62 %. The fact that there was no control group and tenotomy of the LHB and subacromial decompression was performed in most of the patients must be taken into consideration when analysing these results [47].

Biceps tendon has also been used in a bridging construct to diminish tension in MRCT repair. The authors report no statistically significant improvement of the constant score and a retear rate of 41.7 % as opposed to 73.7 % in the non-augmented group [48].

In summary, biological enhancement is for sure one of the future trends for MRCTs with inherent poor biology. Nevertheless, further clinical trials are needed to identify the best sources and techniques to the use of grafts. At present, when a graft is used, the best evidence, considering clinical result and retear, consists in the use of dermal grafts either as augmentation or as a bridging construct. Synthetic grafts used with this last technique may develop, associated with cell engineering, into a viable solution.

48.2.6 Tendon Transfers

Tendon transfers to deal with irreparable MRCTs have first been described for open surgery. The goal is to achieve stable kinematic by restoring rotational strength and force coupling about the joint. Classically for an anterosuperior tear, a pectoralis major transfer was indicated. For the time being, there are no arthroscopic techniques described for this procedure [49].

For posterosuperior tears, the ideal candidate, for a latissimus dorsi transfer, is a young patient, with an anterior flexion of 90° and an infraspinatus pseudoparalysis [50]. The subscapularis tendon must be intact or have a repairable tear. Results are better in the first case. Non-repairable subscapularis tear is a contraindication for this procedure, and as previously said, teres minor fatty degeneration has a negative influence in the results.

Techniques for arthroscopic assisted latissimus dorsi transfer consist in an open harvest of the latissimus dorsi by an axillary approach and the arthroscopic assisted transfer of the prepared tendon. The subacromial bursa, tendon edges and great tuberosity have been previously prepared using arthroscopy as for a tendon repair. The standard lateral portal is used for visualization and the tendon sutures, inside two silicon drain tubes, to prevent twisting of the tendon, are retrieved from the axillary incision trough the posterior portal under direct visualization in the space between teres minor and deltoid (Fig. 48.9). The sutures are then moved out the anterior portal, thus pulling the tendon over the tuberosity. The first anchor is inserted at the anterior aspect of the greater tuberosity, close to the articular cartilage and the superior margin of the subscapularis (Fig. 48.10). Two to three anchors are inserted fixing the tendon to the tuberosity until it is stable [51]. Other authors prefer to use interference screws and tubulization of the tendon in order to achieve a better primary stabilization and permit early rehabilitation [52]. Gerber et al. [53] have reported significant improvement of outcome scores with an average follow-up of 53 months. Results of arthroscopic latissimus dorsi transfers have also been reported equal to open procedures [54].

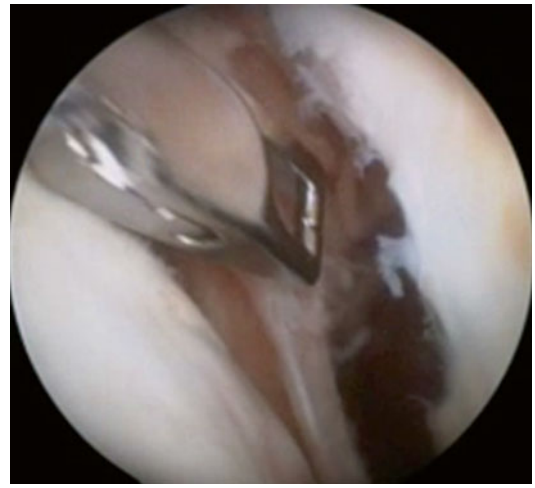

Fig. 48.9 Direct visualization between teres minor and deltoid

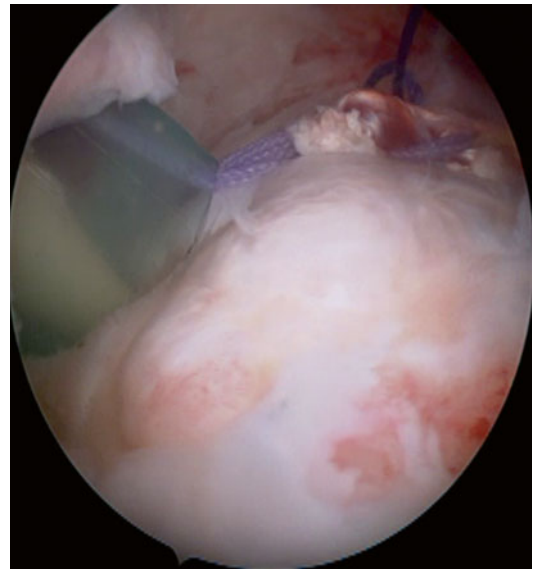

Fig. 48.10 The first anchor is inserted at the superior margin of the subscapularis

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Long Head of the Biceps Pathology

49

Boris Poberaj

49.1 Diagnosis

The long head of biceps (LHB) has been known as one of the pain generators in the shoulder. It has been found that LHB is innervated by a network of sensory sympathetic fibers, especially at its origin, which may play a role in the pathogenesis of shoulder pain [1]. A pain relief after spontaneous long head ruptures in patients aged over 50 years is a common finding. The function of the LHB tendon and its role in shoulder kinematics despite cadaveric and in vivo studies still remains controversial. It is not known how much load is physiologic for the LHB tendon, although calculations and predictions vary from 11 to 55 N [2]. Interestingly, electromyographic studies show that LHB becomes electrically active with elbow flexion and extension, rather than with shoulder motions [3].

LHB pathology is mostly present at its intra-articular portion. Two most common anatomical sites of LHB pathology are its origin (SLAP) and as it enters the bicipital sulcus (Figs. 49.1 and 49.2) (biceps instability), especially in conjunction with subscapularis tears. Biceps tendinitis has typically been characterized as a secondary

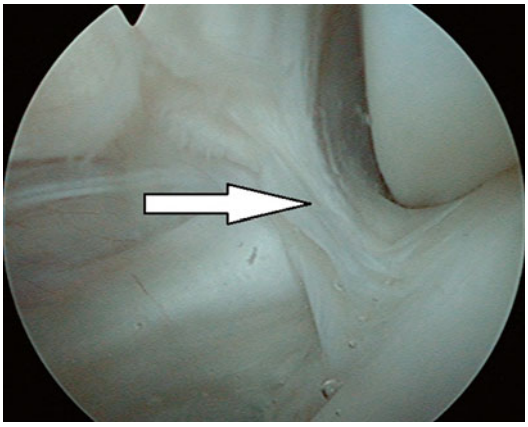

Fig. 49.1 Normal anterior biceps pulley in the right shoulder (*white arrow*)

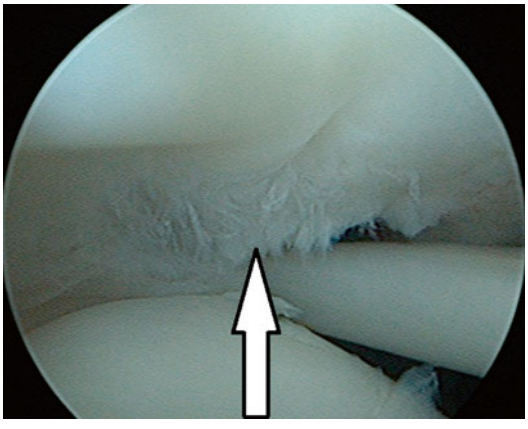

Fig. 49.2 Partial rupture of anterior supraspinatus tendon and concomitant posterior pulley lesion (*white arrow*) in the left shoulder

B. Poberaj, MD
Surgery Department, Aspetar – Orthopaedic and Sports Medicine Hospital, Doha, Qatar
e-mail: boris.poberaj@aspetar.com

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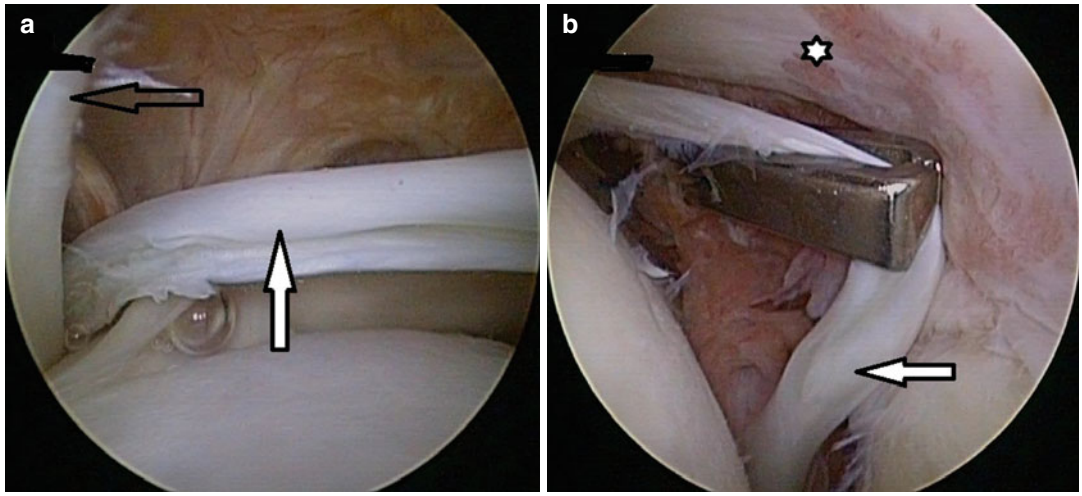

Fig. 49.3 (**a**) Labral lesion (*white arrow*) extending to the partial rupture of the long head of biceps tendon (*black arrow*) in the left shoulder. (**b**) Repositioning of the labrum (*white arrow*) with the tissue grasper. Biceps is marked with an asterisk

process due to surrounding shoulder pathology, such as rotator cuff lesions.

Physical examination for LHB pathology is one of the most challenging and probably the least reliable entity in the shoulder diagnostics. This is due to usually concomitant soft tissue pathology (rotator cuff, pulleys, labrum) (Fig. 49.3a, b) and cartilage disease, which interfere at the time of testing. Also there is no known pain pattern specific for the biceps tendon.

Several kinds of compression rotation test have been proposed for SLAP lesions, but these are also inconsistent and all have proven difficult to validate. Precise patient history with description of the mechanism of injury has been one of the key diagnostic values. In partial biceps tendon tears, the Speed's test had a sensitivity of 50 % and a specificity of 67 % [3]. Tenderness over the bicipital groove doesn't add much to examination value and is rather not specific for biceps tendon injury.

49.2 Exploration

The origin and the intra-articular course of the long head of the biceps can be best seen with magnetic resonance imaging (MRI) arthrography or with computer tomography (CT) arthrography. Care must be taken because of the high incidence of false-positive radiological interpretations of SLAP lesions on MRI scans [4]. In the case of LHB instability due to biceps pulley lesions, diagnostic ultrasound has an advantage, as it is a dynamic examination and can clearly show the upper, unstable part of the tendon.

Arthroscopy is by far the most accurate diagnostic investigation of the proximal biceps pathology. Stability of the LHB can be easily assessed, as well as the intertubercular part of the tendon by pulling it inside the joint. Difficulty persists in the interpretation of what intraoperative findings represent SLAP II lesions (Snyder classification) and what is a normal variant requiring no treatment.

49.3 Treatment Indication

Surgical treatment of LHB tendon is often recommended in cases of isolated symptomatic pathology, such as SLAP II (or higher stages of Snyder classification), partial tears, hour-glass deformity, or in concomitant rotator cuff lesions with biceps instability and tendinitis and finally at the time of shoulder arthroplasty.

Treatment of SLAP lesions is very specific in this group. Since its description in 1985, several

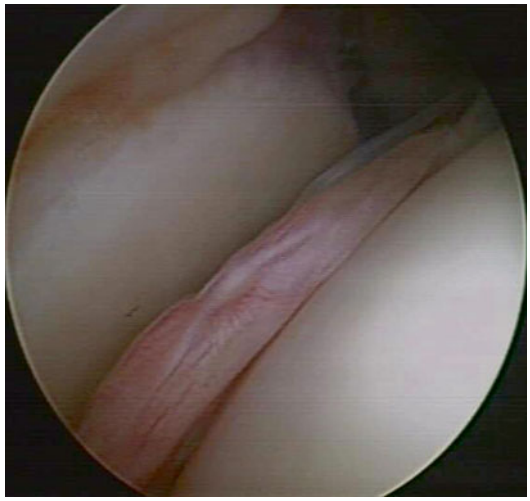

Fig. 49.4 SLAP IV in the right shoulder

biomechanical studies of type II lesions have investigated various repair techniques of suture anchor placement and optimal suture loop constructs [8, 9] without any clear advantage for specific repair type. Surgical trends in the treatment of SLAP lesions (Fig. 49.4) over the last years have revealed decreased rate of labral re-fixation, while the rate of biceps tenodesis and tenotomy increased. This was found for SLAP tears with and without rotator cuff repair [10, 11].

49.4 Techniques

In general, there are two surgical techniques for LHB abnormalities: tenotomy or tenodesis. Tenotomy, as a surgical option, can be a simple cut of the tendon at the very base of the origin or a release of the LHB with a piece of superior labrum. The last variant is the so-called fish tail or T-wedge technique and is sometimes recognized as a soft tissue tenodesis while catching beneath the transverse humeral ligament [5]. Tenotomy is much easier to perform and requires less complicated rehabilitation, and it allows earlier return to daily activities [6].

Tenodesis group represents various fixation techniques which can be done as open or mini-open surgery or arthroscopic procedure. They may be further divided into soft tissue, osseous and intraosseous fixation techniques [7], with or without use of implants. The level can be proximal intra-articular, inside the bicipital groove, suprapectoral, or distal subpectoral. It is important to maintain the muscle length-tension relationship and not to put the final fixation under too much tension.

The soft tissue fixation comprises wedge tenodesis where proximal part of LHB is tied into a ball with strong suture, suturing of LHB within rotator cuff, the rotator interval or the transverse humeral ligament using suture material. This kind of procedure is termed percutaneous intra-articular transtendon technique. Distally the LHB can be sutured to pectoralis major tendon by mini-open approach.

The most common osseous fixation is arthroscopic suture anchor tenodesis. The anchor is usually double loaded with No. 2 non-resorbable, high-strength sutures, placed adjacent to the articular margin of the humeral head, along the bicipital groove or at the suprapectoral region. Alternatively, unicortical intramedullary button can be used [12].

The oldest intraosseous fixation method is an open key-hole technique at the level of bicipital groove. The most studied one is with the usage of interference screws of different kinds and at different anatomic levels. It has been shown no difference in biomechanical properties among screw diameters, but the placement of a tenodesis screw flush to the humeral cortex is preferred for maximum fixation strength [13]. Alternative method is described with the use of suspensory fixation system of metallic plate which is placed on posterior cortex of the proximal humeral cortex and knotless suture loop to which the biceps tendon is attached. There are some implant-less techniques, such as subpectoral bone tunnel biceps tenodesis, published by Mazzocca et al. [14], the suture-only biceps tenodesis technique described by Sampatacos et al., and suprapectoral, intraosseous, and cortical-bridge tenodesis with Cobra guide (Fig. 49.5a, b), as preferred procedure of the author (B.P.).

49.5 Complications

SLAP repair residual symptoms are recently more studied and comprise persistent discomfort, loose hardware, persistent rotator cuff defects, articular cartilage injuries, persistent synovitis, and low rates of return to sport [4].

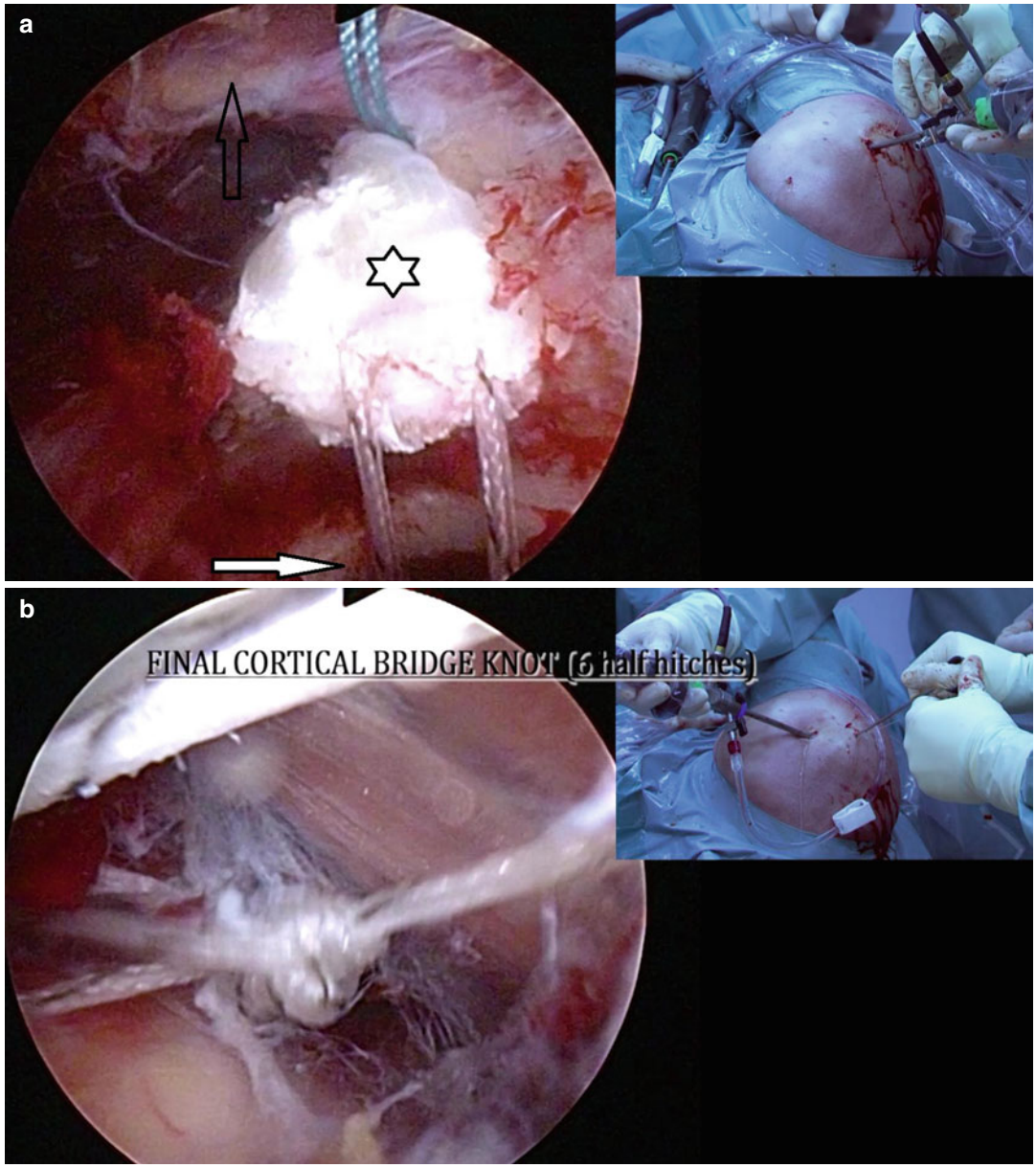

Fig. 49.5 (**a**) Suprapectoral implant-free biceps tenodesis. Entrance of the intraosseous tunnel (*white arrow*), biceps tendon (*black* asterisk), upper edge of pectoralis major tendon (*black arrow*) in the right suprapectoral space. (**b**) Final fixation of the biceps tendon intraosseously with the knot tying over the lateral humeral cortex

Tenotomy of LHB, as the quickest and well-tolerated surgical option, has been reported to have complications, such as cosmetic deformity (Popeye deformity), cramp-like arm pain, decrease in elbow flexion strength and supination peak torque, and fatigue discomfort. It seems that only male sex is patient-related factor which correlates with occurrence of Popeye deformity in 45% [15]. Other patient-related factors, age, involvement of the dominant arm, and body mass index, are not correlated with deformity, elbow flexion strength, and cramp-like arm pain.

Tenodesis-related complications have been described as intraoperative, such as neurovascu-

lar (musculocutaneous nerve entrapment) [16] and humeral fractures. Postoperative complications include implant failure, bioabsorbable screw reaction, tenodesis failure due to biceps tendon rupture, and persistent pain. Hsu et al. found that tenodesis had a 25 % incidence of cosmetic deformity [17].

49.6 Results of Literature Review

There is not a consensus on the ideal treatment of LHB pathology in the literature. Majority of the clinical studies compare tenotomies and tenodesis in concomitant rotator cuff repairs rather than isolated procedures. Few of them compare biceps strength and endurance, but rather contain subjective follow-up evaluation after tenotomy or tenodesis. Most recent clinical study done by Zhang et al. [18] has been shown equal subjective results for tenotomy and tenodesis with suture anchors in patients older than 55 years with reparable rotator cuff tears at average follow-up of 2 years. A postoperative study on strength and endurance after tenotomy and tenodesis, done by Wittstein et al. [6], has been shown subjective outcomes similar for both procedures, but decreased supination torque in tenotomy group relative to the nonoperative side and tenodesis. Male sex seems to be a patient-related factor with higher prevalence of Popeye deformity.

There are few clinical studies comparing different kinds of LHB tenodesis. Scheibel et al. [7] recommend a bony fixation over soft tissue fixation. In this study, soft tissue procedure described by Sekiya et al. was compared with suture anchor tenodesis, which provided significant advantages concerning the clinical and structural outcome.

Many biomechanical comparisons of different tenodesis techniques were published. Most of them show superiority of interference screw fixation. On the other hand, newly developed intraosseous techniques like ABIT (arthroscopic biceps intraosseous tenodesis) [19], or author's preferred intraosseous cortical-bridge fixation, have shown higher failure loads compared with interference screws due to better absorption and restoration of energy of the construct. For this reason, different kinds of biceps-holding sutures were studied. Kaback et al. [20] have studied fixation strength of Krakow stitch, simple suture, and lasso loop combined with a knotless fixation implant and found superiority of Krakow stitch, providing better ultimate and fatigue strength. This finding is very important, as type of suturing technique may be the weakest link in such construct.

Proposed consensus for biceps tenodesis would be patients under 55 years of age, predominantly manual workers and athletes. Bony-type fixation is advocated, although many new techniques are evolving and selection is left to individual surgeon's preference.

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AC Joint Pathology and Instability

50

Natascha Kraus and Markus Scheibel

50.1 Introduction

In contrast to the small size and area of the acromioclavicular (AC) joint, it nevertheless plays a major role in the function of the upper extremity and the stability of the shoulder girdle. In addition to the AC joint capsule and its ligaments, of which its superior and posterior parts are primarily allocated a horizontal-stabilizing function, the coracoclavicular (CC) ligaments that provide vertical and horizontal stability have been described as one of the most relevant factors in AC joint function and stability [1–3]. Musculotendinous structures, often referred to as the deltotrapezoidal fascia, are named as dynamic stabilizers; however, neither their structure nor their influence on AC joint stability is known thoroughly.

In the majority of cases, injury to the stabilizing structures results from a direct fall on the adducted arm and shoulder girdle with an inferiorly oriented force on the scapula, which in accordance to trauma severity may lead to an AC and/or CC ligament rupture as well as a musculotendinous avulsion of the clavicle. As a result of the trauma and ligament injury, an increase of static and/or dynamic translation as well as a higher strain on still intact structures can be noted [4]. Up to 12 % of all injuries to the shoulder girdle are AC joint instabilities. The incidence is reported to be 1.8/1,000 citizen/year. Especially in the USA, contact sports such as rugby, wrestling or hockey are well studied and associated with a high risk for injuries to the shoulder girdle and the AC joint. In young athletes, incidences of AC joint injury are as high as 9.2/1,000 person-years [5]. On average, 18 days are lost to injury in cases of low-grade and 64 days in cases of high-grade injury. Similar data is available regarding return to work. Manual workers are usually able to return to work after 4–8 weeks following minor AC injury. Non-manual work can usually be performed after about 1–2 weeks [6]. Due to the potentially longer interval after surgical repair with up to 12 weeks, socioeconomic factors are not completely negligible [7]. Finally, the development of a chronic AC joint instability accompanied by a significant longer sick leave needs to be taken into account as well. High-grade AC joint instabilities may lead to an instability of the shoulder girdle due to the role of the AC joint in the scapula-thoracic rhythm and may therefore cause a scapula-thoracic disbalance or even a SICK scapula syndrome (scapular malposition, inferior medial scapular winging, coracoid tenderness and scapular dyskinesis) [8]. In the secondary functional complaints, but also structural injury to the AC, the scapula-thoracic and the glenohumeral joint may develop. This mechanism has been described as one of the reasons for

N. Kraus • M. Scheibel (✉)
Shoulder and Elbow Surgery,
Center for Musculoskeletal Surgery,
Charité-Universitaetsmedizin Berlin,
Augustenburger Platz 1, Berlin 13353, Germany
e-mail: markus.scheibel@charite.de

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developing chronic AC joint instability. In addition to that, low- and medium-grade injuries may lead to persisting problems as well (Table 50.1).

50.1.1 Clinical Diagnosis

A moderate- to high-grade AC joint dislocation can be easily diagnosed clinically by the visible asymmetry of the superior aspects of both shoulders. Visually, the clavicle imposes as being translated upwards. However, on closer inspection, the scapula has rotated anteroinferiorly around the thorax. Mild sprains might present with a tenderness to palpation only. General range of motion of the shoulder is only reduced in the acute situation due to pain. Several AC joint provocation tests have been published, none of which demonstrate a significant diagnostic accuracy [9]. Especially in the chronic situation, care needs to be taken to distinguish between degenerative or secondary glenohumeral pathologies and a symptomatic chronic AC joint instability. Examination needs to take a disturbed scapulothoracic rhythm, a scapular disbalance and a SICK scapula syndrome into account. In addition to a visible vertical instability in acute and chronic situations, an accompanying dynamic posterior translation (DPT) of the clavicle because of the anteroinferior scapular rotation may result. This enlarged DPT can be tested clinically by fixing the acromion with one hand and moving the clavicle anteroposterior with the other. Comparison to the non-affected side is essential, as a congenital hyperlaxity may be present.

Table 50.1 Possible causes for the development of chronic symptoms after acute AC joint dislocation

Low-grade AC joint dislocation (type I/II)	Injury to AC joint capsule and ligaments
	Loose intra-articular bodies
	Intra-articular chondral and discus lesions
	Microinstability with/without instability arthritis
Medium-grade AC joint dislocation (type III)	Loose intra-articular bodies
	Intra-articular chondral and discus lesions
	Persisting instability
High-grade AC joint dislocation (type V)	Loss of shoulder girdle stability and changes in biomechanical relations

50.1.2 Radiological Exploration

The classification according to Rockwood is the most widely used basis to grade the severity of acute AC joint dislocation. The coracoclavicular (CC) distance measured in comparison to the contralateral side on bilateral stress views with 10 kg of axial load is the major factor to distinguish between injury types (Fig. 50.1a–c). Rockwood type I and II injuries that are mostly treated conser-

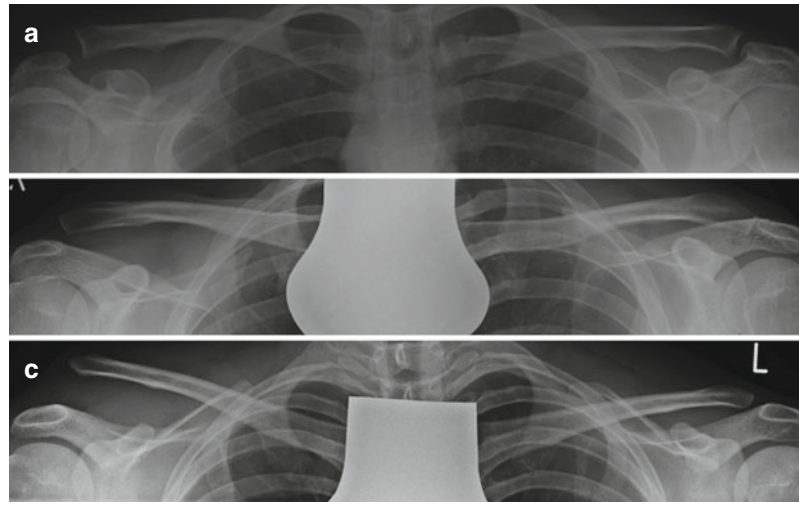

Fig. 50.1 (**a**–**c**) AC joint dislocation displayed on bilateral anteroposterior stress views. (**a**) Low-grade AC joint dislocation type II according to Rockwood. (**b**) Mid-grade AC joint dislocation type III according to Rockwood. (**c**) High-grade AC joint dislocation type V according to Rockwood

vatively display a CC difference of 0–10 % and 11–25 %. This is supposed to be due to an incomplete AC injury (type I) or a tear of the AC ligaments and partial injury to the CC ligament complex. A Rockwood type III separation shows a CC distance of 25–100 % in comparison to the contralateral side and is described as the results of a complete tear of both the AC and CC ligaments. A type IV injury is characterized by a static posterior dislocation of the clavicle with a varying CC distance. An AC joint dislocation with a CC difference of 100 % and more is classified as a type V injury with a rupture of all AC-stabilizing structures. The type VI injury according to Rockwood describes a rare inferior dislocation of the clavicle beneath the coracoid, which is found in case reports only and may be subject to a different trauma mechanism. A DPT is common in low- and high-grade injuries and is not considered in Rockwood's classification. A DPT can be evaluated on dynamic axillary or bilateral Alexander views [10, 11]. DPT can be graded into a non-dislocated situation (Fig. 50.2a) and a partial (Fig. 50.2b) and a complete translation (Fig. 50.2c). Persisting complete DPT on Alexander views is associated with worse clinical results after surgical stabilization [12]. Unpublished own data show that patients with a complete DPT present with a clinically worse

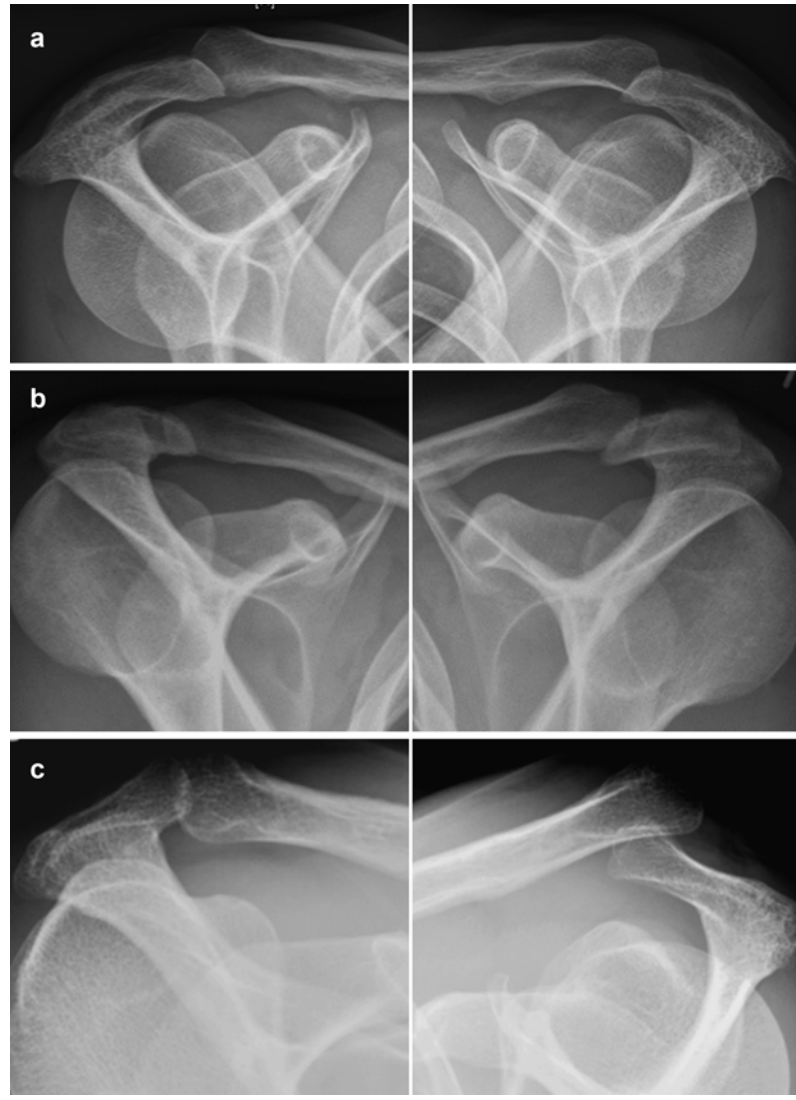

Fig. 50.2 (**a**–**c**) Evaluation of severity of dynamic posterior translation (DPT) (*left side*, healthy; *right side*, affected side). (**a**) Stable situation without DPT. (**b**) Partial DPT: enlarged translation of the clavicle with a reduced overlapping of clavicle and acromion in comparison to the contralateral side. (**c**) Complete DPT: no overlapping of clavicle and acromion, clavicle posterosuperior dislocation more than one shaft width

Table 50.2 A new classification of AC joint instability

Type I: partial vertical instability (CCD <30 %)	A: None/partial dynamic horizontal translation
	B: Complete dynamic horizontal translation
Type II: complete vertical instability (CCD >30 %)	A: None/partial dynamic horizontal translation
	B: Complete dynamic horizontal translation

situation in the acute posttraumatic setting (maximum 7 days posttraumatic) in comparison to patients without or with a partial DPT. This seems to be independent of CC distance. Furthermore, patients with a CC difference of <30 % achieved significantly better clinical results in comparison with patients with a higher CC difference of >30 %, whereas there was no difference in patients with a Rockwood type III (25–100 %) and type V (>100 %) injury. Therefore, we use a new classification of AC joint instability (Table 50.2). This classification subdivides a type I, which is characterized by an incomplete vertical translation with a CC difference of <30 % on bilateral anteroposterior stress views with 10 kg axial load, and a type II, which is a complete vertical translation with a CC difference of >30 %. Both are further defined into none or partial DPT (a) and complete DPT (b). Today, it is still unknown if a complete DPT with low-grade CC translation necessitates a surgical intervention. However, if surgical stabilization is indicated, DPT should be addressed as well.

50.1.3 Indication

Currently, there is no level I evidence as to which acute AC joint dislocation should be treated conservatively or surgically. However, the majority of authors favours conservative treatment in low-grade instabilities (Rockwood type I/II). In some cases, as has been described earlier, pain with development of a chronic AC joint instability may persist. Surgical treatment of chronic AC joint instability should be considered after a 3–6-month period of conservative therapy with training of scapula-stabilizing muscles. In cases of low-grade chronic AC joint instability, if secondary arthritis is the main problem, a lateral clavicle resection may be indicated. High-grade chronic instabilities should be considered for a stabilizing technique accounting for the reduced biologic healing capacity in this chronic situation. In combined vertical and horizontal instabilities, the horizontal component should be addressed as well.

Treatment of acute complete instabilities (Rockwood types IV–VI) depends on patient-specific factors, such as age, functional and cosmetic demands. In the majority of cases, these high-grade injuries are treated surgically due to the complete tear of all ligamentous stabilizers that may cause loss of stability of the shoulder girdle and lead to scapula-thoracic disbalance. Rockwood type III injuries are still a matter of debate with a lack of evidence regarding the indication for conservative or surgical treatment [7]. Smith et al. found that surgical stabilization led to better cosmetic results but also had a longer sick leave. There was no difference regarding pain, strength, range of motion or posttraumatic AC joint arthritis. Korsten et al. included eight studies in their meta-analysis and found better subjective and objective results yet also a higher complication rate and more radiologic abnormalities such as arthritis and CC ossification in the surgically treated group [13]. They concluded that there was no conclusive evidence but stated that there was a potential advantage of surgical treatment for young and active patients. Currently, treatment decisions are mainly based on individual functional demands. Cosmetic aspects should also be taken into account, and patients need to be aware of a persisting asymmetry after conservative treatment. Besides regarding indication for surgery, a complete DPT should be taken into account.

50.2 Techniques

50.2.1 Acute AC Joint Instability

Numerous open and lately arthroscopic techniques for acute AC joint stabilization have been described. The majority of techniques use either an AC (e.g. hook plate, K-wire fixation) or a CC stabilization (e.g. Bosworth screw, PDS cerclage). To allow for a permanent soft tissue healing, the aim of surgical treatment is to provide AC stability as well as to approximate the torn ligaments. Therefore, synthetic augmentation of the CC and new and/or modified techniques of the AC ligament complex is

used. In the early days of arthroscopic AC joint stabilization suture anchor systems, CC cerclage or cannulated screws were used [14–17]. Besides currently still utilized open techniques such as the temporary hook plate retention, pulley-like implants (e.g. TightRope, Arthrex, USA) are increasingly applied. In order to provide an anatomical reduction and to avoid early secondary dislocation, two pulley-like implants should be used. Regarding load to failure in the vertical and horizontal plain, this technique has been proven to be superior in biomechanical studies [18]. Due to the high rate of persisting DPT in a solely CC stabilization, a further development of this technique adds an AC cerclage in order to provide additional horizontal stability (Fig. 50.3). Currently, these pulley-like implants experienced a modification in such that a single implant (Dog Bone, Arthrex, USA) with a smaller drill hole, whose buttons allow for a wider suture material (FiberTape, Arthrex, USA) to be passed through, is used for CC stabilization. Whether this technique is able to provide a stable situation and similarly good clinical results regardless of its potentially reduced rotational stability currently remains unknown. The principal advantage of arthroscopic techniques consists of the diagnosis and possible treatment of associated glenohumeral lesions that are described in up to 30% of patients [19]. However, so far no evidence certifying the necessity of treatment exists. Jensen et al. found a superiority for the arthroscopic technique when comparing temporary hook plate retention and the double TightRope technique due to the necessity of implant removal and a second sick leave with hook plate [20]. Complications such as acromion osteolysis and fracture are described as well [21]. Further potential disadvantages of open reconstruction techniques are extensive soft tissue preparation with consecutive relevant approach morbidity. In contrast to that, arthroscopic and arthroscopically assisted techniques offer a potentially lower infection risk and with regard to cosmetic reasons a higher patient acceptance. However, they are often technically demanding and have a longer learning curve.

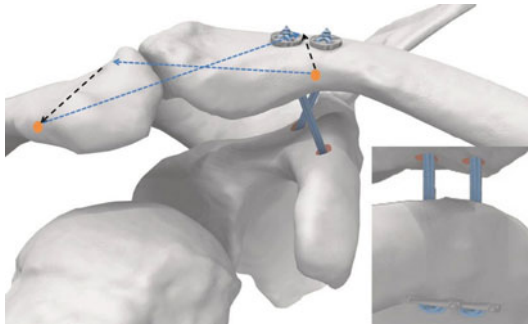

Fig. 50.3 Arthroscopically assisted coracoclavicular and acromioclavicular stabilization in a double TightRope technique with additional AC cerclage (From [31])

50.2.1.1 Arthroscopically Assisted Combined CC and AC Stabilization

The patient is placed in a beach chair position under general anaesthesia and perioperative antibiotics (Fig. 50.4). It is advisable to use a small

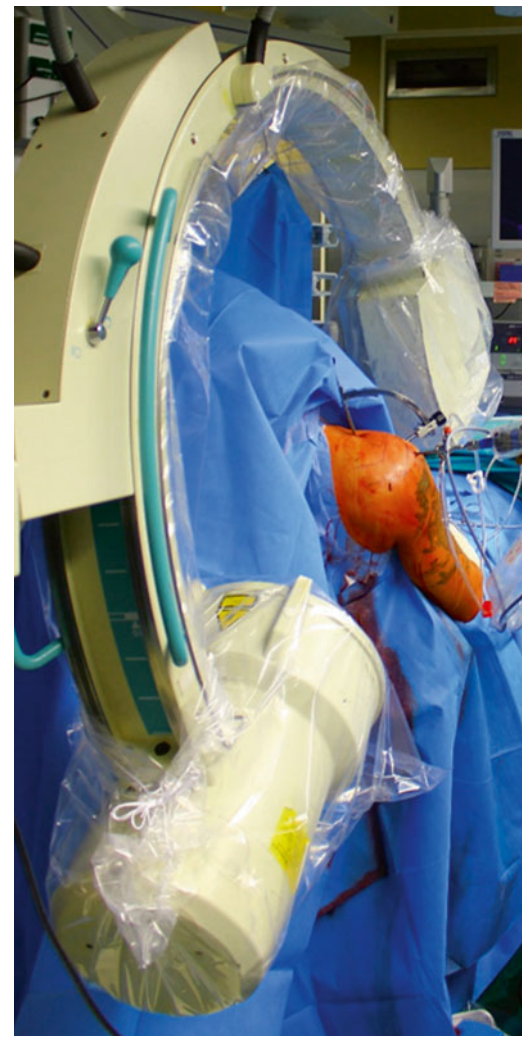

Fig. 50.4 Patient positioning

headrest and to tilt the head carefully to the contralateral side in order to facilitate the placement of drill holes. All Kirschner wire and drill hole placements should be carried out under fluoroscopic control in addition to the arthroscopic view to ensure adequate mediolateral placement in the clavicle. After a diagnostic arthroscopy via a posterior standard portal, two additional portals (anteroinferior and lateral) and a 1.5 cm incision superior to the clavicle and approximately 3 cm medial of the AC joint are created (Fig. 50.5). With the exception of LHB tenodesis, associated glenohumeral lesions are treated after AC stabilization. The camera is placed in the anterolateral portal. Hence, the undersurface of the coracoid and the subcoracoidal space is prepared using an electrothermic device via the anteroinferior portal (Fig. 50.6a). To ensure exact drill hole placement, the marking hook of an ACL drill guide is placed under the medial part of the coracoid process (Fig. 50.6b). The drill sleeve is placed above the clavicle at the desired entry point about 4.5 cm medial from the lateral clavicle edge to augment the conoid ligament. In general, an excessively anterior drill hole position is to be avoided. In addition to that, in order to achieve anatomic reconstruction, the trapezoid drill hole should be placed posterior to the conoid ligament. The first oblique drill hole is placed transclavicular-transcoracoidal (Fig. 50.7). First, a 2.0 mm Kirschner wire (K-wire) is placed and overdrilled using a 4.0 mm cannulated drill bit (Fig. 50.7a, b). A nitinol suture passing wire is introduced through the drill bit and retrieved via the anteroinferior portal (Fig. 50.7c). The drill bit is removed. The second drill hole is established in a similar fashion in line with the trapezoid ligament (Fig. 50.8a–c). Next, the drill holes for the AC cerclage are established. First, the marking hook is placed posterior to the clavicle via the

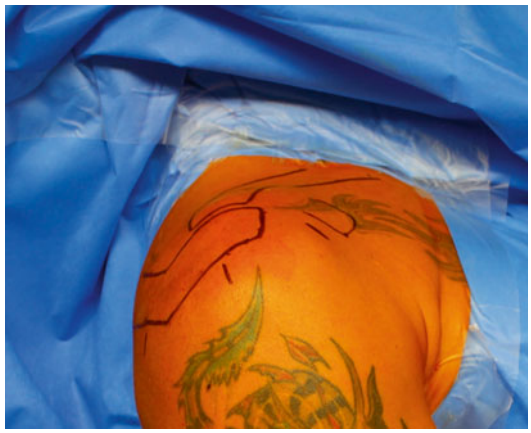

Fig. 50.5 Portals and incision

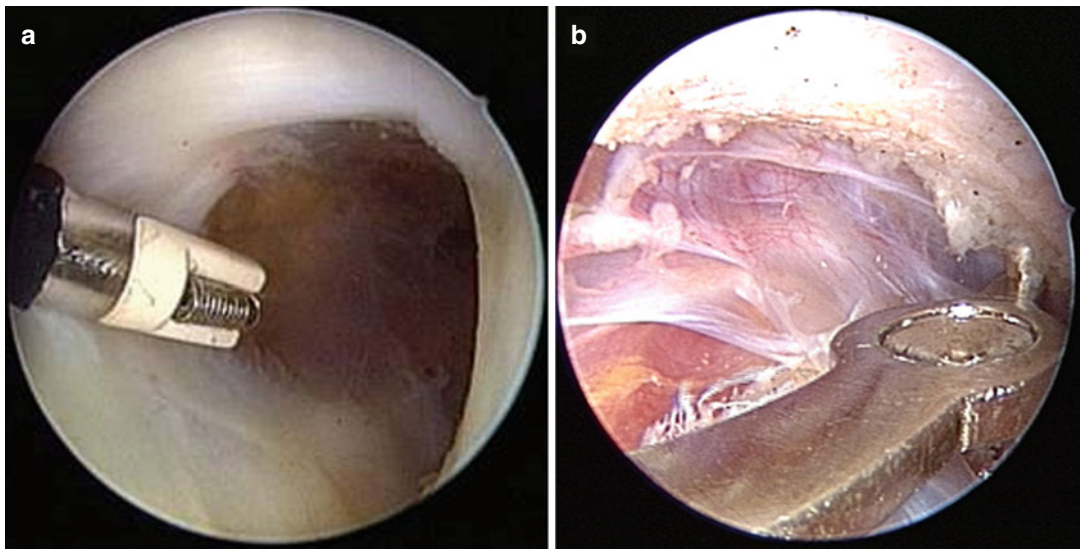

Fig. 50.6 (**a**, **b**) Preparation of the subcoracoidal space and the base of the coracoid (**a**) as well as placement of the marking hook of an ACL drill guide beneath the coracoid

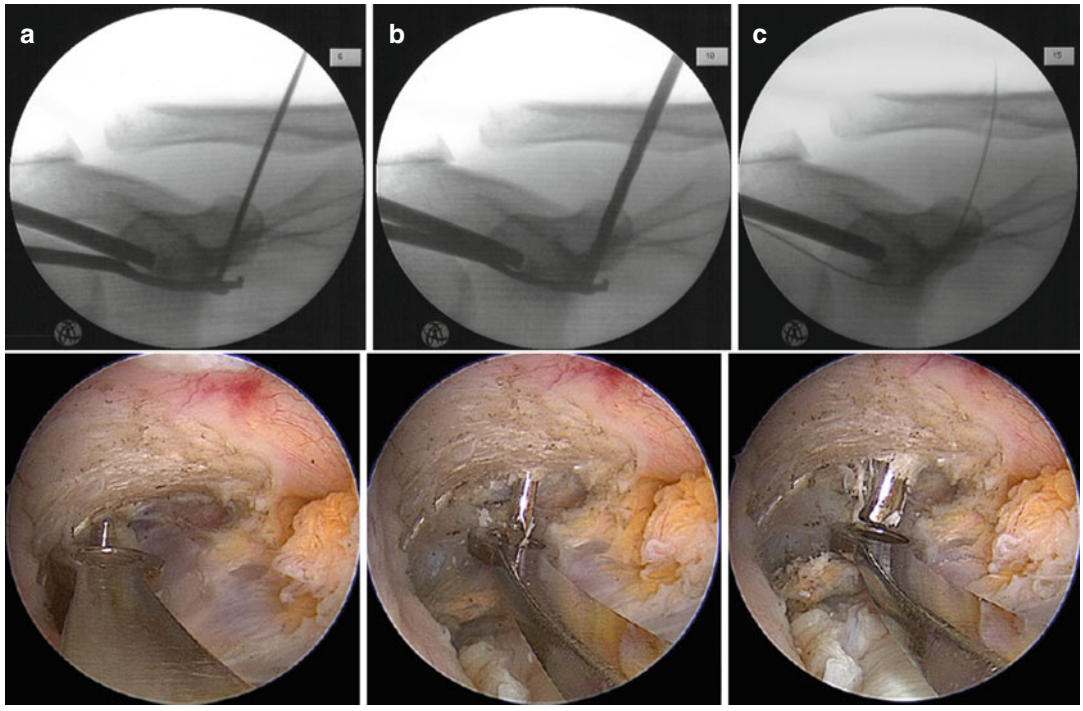

Fig. 50.7 (**a**–**c**) Placement of the first medial transclavicular-transcoracoidal drill hole. (**a**) Placement of a 2.0 mm Kirschner wire. (**b**) Cannulated overdrilling (4.0 mm). (**c**) Insertion of nitinol suture passing wire

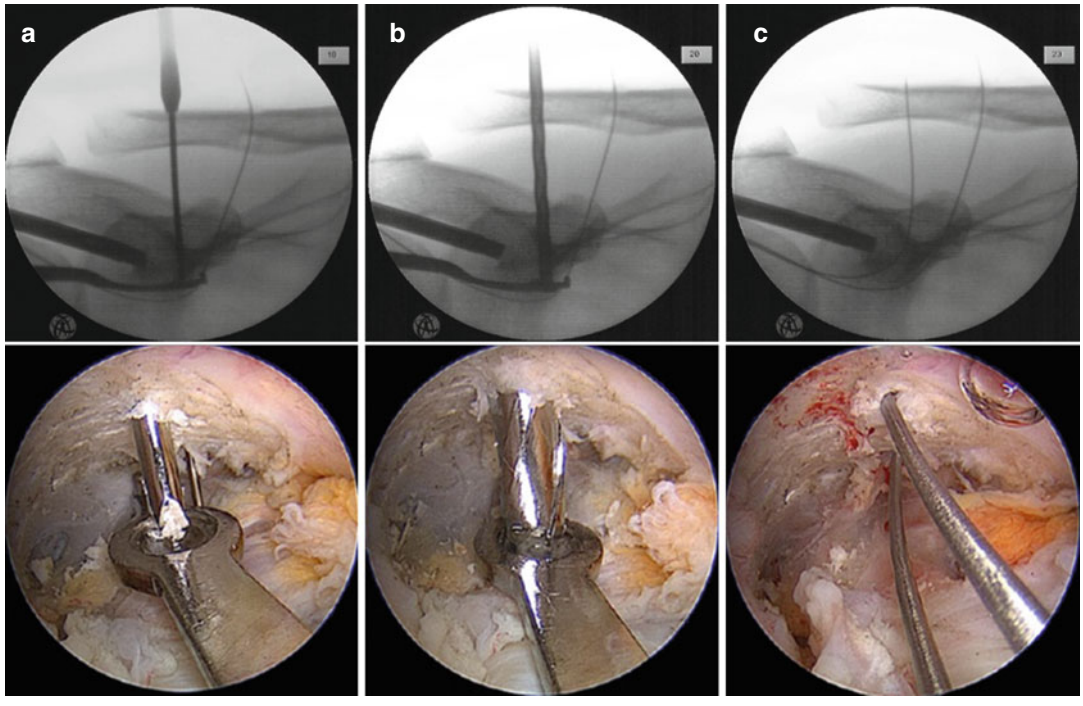

Fig. 50.8 (**a**–**c**) Placement of the lateral transclavicular-transcoracoidal drill hole

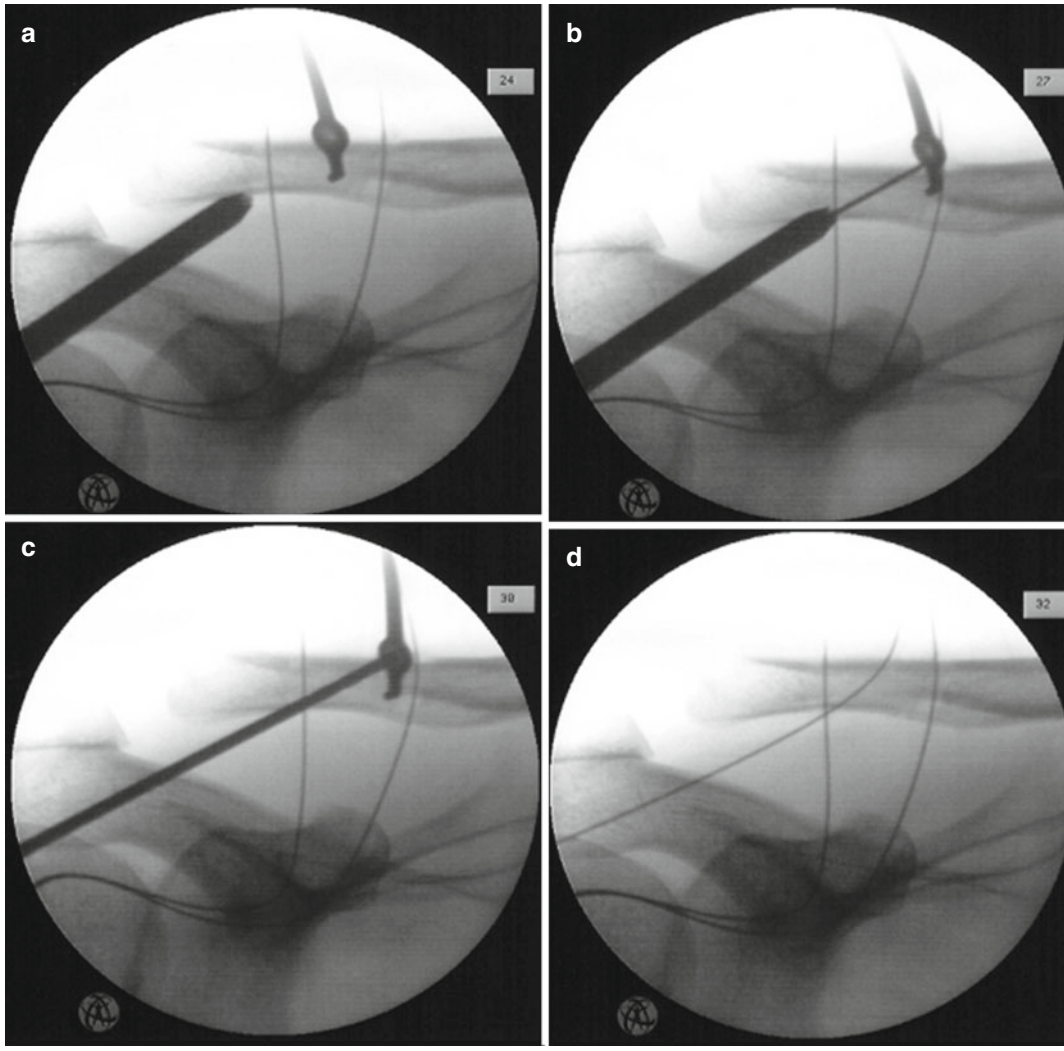

Fig. 50.9 Placement of the anteroposterior transclavicular drilling. (**a**) Positioning of the marking hook dorsal of the clavicle and the drill sleeve via the anteroinferior portal. (**b**) Placement of a 1.25 mm Kirschner wire. (**c**) Overdrilling with a 2.7 mm cannulated drill bit. (**d**) Insertion of a nitinol wire

superior incision, and the drill sleeve is introduced via the anteroinferior portal and placed anteriorly on the clavicle between both drill holes (Fig. 50.9a). A 1.25 mm K-wire is placed transclavicularly and overdrilled with a 2.7 mm cannulated drill bit (Fig. 50.9b, c). After inserting a nitinol wire, the transacromial drilling is done in the same way through the lateral portal and superior and posterior of the AC joint (Figs. 50.9c and 50.10). Hence, the TightRopes are shuttled via the first two nitinol wires and inserted into the subcoracoid space under arthroscopic control (Fig. 50.11). Next, the clavicle is reduced, and the TightRopes are knotted securely. The AC cerclage is performed by inserting a FiberTape via the last two nitinol wires (Fig. 50.12). The clavicular incision and the arthroscopic portals are closed in a standard fashion.

50.2.2 Chronic AC Joint Instability

Due to the lack of intrinsic healing and scar-forming potential of the ligamentous tissue, chronic

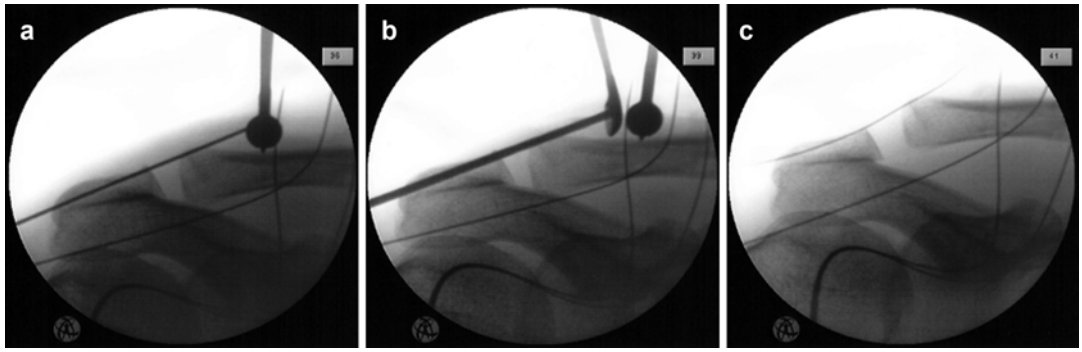

Fig. 50.10 (**a**–**c**) Placement of the transacromial drill hole. (**a**) Placing of a 1.25 mm Kirschner wire through the lateral portal. (**b**) Cannulated overdrilling with a 2.7 mm drill bit. (**c**) Insertion of a nitinol wire

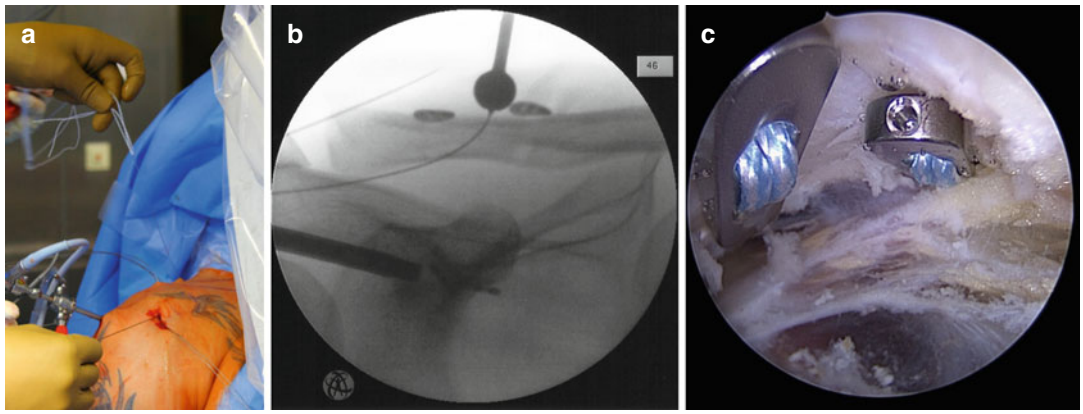

Fig. 50.11 Insertion of the TightRopes with the aid of the first two nitinol wires, manual reduction of the clavicle under fluoroscopic control and knotting of the sutures

AC joint instability is not sufficiently addressed with temporary retention or an isolated synthetic augmentation. Therefore, high-grade instabilities require biologic augmentation techniques such as a transfer of the coracoacromial (CA) ligament (Weaver-Dunn transfer) or a free tendon graft. Low-grade instabilities can be addressed with a restrictive AC joint resection, especially if secondary arthritis is the major complaint. One-directional vertical high-grade instabilities can mostly be treated in an all-arthroscopic CA ligament transfer (Fig. 50.13a). A modification of this technique includes an additional synthetic augmentation with a transclavicular-transcoracoidal stabilization with a TightRope (Arthrex, Naples, Florida) implant and has been shown to provide better results regarding anterior and superior translation of the clavicle. However, in comparison to the intact joint, a significant difference regarding posterior translation and maximum resistance to traction was found [22] (Fig. 50.13b). Combined vertical and horizontal high-grade instabilities require a more stable reconstruction method such as a free tendon graft (e.g. gracilis or semitendinosus tendon) and an additional synthetic augmentation with a pulley-like implant to correctly restore the anatomical and biomechanical situation of the native CC ligament complex [23]. A modification of this technique includes an additional AC stabilization to treat horizontal instability sufficiently (Fig. 50.14b).

50.2.2.1 Arthroscopic CA Ligament Transfer According to Weaver-Dunn

Patient positioning and preparation is described in Sect. 1.4.1.1. Four portals are needed: a

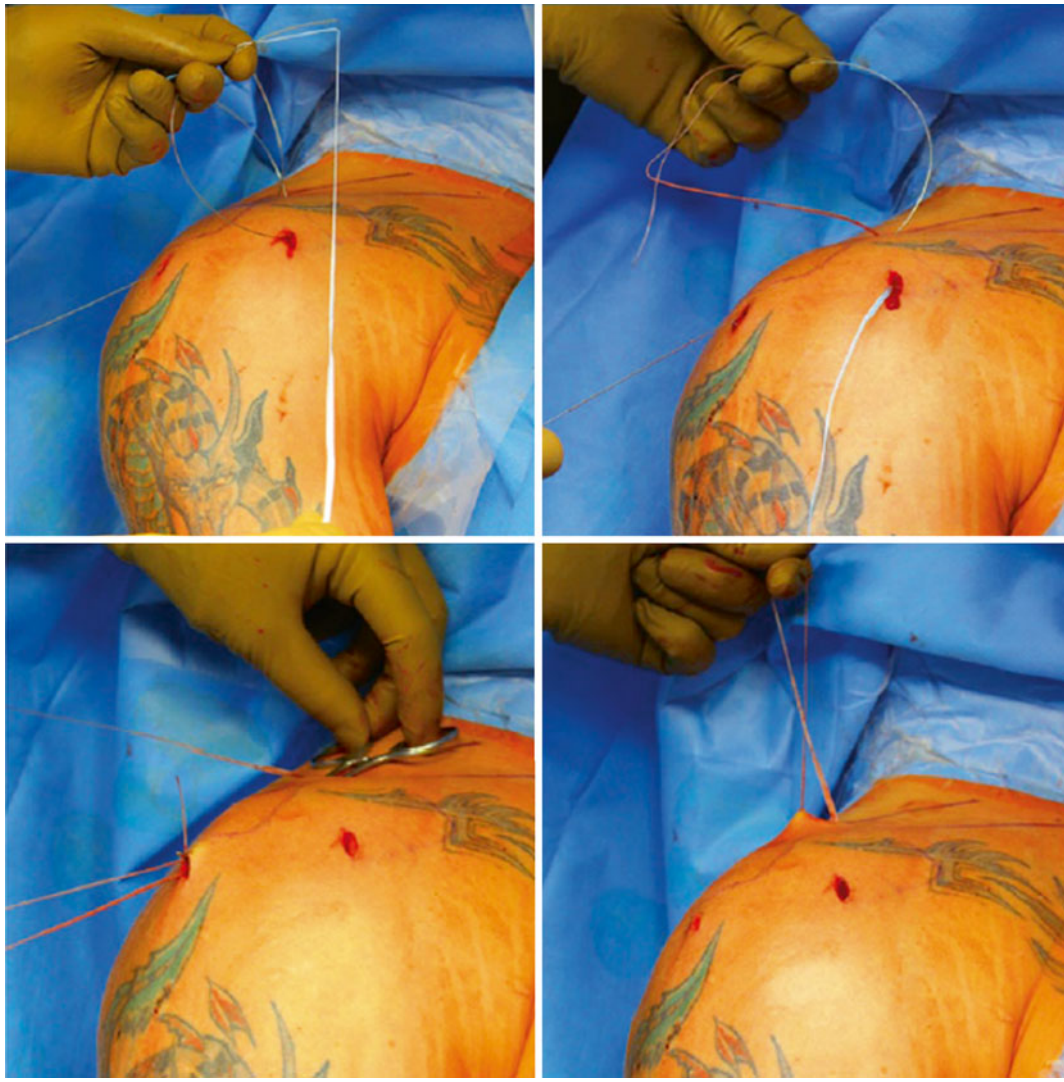

Fig. 50.12 Insertion of the AC cerclage [from 31]

posterior standard, a lateral, an anterolateral and an anteroinferior portal. If an additional synthetic augmentation is desired, a 1–1.5 cm incision superior of the clavicle is required (Fig. 50.15a). In this case, first, the TightRope drill hole, as described in Sect. 1.4.1.1, is placed (Fig. 50.15b). Next, the arthroscope is introduced into the subacromial space via the posterior portal, and a partial bursectomy is carried out (Fig. 50.15c). The CA ligament is identified and armed using two No.2 FiberWire sutures in a lasso-loop technique (Fig. 50.15d). Hence, the ligament is dissected electrothermically from its insertion at the acromion (Fig. 50.15d). Next, the lateral clavicle is prepared (Fig. 50.15e). Therefore, a groove is created with a chisel in the lateral clavicle to receive the armed ligament (Fig. 50.15f). Two K-wires are placed lateral of the TightRope drill hole in a lateral orientation and directed in the anterior and posterior parts of the groove. The Kirschner wires are overdrilled with a 2.7 mm cannulated drill bit, and two nitinol wires are inserted (Fig. 50.16a). The TightRope is pulled into the first drill hole, the clavicle is reduced and the TightRope is securely knotted (Fig. 50.16b). Next, the CA ligament is introduced into the prepared groove by attaching the FiberWire sutures to the remaining two nitinol wires (Fig. 50.16c).

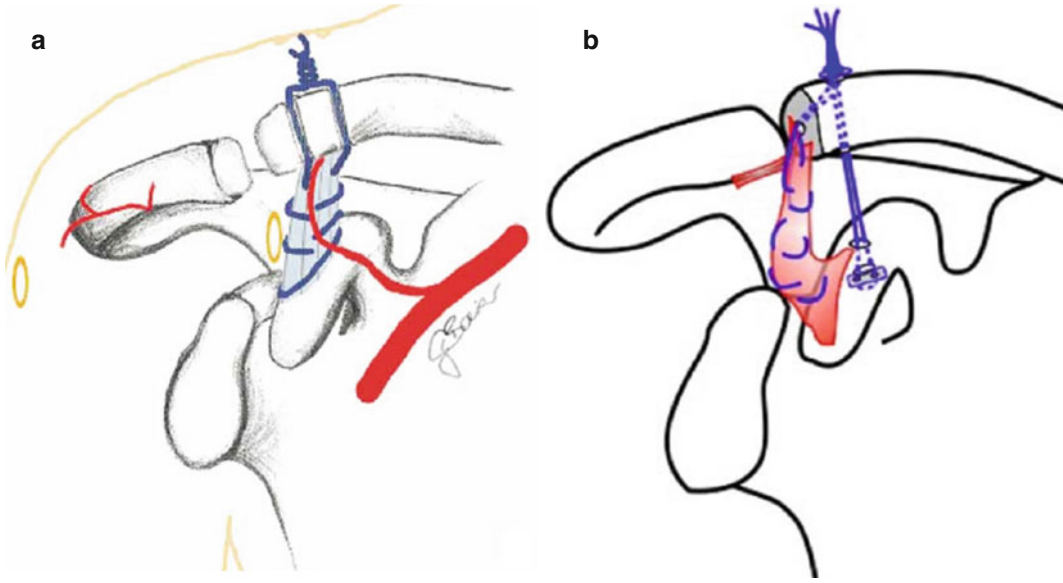

Fig. 50.13 (**a**, **b**) Arthroscopic coracoacromial ligament transfer without (**a**) and with (**b**) single TightRope augmentation [from 21, 22]

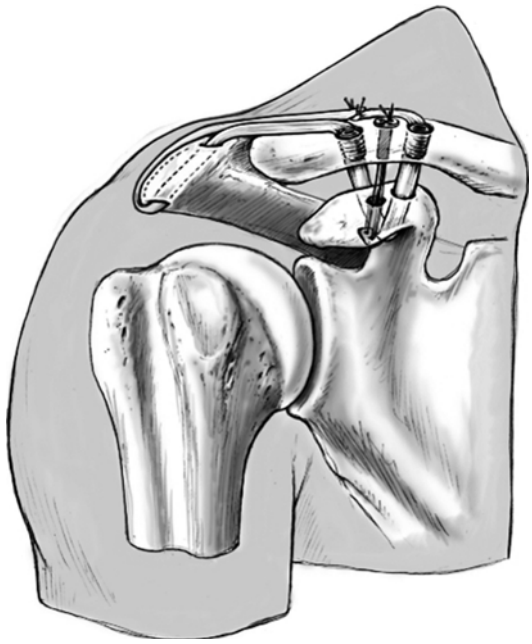

Fig. 50.14 Arthroscopically assisted stabilization with a free tendon graft and TightRope augmentation in a combined coracoclavicular and acromioclavicular technique (from [32])

Both FiberWires are knotted securely. The clavicular incision and the arthroscopic portals are closed in a standard fashion.

50.2.2.2 Arthroscopically Assisted Stabilization with Autologous Tendon Graft and Synthetic Augmentation

After portal placement and preparation as described above, the tendon graft (gracilis/semitendinosus tendon) is harvested from the ipsilateral knee and prepared as known from ACL surgery. All remaining muscle fibres are removed from the harvested tendon, and both ends of the tendon are tagged with baseball stitches using highly tear-resistant suture material (e.g. No.2 FibreWire, Arthrex, USA) (Fig. 50.17). Tendon diameter is measured in order to determine drill hole sizes. Usually, a tendon length of 24 cm is sufficient for CC and AC stabilization. The tendon is manually pretensioned to prevent a giving-way phenomenon in vivo. Next, the arthroscope is reintroduced into the joint, and the first transclavicular-transcoracoidal drill hole as mentioned above is created (Fig. 50.18). Therefore, a 5 mm and a 4 mm cannulated drill bits are used on the clavicular and the coracoidal side. This drill hole is used for the first passage of the tendon graft. The second transclavicular-transcoracoidal TightRope drill hole is aimed 1 cm lateral and performed in a similar fashion. The third transclavicular drill hole

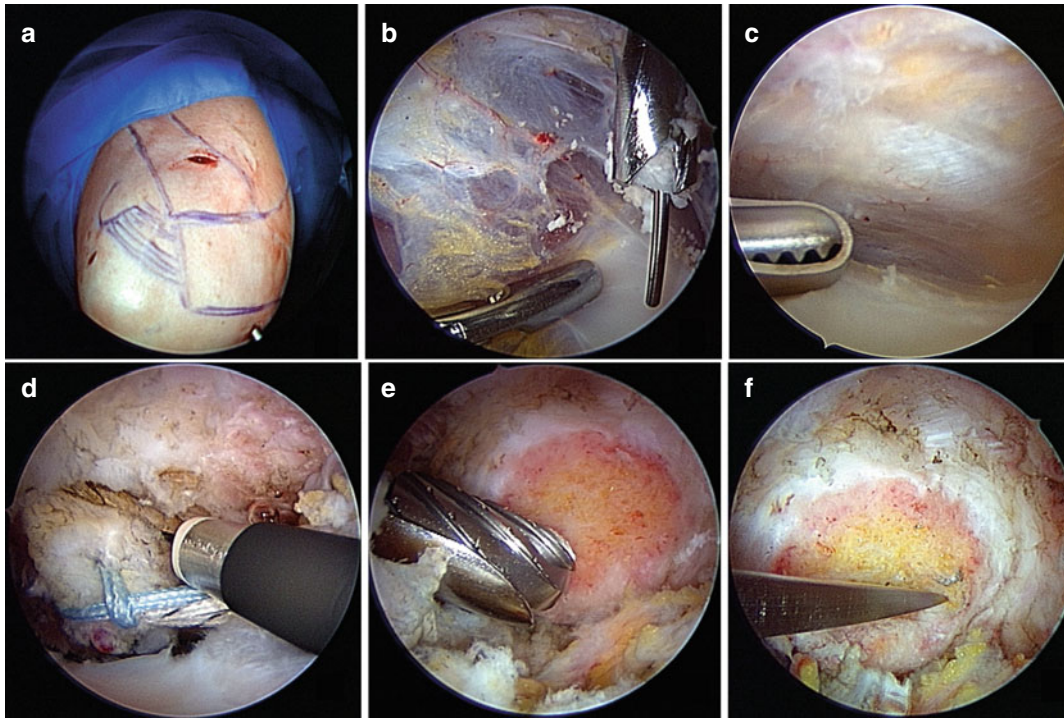

Fig. 50.15 (**a**–**f**) Preparation of the coracoacromial ligament. (**a**) Incision superior to the clavicle for synthetic augmentation. (**b**) TightRope placement. (**c**) Partial subacromial bursectomy and identification of the CA ligament. (**d**) Arming with two No.2 FiberWire sutures in a lasso-loop technique and electrothermic dissection. (**e**) Preparation of clavicle side. (**f**) Creation of a groove in the lateral clavicle with a chisel

is placed 1 cm lateral of the second drill hole, approximately 2.5 cm from the lateral edge of the clavicle (Fig. 50.19). Next, the TightRope is introduced into the coracoclavicular space via the second drill hole, the clavicle is reduced under fluoroscopic control and the sutures are tied, thereby reducing the clavicle. The tendon graft is now pulled into the medial drill hole via the first nitinol wire and retrieved through the anteroinferior portal (Fig. 50.20a, b). Next, the graft is shuttled back via the third transclavicular portal lateral to the coracoid (Fig. 50.20c). Each graft end is attached with a PEEK-tenodesis screw (Arthrex, Naples, Florida) while applying tension to both ends. Hence, the AC stabilization is carried out. Therefore, a transacromial drill hole is placed, as described in Sect. 1.4.1.1 (Fig. 50.21a–c). The drill hole diameter depends on measured tendon width. The long end of the tendon graft is then pulled through the acromion and above the AC joint. With the aid of an arthroscopic knot pusher, the graft is pushed subcutaneously superior of the acromion and returned to the incision above the clavicle. Both graft ends are sutured together. A careful AC joint resection can be added in cases of symptomatic secondary AC joint arthritis. Next, the clavicular incision is closed with reconstruction of the deltotrapezoidal fascia. The arthroscopic portals are closed in a standard fashion.

50.3 Rehabilitation

After arthroscopically assisted combined CC and AC stabilization in the acute setting, the shoulder is protected in a 20–30° abduction brace for 6 weeks. After CA ligament transfer and free tendon graft augmentation, this is prolonged for 8 weeks postoperatively. During the first 3 weeks, passive range of motion is restricted to 45° of flexion and abduction. After tendon graft augmentation, the shoulder is immobilized for

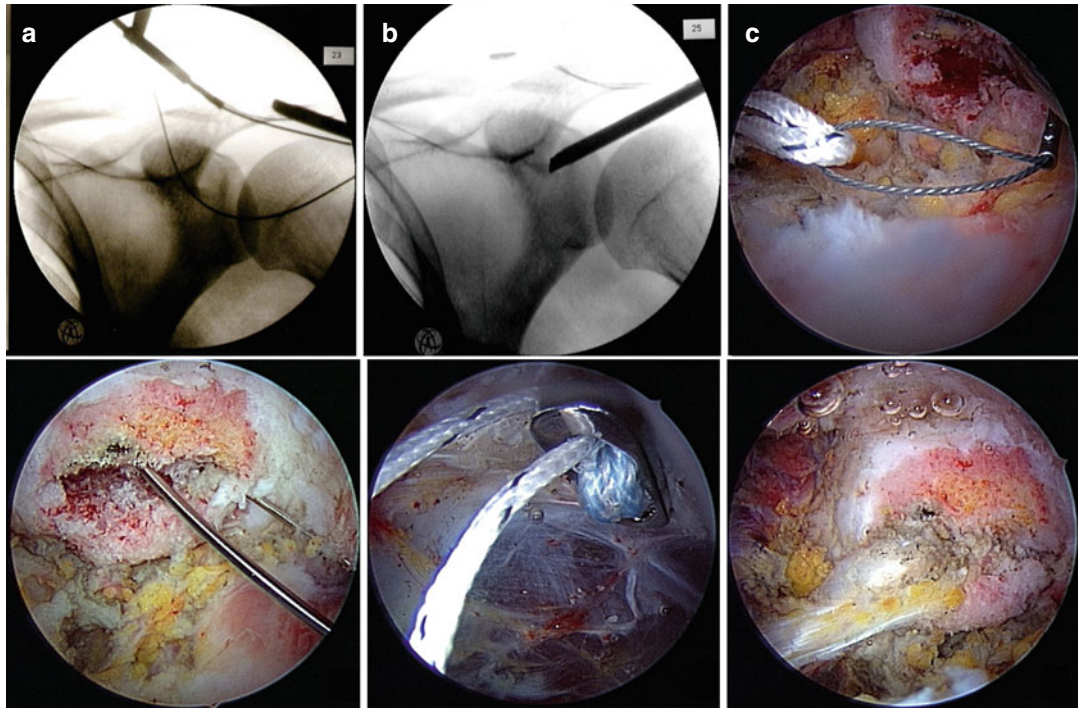

Fig. 50.16 (**a**–**c**) Attachment of the CA ligament to the lateral clavicle. (**a**) Placing of two Kirschner wires lateral of the TightRope drill hole into the groove, overdrilling with a 2.7 mm cannulated drill bit and insertion of two nitinol wires. (**b**) TightRope insertion. (**c**) Introduction of the CA ligament into the prepared groove

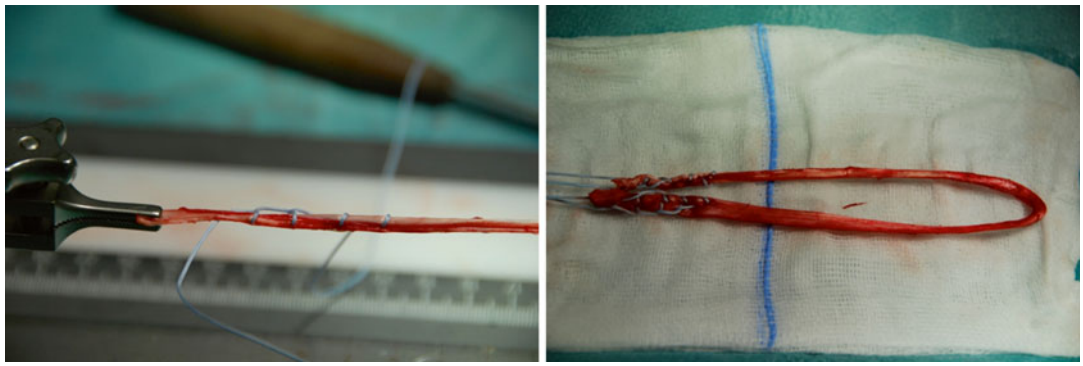

Fig. 50.17 Harvested tendon and preparation of both ends with baseball stitches

2 weeks with mobilization of hand and elbow only in order to preserve the construct until tendon integration has begun. The following 3 weeks passive range of motion is limited to 90° flexion and abduction. From the seventh or ninth week, passive range of motion is unlimited, and active movement may be started. Forceful, AC joint-straining movements and carrying heavy loads are discouraged for 12 weeks postoperatively. Muscle-strengthening exercises and sport-specific training are delayed up to 10–12 weeks.

50.4 Complications

A variety of complications such as implant migration and irritation, CC ossification, drill hole enlargement, recurrent vertical and/or

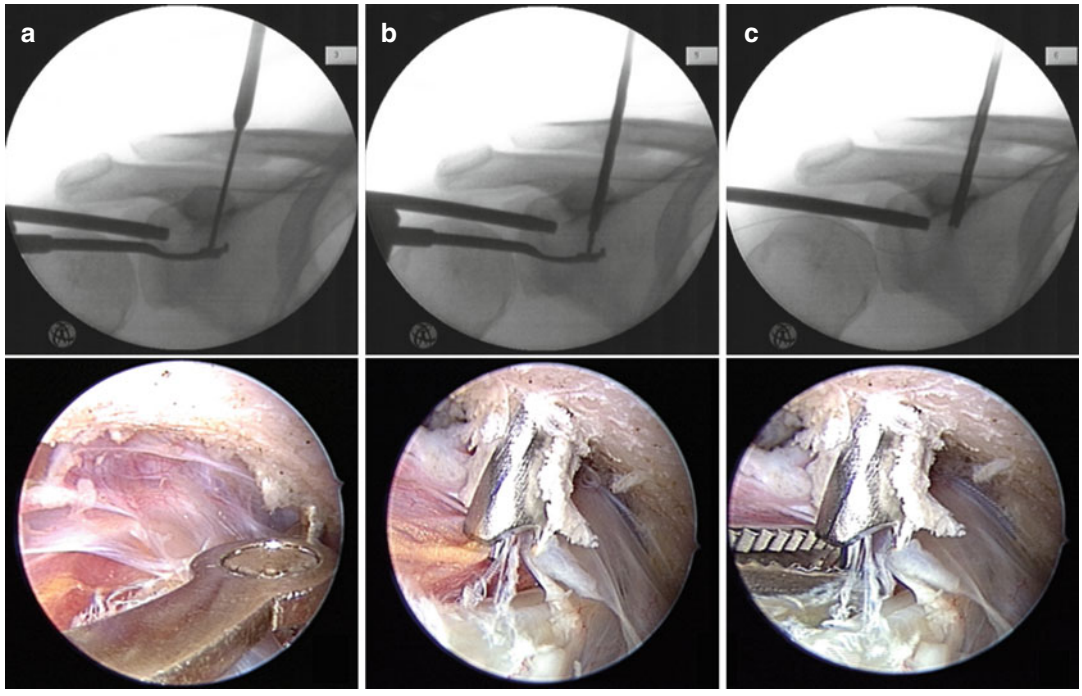

Fig. 50.18 (**a**–**c**) Placement of the first transclavicular-transcoracoidal drill hole

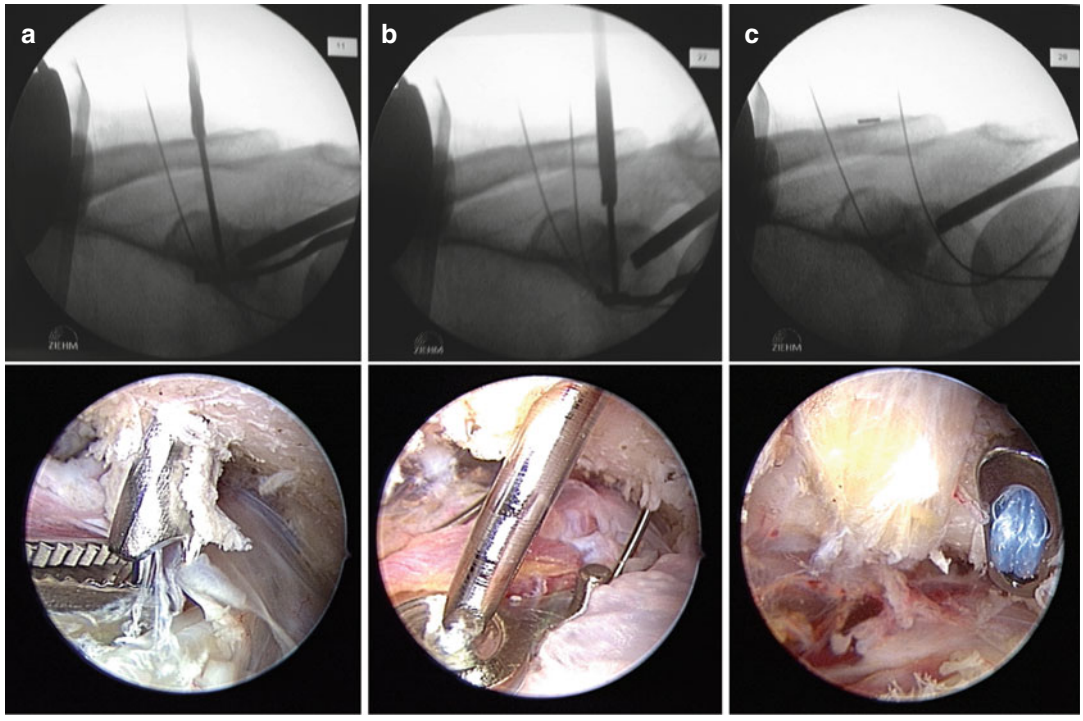

Fig. 50.19 (**a**, **b**) Placement of the second transclavicular-transcoracoidal and the third solely transclavicular drill hole. (**a**) Placement of Kirschner wire and overdrilling. (**b**) Drill hole positioning for the TightRope. (**c**) Insertion of the TightRope

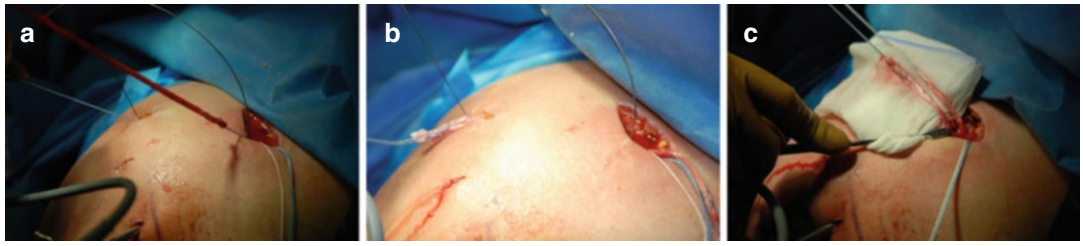

Fig. 50.20 (**a**–**c**) Insertion of the tendon graft. (**a**) Insertion through the first transclavicular and transcoracoidal drill hole. (**b**) Retrieved via the anteroinferior portal. (**c**) Transclavicular return through the third drill hole and fixation with two PEEK-tenodesis screws

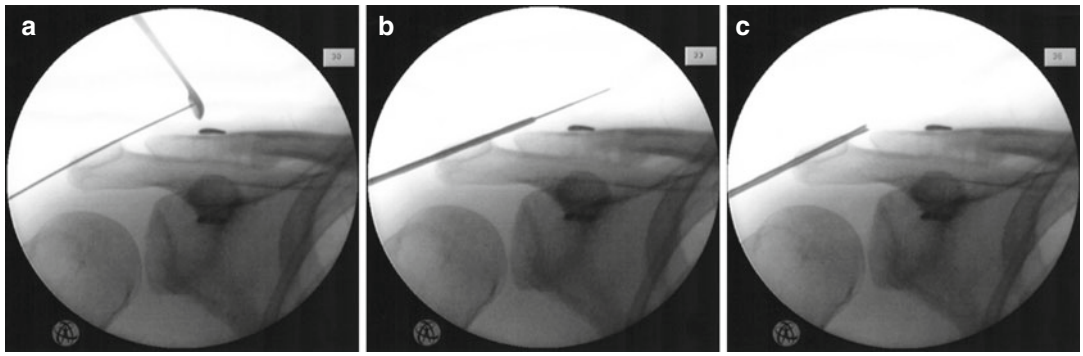

Fig. 50.21 (**a**–**c**) Placement of the transacromial drill hole. (**a**) Placing a 1.25 mm Kirschner wire through the lateral portal. (**b**) Cannulated overdrilling (size of drill bit depending on tendon width). (**c**) Insertion of a nitinol wire

horizontal dislocation and even coracoid and clavicle fractures has been associated with arthroscopic and open techniques in both acute and chronic situations. Implant migration occurred when using the first-generation implant of the TightRope but was not associated with a major loss of reduction [12]. Since a modification of the device with larger buttons exists, implant migration has become rare. On the other hand, implant irritation due to the suture material above the clavicle may still be a cause of symptoms and may necessitate partial implant removal. Later on, redislocation after removal has not been seen in our cases. Ossification in the area of the former CC ligaments occurs in up to 75 % of patients 2 years after surgery [12]. In how far the presence of ossification is a positive or negative outcome, predictor remains unclear. So far, ossification did not lead to worse clinical results or a restricted range of motion. On the contrary, patients with combined CC ossification in both ligaments tended to have a significantly lower CC distance and less DPT. Clavicular drill hole enlargement has been described in the literature [24]. A parallel drill hole orientation led to a cone-shaped and a V-shaped orientation to an equally distributed enlargement. Influence on clinical or radiographic outcome has not been noted.

Vertical and/or horizontal recurrent instability occurs in up to 15–20 % of cases unrelated to the chosen arthroscopic or open technique. The majority of cases remain cosmetically dissatisfying yet asymptomatic. A symptomatic recurrent instability might require a secondary procedure with biologic augmentation. Coracoid fractures after TightRope stabilization are rare but have been reported to occur. In order to avoid eccentric drill hole placement and wrong implant position that might predispose to coracoid fracture, fluoroscopic control is mandatory in this procedure.

Considering the potentially more difficult situation in chronic instabilities due to previous surgery or long duration of symptoms, a higher risk of complications such as infection, redislocation

or implant failure exists. Furthermore, there seem to be some patients with bidirectional, high-grade chronic AC joint instability that shows early and repeated failure after surgical intervention. It is possible that in these patients, we underestimate the true extent and severity of injury. Future investigations have to provide reasons for these failures both in the acute and in the chronic setting and help to identify risk factors for non-healing.

50.5 Results

In the majority of cases, good to excellent clinical results after surgical stabilization of acute AC joint stabilization are described in the literature, regardless of the chosen technique [12, 25–27]. However, as mentioned before, likewise unrelated to the technique, recurrent instabilities are reported in up to 10–20 % of cases. So far, reasons remain unknown. In a currently undefined subgroup of patients, the biologic healing capacity seems to be reduced.

In comparison to open techniques, lately developed and modified arthroscopic techniques provide at least similar outcomes with known potential benefits of arthroscopic surgery.

The arthroscopically assisted CC stabilization in a double TightRope technique achieved good to excellent clinical results after a midterm follow-up. Some patients displayed a radiographically evident partial vertical recurrent instability without clinical relevance as has been described in various other techniques as well [12]. However, a persisting DPT could be associated with a worse clinical outcome. Therefore, an acromioclavicular cerclage was added to the procedure. So far, patients with an additional AC cerclage displayed comparable clinical results to the isolated CC stabilization with a lower rate of DPT. A partial DPT was not associated with worse clinical results. So far, only a complete DPT seems to have influence on the clinical outcome. Nevertheless, long-term results are currently lacking.

Surgical treatment of chronic AC joint instability remains a challenge not least due to the reduced ligament healing potential. CC stabilization with free tendon grafts displayed good clinical results with a pain reduction and a radiographically stable situation in a revision setting [28]. A semitendinosus graft has been associated with better clinical results in comparison to a CA ligament transfer [29]. However, an isolated biologic augmentation led to high rates of failure, osteolysis of the lateral clavicle and drill hole enlargement. Biomechanically, an additional transacromial stabilization provided more horizontal stability compared to an isolated CC stabilization and was comparable to the native situation [30].

Patients in our own institution achieved on average 86 points in the constant score, 91 % in the subjective shoulder value, 10.8 points in the taft score and 87 points in the acromioclavicular joint instability score. Thirteen patients had previous surgery. Nevertheless, these results are comparable to published outcomes in the acute situation. One patient displayed a visible asymmetry between both clavicles. Radiographically, there was no difference between the coracoclavicular distances on both sides. However, three patients had a recurrent vertical instability and required revision tendon augmentation. One patient displayed a complete DPT.

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Glenohumeral Cartilage Damage and Arthritis

51

Bartek Kordasiewicz, Claudio Rosso, and Bruno Toussaint

Glenohumeral arthritis typically affects patients after the sixth decade of life; however younger patients can also be afflicted.

Glenohumeral arthritis prevalence is approximately 22 % [1].

Shoulder arthroplasty is considered "a gold standard" in shoulder OA in older population. In younger patients, often with high functional demands, shoulder arthroplasty is still an option, but concerns regarding polyethylene component wear, loosening and potential need for multiple revisions create necessity to find other solutions. Prior reports indicate that some surgical procedures could be proposed optionally in shoulder OA: arthroscopic treatment, humeral head resurfacing (partial or total) with or without glenoid treatment and finally total shoulder arthroplasty (anatomical or reverse). Our goal is to review current concepts regarding surgical options of treatment.

Different types of arthritis exist. Centred omarthrosis is the form that has allowed the development of arthroplasties. This can be accompanied by bone destruction that reduces bone mass. A particular form is posterior subluxation osteoarthritis, which rapidly evolves into a biconcave glenoid.

Inflammatory arthritis rapidly destroys the cartilage with a significant synovial proliferation that promotes periarticular bone destruction.

Cuff tear arthropathy results from the development of a large rupture of the rotator cuff, with an ascent of the humeral head in contact with the acromion. Secondarily, the glenoid and acromion can be progressively destroyed.

Neurological diseases can cause articular deterioration, which is accompanied by bone destruction.

The Anglo-Saxons describe capsulorrhaphy arthropathy, which is secondary to a shortening of the ligamentous structures, which causes a modification in the articular mechanic and increases the pressure in the cartilage with an accelerated deterioration of the joint.

In proximal stabilisation surgery by fixation of bone block or in Latarjet intervention, the bone contact of the fragment fixed to stabilise the joint can cause a premature wearing of the cartilage. But this wear can progress to cartilage damage associated with the luxations preexisting to surgery.

Posttraumatic osteoarthritis is the result of bone deformations or articular sequelae but it can also be associated with osteonecrosis, which causes a deformation of the head of the humerus and direct cartilaginous alterations.

B. Kordasiewicz, MD (✉)
Shoulder Unit, Trauma and Orthopedics Department, Postgraduate Medical Education Center, SPSK A. Grucy, Otwock, Poland

C. Rosso, MD, MSc, PD Dr med
ALTIUS Swiss Sportmed Center, Habich-Dietschy-Strasse 5a, Rheinfelden 4310, Switzerland

B. Toussaint, MD
Clinique générale, 4 chemin Tour de la reine, Annecy 74000, France

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Proximal osteonecrosis (atraumatic avascular necrosis) causes the disappearance of the sphericity of the humeral head and direct damage of the cartilage.

51.1 Mechanisms of Arthritis

The mechanics of the shoulder and modifications to ligament balance are elements that appear to be important in the genesis of arthritis.

Biological phenomena are important too in explaining the onset of arthritis. J.P. Wanner shows that biology finds the presence of interleukins in the synovial fluid of the shoulder, such as are already found in the joints of the lower limbs: cytokines IL 6 and IL 8. Cytokine IL 8 causes differentiation of the altered chondrocytes and calcification and it also increases the prostaglandins in the synovial fluid, which provokes alteration of the cartilage.

The reduction of serpins in the synovial fluid allows protease activity, which results in the destruction of the cartilage.

Aggrecan and cartilage oligomeric matrix protein (COMP) can be biomarkers of arthritic degradation [2].

This understanding of the biological phenomena at the source of arthritis makes it possible to adopt a medical and drug approach to arthritis in the future.

51.2 Clinical Findings and Evaluation

Symptomatology is poor. This can be summarised by pain, which is poorly controlled by analgesics, and by ankylosis that sets in parallel.

The clinical examination reveals a relative muscle loss with an increase in volume of the joint and a reduced mobility in all areas, but more significant in external and internal rotation. Crunches can be heard when the shoulder is mobilised. It is important to assess muscle strength and the presence of the minor teres muscle.

X-ray is used to guide the diagnosis together with the history of the disease. The CT scan allows the bone capital to be assessed and specifies the location of the osteochondromas (loose bodies).

Centred omarthrosis requires the assessment of the rotator cuff and the muscle quality, which largely depends on the outcome of the surgery. It relies primarily on the CT scan arthrography or the MRI arthrography. Damage to the rotator cuff is rare in centred omarthrosis, as B.K. Moor has shown with the calculation of the critical shoulder angle.

A certain number of classifications arise from the X-ray exploration.

- Classification of glenoid morphology in primary glenohumeral osteoarthritis according to Walch et al. [3]:
  The authors classified the glenoid morphology into three types based on the CT scan findings out of 113 patients. Intraobserver reproducibility and anterobserver reliability were good with a kappa index that ranged from 0.65 to 0.70.
  Type A (59 %): The humeral head was centred, and the resultant strengths were equally distributed against the surface of the glenoid. Glenoid retroversion average was 11.5°. The erosion may be minor, type A1 (43 %), or major, type A2 (16 %), marked by a central erosion that led to a centred glenoid cupula. In advanced cases, the humeral head protruded into the glenoid cavity.
  Type B (32 %): The humeral head was subluxated posteriorly, and the distributed loads were asymmetric. The CT scan revealed numerous anatomical changes, more pronounced on the posterior margin of the glenoid. The retroversion average was 18 %. Two subgroups were identified: B1 (17 %) showed narrowing of the posterior joint space, subchondral sclerosis and osteophytes, and B2 (15 %) demonstrated a posterior cupula that gave an unusual biconcave aspect of the glenoid. In type B2, there was an excessive retroversion of the glenoid according the Friedman et al., but the value of the retroversion does not explain the biconcavity of the glenoid.

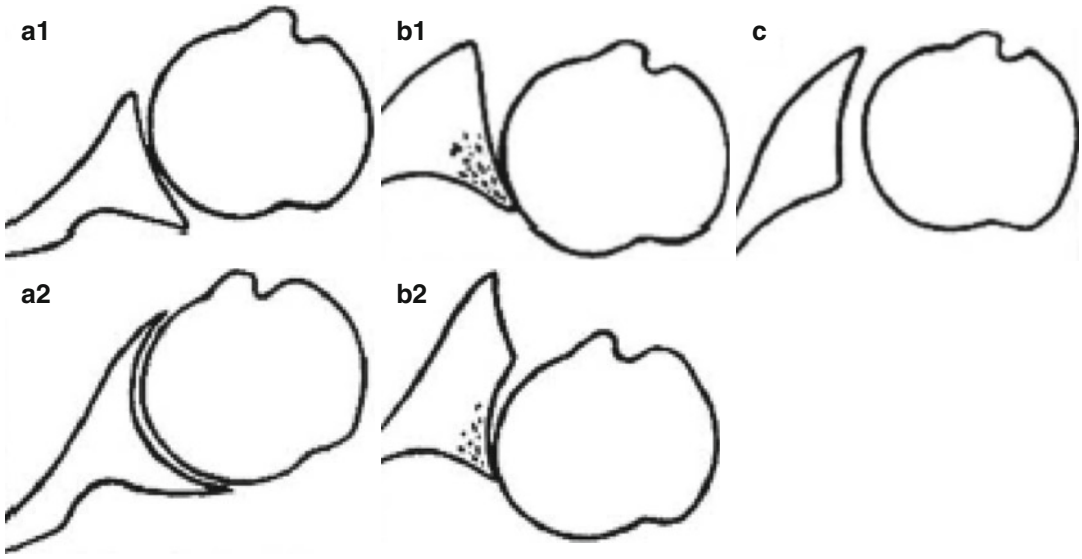


Fig. 51.1 Walch classification of glenoid morphology in primary osteoarthritis in the transaxial plane

Type C (9%): This type of glenoid morphology was defined by a glenoid retroversion of more than 25°, regardless of the erosion. The average retroversion was 35.7° (Fig. 51.1).

- Classification of vertical glenoid morphology according to Habermeyer in centred osteoarthritis [4]:
  In this investigation the coracoid baseline is reproducible because the AP view is taken into a standardised standing position of the patient, so that inferior border of the X-ray film is parallel to the bottom and the lateral base of the coracoid does not change with the rotation of the scapula.
  Type 0 represents normal glenoids; the coracoid baseline and the glenoid line run parallel. Both lines intersect below the inferior glenoid rim in type 1 glenoids. In type 2 glenoids, the coracoid baseline and the glenoid line intersect between the inferior glenoid rim and the center of the glenoid. In type 3 glenoids the lines intersect above the coracoid base.
- Classification of osteoarthritis with massive rotator cuff tears according to Favard et al. [5]:
  Group 1: this group is characterised by upward migration of the humeral head, superior glenohumeral joint space narrowing, an acromion changed in shape due to the imprint of the humeral head and subacromial arthritis.
  Group 2: this group is characterised by central glenohumeral joint space narrowing and a little alteration in the shape of the acromion, which does not have a humeral head imprint.
  Group 3: this group is characterised by signs of bony destruction in the form of lysis of either the head or the acromion. The bony elements, not affected by the lysis, do not undergo any modification in their shape. For example, the greater tuberosity is not eroded and the acromion does not have humeral head imprint. Glenohumeral joint space narrowing is either minima or nonexistent (Fig. 51.2).
- Classification of cuff tear arthropathy according to Seebauer et al. [6]:
  Analysis of cuff arthropathy and failed treatment has led to a biomechanical classification of cuff tear arthropathy. Four distinct groups have been formed on the basis of the biomechanics and clinical outcomes of arthroplasty. The four types are distinguished by the degree of superior migration from the centre of rotation and amount of instability of the centre of

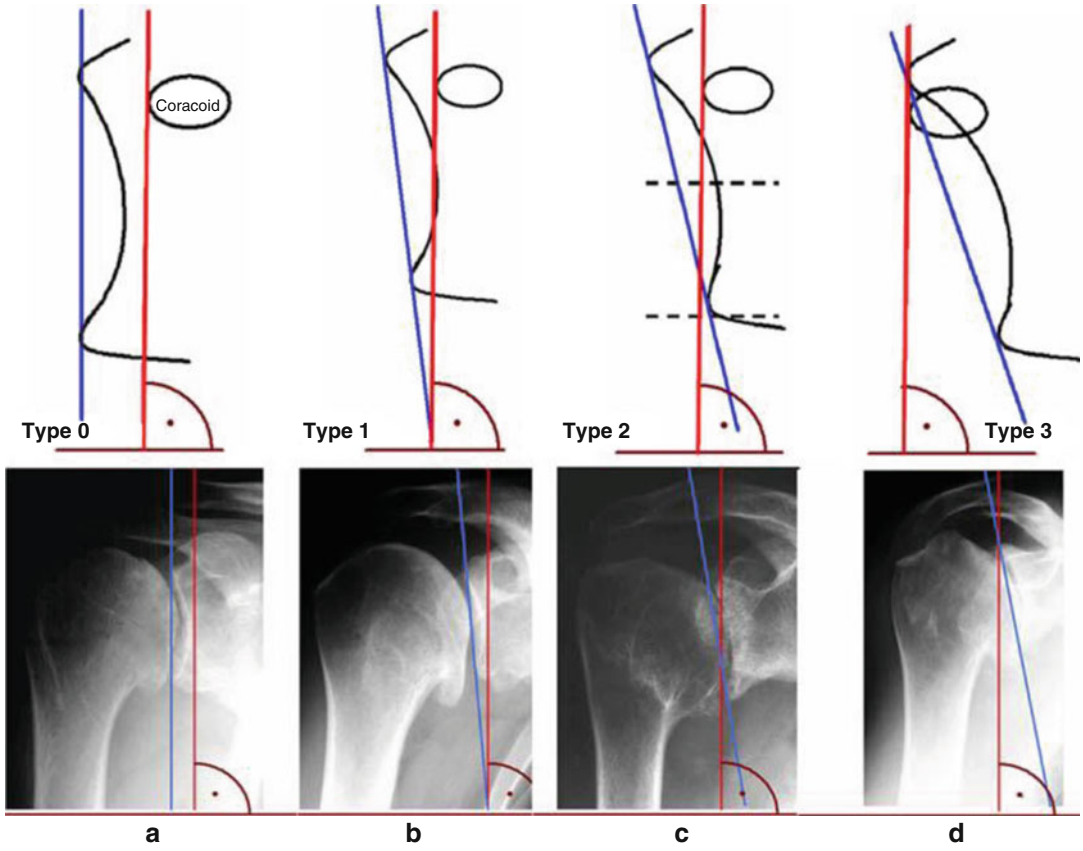


Fig. 51.2 Classification of glenoid inclination. (**a**) In type 0, the coracoid base line (*red*) and the glenoid line (*blue*) run parallel (the *brown line* represents the inferior border of the radiograph). (**b**) In type 1, the coracoid base line and the glenoid line intersect below the inferior glenoid rim. (**c**) In type 2, the coracoid base line and the glenoid line intersect between the inferior glenoid rim and the centre of the glenoid. (**d**) In type 3, the coracoid base line and the glenoid line intersect above the coracoid base (From Habermeyer [4]. Classification of osteoarthritis with massive cuff tears according to Favard in The Cuff)

rotation. This classification has proposed benefits in surgical decision-making for optimal implant type, goals of reconstruction and outcomes (Fig. 51.3).

- Classification of cuff tear arthropathy according to Hamada et al. [7]:
  Roentgenographic grades of massive cuff tears were proposed. These were based chiefly on the acromiohumeral interval (AHI), which has been considered in the literature to be a sensitive indicator for the full-thickness cuff tear. Five grades were classified:
  Grade 1: the AHI was more than 6 mm.
  Grade 2: the AHI was 5 mm or less.
  Grade 3: acetabularisation was added to the grade 2 characteristics.
  Grade 4: narrowing of the glenhumeral joint was added to the grade 3.
  Grade 5: comprised instances of humeral head collapse with characteristics of cuff tear arthropathy (Fig. 51.4).
- Classification of glenoid erosion in glenohumeral osteoarthritis with massive rupture of the cuff according to Sirveaux et al. [8]:
  Radiologically, the authors defined four types of glenoid erosion. In type E0, the head of the humerus migrated upwards without erosion of the glenoid. Type E1 was defined by a concentric

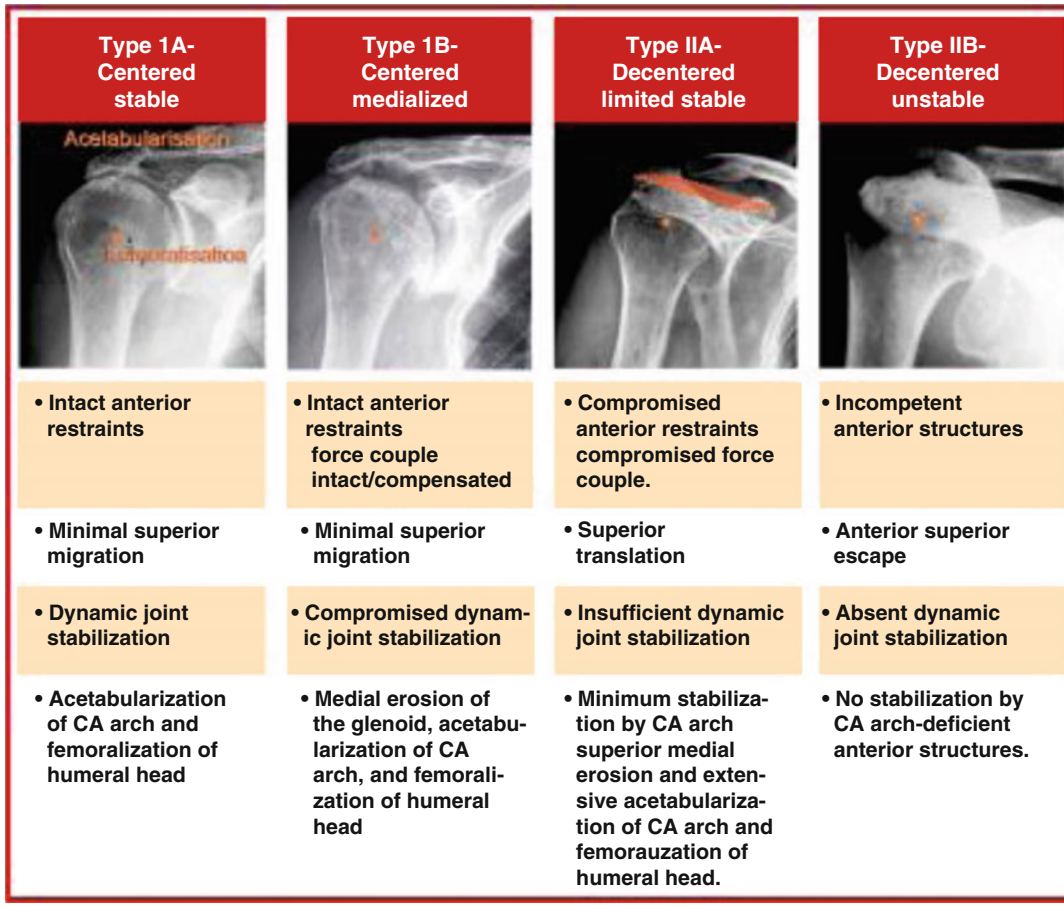


Fig. 51.3 Seebauer classification of cuff tear arthropathy (From Visotsky et al. [6]

erosion of the glenoid. In type E2 there was an erosion of the superior of the glenoid and in type E3 the erosion extended to the inferior part of the glenoid (Fig. 51.5).

- Radiographic classification of dislocation arthropathy of the shoulder according Samilson and Prieto [8]:
  Radiographic evidence of arthrosis was graded as mild, moderate or severe and was evaluated in the anteroposterior view.
  Mild arthrosis was indicated on the AP view of either an inferior humeral or glenoid exostosis or both, measuring less than 3 mm in height.
  Moderate arthrosis was indicated by evidence on the AP view of either an inferior humeral or glenoid exostosis or both, between 3 and 7 mm in height, with slight glenohumeral joint irregularity.
  Severe arthrosis was indicated by evidence on the AP view of either an inferior humeral or glenoid exostosis or both that was more than 7 mm in height, with narrowing of the glenohumeral joint and sclerosis (Fig. 51.6).
  By studying muscles through CT scan and MRI, an assessment can be made on muscle volume and the fatty infiltration of the rotator muscles without forgetting the teres minor muscle.
  These various classifications allow for an operative planning in case of prosthetic replacement.

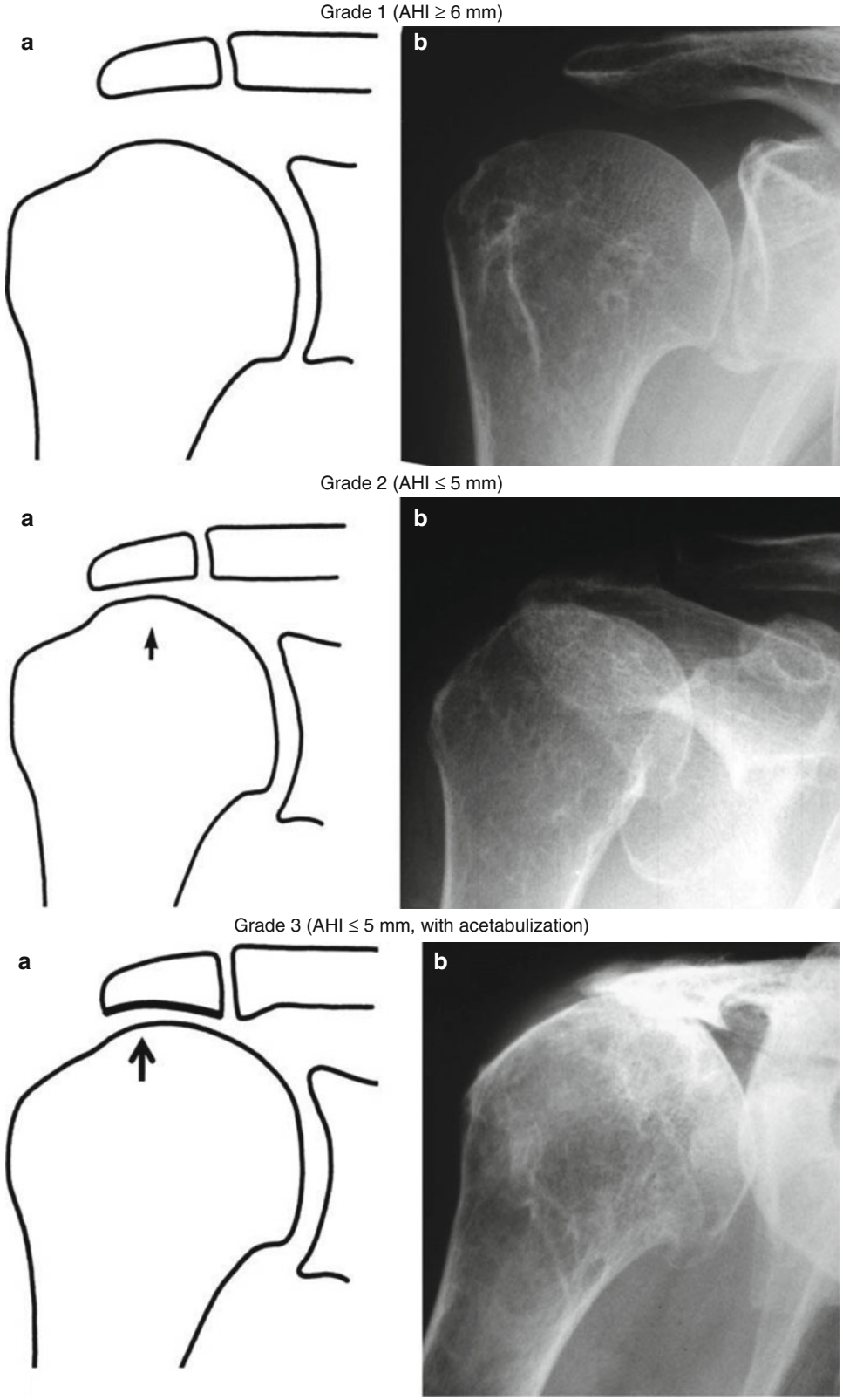
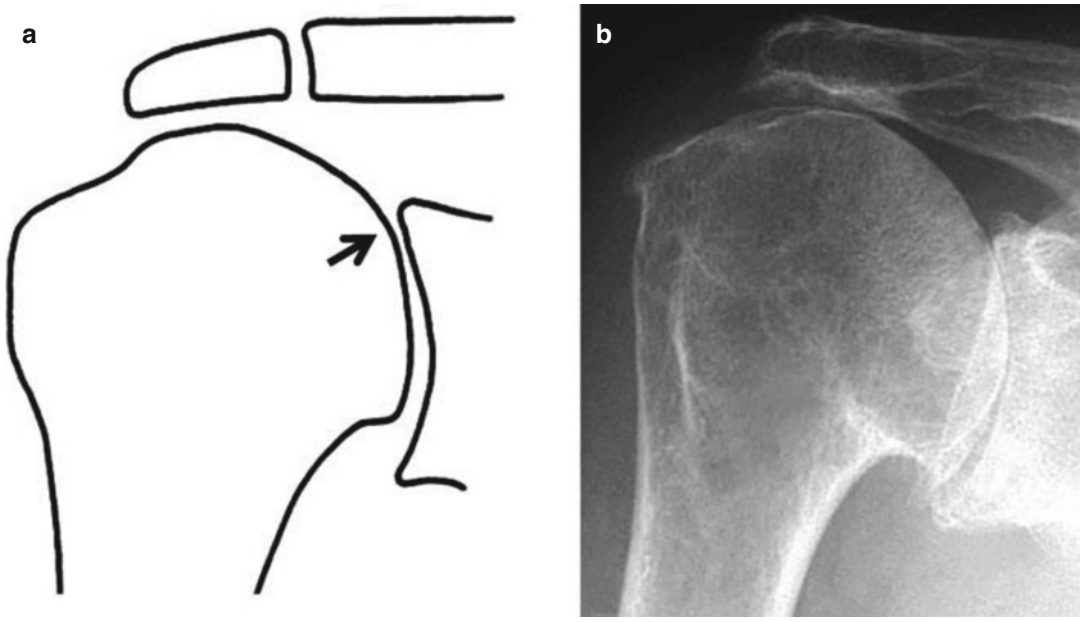


Fig. 51.4 Five stages of Hamada classification of massive rotator cuff tears. (It's possible to do one picture with the five stages; the pictures are from the article in the clinical orthopaedics 2011)

Grade 4A (glenuhumeral arthritis, without acetabulization)



Grade 4B (glenuhumeral arthritis, without acetabulization)

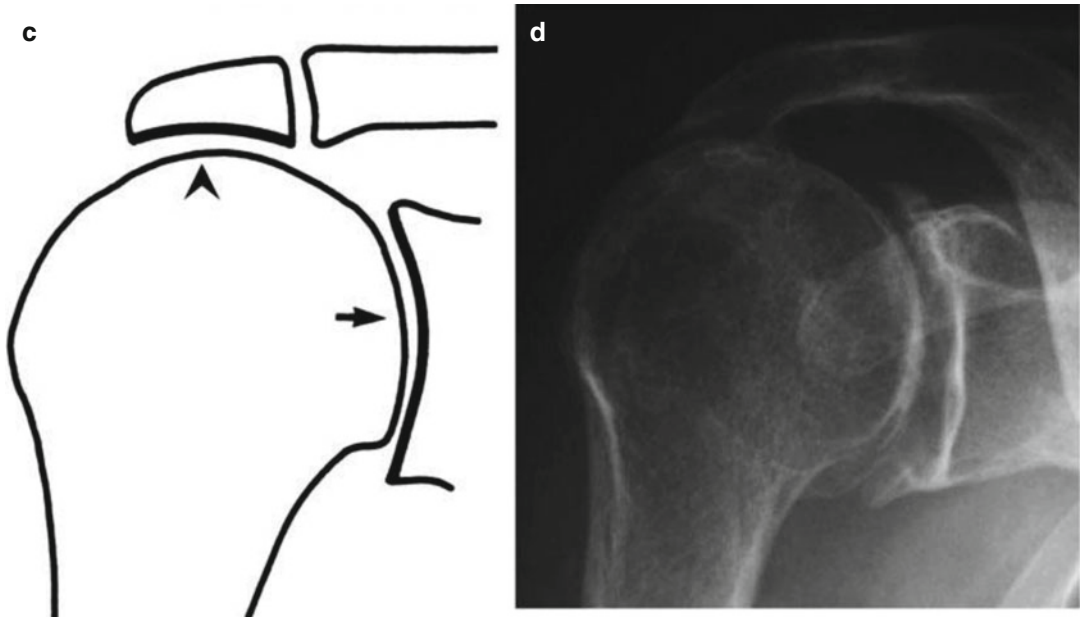


Fig. 51.4 (continued)

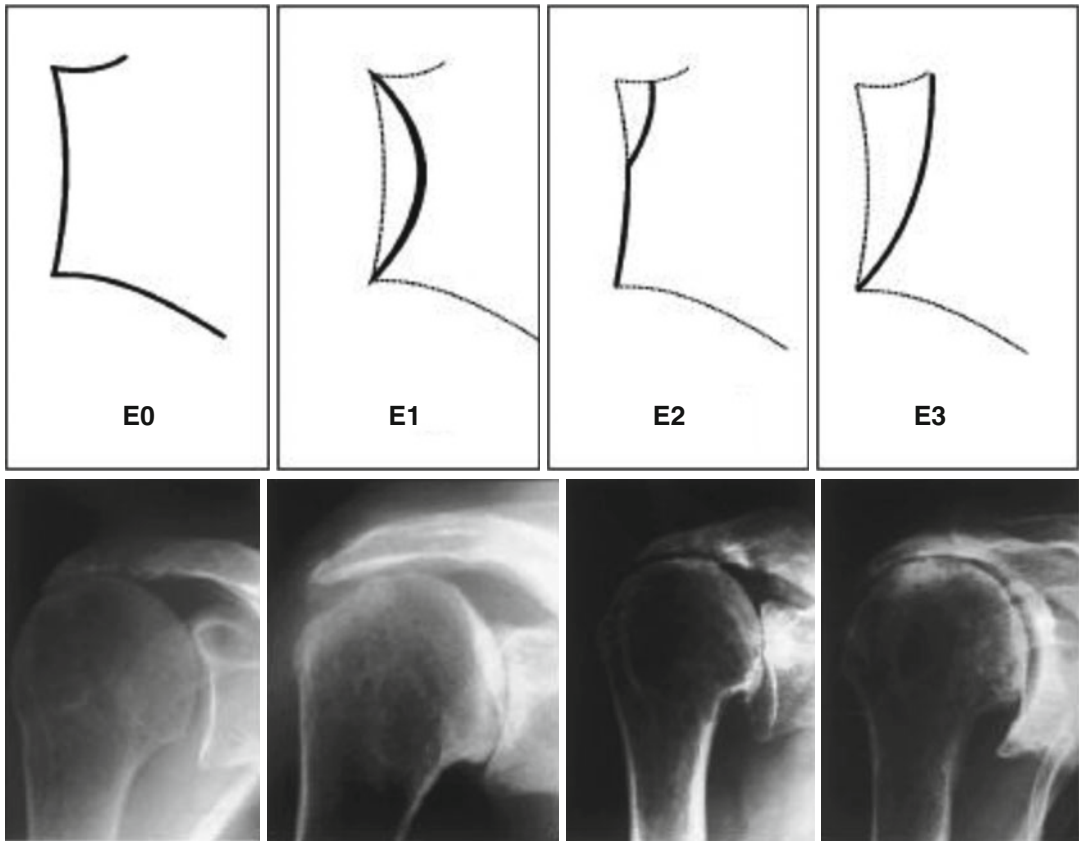


Fig. 51.5 Diagrams and radiographs show classification of glenoid erosion in osteoarthritis with massive rotator cuff tear (From Sirveaux et al. [8])

51.3 Indications

Therapeutic indications depend primarily on mobility, X-ray appearance of the joint and aetiology.

51.3.1 Centred Omarthrosis

Medical treatment is indicated when the mobility of the shoulder is well preserved and in younger patients.

Arthroscopic treatment follows this conservative therapy and can, in some circumstances, lead to recovery of articular amplitude in the absence of deformation of the sphericity of the humeral head. In case of localised damage, it can allow fresh humeral head allograft or tissue resurfacing of the glenoid cavity or partial prosthetic resurfacing to be carried out (Fig. 51.7).

Posterior subluxation omarthrosis, including the risk of failure after implantation of a total prosthesis, is unique and requires the continuation of medical treatment for as long as possible.

When deformation of the humeral head or the glenoid surface or both is too significant and is the source of loss of mobility, prosthesis is indicated (Fig. 51.8).

The type of prosthesis is chosen after assessment of the rotator cuff. If there is significant damage to the shoulder or the rotator cuff, the implant of a reverse prosthesis is recommended up to a minimum age limit. Under 70 years the benefit-risk must be exposed in order to decide on the type of implantation. It is possible to use an anatomical prosthesis by increasing the

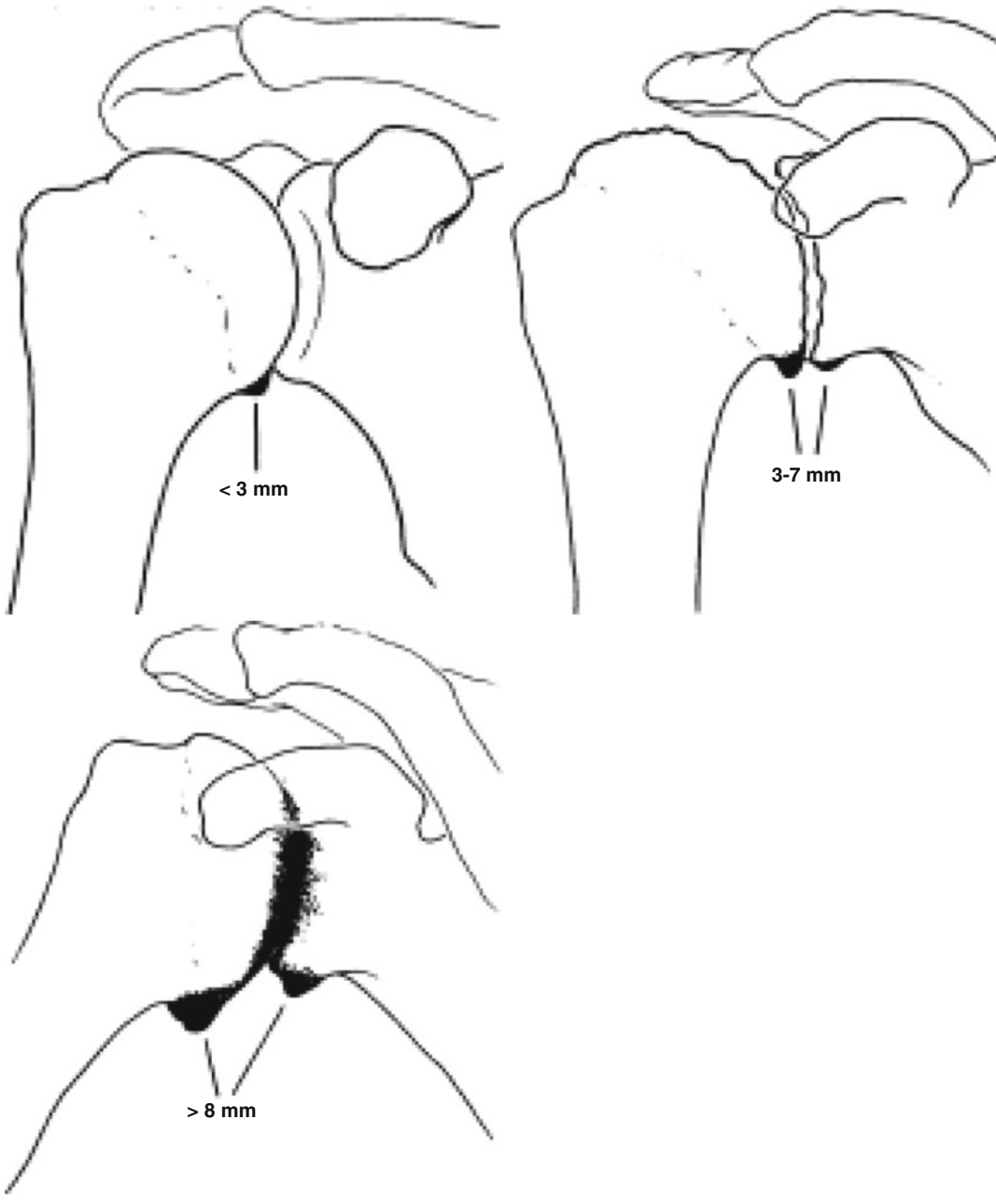


Fig. 51.6 Mild arthrosis in Samilson-Prieto classification. Moderate arthrosis in Samilson-Prieto classification. Severe arthrosis in Samilson-Prieto classification

diameter of the humeral head or with a specific design for cuff tears arthropathy (CTA) [10].

If the cuff is retained without major injury or with minimal damage that can be repaired, the implant of an anatomical prosthesis is indicated. This type of prosthesis can significantly reduce the minimum age limit of the implant.

The anatomical prosthesis must be total given the bipolar lesions of arthritis.

Respect of the bone stock appears to be a significant factor in both these types of protheses.

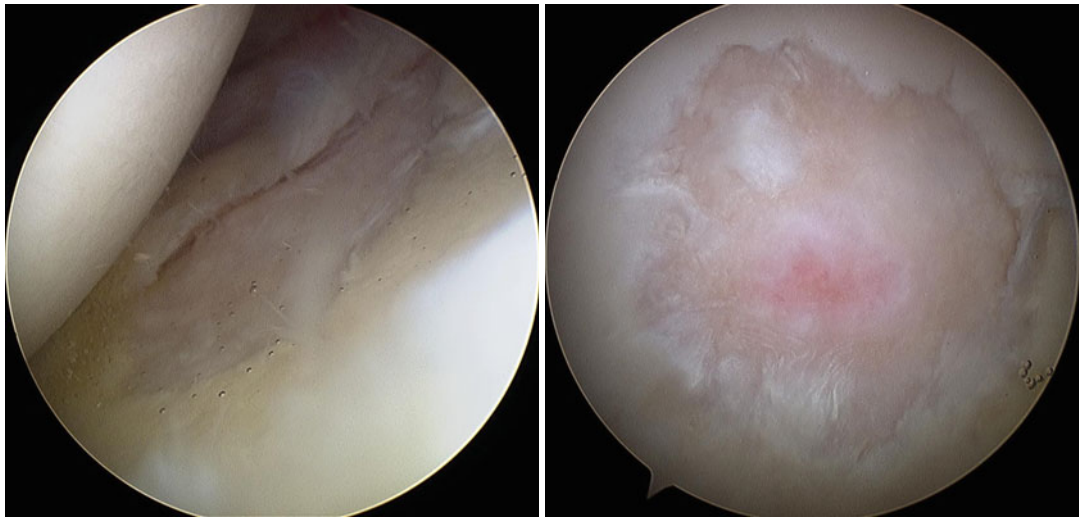


Fig. 51.7 Glenoid cartilage damage: arthroscopic view. Cartilage damage in humeral head

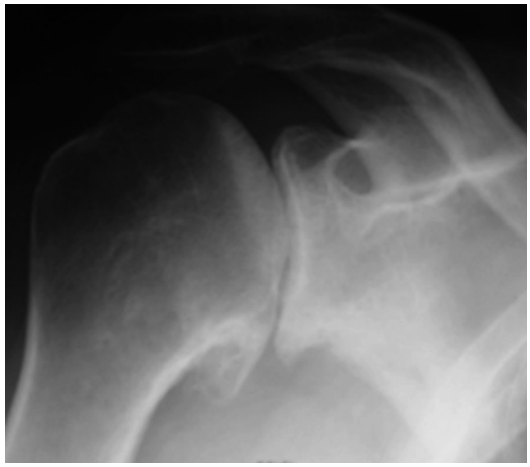


Fig. 51.8 Centred arthritis

Where the bone stock is sufficient, it is logical to use stemless prostheses, as it allows for an easier implant without the risk of malposition related to the posterior offset and an easier revision of the prosthesis on the humeral side.

When the bone stock is insufficient, the use of short stem or regular stem is required.

The use of a modular prosthesis may be an interesting option in the case of revision of the prosthesis for a tear of the rotator cuff after the first implantation.

51.3.2 Cuff Tear Arthropathy

Medical treatment is justified as long as functional mobility is preserved and corticosteroid injections control painful phenomena.

Arthroscopy may be indicated in the case of refractory pain in order to make a tenotomy of the long head of the biceps or the installation of a spacer (absorbable balloon).

If mobility is retained, CTA hemiarthroplasties or a relative increase in the size of the humeral head may be used.

The loss of mobility and the pseudoparalysis of the shoulder require the use of the reverse prosthesis, whose only limit is the glenoid bone stock for the implantation of the metaglenoid and of the glenosphere [11, 12] (Fig. 51.9).

A particular situation is the absence or insufficiency of the teres minor muscle, which is manifested by the absence of active arm external rotation along the body. The reverse prosthesis cannot restore external rotation, and a muscular transfer of the latissimus dorsi muscle and teres major muscle is indicated either by a double access using the technique of L'Episcopo or an anterior access through the modification of Merle d'Aubigné.

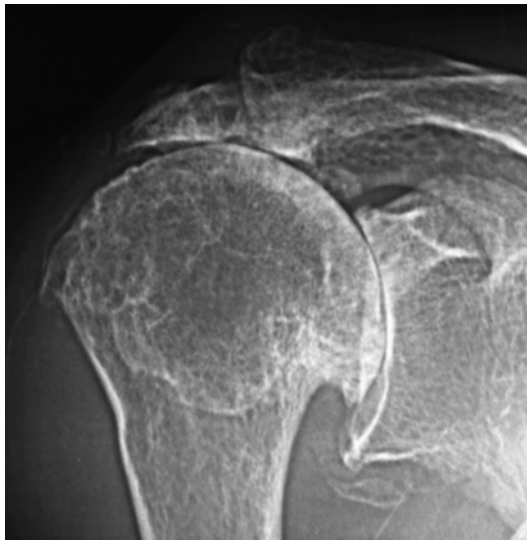


Fig. 51.9 Excentred arthritis

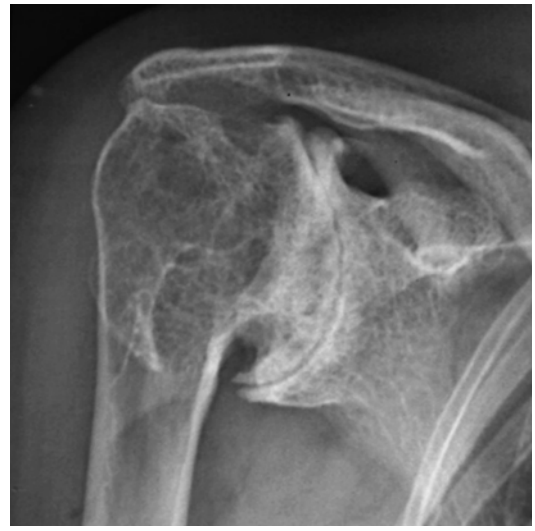


Fig. 51.10 Inflammatory arthritis

51.3.3 Inflammatory Arthritis

Medical treatment is the aetiological treatment of inflammatory disease.

Surgical treatment is indicated when medical treatment fails or when there is significant joint destruction.

Benjamin's osteotomy in rheumatoid arthritis has now been now totally abandoned.

The indication of prosthesis depends on the quality of the rotator cuff. In cases of a too significant alteration, the use of the reverse prosthesis is recommended.

The anatomical prosthesis should be reserved for arthritis without damage to the tendons of the rotator cuff.

The bone stock is, however, a delicate problem, which often requires the use of stems for a sufficient humeral fixation [13] (Fig. 51.10).

51.3.4 Neurological Damage [14]

The problem is often different. Bone destruction is in the foreground and pain is minimal or absent.

Bone destruction requires an arthroplasty, but the survival of the arthroplasty depends on the neurological lesion; damage to deep sensitivity is almost always incompatible with the implantation of an anatomical or reverse prosthesis.

51.3.5 Capsulorrhaphy Arthropathy or After Instability Surgery

Medical treatment is indicated first in this young population in the absence of massive cartilage destruction and osteophytosis causing a limitation in mobility.

If joint damage is significant, the use of an arthroplasty is indicated. The assessment of the subscapularis is crucial because it has often been damaged by the sometimes iterative shoulder stabilisation surgeries. Too great damage to the subscapularis significantly reduces the quality of the postoperative outcome.

Bone stock is often good as the patient population is young. Stemless arthroplasties are an excellent indication (Fig. 51.11).

51.3.6 Posttraumatic Osteoarthritis

Treatment is surgical but it depends on the presence of significant or tolerable bone deformation.

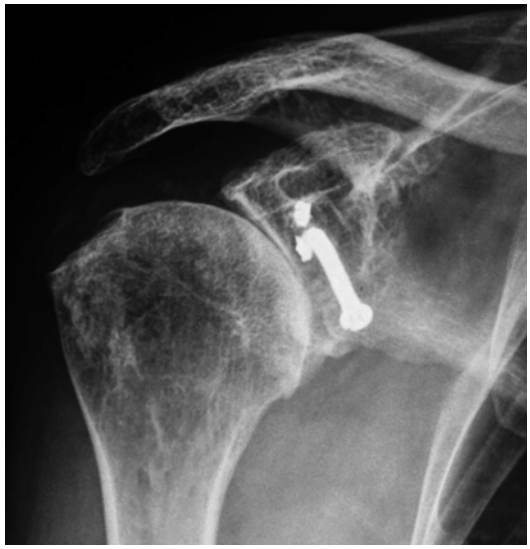


Fig. 51.11 Capsulorrhaphy and Latarjet arthropathy

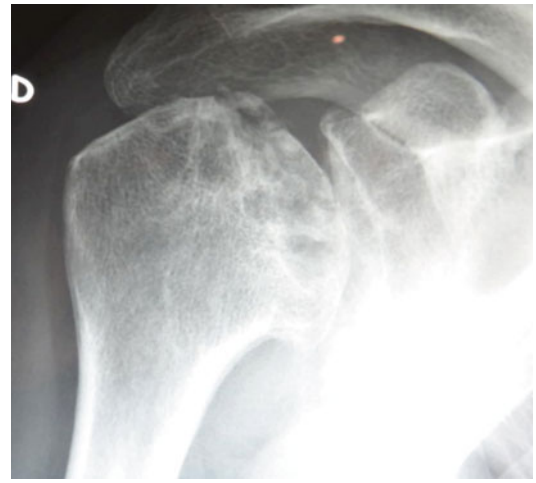


Fig. 51.12 Osteonecrosis

In major malunion, it should be planned to correct bone deformation during the arthroplasty operation. The use of stem prosthesis allows the rigid fixation of the correction osteotomy of the malunion.

If the deformation is minimal or valgus, the implant of a stemless prosthesis is indicated since it facilitates the implantation. Humeral deformation can sometimes require a customised design of the stem.

Finally, it is not always necessary to use a total arthroplasty. A hemiarthroplasty may be sufficient.

51.3.7 Osteonecrosis of the Humeral Head

Surgical treatment is indicated in case of non-response to medical treatment.

Given the very rare nature of damage to the glenoid cavity, hemiarthroplasty is indicated. Respect of bone stock is the rule. Damage to the rotator cuff is exceptional and arthroplasty is practically always anatomical [15] (Fig. 51.12).

51.4 Technique

51.4.1 Nonoperative Treatment

Medical treatment is based on corticosteroid injections and physical therapy to regain the articular amplitude of the glenohumeral joint.

More recently visco-supplementation by injection of intra-articular hyaluronic acid can delay the progression of glenohumeral arthritis.

Studies on PRP injections look promising for the treatment of osteoarthritis.

Medical treatment is indicated at the beginning of evolution but becomes exhausted relatively quickly, giving way to surgical treatment.

51.4.2 Non-prosthetic Treatment

Arthroscopy allows articular debridement with a synovectomy using the shaver and a possible capsulotomy with frequent X-ray. Circumferential capsulotomy may be necessary.

The resection of osteophytes can be difficult, because they are not always easy to expose.

Acromioplasty is only justified if there is a significant subacromial spur, which creates a conflict with the rotator cuff.

On the humeral side, cartilaginous cleaning is done using the shaver to remove the scraps that are no longer attached to the subchondral bone. The subchondral bone may be perforated to promote vascularisation and the formation of a neo-cartilage.

The use of a specific ancillary of partial resurfacing of the humerus (Arthrex) allows the carrying out of fresh allograft of impacted cartilage in the subchondral bone.

The same material allows the installation of a partial resurfacing of the humeral head.

On the glenoid side, the fixation of meniscus allograft or fascia lata by anchors allows the glenoid cavity to be resurfaced. It can be isolated or combined with a partial resurfacing of the humeral head [16].

The resurfacing gestures require a postoperative immobilisation depending on the materials used.

51.4.3 Arthroplasties

51.4.3.1 Anatomical Implants

The first approach is the deltopectoral approach. The skin incision may be laterally shifted. The cephalic vein is reclined on the deltoid side. To improve the exposure of the upper part of the pectoralis major tendon, it is incised over 2–3 cm.

The circumflex vessels are ligated to the anterior surface of the subscapularis. The opening of the subscapularis may be made by a tendon incision leaving a fragment sufficient for closure on the humeral side or by an osteotomy of the lesser tuberosity, which cannot be used in stemless prostheses because it weakens the metaphyseal region and reduces the primary stability of the prosthesis.

The humerus is then luxated. The osteophytes are resected. The humeral cut is made using the guide. The arthrolysis is made by the almost circumferential section of the capsule to the glenoid cavity. This time allows the humerus to be luxated backwards and exposes the glenoid cavity. The preparation of the humerus can be continued. For stemless prostheses the humeral implant is centred on the humeral cup without taking account of the diaphysis. For stem protheses the diaphysis must be bored which will then produce the posterior offset.

The glenoid cavity is then prepared according to the implant used. The use of cement is frequent for glenoid cavities in polyethylene [17, 18].

Reduction of the prosthesis is done at the end of surgery and the stability of the implant is checked. This stability control is done again after closing of the subscapularis. The centre of the humeral head should not exceed the posterior margin of the prosthetic glenoid cavity [19].

Postoperative immobilisation is necessary for the healing of the subscapularis.

51.4.3.2 Reverse Implants (Reverse Shoulder Arthroplasty (RSA))

The surgical approach can be deltopectoral or anterior-superior (Mackenzie).

The first anterior-superior surgical access is at the middle part of the acromioclavicular joint. The deltoid is detached from the acromion but remains attached to the aponeurotic plane in continuity with the acromioclavicular joint, in front and behind. An acromioplasty improves exposure. The upper part of the subscapularis is incised and the tendon of the long head of the biceps is cut. The axis of the diaphysis is marked and the guide allows, after boring of the diaphysis if using a stem, the section of the humeral head at 155°. It must be as economical as possible.

The arthrolysis is done in a section of the capsule at the glenoid cavity. After locating the pillar of the scapula, the glenoid cavity is prepared in the lowest possible position, but without significant lower tilt. The metaglenoid is positioned directly above the lower edge of the glenoid cavity [20–23].

It is always recommended to use the larger diameter glenosphere [24].

The preparation of the humerus changes if a stemless prosthesis is used, as it is centred on the humeral cup and impacted. In stem implants, the calculation of the posterior offset is required.

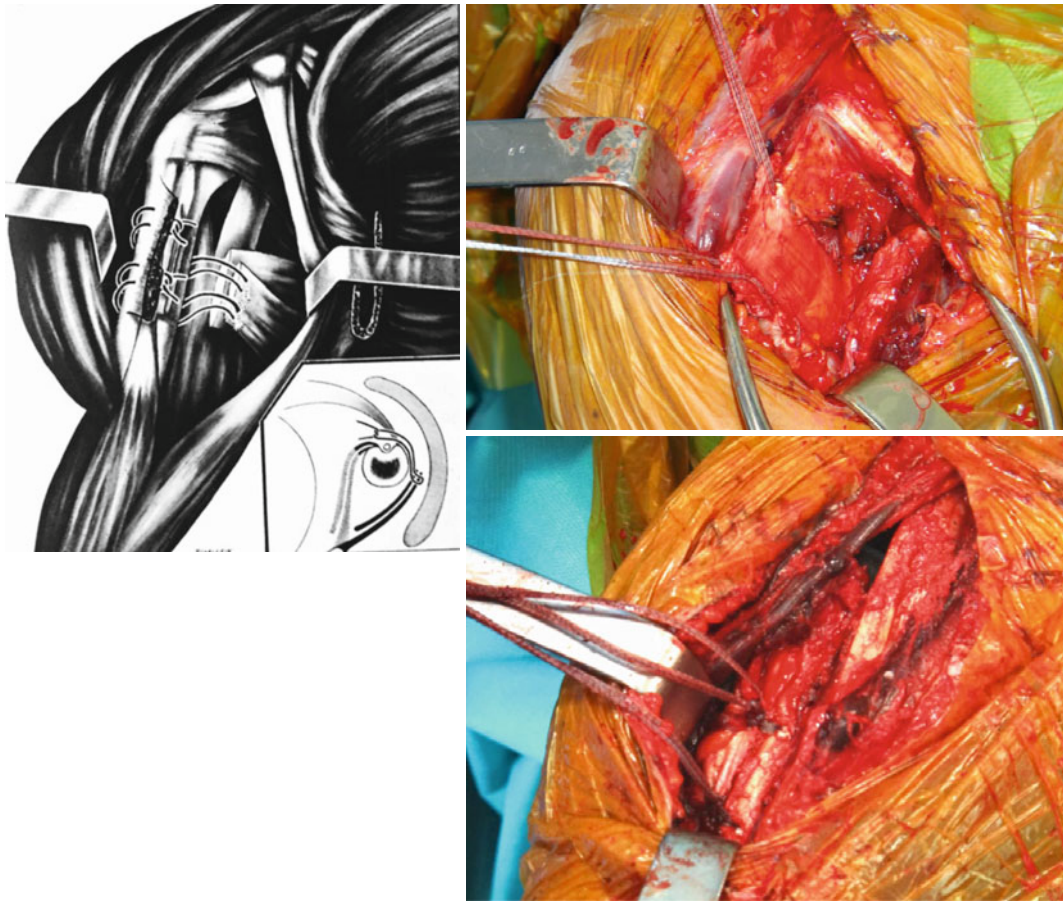


Fig. 51.13 Latissimus dorsi transfer in Merle d'Aubigné approach (Masson- 1956)

The trial prosthesis is reduced, and stability is tested before the implantation of the definitive prosthesis. Palpation of the finger of the conjoint tendon (in flexed elbow position) is an excellent indicator of final muscle tension.

The suture of the subscapularis is not always possible due to the lateralisation of the humerus. It does not seem to be a factor of essential stability [25].

The closure is made by a trans-osseous reinsertion of the deltoid.

Postoperative immobilisation is shorter than for anatomical prostheses.

To produce a transfer of the latissimus dorsi muscle and the teres major muscle at the same time, the surgical approach for implanting the prosthesis is delto-pectoral.

It can be unique if the tendon of the latissimus dorsi muscle and teres major muscle is sampled according to the modification made by Merle d'Aubigné to the L'Episcopo technique; otherwise it is combined with an axillary approach for the sampling of tendons [26] (Fig. 51.13).

In the modification of Merle d'Aubigné, widely diffused by P. Boileau, the incision is enlarged downwards and I recommend the full opening of the pectoralis major muscle. The tendon of the latissimus dorsi muscle is often hardly distinguishable from the tendon of the teres major muscle, which means that both tendons have to be sampled at the same time.

The deltopectoral approach requires the full section of the subscapularis and, in particular, the pure muscular portion rarely damaged during rotator cuff tears.

The two tendons are then externally diverted back to their insertion to turn them into external

rotators. After implantation of the prosthesis, the tendons are secured by two reinsertion anchors or buttons at the level of the pectoralis major muscle insertion by a strong suture. The same anchor points allow the reintegration of the pectoralis major muscle, which becomes the predominant element in the stability of the prosthesis. The subscapularis cannot always be reinserted.

For both arthroplasties (TSA and RSA), customised glenoid implants could be used. The use of three-dimensional imaging and templating, with or without patient-specific instrumentation, showed a significant improvement achieving the desired implant position within 5° of inclination or 10° of version when compared with two-dimensional imaging and standard instrumentation [27].

51.5 Complications

51.5.1 After Nonoperative Treatment

The major complications are infection after the injections and the side effects of the drugs used. Exceptionally, also an algoneurodystrophy may develop [28].

51.5.2 After Non-prosthetic Treatment

The main complication after arthroscopic treatment is the absence of efficacy by allograft resorption or chondrolysis of the osteocartilaginous allografts which can aggravate articular ankylosis.

The risk of infection is usually low in arthroscopic surgery.

51.5.3 After Arthroplasty

Complications after reverse shoulder arthroplasty are as follows. The main complication is the appearance of the lower notching of the glenoid cavity, the gravity of which is assessed by the classification of C. Nerot. Scapular notching can be evolutive by reducing the survival of the prosthesis or stable and non-evolutive [29, 30] (Fig. 51.14).

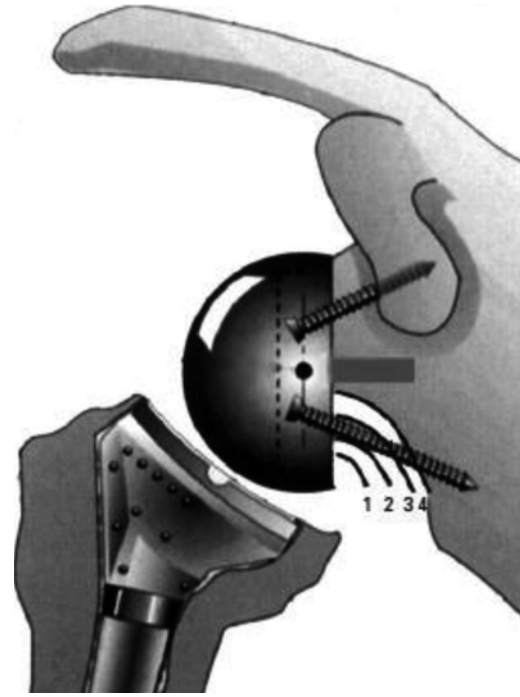


Fig. 51.14 Sirveaux classification of scapular notching

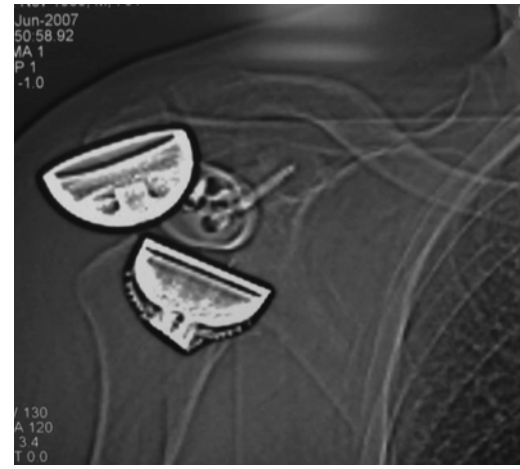


Fig. 51.15 Components dissociation

Secondary instability is a difficult complication to treat in the absence of a cam effect or a malposition of the implants [31].

Other complications are postoperative haematoma, fracture of the acromion or of the spine of the scapula, infection or humeral or glenoid component dissociation [32, 33] (Fig. 51.15).

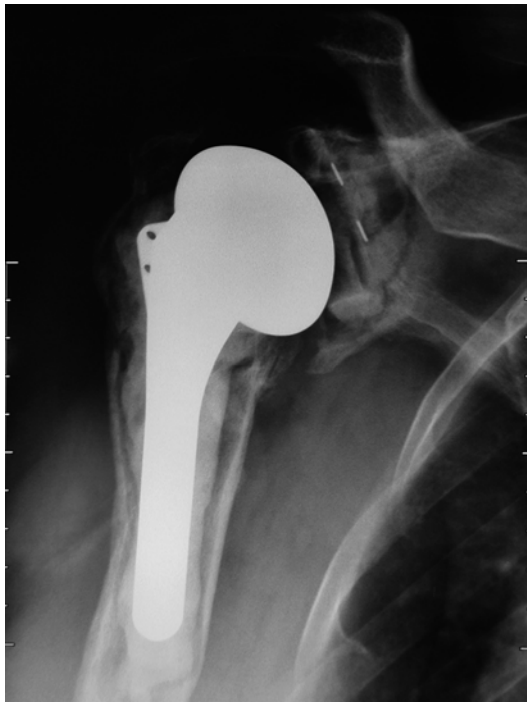


Fig. 51.16 Aseptic loosening

At 10 years of follow-up, loosening of the glenoid component is present in 80 %, but only a third shows significant damage.

Today, there does not seem to be any difference in superiority between pegged glenoids and keeled glenoids [36].

Glenoid component wear can be of three types: diffuse, central or peripheral. It also compromises the survival of the arthroplasties by the release of polyethylene particles in contact with the implants [18].

Loosening of humeral component is relatively rare between 1 % and 7 %. A reoperation is not automatically applicable (Fig. 51.16).

Instability is a more delicate problem. Anterior dislocation is an evidence of subscapularis insufficiency. Treatment is complicated by static or dynamic stabilisation (the recurrence rate after revision is 50 % in the various studies).

Upper instability is evidence of the secondary tear of the rotator cuff and can be treated by switching to a reverse prosthesis [37].

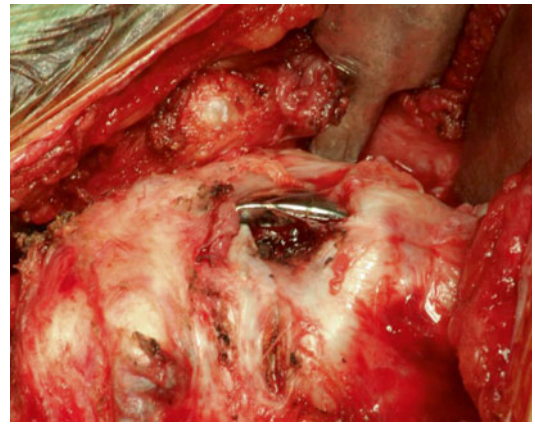


Fig. 51.17 Rotator cuff tear after TSA

Posterior instability, initially attributed to excessive retroversion, can be corrected by a posterior capsulorrhaphy and a modification in the version of the prosthetic glenoid cavity.

Lower instability is often associated with a humeral shortening.

The tear of the rotator cuff has a prevalence of 1 % of which 50 % is a lesion of the subscapularis (Fig. 51.17).

Neurological complications. Damage can affect the brachial plexus or a peripheral nerve. The axillary nerve but also the suprascapular nerve (by the screwing of the glenoid fixation) could be damaged.

The infection has a prevalence of 0.6 %. The most frequently encountered germs are *Staphylococcus aureus*, staphylococcus species and *Propionibacterium acnes*. In a study in 2001, Sperling showed that debridement and change of the prosthesis at the same time produced a 50 % recurrence of the infection [38].

51.5.3.1 Periprosthetic Fractures

Intraoperative fractures. They are high or low diaphyseal. Treatment requires bending and a long stem, which exceeds the fracture line by at least two diameters of diaphysis in length.

Postoperative fractures: if the fracture is only slightly displaced and has a satisfactory alignment, a conservative treatment is possible. In the absence of consolidation within 3 months, surgical intervention is required.

51.6 Review of the Literature

51.6.1 Arthroscopy

Arthroscopic capsular release and joint debridement have been described as achieving pain relief and restoring motion in some patients with glenohumeral arthritis. The goal of arthroscopy is to provide temporary improvement in symptoms in order to delay the use of shoulder arthroplasties.

In 2000 Weinstein et al. reported 25 patients (mean age 46 years) who underwent debridement for treatment of early osteoarthritis. Arthroscopy included joint lavage, debridement of labral and chondral lesions, loose body removal, partial synovectomy and subacromial bursectomy. The reported results were excellent in 8 % and good in 72 % of patients with a mean follow-up of 34 months [39].

Cameron et al. reported 61 patients with chondral lesions of grade 4, who were treated with debridement with or without arthroscopic capsular release. With a minimum 2-year follow-up in 45 of these patients, 88 % reported significant improvement in pain and function. Authors concluded that the ideal patient for this procedure had a congruent joint with minimal osteophytes, minimal subchondral sclerosis or cyst formation and a focal lesion no larger than 2 cm^2 [40].

In 2004, Safran and Baillargeonet suggested that arthroscopic debridement is a low-risk procedure, can improve pain symptoms in severe glenohumeral arthritis in nearly 80 % of patients by 3 months and may provide relief for more than 4 years [41].

Van Thiel et al. reported substantial pain relief at a mean follow-up of 27 months in 55 of 71 patients who underwent arthroscopic debridement. Nevertheless, authors suggested that debridement of shoulder arthritis requires careful patient selection, with a high risk of failure in patients with a grade 4 bipolar disease, joint space of less than 2 mm or large osteophytes [42].

In 2015 Skelley et al. reported the results of 33 patients who underwent arthroscopic debridement and capsular release. In average clinical follow-up of 40 weeks, they reported initial improvement in range of motion and pain scores, but patients returned to preoperative levels approximately 3.8 months after surgery. 60.6 % patients were not satisfied. Total shoulder arthroplasty was undertaken in 42.4 % patients at a mean of 8.8 months after arthroscopy. In patients without total shoulder arthroplasty, the results were similar preoperatively and at final telephone follow-up. Authors concluded that isolated arthroscopic debridement and capsular release without any other procedures were associated with only temporary pain relief and motion improvement, so it may not provide substantial benefit to justify its use [43].

In 2011 Millet and Gaskill decribed CAM procedure (comprehensive arthroscopic management) for young high-demand patients. This technique combines traditional glenohumeral debridement and capsular release with inferior humeral osteoplasty and arthroscopic transcapsular axillary nerve decompression. In 2013 Millet et al. published their results on 29 patients (30 shoulders) who underwent this procedure. Six shoulders progressed to an arthroplasty at a mean of 1.9 years. Patients that did not progress to arthroplasty (the mean follow-up was 2.6 years) reported substantial pain relief and improved shoulder function. Survivorship analysis showed a 92 % survival rate at 1 year and 85 % at 2 years. Authors concluded the CAM procedure reduced pain and improved function, so it could serve as a joint-preserving alternative to arthroplasty. Patients with less than 2 mm of joint space had a significantly higher failure rate [44, 45].

Microfractures are another procedure that could be added to spectrum of arthroscopic treatment. It was shown to be an effective surgical treatment for isolated full-thickness cartilage defects. Frank et al. reported a significant decrease in VAS and improvement in SST score after surgery with 93 % of patients declaring they would have had the surgery again [46].

Millett et al. reported significant reductions in pain with improvements in ASES scores (from 60 to 80). All patients involved in sport activity reported that their ability to compete improved significantly [47].

Siebold et al. proposed combination of microfractures and periosteal flap in open surgery for chondral defects of humeral head. He reported functional and pain improvements in five patients at a mean follow-up of 25.8 months: the Constant score significantly improved from 43.4 % to 81.8 % and pain to 18.6 points [48].

As shown above the role of arthroscopy remains not completely clear. It could be beneficial to use the Markov model created by Spiegl et al. This theoretical model was constructed to compare arthroscopy and TSA in patients with glenohumeral osteoarthritis. The rates of surgical complications, revision surgery and death were derived from the literature and analysed. Based on this information arthroscopic treatment was the preferred strategy for patients younger than 47 years, primary TSA was the preferred treatment for patients older than 66 years and both treatment options were reasonable for patients aged between 47 and 66 years [49].

51.6.2 Cartilage Reconstruction Procedures

51.6.2.1 Autologous Chondrocyte Implantation

Autologous chondrocyte implantation (ACI) involves harvest of autologous cartilage, in vitro growth of cells and application to the chondral defect with hyaline or hyaline-like cartilage. There are very few publications on the application of this technique to the shoulder. One case report described a 16-year-old patient who underwent ACI using cartilage from intercondylar notch of the knee for a humeral head defect. At 1 year of follow-up, excellent clinical result with no pain and full range of motion was reported [50].

Buchmann et al. reported three of four patients were satisfied with the results after ACI at 41 months of follow-up, although all of them had good to excellent outcomes as reflected by the Constant score [51].

Warner tried this procedure in two cases of isolated chondral defects of humeral head. In both patients the procedure failed. The failure was confirmed by a second-look arthroscopy. Further studies are necessary to precise the results; so far it could be estimated as experimental treatment in selected cases [52].

51.6.2.2 Osteochondral Autograft and Allograft

Scheibel et al. reported eight patients who underwent osteochondral autograft transfer (OAT) from the knee to the shoulder for grade 4 defects of mean size 150 mm^2. With a second-look surgery and a MRI, good integration was recorded, except for one patient, as well as improvement of Constant score at 32 months of follow-up. Despite relatively good results, the authors noted radiographic progression of glenohumeral arthritis in these patients [53, 54].

Kircher reported good results in all of seven patients who underwent an OATS procedure at 9 years of follow-up. The mean Constant score improved from 76 to 90 postoperatively, though radiologically progression of osteoarthritis was significant [55].

Osteochondral allograft involves size-matched fresh allograft providing the ability to address extensive lesions without limitation of size and without the morbidity of donor site. There are some studies reporting the successful use of this technique for treatment of osteochondral defects in the shoulder, but concerning rather bony deficits in shoulder instability or osteochondritis dissecans. In the young patient with large defects, this provides an attractive promising alternative, but it lacks exact reports about results in arthritis [56–58].

Gross et al. concluded that "a variety of options exist" for the treatment of articular cartilage defects of the glenohumeral joint, although the degree of pain relief and functional return may not be clearly predictable. More research is necessary and so far there are very few high-quality evidence to make strong recommendations [59].

51.6.2.3 Glenoid Interposition Arthroplasty

Biologic glenoid resurfacing with or without prosthetic humeral replacement was proposed as an alternative to total shoulder replacement in the young patient to avoid concerns for glenoid longevity with polyethylene implants. Various

interposition materials could be used, including anterior capsule, autologous fascia lata and Achilles' tendon allograft [16].

Savoie et al. reported a series of 23 young patients who underwent arthroscopic biologic resurfacing without humeral head replacement. Fifteen of them (75%) were satisfied with their surgery at a 6-year follow-up, with significant improvement in pain and function [60].

De Beer reported his midterm results with use of acellular human dermal scaffold for glenohumeral arthritis, with successful outcome in 23 patients (72%) and failure in 9 (28%). There were five conversions to arthroplasty in the failures group [61].

Krishnan et al. reported their series of 36 shoulders in patients (average age, 51 years) who underwent soft tissue resurfacing of the glenoid using different materials for interposition with humeral head replacement. At 7-year follow-up, results were excellent in 18 shoulders, satisfactory in 13 and unsatisfactory in 5 [62].

Wirth followed up 24 patients who had placement of lateral meniscal allograft resurfacing of the glenoid with humeral head replacement. At a mean follow-up of 3 years, the clinical results were good but he had concern about durability of the graft, as progressive glenohumeral joint space narrowing was noted [63].

In opposition to these good results, some other studies report poor outcomes with the use of this procedure.

Elhassan et al. used similar technique and reported very poor results in 12 of 13 cases using Achilles' tendon allograft. He noted disintegration of the graft and glenoid wear upon revision. The younger age of the cohort (average of 34 years) was considered a possible reason for the discrepancy. The authors concluded this did not provide durable construct in active patients aged younger than 50 years old [64].

In 2014, Strauss et al. reported high failure rate of biologic glenoid resurfacing. In 41 of 45 patients (mean age, 42.2 years) available for follow-up at a mean of 2.8 years, lateral meniscal allograft resurfacing was used in 31 patients and human acellular dermal tissue matrix interposition in 10. Hemiarthroplasty or HemiCAP procedures were performed, respectively, in 38 and 7 patients.

The lateral meniscal allograft cohort had a failure rate of 45.2%, with a mean time to failure of 3.4 years. Human acellular dermal tissue matrix interposition had a failure rate of 70.0%, with a mean time to failure of 2.2 years. There were eight patients who required conversion to arthroplasty: seven patients underwent total shoulder arthroplasty and one reverse total shoulder arthroplasty. Authors stated that, despite initial clinical improvement, biologic resurfacing of the glenoid resulted in a high, inacceptable rate of clinical failure at midterm follow-up.

The use of biologic glenoid resurfacing with or without humeral head replacement remains controversial. The idea of temporarily decreased glenoid erosion after hemiarthroplasty through use of interposed tissue placed on the glenoid surface remains interesting, but the long-term structural integrity of such grafts remains in question. This is the reason why we recommend caution in the use of such techniques until further clinical studies provide stronger levels of evidence for clinical effectiveness.

51.7 Humeral Head Resurfacing

Cementless surface replacement arthroplasty (CSRA) of the shoulder was introduced in 1986 by Copeland as a treatment for glenohumeral arthrosis in an attempt to restore anatomy, preserve bone and avoid humeral head resection. Preservation of the bone stock makes future revision surgery easier and this should always be considered. It was estimated that 60% of the native humeral head was necessary to support the prosthesis [65] (Fig. 51.18).

This arthroplasty could be performed as a total or hemiarthroplasty. In 2001 Copeland and Levy reported midterm results (6.8 years) in 103 Mark II prosthesis: 93.9% of patients declared to have better results than prior to surgery. The best results were achieved in primary osteoarthritis, better for total shoulder replacement than for hemiarthroplasty: 93.7% vs 73.5%, respectively. The poorest results were in patients with rotator cuff arthropathy

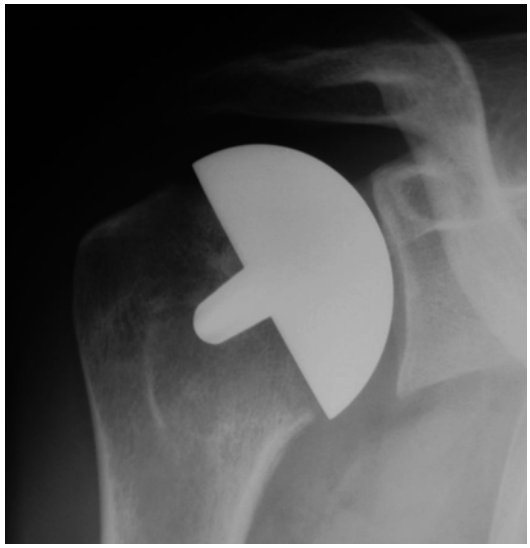


Fig. 51.18 Resurfacing

and posttraumatic arthropathy. Eighty-eight shoulders were available for radiological review. In 69.3 % no radiolucencies were reported, in 28.4 % less than 1 mm radiolucent line was seen and in two cases more than 2 mm radiolucencies were detected. In 59 glenoid components, no radiolucencies were reported in 35.6 %, in 59.3 % and in three shoulders (5.1 %), respectively, 1 mm and more than 2 mm radiolucent lines were observed. Six revision procedures were performed: two patients went into arthrodesis and four had conversion to stemmed arthroplasty [66].

In 2015 Levy et al. reported results of 54 CSRA on 49 patients aged younger than 50 years old with a long-term results: the mean follow-up was 14.5 years (range: 10–25 years). The mean relative Constant score increased from 11.5 % to 71.8 %. The mean patient satisfaction was 8.7 of 10. 81.6 % of the patients were satisfied with the results. Contrary to previous study the mean relative Constant score for the humeral head resurfacing with microfracture of the glenoid improved to 77.7 % compared with 58.1 % for total resurfacing arthroplasty. Two patients required early arthrodesis due to instability and deep infection. Ten patients (18.5 %) underwent revision arthroplasty: seven to stemmed prosthesis and three to stemless reverse total shoulder arthroplasty due to rotator cuff failure [67].

Another long-term follow-up results were reported by Pritchett in 2011. He studied 74 shoulders (41 total shoulder resurfacings and 33 humeral head resurfacings) in 61 patients with a mean age of 58 years. The follow-up was longer than 20 years in all patients (mean, 28 years). The patient satisfaction was 95 %. The survival rate of the humeral component at the time of final follow-up was 96 %. Thirty-eight shoulders (of 41) with glenoid resurfacing were available for radiographic follow-up. Three patients required revision surgery because of loosening and 12 had radiographic evidence of loosening. Patients with total resurfacing fared slightly better at final follow-up [68].

Also some other authors reported good results in young patients, however, in short-term follow-up. Bailie et al. reported good results at 2-year follow-up and 30 of the 36 patients were satisfied and able to participate in their activities including sports [69].

Lee et al. reported the results of surface replacement hemiarthroplasty of the shoulder with biologic resurfacing of the glenoid with interposed anterior capsule in 18 shoulders with average follow-up of 4.8 years. Eighty-three percent of patients were satisfied with their results. None of the implants were loose, but 56 % of glenoids showed moderate to severe erosion [70].

Levy thinks good outcomes after resurfacing arthroplasty are linked with some procedures in glenoid compartment comparing to stemmed hemiarthroplasty. In his opinion, the crucial step is a 360° release around the glenoid to achieve good soft tissues balance. In his series, moderate to severe glenoid erosion was present in 32 % (4 severe and 8 moderate) of the shoulders at an average follow-up of more than 14.5 years [67].

In 2008 Buchner et al. compared the results after humeral resurfacing and total shoulder arthroplasty in two groups of 22 patients. Two patients with humeral resurfacing required revision due to glenoid erosion and pain (conversion to TSA). Patients after humeral resurfacing showed significantly better perioperative results (time of surgery, blood loss, days of inpatient treatment) compared to the patients in the TSA group. Results at 6 and 12 months revealed

significant improvement of clinical function, significant pain reduction and high subjective satisfaction rates in both groups. They reported tendentially better results in the TSA group at 12 months of follow-up but only the criteria "mobility" and "abduction" revealed statistical significance. Regarding the relative improvement at 12 months compared to the baseline status, patients treated with TSA showed a significant better benefits in the Constant score and in the range of flexion and abduction. Regarding the subjective assessment, there was no statistically significant difference: 91 % of patients (20/22) in the TSA group and 77 % (17/22) in the humeral resurfacing group had very good or good subjective results. Authors concluded surface replacement should be limited to very well-selected patients and relatively high risk of revision (9 %) should be taken under consideration [71].

Some authors think the indication for humeral resurfacing should be limited to OA and rheumatoid arthritis, as functional outcomes are worse in patients with avascular humeral head necrosis, post-traumatic arthritis and cuff tear arthropathy [72].

51.8 Partial Resurfacing

In partial humeral head defects, including post-traumatic, degenerative or osteonecrotic cartilage defects, it is possible to use partial resurfacing arthroplasty. Humeral head inlay arthroplasty could be a joint-preserving alternative that maintains the individual head-neck-shaft anatomy and allows placement of a contoured articular component that is matched to the patient's defect size, location and individual surface geometry [73].

There are not many studies, as first reports were published in 2009 by Uribe and Bemden. They reported series of 12 shoulders in 11 patients who underwent partial humeral head arthroplasty for osteonecrosis with a mean follow-up of 30 months. The surgical time averaged 41 min, with a range of 23–62 min, and the estimated blood loss was less than 100 mL. All patients reported significant pain relief and improvement in function (from 94 to 142° in forward elevation). Authors reported no intraoperative nor postoperative complications. Postoperative radiographs showed solid fixation of the implant components [74].

In 2014 Delaney et al. reported less enthusiastic study regarding the same implant. They performed a retrospective study of 39 shoulders in 38 patients, with a mean follow-up of 51.3 months. Twenty-five shoulders (64.1 %) showed functional improvement and decreased pain. However, at a mean of 26.6 months of follow-up, the failure group included six patients (15.3 %) who underwent revision and another four (10.2 %) who were recommended to undergo revision. Five patients with no prior or concomitant procedures had the most reliable results, with no failures. In the group of 24 patients with prior procedures, 5 underwent revision, and the clinical outcome scores for the remaining patients were consistently lower than those seen in patients without prior procedures. Authors concluded that concomitant pathology and prior or concomitant surgical procedures potentially compromise the outcome and could be a contraindication. Successful results could be expected in patients with isolated chondral injuries, similarly to Uribe and Bemden's study [75].

In 2015 Sweet et al. reported the results in 19 patients (20 shoulders: 16 osteoarthritis and 4 osteonecrosis). The mean follow-up was 32.7 months. There was significant improvement in pain and function and 75 % reported their results as excellent and good, 20 % as somewhat good and 5 % as poor. Three patients had postoperative complications unrelated to the implants: one partial rotator cuff tear treated with physical therapy, one preexisting glenoid wear treated with arthroscopic debridement and microfracture and one infection complicated by subscapularis rupture requiring several subsequent surgical procedures but with retention of the implant [76].

In 2014 Anderl et al. reported partial humeral head resurfacing under arthroscopy control. This technique had the advantages of bone stock preservation and the maintenance of an intact subscapularis tendon that allowed immediate postoperative mobilisation. The results in 11 patients (4 females, 7 males; median age, 59 years) were reported with 2-year follow-up.

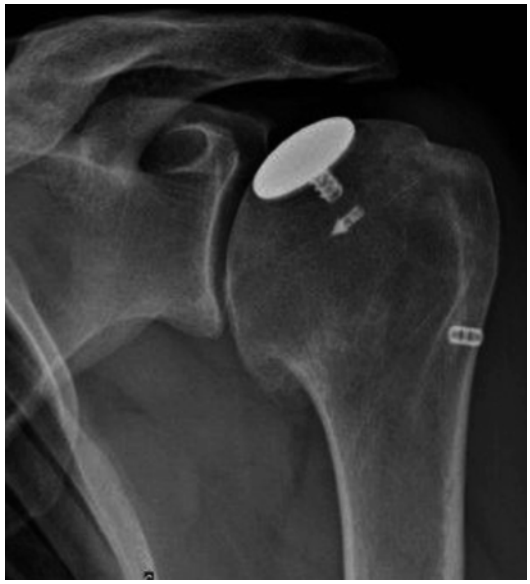


Fig. 51.19 Partial resurfacing of humeral head performed in arthroscopy

The mean Constant score improved significantly from 54.6 ± 13.6 preoperatively to 86.5 ± 14.3 points postoperatively. There were three revision surgeries: one patient required surgery because of a technical failure and two patients due to rapidly progressive osteoarthritis. Ten of 11 patients (91 %) claimed that they would undergo arthroscopic partial shoulder resurfacing again [77] (Fig. 51.19).

51.9 Stemmed Arthroplasty

Stemmed hemiarthroplasty (HA) still remains an option in patients with no glenoid pathologies, particularly in fractures. However lots of data prove that it is associated with glenoid erosion, resulting pain and gradual worsening of the results. This is the reason why total shoulder arthroplasty (TSA) became a more routine procedure, even in young patients (Fig. 51.20).

In 2002 Mansat et al. reviewed their 48 patients (51 shoulders) with a mean follow-up of 60 months. Authors concluded that the intensity of pain relief in patients with HA was not as great nor as predictable as in TSA. Also, clinical results seemed to deteriorate with time comparing to the results of

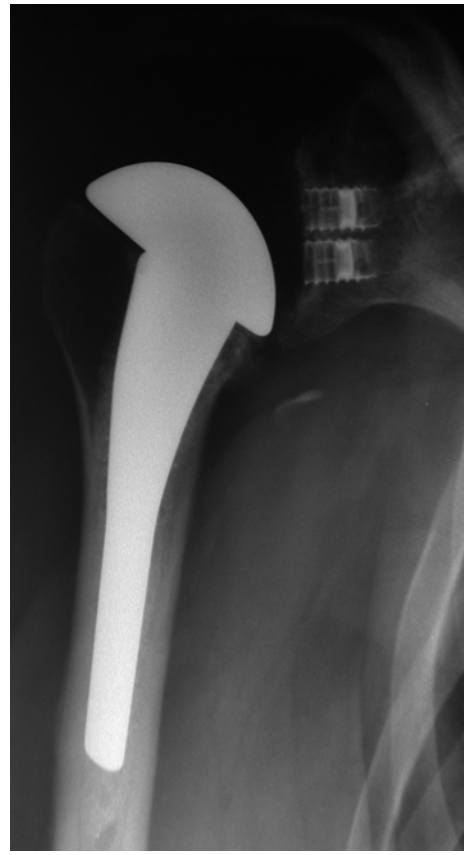


Fig. 51.20 Total shoulder arthroplasty

total shoulder arthroplasty that continued to be excellent with longer follow-up period [78].

Smith et al. reported that about half of 31 patients who underwent HA for avascular necrosis of the humeral head had unsatisfactory outcomes and high rates of glenoid erosion at 12 years of follow-up [79].

Levine et al. reported long-term (average 17.2 years, range: 13–21) results in 30 patients after hemiarthroplasty (31 shoulders) for OA. There were 8 revisions (3 of 15 shoulders with concentric glenoids and 5 of 16 with eccentric glenoids). Twenty-five percent of patients were satisfied with their outcome; however patients with concentric glenoid wear had better outcomes than those with eccentric glenoid wear and secondary osteoarthritis. Patients in both groups experienced deterioration of results over time [80].

Bryant et al. performed a systematic review of the literature to estimate the impact of hemiarthroplasty compared with total shoulder arthroplasty on function and range of motion in patients with shoulder OA. A significant difference was detected in the function, pain score and forward elevation in favour of total shoulder arthroplasty [81, 82].

Sperling et al. reported the results after stemmed arthroplasty in patients aged younger than 50 years with a mean follow-up of 15 years. The rates of survival of the hemiarthroplasty were 82 % at 10 years and 75 % at 20 years, and the rates of survival of the TSAs were 97 % and 84 %, respectively. Revision rate was 22 % and 14 %, respectively, in hemiarthroplasty and total arthroplasty. Sixty percent of patients with hemiarthroplasty and 48 % of patients with total arthroplasty were unsatisfied with the results. Additionally they reported 72 % of glenoid erosion for a stemmed prosthesis hemiarthroplasty [83–85].

Also Bartelt et al. reported results similar to previous study. Thirty percent of the patients with hemiarthroplasty underwent revision arthroplasty after a mean of 4.5 years from the surgery and 7 % of the patients with total shoulder arthroplasty after a mean of 10.9 years. Glenoid loosening was present in 10 of 34 (29.4 %) of the patients with TSA at a mean follow-up of 7 years [86, 87].

In 2015 Sayegh et al. reviewed 32 studies involving a total of 1,229 shoulders to assess the surgical procedures performed in OA in patients younger than 60 years old. Pain scores improved significantly more after total shoulder arthroplasty (TSA) than after hemiarthroplasty (HA). Patient satisfaction was similar after HA and TSA. Revision surgery was equally likely after HA, TSA and arthroscopic debridement (AD). Complications were significantly less common after AD than after HA and TSA. AD and TSA resulted in better recovery of active forward flexion and external rotation than HA. At radiological follow-up, subluxation was similarly common after HA and TSA. Authors concluded TSA provided greater improvement of pain and range of motion than HA. Additionally they stated that arthroscopic debridement was an efficacious and particularly safe alternative in the short-term follow-up for young patients [88].

51.10 Stemless Arthroplasty

There is a natural tendency to minimise the "volume" of prosthesis preserving as much as possible natural bone stock and anatomy. Stem-related complications enhanced to create short stem or stemless humeral components. It permits to avoid periprosthetic humerus shaft fractures and makes future revision easier. Additionally, metaphyseal fixation provides the ability to perform anatomical reconstruction regardless of posterior offset of the proximal humerus as well as to implant the prosthesis in malunited proximal humeral deformities. It is important to remember that stemless prosthesis is in clinical trials to receive approval of the FDA in the USA [89].

There are very few literature data regarding this type of implants [90] (Fig. 51.21).

In 2010, Huguet et al. reported the results of 63 Biomet TESS implants, 44 hemiarthroplasties and 19 total shoulder arthroplasties with a minimum of 3-year follow-up. Intraoperative complications included lateral humeral cortical fracture in five patients, with all fractures healed without complications over a 2-month period. The revision rate was 11.1 %: four implants were removed

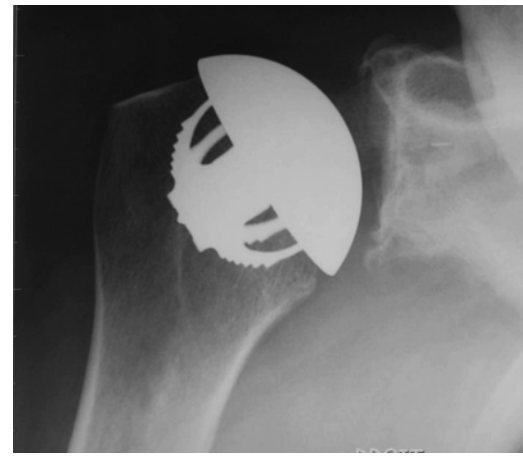


Fig. 51.21 Stemless shoulder arthroplasty

due to infection, two due to massive cuff tears and one due to instability. The mean Constant score was 75 points with a gain of 45 points over the preoperative score. Mean flexion and external rotation were 145° and 40°, respectively. At 3 years of follow-up, there were no signs of humeral implant subsidence, osteolysis or stress shielding [91].

In 2011, Kadum et al. analysed a group of 56 patients treated for a variety of shoulder conditions with Biomet short-stem implants at 14 months of follow-up. Unfortunately, because of the marked heterogeneity of the patients group, regarding preoperative condition and treatment rendered, few conclusions can be drawn [92].

In 2013 Razmjou et al. reported a prospective longitudinal study comparing three different shoulder arthroplasty designs, including also stemless TESS shoulder prosthesis. At the final follow-up, all three groups showed significant improvements in Western Ontario Osteoarthritis of the Shoulder, American Shoulder and Elbow Surgeons, relative Constant-Murley and QuickDASH (short version of DASH questionnaire) scores as well as in active and passive range of motion. Radiographic analysis, completed for all groups at 24 months, identified humeral component lucent lines in 18% of patients with a Neer II prosthesis and in 8% of patients with a Bigliani-Flatow prosthesis, whereas there was no evidence of lucent lines or stress shielding in the TESS group [93].

In 2011, Schoch et al. published the first report regarding the Eclipse implant (Arthrex). Between 2006 and 2009, 115 patients were operated. Ninety-six patients had a diagnosis of primary osteoarthritis and 19 had posttraumatic arthritis. At 1 year of follow-up 87.5% of patients were very satisfied or satisfied in the primary osteoarthritis group, comparing to 78.9% of cases in the posttraumatic group. Early complications included one hematoma, three cases of rotator cuff insufficiency and two cases of glenoid loosening [94].

In 2012, Brunner et al. reported good results on 233 patients (114 hemiarthroplasties and 119 total shoulder arthroplasties) who received the Arthrex Eclipse for various indications: primary osteoarthritis in 100 patients, fracture deformity in 70, instability in 29, rheumatoid arthritis in 16, avascular necrosis in 6, postinfectious osteoarthritis in 4 and cuff tear arthropathy in 3. The mean follow-up period was 23 months. Patients had significant improvements in the gender- and age-adjusted Constant score, from 51.6 to 78.9 points, as well as in range of motion in flexion, abduction and external rotation. Radiological review at a mean of 23 months of follow-up indicated that 92.2% of patients did not have lucent lines, 3.9% had incomplete lucent lines of less than 2 mm, 2.4% had incomplete lucent lines greater than 2 mm, 0.9% had complete lucent lines greater than 2 mm and one additional patient had obvious prosthetic loosening. Complications included 1 case of implant loosening, two periprosthetic fractures, two rotator cuff tears, heterotopic ossification, impingement, two nerve lesions and one case of glenoid erosion. Six patients underwent revision due to loosening (1), infection (3) or conversion to reverse arthroplasty (2) [95].

In 2013 Berth and Pap reported a prospective randomised study comparing the results of the Biomet TESS stemless implant with the Mathys Affinis stemmed prosthesis. Eighty-two patients with OA received a total shoulder arthroplasty. Intraoperative humeral-side complications included a greater tuberosity fracture in the Affinis stemmed group, which healed without further treatment. The mean hospital stay was not significantly different between the groups. The mean operative time was significantly longer in the cemented Affinis stemmed arthroplasty group (106.2 min) compared with the TESS group (91.5 min). At 2-year minimum follow-up, no differences between the groups were identified in clinical scores and range of motion. At the last follow-up, radiographic analysis indicated no evidence of radiolucent lines or osteolysis around any of the stemmed or stemless implants [96].

51.11 Reverse Shoulder Arthroplasty

In 1893 with the first shoulder prosthesis carried out by Péan, it was decided to dispense with the rotator cuff and use only the deltoid muscle as motor of the prosthesis.

The use of Swanson bipolar prosthesis, and then constraint prostheses of Bickel, Fenlin,

Floating-socket, Gerard, Kessel, Kölbel, Liverpool, Michael Reese, Reeves, Stanmore, Trispherical, Wheble-Skorecki, Zippel and P.M. Grammont, was introduced.

The concept of reverse prostheses was finalised in the early 1990s with the delta prosthesis.

The lateralisation of the centre of rotation allows to increment the lever arm of the deltoid muscle and provides the return of mobility and partial muscular strength [97].

This work showed that the shoulder's centre of rotation must be as close as possible to the glenoid bone-prosthesis interface and that the lateralisation of the lever arm of the deltoid muscle must be at maximum.

Constantini showed lateralisation of the centre of rotation leads to an increase in the overall joint contact forces across the glenosphere. Moment arms of the deltoid consistently decreased with lateralisation. Bending moments at the implant interface increased with lateralisation. Progressive lateralisation resulted in improved stability ratio [98].

Different studies compared lateralised and non-lateralised glenospheres and some authors did not find a higher rate of complications at the level of the glenoid side.

In 2011 Favard et al. showed that the survivorship free of revision in 527 reverse shoulder arthroplasties was 89 % at 10 years [99].

Other authors report good results with the reverse shoulder arthroplasty and low ratio of complications [100–102].

Kempton reported 200 reverse shoulder prosthesis in 4 years. Forty of the 200 arthroplasties were revision arthroplasties; 19 shoulders involved local complications (9.9 %), including 7 major and 12 minor complications. Nine involved perioperative systemic complications (4.7 %), including 8 major complications and 1 minor complication. The local complication rate was higher in the first 40 shoulders (23.1 %) versus the last 160 shoulders (6.5 %). Seven of 40 (17.5 %) revision arthroplasties involved local complications, including 2 major and 5 minor complications compared to 12 of 152 (7.9 %) primary arthroplasties, including 5 major and 7 minor complications. Nerve palsies occurred less frequently in primary arthroplasties (0.6 %) compared to revisions (9.8 %) [103].

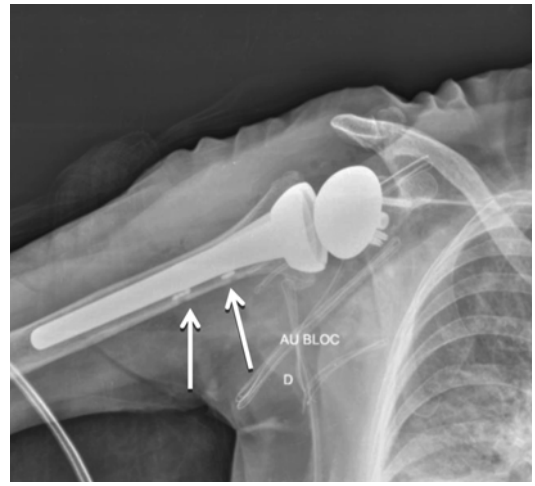


Fig. 51.22 RSA with latissimus dorsi transfer with two fixation of the transfer (*white arrows*)

This confirms the earlier work by Guery et al. in 2006, but results over 10 years of follow-up are still unknown, which drives authors to advise against the implantation of a reverse prosthesis in young patients [104].

Alta et al. specified the quality of strength after the implantation of a reverse prosthesis, which they assessed on a series of 23 patients. The results of strength in abduction and adduction varied between 17 % and 76 % of a normal shoulder with the same values for the rotations [105].

Edwards demonstrated that placing the glenoid component with inferior tilt does not reduce the incidence or severity of radiographic scapular notching after reverse shoulder arthroplasty. No clinical differences were observed between the groups [106].

Simovitch et al. showed that the fatty infiltration of the teres minor muscle affects the clinical outcomes by decreasing the active external rotation; in these cases a reverse shoulder arthroplasty alone cannot restore a complete range of motion [107].

Gerber and Boileau showed that in the presence of severe loss of active elevation and external rotation, combined latissimus dorsi transfer and reverse total shoulder arthroplasty can restore elevation and external rotation, at least in the short-term follow-up [108–111] (Fig. 51.22).

Tessier reported the results of 105 stemless reverse shoulder arthroplasties (RSA). The

outcomes of stemless RSAs were comparable to the results of other RSA systems. Stemless RSA needs good bone stock to have primary stability but it is a reliable and less invasive system [112].

Conclusion

The treatment of the glenohumeral cartilage damage and degenerative osteoarthritis made considerable progress in the last 30 years and in particular with shoulder prosthesis. Currently, results in total shoulder arthroplasty are definitively more predictable thanks to the third generation of prosthesis, more similar to the shoulder anatomy, and to a better understanding of the biomechanics of the shoulder. The coming of the reverse shoulder arthroplasty, the reliability of which is not to be anymore demonstrated, allows to offer safe opportunity to treat pseudoparalytic shoulder in cuff arthropathy and in excentred arthritis.

Biology will certainly permit to treat the first damages of the cartilage and will delay the evolution of them in the future. It will probably help overcome the shoulder prosthesis indications.

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Management of the Stiff Shoulder

52

Lennard Funk and Avanthi Mandaleson

52.1 Definition

The stiff shoulder has had many terms attached to it over the centuries. It was initially termed 'periarthritis' [1, 2], then 'frozen shoulder' [3] and then 'adhesive capsulitis' [4]. Codman described the pathophysiology of a chronic inflammatory process involving the capsule of the shoulder causing a thickening and contracture of this structure which secondarily becomes adherent to the humeral head. Zuckerman and colleagues in 2011 aimed to have a consensus definition of adhesive capsulitis. It was defined as 'a condition characterized by functional restriction of both active and passive shoulder motion for which radiographs of the glenohumeral joint are essentially unremarkable except for the possible presence of osteopenia or calcific tendonitis' [5].

The presence of a stiff shoulder must raise the suspicion of other pathologies. The diagnosis of a frozen shoulder is essentially a diagnosis of exclusion. The musculoskeletal differential diagnosis should include bursitis, biceps and rotator cuff pathology, arthritides and trauma.

L. Funk (✉) • A. Mandaleson
Upper Limb Unit, Wrightington Hospital,
Appley Bridge, Wigan WN6 9EP, UK
e-mail: lenfunk@shoulderdoc.co.uk

52.2 Presentation and Aetiology

The natural history of frozen shoulder has been well delineated and was classically characterized by Reeves into three clinical stages, shown in Fig. 52.1 [6]. Neviaser described four arthroscopic stages of adhesive capsulitis, outlined in Table 52.1. Hanchard more recently simplifies the stages into 'pain predominant' and 'stiffness predominant' [14]. Despite the different classifications, they all highlight the fact that symptom progression is a continuous spectrum rather than distinct stages.

The most common age of presentation is 40–60 years of age [7]. There are a number of well-known associated risk factors, some of which are listed in Table 52.2. The incidence of frozen shoulder in the general population ranges between 2% and 5% [9]; in the diabetic population, this

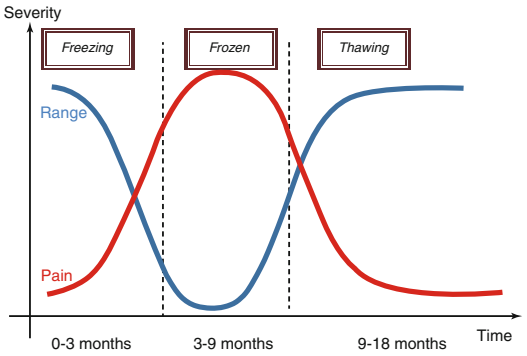

Fig. 52.1 Clinical stages of frozen shoulder – stage I, 'freezing'; stage II, 'frozen'; and stage III, 'thawing'

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Table 52.1 Stages of frozen shoulder

Stage	Duration	Pathophysiology and clinical findings
I	0–3 months	Pre-adhesive stage. Minimal or no limitation of motion. Synovial inflammation detected only by arthroscopy
II	4–9 months	Acute proliferative synovitis with adhesion formation
III	10–15 months	Maturation stage. Synovitis resolving. Obliteration of axillary fold
IV	Chronic stage	Mature adhesions with marked restriction in motion

Table 52.2 Predisposing factor for shoulder stiffness

Risk factors	Example
Injury	Bone and soft tissue trauma, shoulder surgery
Non-shoulder surgery	Proximity to shoulder girdle:
	Cervical neck/axillary dissection
	Cardiac (catheterization, sternotomy, thoracotomy)
Immobility	
Diabetes mellitus	Insulin dependent and poor glycaemic control – greater risk
Cervical spine disease	Degenerative disc disease
Thyroid disorders	Hyper-/hypothyroidism
Cardiac disease	IHD
	Shoulder-hand syndrome
Pulmonary disorders	Emphysema
	Chronic bronchitis
	TB
Neoplastic disorders	Bronchogenic carcinoma
	Primary or metastatic tumours of the humerus
Neurological conditions	Parkinson's disease
	Parsonage-Turner syndrome
	Cerebral haemorrhage/tumours
	Compressive neuropathies
	Stroke/hemiplegia
Medication	Isoniazid
	Protease inhibitors (e.g. indinavir)

can involve both shoulders in up to 40 % [6, 8] and up to 20 % in non-diabetics [9, 10].

Adhesive capsulitis can be classified into primary or secondary [5] or as idiopathic or post-traumatic [6, 7]. Secondary frozen shoulder can be subclassified into intrinsic and extrinsic; however, this is less widely accepted [5].

52.3 Diagnosis

A thorough history and examination is the mainstay of clinical assessment, with a reduction of passive glenohumeral joint movement being the primary diagnostic criteria for a 'stiff shoulder'. Radiological exclusion of underlying pathology such as glenohumeral arthritis is the mainstay for diagnosing an 'adhesive capsulitis'.

Investigations are aimed at excluding other intra-articular or local pathologies. In the majority of cases, orthogonal view plain radiographs are the only necessary investigation.

More recently, there has been increased use of MRI. Classic findings show thickening of the joint capsule and synovium greater than 4 mm [11]. There is also thickening of the coracohumeral ligament and axillary recess capsular tissue and obliteration of the normal subcoracoid fat in the rotator interval [12] (Figs. 52.2 and 52.3). Fat suppression sequences may also show inflammation in the rotator interval and inferior capsule on the coronal images.

Arthrography is less commonly used. Findings are that of decreased joint capacity, obliteration of the reflected axillary fold, variable filling of the biceps sheath [13] and obliteration of the subscapularis bursa [9].

Arthroscopy should not be used as a means of establishing a diagnosis. Arthroscopic techniques can be used in conjunction with the treatment of other intra-articular pathologies, for assessment of the effects of closed manipulation or for capsular release.

52.4 Treatment

Although adhesive capsulitis follows a generally predictable disease process, passing through the stages above, it is difficult to accurately predict the disease progression for an individual patient. Therefore, the decision for treatment should not be based on the 'stage' of the disease

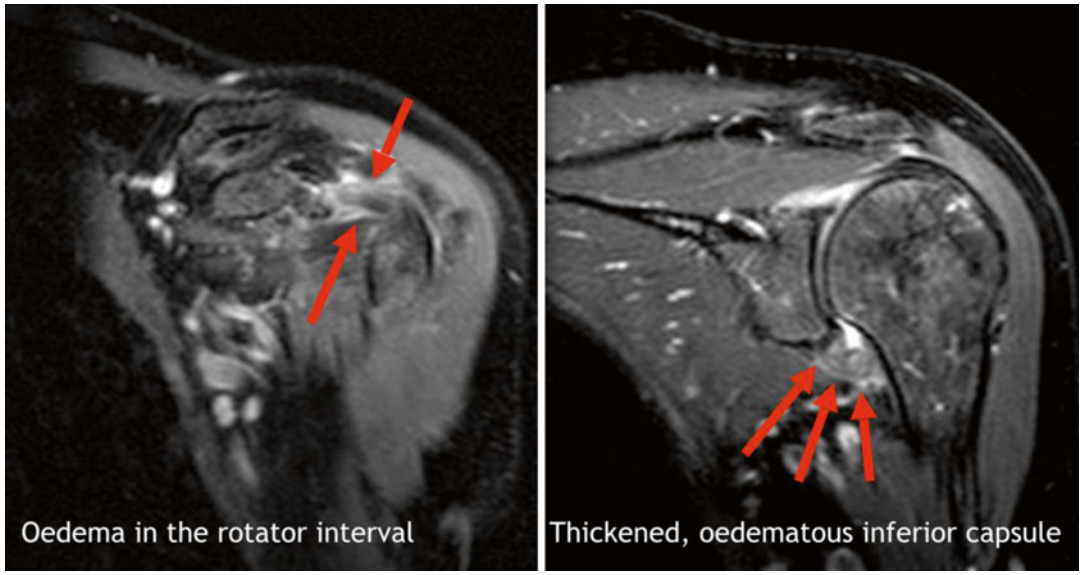

Fig. 52.2 Thickening and oedema of the axillary recess capsular tissue, thickening and oedema of the coracohumeral ligament and obliteration of the subcoracoid fat

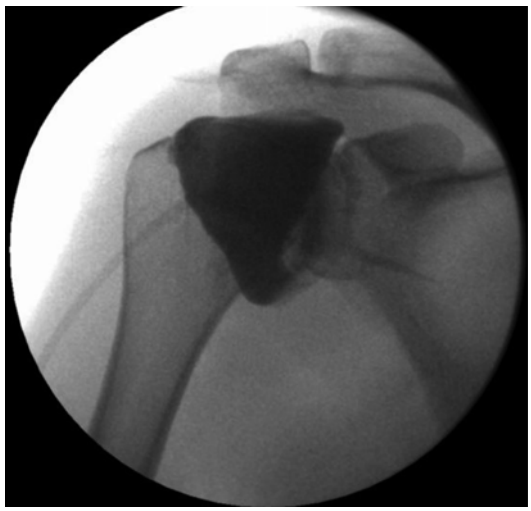

Fig. 52.3 Arthrography in conjunction with hydrodilatation

but on the patient's current symptoms. Some patients do not have severe pain and can manage with less intervention, whilst others have disabling pain that will clearly not respond to simple measures. Likewise, there is a range of functional limitations dependent on the degree of stiffness and the individual patient's functional requirements.

Table 52.3 Management options for frozen shoulder

Nonoperative management	Operative techniques
Education and watchful waiting	Manipulation under anaesthesia
NSAIDS	Arthroscopic release
Physiotherapy	
Corticosteroid injections	
Nerve blocks	
Hydrodilatation	

We prefer a patient-orientated approach to management and base our treatment decisions on a laddered approach, depending on the level of pain and functional disability. We combine this with the 'pain predominant' or 'stiffness predominant' classification [14–16] (Table 52.3).

'Pain predominant' treatment utilizes supportive measures with simple analgesia and gentle passive and active stretching in a hospital-based physiotherapy regime. If pain severity increases, we use an intra-articular corticosteroid injection for treatment of painful synovitis. If there is functional limiting stiffness with the pain, we have a low threshold for a hydrodilatation procedure to improve pain and range of motion.

Nerve blockade has shown some promising results. The suprascapular nerve supplies 70 % of

the sensory fibres to the shoulder [16]. It can therefore be blocked to provide pain relief. Under ultrasound guidance, a needle is passed to the suprascapular notch below the transverse scapular ligament from medial to lateral, and nerve blockade can be safely performed in an outpatient setting [17–19].

Our 'stiffness predominant' treatment is based on physiotherapy in conjunction with intra-articular steroid injection if required. In our experience, hydrodilatation is less effective for severe functionally limiting stiffness, but it is less invasive than surgery and may improve enough range to restore some function for that patient.

Indications for surgery are those patients who have a prolonged 'stiffness predominant' frozen shoulder or those that have failed conservative treatment. Surgical intervention needs to be coupled with early physiotherapy to maximize outcomes.

52.5 Techniques

52.5.1 Hydrodilatation

Hydrodilatation or hydrodistension of the shoulder is an effective treatment modality that can provide sustained pain relief and improved range of motion regardless of aetiology [20, 21]. A proposed mechanism of its effects is from the anti-inflammatory effect of cortisone and the mechanical effect of capsular distension, reducing stretch on pain receptors in the joint capsule and its periosteal attachments [22]. Capsular rupture has not been shown to affect range of motion and pain [23, 24]. Our hydrodilatation protocol is performed by a specialist musculoskeletal radiologist in an ambulatory setting. An anterior approach is taken, with fluoroscopic guidance. An 18G needle is placed in the glenohumeral joint and position confirmed using contrast. Local anaesthetic, steroid and normal saline is injected until either no more fluid can be insufflated or a popping sound is heard. Patients proceed to a standardized physiotherapy programme, which commences within 1 week of the procedure. Our prospective data with 2-year follow-up show significant improvements in all objective and patient-reported outcome measures [23].

52.5.1.1 Complications

The most commonly reported problem with hydrodilatation is that of pain during the procedure. In our experience, it is relatively well tolerated and patients return home on the day of the procedure.

52.5.2 Manipulation Under Anaesthesia (MUA)

MUA is generally performed under general anaesthesia and/or interscalene block. A pre-manipulation assessment of ROM is recorded. The patient is placed supine; the scapula is stabilized with one hand whilst the other hand grasps the humerus above the elbow. The arm is abducted and externally rotated, taking it above the patient's head, reduced to 90° and then internally rotated and adducted. Typically, an audible popping of the capsule is heard as the arm is manipulated. Some studies report >90% satisfaction with their outcome at a minimum of 6-month follow-up, and most patients regained the ability to do daily tasks within days of the procedure [24]. These results can be sustained for up to 15 years after the procedure [25].

52.5.2.1 Complications

Proper technique is essential so that the inferior capsule is ruptured from the humerus without causing humeral fracture. Other complications include subscapularis tear, labral tears and biceps tendon injuries [1, 7].

52.5.3 Arthroscopic Capsular Release

Arthroscopic capsular release has superseded MUA as it allows inspection of the joint, confirmation of the diagnosis, identification of concurrent pathology and a more precise capsulotomy without the risks of manipulation [1, 7]. Compared with MUA, it has shown improved pain relief and restoration of function with results maintained at long-term follow-up [20, 21]. Capsular release is used for stiffness predominant frozen shoulder to improve range of motion.

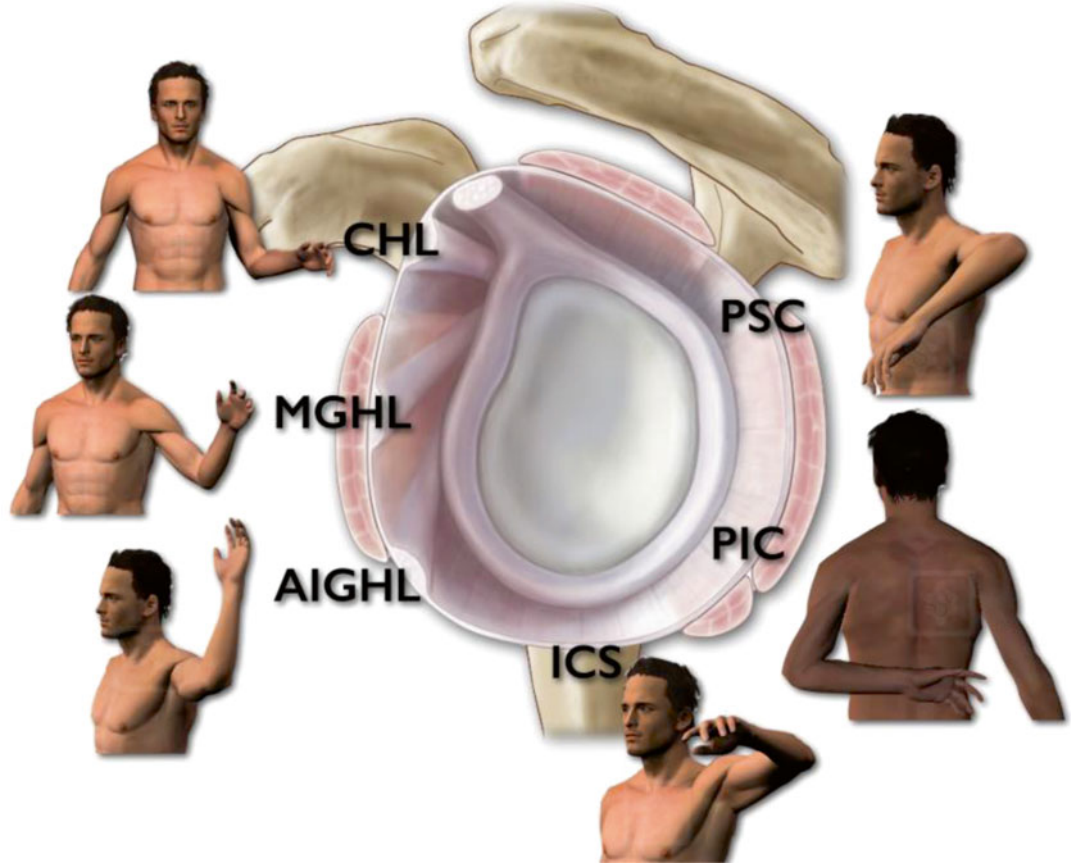

Fig. 52.4 Ligaments contributing to stiffness of the glenohumeral joint: *CHL* coracohumeral ligament, external rotation with no abduction; *MGHL* middle glenohumeral ligament, external rotation at 45° abduction; *AIGHL* anterior inferior glenohumeral ligament, external rotation above 45° abduction; *ICS* inferior capsule, abduction in neutral rotation; *PIC* postero-inferior capsule, internal rotation in neutral; and *PSC* postero-superior capsule, internal rotation in abduction

Anatomic structures that contribute to stiffness are outlined in Fig. 52.4. These should be released in a stepwise progression: (1) inflammatory synovium in the rotator interval (RI), including the coracohumeral ligament, (2) superior glenohumeral ligament (SGHL), (3) subscapularis tendon and (4) inferior capsule. Most studies demonstrate excellent results without the need for subscapularis release and this is our practice. Posterior capsular release is also not required for most cases [28] (Fig. 52.5).

52.5.3.1 Positioning

It is performed under general anaesthetic and interscalene block, with the patient in the beach chair or lateral position.

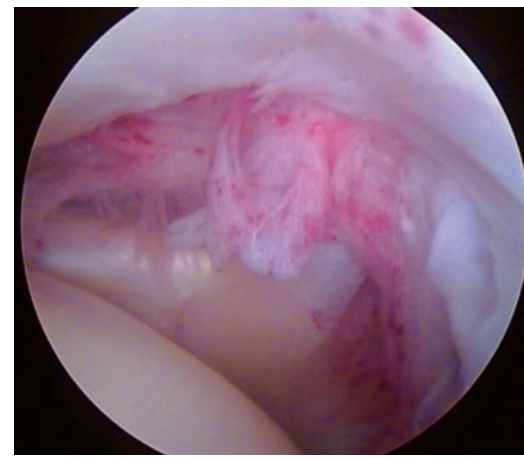

Fig. 52.5 Inflamed rotator interval with villonodular synovitis

52.5.3.2 Portal Position

Standard posterior and anterior portals are used for most cases, with the scope inserted via the posterior portal and instruments anterior. If severe joint contracture prevents insertion of the arthroscope through the posterior portal, a simple closed forward elevation manoeuvre can facilitate insertion of the arthroscope. It can be difficult in very stiff shoulders to enter the joint via the posterior portal initially. In these cases, we use the anterior portal, via the rotator interval to enter the joint initially (Fig. 52.6).

52.5.3.3 Procedure

Via the anterior rotator interval (RI) portal, the rotator interval with the coracohumeral ligament (CHL) is released. This is performed with an ablation wand. The rotator interval is often very thick and impossible to discern individual structures. Resection of the entire interval to expose the lateral coracoid ensures a thorough release of the RI and CHL. The middle glenohumeral ligament (MGHL) is then divided without damaging the subscapularis tendon. In some cases, it is easier to release the MGHL before the rotator interval structures. Following the release of MGHL, the anterior band of the inferior glenohumeral ligament is divided towards the axillary recess, stopping between the 5 and 6 o'clock positions. The inferior and posterior capsules are released by a gentle manipulation of the shoulder in abduction and external rotation, followed by adduction and internal rotation. This should be performed gently and gradually. The anterior capsular release is then extended posteriorly by this manoeuvre (Figs. 52.7 and 52.8).

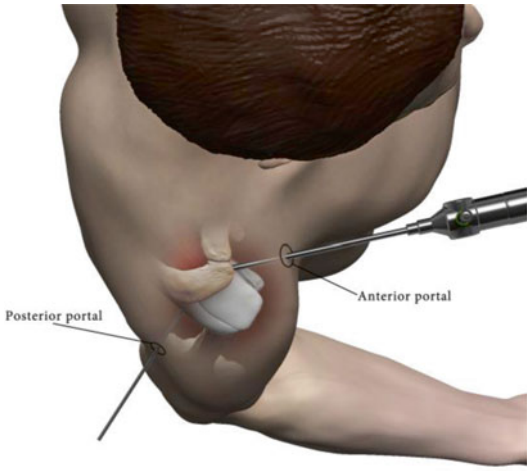

Fig. 52.6 Anterior and posterior portal placement

52.5.3.4 Extended Release

Lafosse describes a 360° capsular release for the recalcitrant frozen shoulder which includes idiopathic and postsurgical or post-traumatic groups [26]. The technique uses a combined intra- and extra-articular approach. The rotator interval is opened from an extra-articular mid-lateral subacromial viewing portal and anterolateral instrument portal to allow ablation of the coracohumeral ligament and opening of the rotator interval. Whilst continuing to view through the mid-lateral

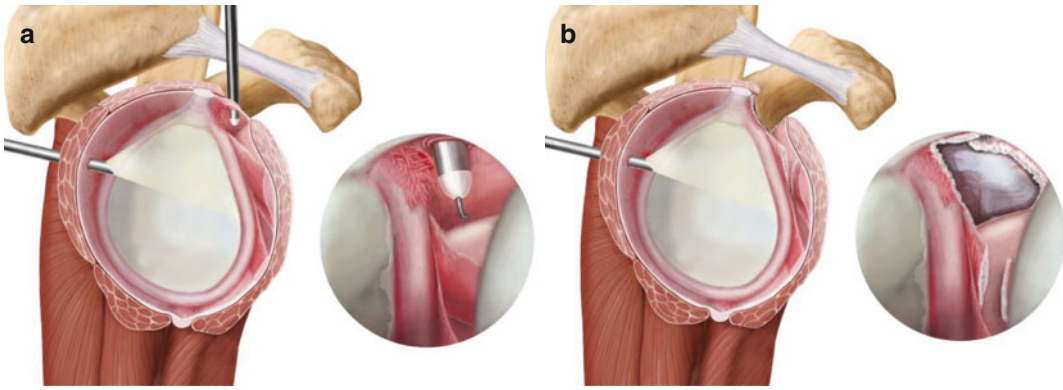

Fig. 52.7 (**a**, **b**) Release of the rotator interval and coracohumeral ligament

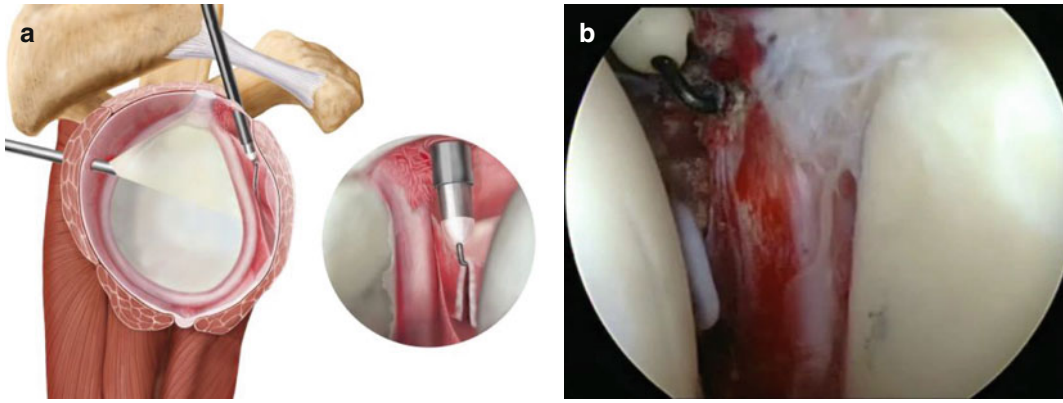

Fig. 52.8 (**a**, **b**) Release of the middle glenohumeral ligament

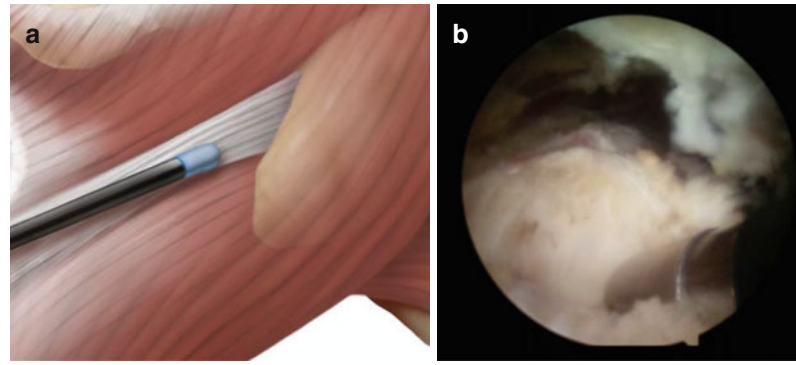

Fig. 52.9 (**a**, **b**) Extra-articular coracohumeral ligament release, before release (viewing from mid-lateral subacromial portal and working via anterolateral portal)

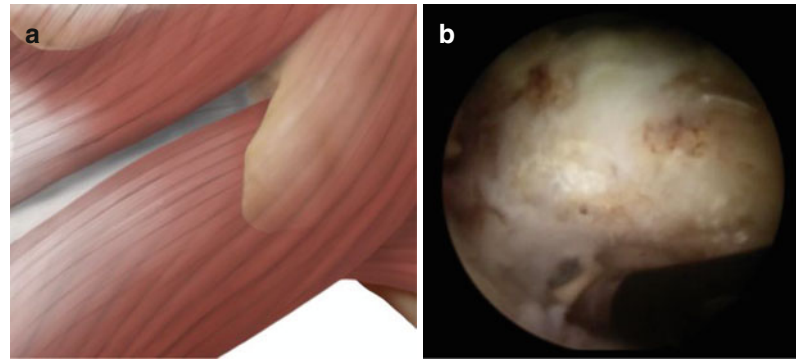

Fig. 52.10 (**a**, **b**) Extra-articular coracohumeral ligament release, after release showing exposed coracoid

portal and rotator interval, a 360° capsular release with division of the superior, middle and inferior glenohumeral ligaments and coracohumeral ligament and biceps tenotomy is achieved. We particularly find this procedure useful for stiff shoulders following open surgical procedures, such as proximal humeral fracture fixation or open rotator cuff surgery (Figs. 52.9 and 52.10).

52.5.3.5 Complications

Care should be taken when performing inferior capsular release to avoid damage to the axillary nerve when dissecting inferiorly. The nerve is closest to the capsule at the midpoint between its humeral and glenoid insertion points. It lies closer to the glenoid in the beach chair position and closer to the humeral neck in the lateral position.

Inferior capsulotomy near the glenoid rim can decrease the risk of axillary nerve injury [26, 27].

52.5.3.6 Post-operative Care

Post-operative pain can be a problem once the interscalene block has worn off. Therefore, adequate pain management is essential to allow early rehabilitation. Indwelling interscalene catheters and indwelling intra-articular catheters have been used, but these require intensive management and medical input, with added complications. We have found good patient education with the use of regular non-steroidal anti-inflammatories and simple analgesics effective. These must commence prior to dissolution of the effect of the interscalene block. Cold compression therapy is also used as an effective and safe pain control regimen.

52.6 Summary

Shoulder stiffness is very common and can be managed effectively without surgery in most cases. A stepwise patient-based approach to the predominant symptoms is sensible, rather than treating the 'stage'. If surgery is required, the current preference is an arthroscopic capsular release. This is a safe and effective procedure in resistant cases, with good results.

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Part IV

Elbow

Pietro Randelli and Paolo Arrigoni

53 Elbow Arthroscopy: General Setup, Portal Options and How to Manage a Complete Elbow Investigation

E. Guerra, A. Ritali, A. Marinelli, G. Bettelli, M. Cavaciocchi, and R. Rotini

53.1 Introduction

The first reports of elbow arthroscopy appeared in 1931 with Burman [1], but that kind of surgery was originally considered to be an unsafe procedure because of the small size of the elbow joint.

The development of smaller arthroscopes by Watanabe [2] in 1971 permitted Ito [3, 4] and Maeda [5] to perform some elbow arthroscopies routinely and to describe some initial portals, but only with Andrews and Carson [5] in 1985, and Johnson [6] on 1986, surgical indications and technique were precisely described.

Unfortunately the first elbow arthroscopies showed a risk of complications between 10 % and 20 % that was considered much higher than in the other joints [7–11].

Over the past decade, the technique has been greatly improved and made more secure thanks to the studies and the technical clarifications of authors such as Baker, O'Driscoll, Poehling and Altchek. Still, however, its diffusion is limited, if one considers that in the USA only 1 % of the orthopaedic surgeons currently use it.

Nowadays, elbow arthroscopy is considered a reproducible, valuable and effective surgical technique if performed through the right approaches and by skilled surgeons.

53.2 Surgical Portals and Anatomical Hazards

The elbow is the set of three joints: the ulnohumeral, the radiohumeral and the proximal radioulnar joints (Fig. 53.1).

Intra-articular space can be divided for practical purposes into an anterior chamber, a posterior one and two lateral recesses (medial and lateral gutter), communicating each other.

Several portals are necessary to perform a complete arthroscopic visualisation of the elbow. These portals have been described and have undergone many changes over the years (Table 53.1, Fig. 53.2).

For example, the anterolateral portal first described by Andrews [5] (2 cm anterior and 2 cm distal to the epicondyle) has been abandoned because of its proximity to the radial nerve (Fig. 53.3).

The currently used portals can be classified in

- Anterior portals
- Posterior portals
- Accessory portals

E. Guerra (✉) • A. Marinelli • G. Bettelli
M. Cavaciocchi • R. Rotini
Reparto Chirurgia della Spalla e del Gomito, Istituto Ortopedico Rizzoli, Bologna, Italy
e-mail: enrico.guerra@ior.it

A. Ritali
Clinica Ortopedica, Azienda Ospedaliera Universitaria di Parma, Parma, Italy

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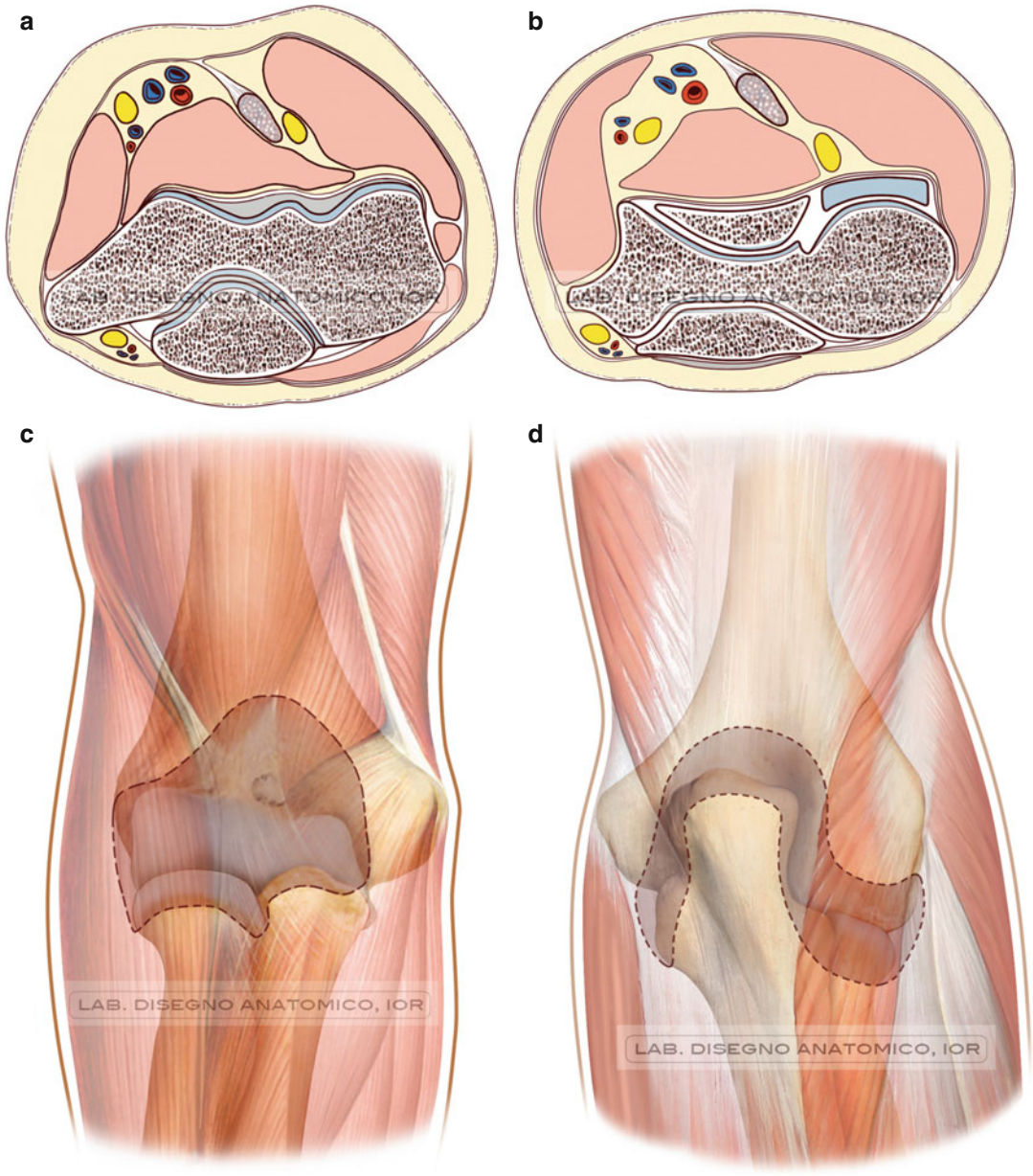

Fig. 53.1 Elbow anatomy: (**a**, **b**) axial view, with two different levels of the trochlea: notice that the radial nerve is proximally protected by the brachial muscle, while more distally (nearby the radial head) it can be separated from the joint capsule just by a thin layer of fat tissue. (**c**) Anterior view of the elbow and (**d**) posterior view of the elbow, highlighting the limit of the capsule (Anatomic drawing, Istituto Ortopedico Rizzoli, Bologna)

53.2.1 Anterior Portals

53.2.1.1 Anteromedial Portal

To create this portal, the landmark is the medial epicondyle, which can be easily found under the skin. Then we should approximately shift 2 cm anterior and 2 cm proximal to the epicondyle.

Be aware that the metric reference system is not always exact due to the different patient sizes.

Table 53.1 Arthroscopic portals

Posterior portal	Anatomical landmark	Approximate position	Structure in danger
Posterocentral portal	Apex of olecranon	3–5 cm proximal	None
Posterolateral portal	Apex of olecranon	2 cm lateral	None
	Soft spot	2 cm proximal	
	Epicondyle		
Mid-lateral portal	Radial head	Soft spot	Cartilage of the joint
Anterolateral portal	Epicondyle	2 cm proximal and 2 cm anterior	Radial nerve
Anteromedial portal	Medial epicondyle	2 cm proximal and 2 cm anterior	Median nerve
			Brachial artery
Proximal posterolateral portal	Triceps	3 cm lateral to the posterocentral portal	None
Direct lateral	Radial head	Articular joint	Articular cartilage
Proximal anterior-lateral portal	Epicondyle	3–5 cm proximal to the anterior-lateral portal	Radial nerve
Proximal anterior-medial portal	Medial epicondyle	3–5 cm proximal to the anterior-medial	Median nerve
			Brachial artery

Once the skin only is incised, by a blunt instrument (like a periosteal elevator), the intermuscular septum can be felt and followed until the humerus. The anterior surface of the humeral epiphysis acts as a guide to enter the joint pointing the instrument towards the radial head.

Be careful not to break the intermuscular septum, moving posteriorly to not interfere with the ulnar nerve.

It's really important to stay close to the bone surface in order to stay behind the brachial muscle and protect the median nerve and the brachial vein/artery.

53.2.1.2 Anterolateral Portal

The landmark is the lateral epicondyle; the technique is the same as reported before (except that the instruments must go towards the coronoid instead of the radial head).

This is probably the most dangerous portal because of the proximity of the radial nerve to the joint capsule, in front of the radial head. For this reason can be suggested to perform this as second portal, after the antero-medial on, either via an in-out technique or through a careful portal placement with an out-in needle placement.

53.2.1.3 Advices for Both the Anterior Portals

- A posterior incision (very close to the lateral or medial epicondyle) would hesitate in a more difficult (or impossible) work during the anterior phase.
- A more distal incision will increase the risk of injury of the neurovascular structures during surgery.

53.2.2 Posterior Portals

53.2.2.1 Posterolateral Portal

Incision is made on the virtual line between the olecranon apex and the lateral epicondyle with the elbow flexed at 90°. The blade cuts the skin and subcutaneous tissue and reaches the osseous lateral surface of the olecranon fossa.

With a periosteal elevator, the capsule is opened, and, following the bone surface, the trocar falls into the fossa.

Be careful to detach the capsule from its insertion to the humerus to avoid its interference with a good visualisation of the joint.

53.2.2.2 Posterior Central Portal (or Posterior)

The posterior central portal is also referred to as the straight posterior portal or the direct posterior portal. This portal is located in the middle of the triceps tendon, approximately 5 cm proximal to the tip of the olecranon, which is the landmark. The blade is obliquely directed through the

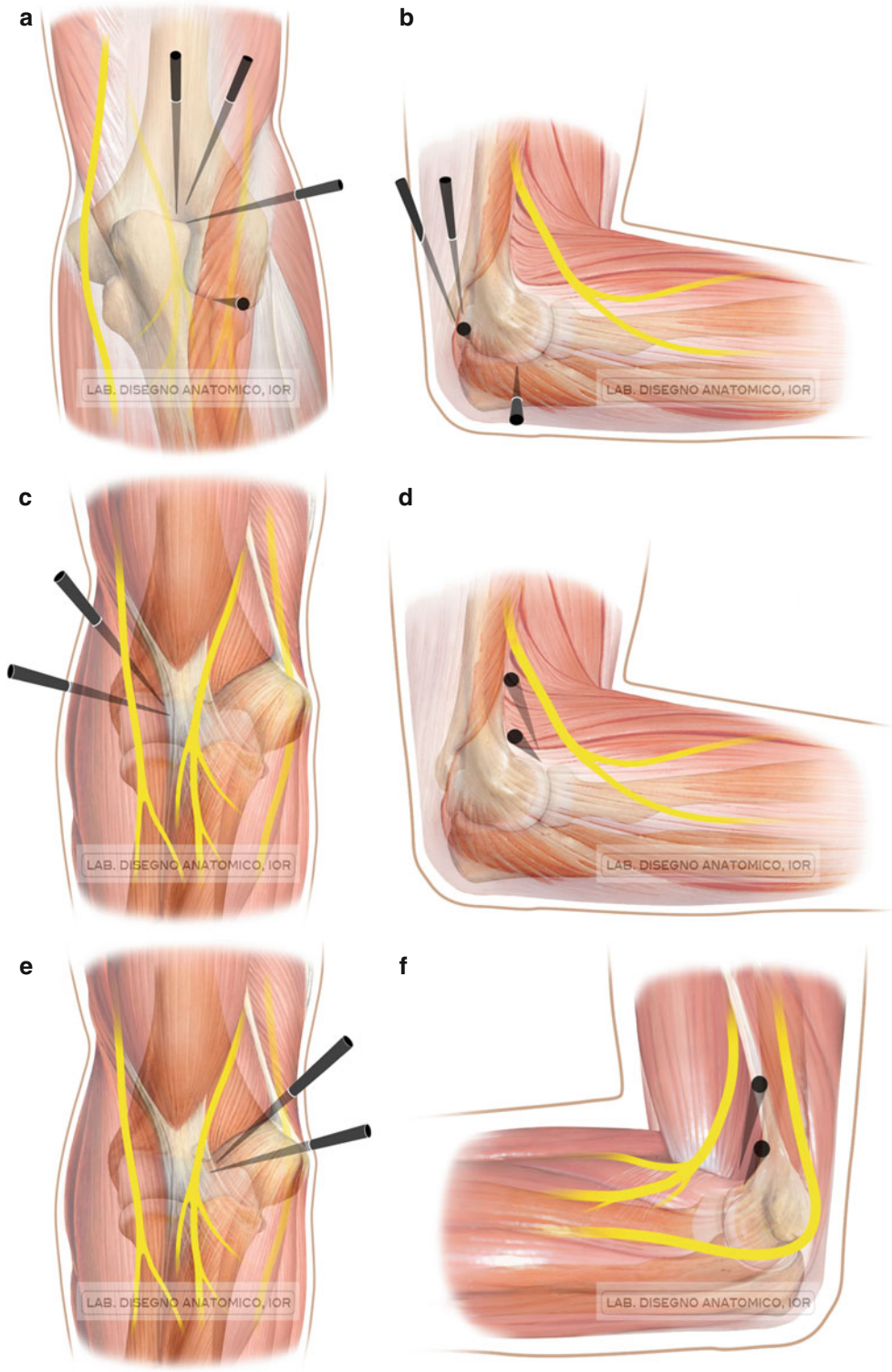

Fig. 53.2 Main arthroscopic portals in the elbow and their connections with nervous and vascular structures: (**a**, **b**) posterior portals (**c**, **d**) anterolateral portals (**e**, **f**) anteromedial portals (Anatomic drawing, Istituto Ortopedico Rizzoli, Bologna)

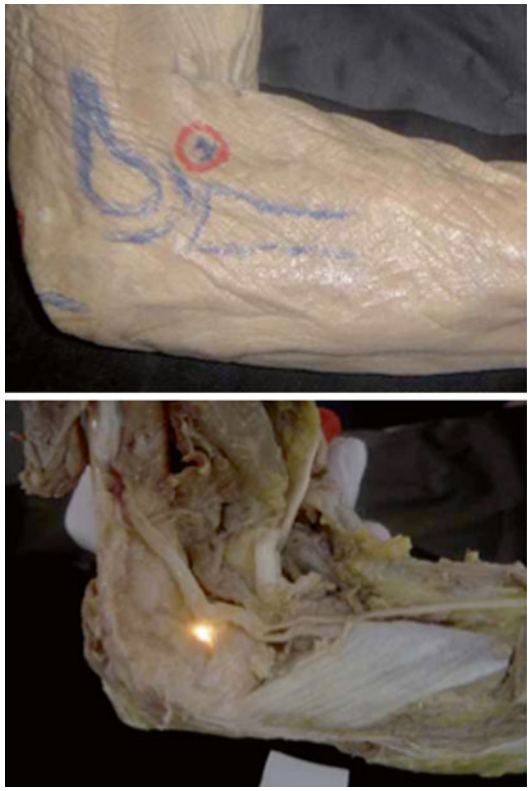

Fig. 53.3 Radial nerve runs very dangerously close to the anterolateral portals, especially if they have been made far from the epicondyle (Anatomic preparation: courtesy of Dr. Fontana, Faenza, RA and Prof. Barquet, Montevideo, Uruguay)

musculotendinous junction of the triceps to the olecranon fossa.

Don't stay too proximal because it will make it difficult to work and see in the olecranon fossa, but neither too close to the olecranon to avoid the incomplete visualisation of the medial and posterolateral gutter.

53.2.2.3 Mid-lateral Portal

This portal is located in the soft spot of the elbow; the soft spot is the centre of the capsular triangle among olecranon, radial head and lateral epicondyle.

Keeping the elbow flexed at 90°, find the radial head, which represents the landmark. Keep in mind to make this portal in a way you can feel comfortable to use the instruments in parallel with the radial head.

To find out the right position of the portal, the out-in exploration with a needle is really advisable.

It is useful to tilt the starting instruments (a Klemer for the divarication and then a smoothed switching stick) towards the posterior radio-ulnar joint, to decrease the risk of damages at the radial humeral cartilage.

Fortunately the elbow has several subcutaneous landmarks, helpful to minimise risks, but neurovascular injuries are a primary concern with elbow arthroscopy and can occur with any of the described portal sites.

To avoid that the surgeon should:

- Know very well the regional anatomy and where the structures are (and where not).
- Use the anatomical landmarks to decide the right portal position (the standard metric reference system can be misleading because of the different patient sizes).
- Study the CT scan and MRI images to decide which portals will be more useful.
- Cut just the skin to avoid the sensitive superficial nerves.
- Perform the portal with a pointed (but not sharp) switching stick before introducing the instruments.
- Make all portals he/she needs to reach every different part of the joint. Anterior and posterior portals described above are routinely performed. Accessory portals are chosen case by case to work better and safely.

53.3 Surgical Technique

- Place the patient in lateral or prone position with a small-size dedicated arm holder.
- The tourniquet is set at the proximal part of the arm. It helps to avoid a skin sore on the holder.
- The affected arm has to be free to be removed and put back on the holder as well as the elbow flexed and extended during the surgery.
- The anatomical landmarks are marked (Fig. 53.4).
- Through a 2–4-cm skin incision, the ulnar nerve is easily identified and protected for a safer posterior phase (when the nerve is

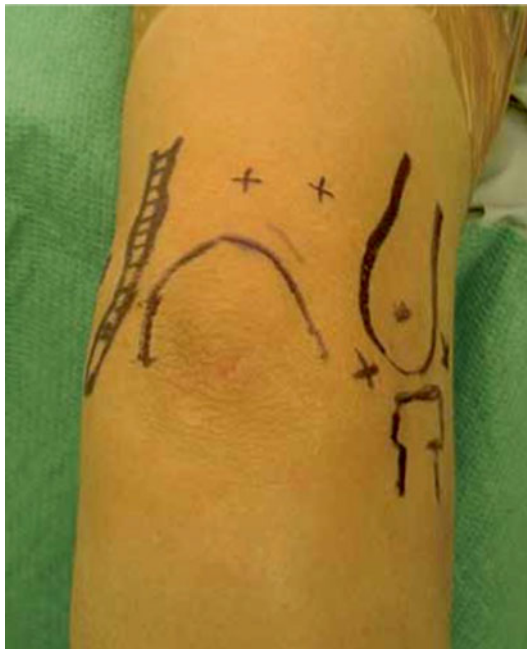

Fig. 53.4 Anatomic landmarks. Clearly visible are the lateral and the medial epicondyle, the apex of olecranon, the radial head and the ulnar nerve path

unstable in the groove or for a less-skilled surgeon). A real dissection is mandatory only in case of nerve compression or during the treatment of elbow stiffness. A larger skin incision will be necessary and could be used also to perform a posteromedial arthrotomy at the end of the surgery if needed.

- Insufflate the elbow joint with 20 mL of saline solution, through the soft spot (inside the joint) or the triceps tendon (in the olecranon fossa). Inflating the capsule increases the distance between the neurovascular structures and the cartilage (but not the capsule) and facilitates the safe entry of the instruments.

Elbow arthroscopy can be divided in two steps: an anterior and a posterior step.

When you need to perform both, it is left to the surgeon's preference to decide which one to perform first.

Usually we start with the exploration of the anterior compartment, and then we go posterior, but it is advisable to start from the more challenging compartment.

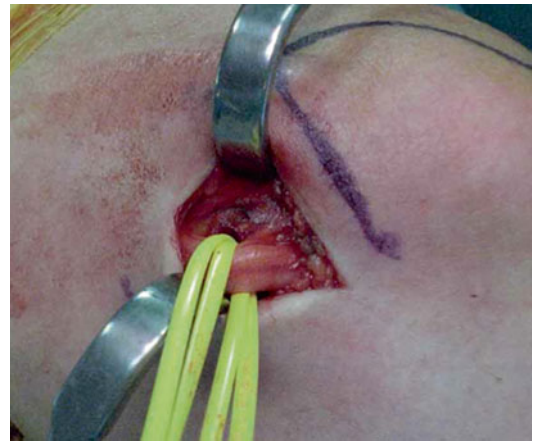

Fig. 53.5 Simple dissection with a small skin incision over the cubital tunnel

53.3.1 Anterior Step

Arthroscopic triangulation between the camera and the instruments can be tricky at the beginning and needs an adequate training [12].

Special attention must always be paid to the regional anatomy because nerve injuries are more common here than in the posterior compartment.

- Cut the skin of the anteromedial portal (starting from the anterolateral portal is possible but is more dangerous).
- Use a pointed switching stick, and, following the medial septum, reach the bone and the joint capsule. Remember to remain anterior to the septum and to direct the switching stick from bottom to top, in the radial head direction.
- By the camera inside the anteromedial portal, it is possible to visualise the radial head, the capitellum, the humeral fossa for the radial head and the anterior side of the capsule; by retracting the capsule, the coronoid appears at the sight.
- With the same technique under scope control, the anterolateral portal is made to insert the working instruments.
- Switching the camera and the instruments from anterolateral portal, the anterior chamber exploration is completed looking better at the coronoid process, the ulno-radial joint, the

radial neck, the coronoid fossa of the humerus and the medial side of the anterior capsule.
- An accessory proximal anterior portal (medial or lateral) is really useful to insert an elevator to lift the capsule up. This enlarges the articular space with a low pressure of the inflow solution.
- An elbow flexion around 90–100° makes the surgery easier reducing the tension of the capsule.

53.3.2 Posterior Step

- The scope is entered in the joint through the posterolateral portal, while the instruments through the posterocentral one (these portals could be performed without any risk of a nerve injury).
- The proximal posterolateral accessory portal could be used to insert a posterior elevator to keep the articular space open.
- In this position it is possible to see the olecranon fossa and the tip of the olecranon. The extension of the elbow from 90 to 60° relaxes the triceps and increases the working space.
- Sinking the scope medially, the "medial gutter" will appear.
- To explore the "lateral gutter", it is necessary to put the camera into the posterior central portal and display the tight recess from the top to the bottom.
- The humero-radial joint could be seen pushing forward the scope through the posterolateral portal downwards to the radial head. The probe or shaver will be inserted using the midlateral portal.
- Just occasionally the soft-spot portal can be used for the camera. Even if it's difficult to work in this position because of the narrow space, it's now possible to take a look in the great sigmoid fossa and the ulno-humeral joint.

When the arthroscopy has been completed, we place two suction drains (in both compartments), and we leave them for at least 24 h. The portals are sutured and covered by sterile dressings.

Put the arm in a 90° sling (or in an extension sling after the arthrolysis), applying a light compression.

For the next 24 h, it is recommended to maintain the arm elevated to improve the fluid reabsorption.

53.4 Pearls and Pitfalls

The elbow, as a superficial joint, is more exposed to the infections, just like the knee. So it is better to carry out the antibiotic prophylaxis before the tourniquet insufflation, in order to have high tissue levels of the antibiotic before starting surgery.

The use of a tourniquet is necessary, but it is recommendable to not exceed the pressure of 250 mmHg and 90 min of time to prevent nervous lesions or hypoxic damages.

As neurovascular structures are nearby the portal position, sharp instruments should not be used, but they should just be pointed and smoothed on the top.

Anatomic landmarks change with the movements of flexion and extension, so we suggest not to move the elbow while the instruments are inside the joint [11].

Many portals are described for the elbow arthroscopy, but not all portals are necessary in all surgeries. It is mandatory to know them all, learn it on the cadaver sessions and not lay up on the numbers of portals made because sometimes a change of just few degrees in the instrumental insertion can make the surgery easier.

Always use a low pressure inflow (20–30 mmHg), and let the fluid drain out of the skin incisions to reduce soft tissue swelling and permit a continuous fluid lavage.

Motorised soft-tissue receptors represent a large group of instruments with innate and different characteristics among them. It is important to always use the appropriate cutter, reminding that the use of suction applied to the shaver is dangerous when the capsule is nearby, above all in rheumatic diseases in which this structure is very thin and weak.

Lastly, the radio-frequency ablators are very useful to detach the soft tissues from bones, but

the really high temperature of the tip can easily burn structures directly or by warming up the fluid. So the ablator tip has to be used in proximity of the bone, for short intervals, and better with suction of the head open.

In conclusion, we would highlight that, even if the safety of elbow arthroscopy has dramatically improved, surgeon training and experience are crucial to the success of this procedure. Orthopaedic surgeons should proceed with elbow arthroscopy after appropriate training and, perhaps, working with an experienced surgeon.

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54 Anatomy at Risk, Portals, and Relevant Attentions to Reduce the Risk of Nerve Injury of the Elbow

Paolo Arrigoni, Riccardo D'Ambrosi, Enrico Guerra, and Pietro Randelli

54.1 Introduction

Arthroscopy of the elbow was described for the first time by Burman in 1931 [1], but he defined in the first time this articulation as not suitable for the arthroscopy because of limited joint space. After Watanabe developed smaller arthroscopes in 1971, Ito [2, 3] and Maeda [4] were describing some new accesses. Andrew and Carson [5] in 1985 and Johnson [6] in 1986 were the first to systematically perform arthroscopy of the elbow defining indications and surgical technique. Subsequently, other authors have pointed out the risks of complications with an incidence occurring between 10 % and 20 % of the cases, considerably higher than that found in other joints [7, 8].

P. Arrigoni, MD (✉)
IRCCS Policlinico San Donato,
San Donato Milanese, Milan, Italy
e-mail: arrigoni.p@gmail.com

R. D'Ambrosi, MD
IRCCS Policlinico San Donato,
San Donato Milanese, Milan, Italy

Università degli Studi di Milano, Milan, Italy

E. Guerra
Reparto di Chirurgia della Spalla e del Gomito,
Istituto Ortopedico Rizzoli, Bologna, Italy

P. Randelli, MD
IRCCS Policlinico San Donato,
San Donato Milanese, Milan, Italy

Dipartimento di Scienze Biomediche per la Salute,
Università degli Studi di Milano, Milan, Italy

Over the past 10 years, thanks to Baker, O'Driscoll, Poehling, Altchek, and other authors, elbow arthroscopy has greatly improved and become safer; the diffusion is still limited. Only 1 % of the American surgeons are performing it [7, 9–11]. Arthroscopy of the elbow can be considered a standardized surgical technique which has been proved to be valid and effective if performed with the right method and with suitable experience.

54.1.1 Arthroscopic Anatomy

The elbow is the set of three joints: the ulnohumeral, the proximal radioulnar, and the radiohumeral.

The most important structures are [12, 13]:

- The trochlea and the capitellum, separated from the conoid area which is the borderline between the ulnohumeral joint and radiohumeral joint, the radial fossa and the coronoid fossa anteriorly, and the olecranon fossa posteriorly.
- The radial head, covered with cartilage at the level of the fovea and for three-fourth of its circumference. The remaining "nonarticular" area is uncovered by cartilage and defined as "safe zone." This is a safe area for plate fixation in case of radial head fractures.
- The trochlear notch of the ulna, covered with cartilage in the posterior and anterior portions

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and separated by a central area named bare spot. Due to the great joint congruency, this area can be visualized only in case of laxity from the anterior portals.

- The coronoid that on the medial side presents the sublime tubercle and the insertion of the anterior bundle of the medial collateral ligament.
- The articular capsule that completely surrounds the three joints. The limits of the capsular insertion are essential during arthroscopy to define the working area. The intra-articular space can be divided into an anterior space, a posterior one, and two lateral recesses (medial and lateral gutters). The anterior chamber includes the anterior joint capsule with the anterior bundle of the medial collateral ligament, the distal humerus (coronoid and radial fossa, front of the trochlea, conoid zone, and the front aspect of the capitellum), the radial head with the annular ligament, and the proximal radioulnar joint. The posterior chamber is formed by the posterior capsule, the olecranon fossa with the olecranon process. The medial gutter presents the most medial recess of the posterior capsule, the posterior region of the epicondyle (which is extra-articular and not visible), and the medial border of the olecranon. At this level, close to the capsule is identifiable the ulnar nerve. In the lateral gutter, wider than the medial one, the joint capsule encloses the lateral profile of the olecranon, the posterior aspect of the capitellum with the radial head, and the proximal radioulnar joint, as reinforcement of the joint capsule pass the ulnar bundle of the lateral collateral ligament.
- Medial and lateral collateral ligaments can be identified as arthroscopic capsular thickening and should be respected for their role as primary stabilizers of the elbow; this function is performed mainly by the anterior bundle of the medial collateral ligament and the ulnar lateral collateral ligament. The annular ligament surrounds the radial head keeping it attached to the ulnar sigmoid notch.
- The radial nerve, the ulnar nerve, and the median nerve, together with brachial artery and brachial veins, are the neurovascular periarticular structures most at risk during arthroscopy of the elbow. The ulnar nerve runs very close to the posteromedial side of the articular capsule at the level of the medial gutter. Anteriorly the relationship between surgical access and neurovascular structures is even more critical. Furthermore, the anteversion of the distal humerus (approximately 30°) on the axis of the shaft tends to displace arthroscopic instruments toward the structures at risk.

The median nerve, the brachial artery, and the brachial veins are separated from the joint by the anterior brachial muscle, which represents a limit that has not to be crossed with arthroscopic instruments.

The posterior interosseous nerve is arguably the most exposed to risk of injury for two reasons:

- During portal establishment: the nerve passes close to the anterolateral portal
- During radial head work: the nerve, in its most proximal region, is protected by the brachialis muscle but at the level of the radial head is separated from the joint capsule only by a thin layer of adipose tissue (Fig. 54.1).

54.2 Portals and Structures at Risk

Various portals are required to perform adequately and safely elbow arthroscopy. These underwent several changes over the years (Table 54.1, Fig. 54.2).

The anterolateral portal described by Andrews [5] was 2 cm anterior and 2 cm distal to the epicondyle. This portal has been shown to be dangerous due to the proximity to the radial nerve and should be considered abandoned.

It's possible to divide surgical accesses as follows:

- Posterior portals
- Anterior portals
- Accessory portals

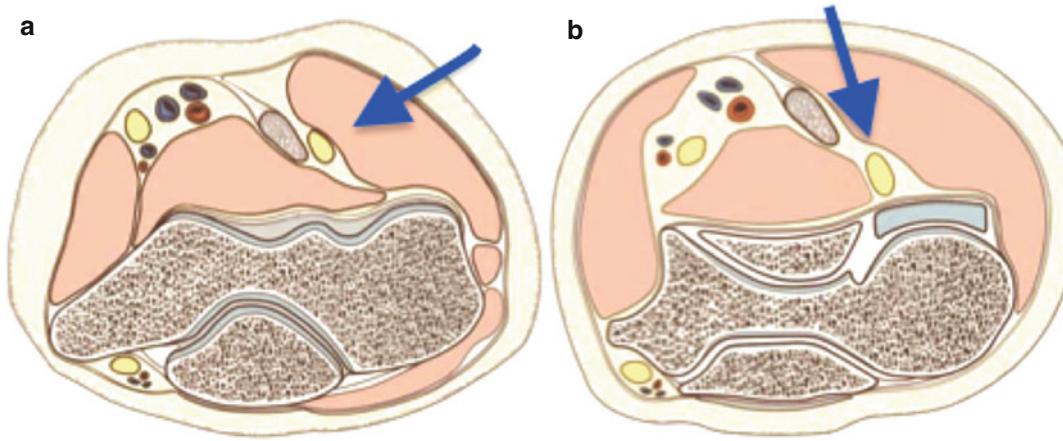

Fig. 54.1 (**a**, **b**) Anatomical drawing: axial section at two different levels of the trochlea. Proximally the radial nerve is protected from the brachial muscle, while distally, it is separated from the joint capsule only by a thin adipose layer

Table 54.1 Arthroscopic portals

Portals	Landmark	Indicative position	Structures at risk
Posterior portals			
Postero-central	Olecranon apex	3–5 cm proximal	None
Posterolateral	Olecranon apex	2 cm lateral	None
	Soft spot	2 cm proximal	
	Epicondyle		
Midlateral	Radial head	Soft spot	Articular cartilage
Anterior portals			
Anterolateral	Epicondyle	2 cm proximal and 2 cm anterior	Radial nerve
Anteromedial	Medial epicondyle	2 cm proximal and 2 cm anterior	Median nerve
			Median artery
Accessory portals			
Posterolateral proximal	Triceps	3 cm lateral to postero-central portal	None
Lateral	Radial head	Joint line	Articular cartilage
Anterolateral proximal	Epicondyle	3–5 cm proximal to anterolateral portal	Radial nerve
Anteromedial proximal	Medial epicondyle	3–5 cm proximal to anteromedial portal	Median nerve
			Brachial artery

While the anterior and posterior portals are performed routinely, the accessories portals are chosen according to requirements; nevertheless they are of equal importance to standard portals, as they are often crucial to complete the surgical procedure or in any case to perform it with greater ease.

Given the complexity of topographic anatomy of the elbow, care must be taken in the portal creation:

- Being familiar with the anatomy and knowing where it's possible to find the structures to be respected.
- Following anatomical landmarks: measuring the landmarks "in centimeters" can be misleading due to the different size of patients. Anatomical landmarks to correct making the incisions are much more precise.

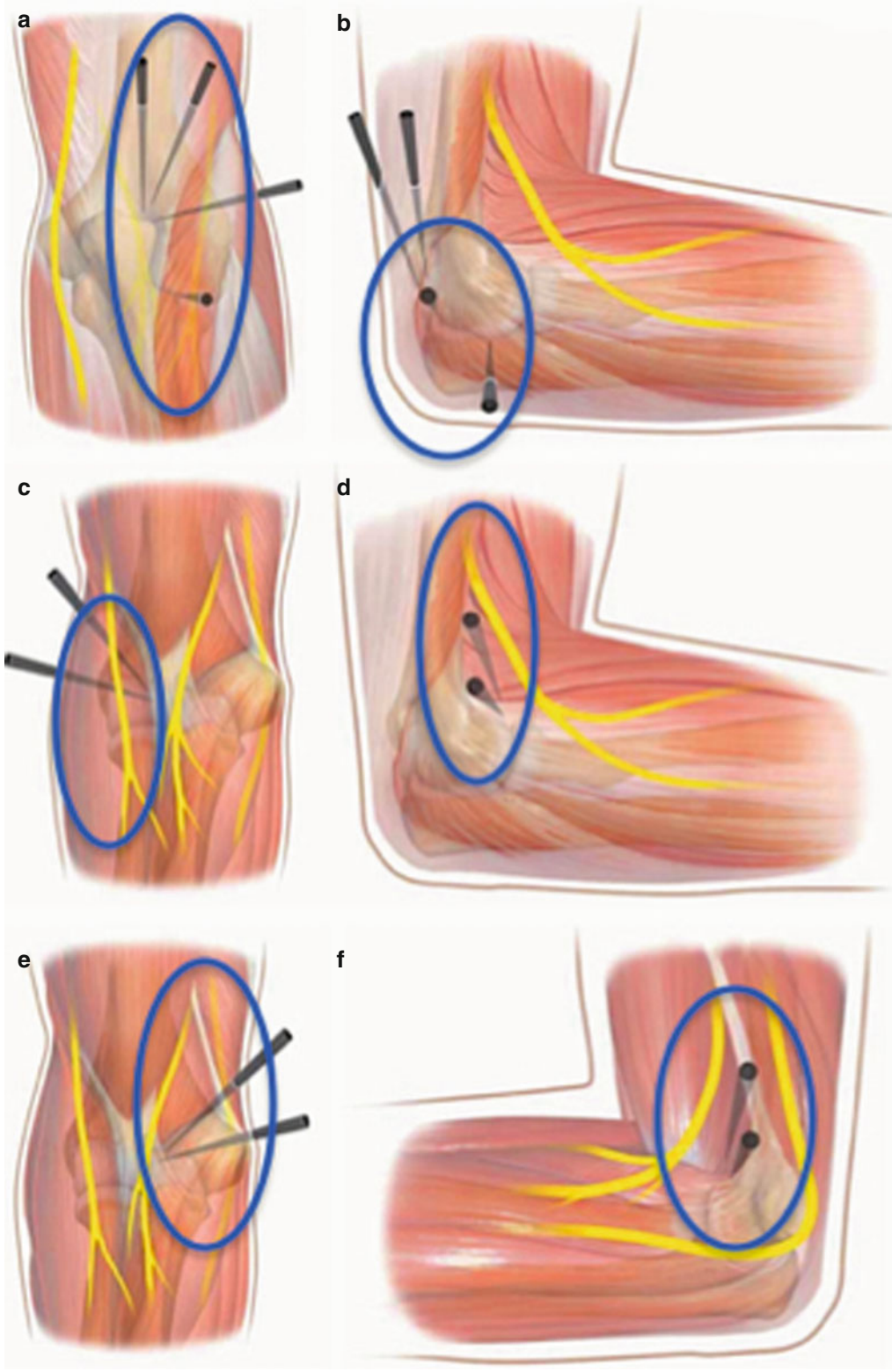

Fig. 54.2 Anatomical drawing. Main arthroscopic portals (**a**, **b**) posterior portals (**c**, **d**) anterolateral portals (**e**, **f**) anteromedial portals

- Studying the images of computed tomography and magnetic resonance to decide where and how many are going to be necessary.
- Incise only the skin with a scalpel to reduce the risk of damaging the superficial sensory nerves.
- Create portals with instruments that are not sharp. There are tools of different diameter that can be used as progressive distractors for the portal establishment.

54.3 Posterior Portals

54.3.1 Posterolateral Portal

The incision is performed on a virtual line drawn between the apex of the olecranon and the epicondyle with the elbow flexed at 90°. With the blade, full-thickness skin, subcutaneous tissue, and soft tissues are cut to reach the bone surface of the side part of the olecranon fossa. By blunt dissection the capsule is perforated, following the bone margin, up to "fall" into the olecranon fossa. Care must be taken to pierce the capsule at its insertion into the humerus, to avoid interference with arthroscopic viewing.

54.3.2 Posterior Portal

The landmark is the upper edge of the olecranon, at flexed elbow. The incision is performed approximatively 5 cm proximal, centrally to the triceps tendon. The blade is sank longitudinally through the tendon and distally in the direction of the olecranon fossa. After the blade has been removed, the portal must be expanded, with a blunt instrument, following the surface of the bone distally to pierce the capsule to enter into the olecranon fossa. A too proximal portal will make it difficult to work/see in the olecranon fossa, while if it's too close to the olecranon there won't be full view of the posterolateral and posteromedial gutters.

54.3.3 Midlateral Portal

This is the accessory portal performed in the soft spot of the elbow. To create this portal, it's necessary to identify the radial head, with the elbow flexed at 90°. It's mandatory, the exploration with a needle, to search for the correct inclination, which should be performed in order to enter the tools parallel or slightly inclined respect to the radial head. A useful tip is to enter toward the radioulnar joint instead of the radiocapitellar one, to reduce the risk of iatrogenic injury to the articular cartilage.

54.4 Anterior Portals

54.4.1 Anteromedial Portal

The reference is the medial epicondyle, which is easily appreciated subcutaneously. The skin can be cut 2 cm anterior and 2 cm proximal to this reference, but this is variable depending on the dimension of the patient. Incising only the skin with a blunt instrument, it's important to "feel" the medial intermuscular septum and gently follow it on the front surface of the humerus. At this point, the front surface of the humeral epiphysis brings the instrument into the joint, toward the radial head. It's fundamental not to pierce the intermuscular septum as the risk is to encounter the ulnar nerve (the nerve identification makes this portal safer). The same care must be used passing as close as possible to the bone surface, to pass under the brachialis muscle, which protects against iatrogenic lesions, the median nerve, and vascular structures.

54.4.2 Anterolateral Portal

Taking as a reference the lateral epicondyle, the technique is the same as the anteromedial portal; in this case the surgeon will have to look for the coronoid instead of the radial head. It is probably the most dangerous portal to the close proximity of the radial nerve/posterior interosseous nerve to the joint capsule. For this reason, we recommend to perform this portal with an out-in technique, controlling the position from the anteromedial portal.

For both anterior portals:

- A proximal incision (close to epicondyles) will make it difficult (and sometimes

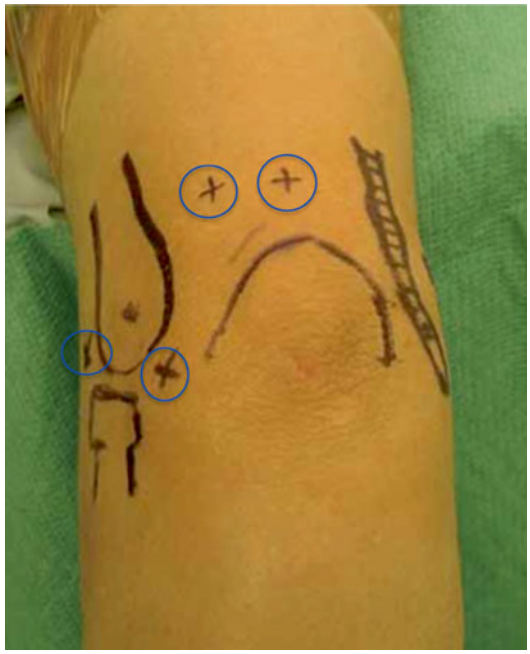

Fig. 54.3 Anatomical landmarks: the epicondyle, the medial epicondyle, the apex of the olecranon, the radial head, and the course of the ulnar nerve

impossible) to get in articulation and view/work into the anterior joint.
- A distal incision on the lateral side will make the portal more dangerous for iatrogenic neurovascular injury [14].

54.4.2.1 Surgical Technique

- Drawing the anatomical landmarks (Fig. 54.3).
- Identify and protect the ulnar nerve to make the posterior arthroscopy safer. A proper neurolysis is performed only when the ulnar nerve is compressed or before an arthroscopic release in case of stiffness. In these cases, the skin incision may be used for an arthrotomic posteromedial accessory access (Fig. 54.4).
- Inject of 20 cc of sterile saline through the soft spot or through the triceps.

Arthroscopy of the elbow can be schematically divided into anterior and posterior phases, and there is no agreement about what space to address first.

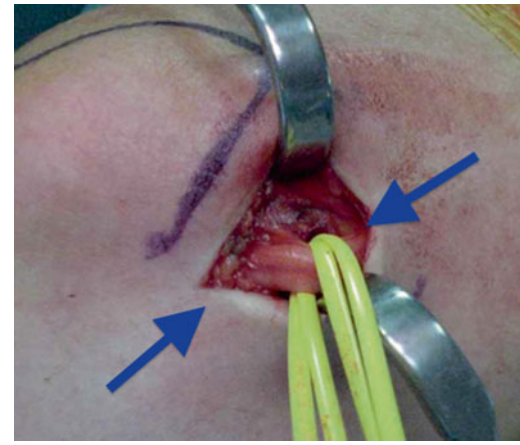

Fig. 54.4 Isolation with little incision in the shower epitrocleo-olecranon

54.4.2.2 Tips and Tricks in Posterior Arthroscopy

- Posterolateral access for the arthroscope and posterior for instruments.
- Visualization of the posterior chamber with the olecranon and its relative fossa: extending the elbow from 90 to 60°, the triceps is released and the working space increased.
- Insertion of the arthroscope into the posterior portal to view from the top the medial gutter as it's a narrow recess.
- Radioulnar joint and the back of the radial head can be visualized by placing the arthroscope in the posterolateral portal and performing a new portal (usually portal midlateral or "soft-spot" portal).

54.4.3 Anterior Arthroscopy

Triangulation between the arthroscope and instruments into the anterior chamber is particularly difficult and requires adequate training. Care must be taken to dangerous neurovascular anatomy so that this surgical procedure requires more skills than the posterior one.

- Incise only the skin of the anteromedial portal (it's possible to start from the anterolateral portal, and then reverse the sequence).

- By blunt dissection, follow the medial intermuscular septum, and follow the bony surface that guides instruments to the joint capsule.
- Just passing the skin, the instruments must be routed from the bottom upwards and in the direction of the radial head (a switching stick may be suitable for the purpose).
- Placing the arthroscope into the joint through the portal, it's possible to view the full radial head, the capitellum, and the lateral joint capsule; to view the coronoid it is necessary to retract the arthroscope; the vision at this stage is difficult since it is easy to get out from the joint.
- With the same technique, perform the anterolateral portal.
- Switching the position of the arthroscope and instruments, the anterior compartment is now fully explored. With the vision of the anterolateral portal, the coronoid, the coronoid fossa, and the anteromedial surface of the articular capsule are evaluated.
- It is always useful to perform at least one accessory proximal portal (medial or lateral) and position a retractor that keeps the joint capsule distended, improves the visualization, and allows working more safely.
- Anterior chamber is facilitated by 90–100° of elbow flexion.
- Ulnar nerve transposition is performed only if necessary. Arthroscopic portals are sutured and then covered with sterile medication. The arm is wrapped with an elastic bandage and generally placed at 90° (in extension after arthrolysis) following surgery.

The elbow, being a superficial joint, is more exposed to infections and is therefore recommended to perform preoperative antibiotic prophylaxis before inflating the tourniquet, so that antibiotic is diffused into the blood flow during surgery. Skin incisions do not always heal by primary intention, with prolonged loss of serous fluid for days after surgery. This complication is much less common if suture of the wounds is performed, rather than with simple medications left in place. The use of tourniquet is necessary in this type of surgery. Given the proximity of the arthroscopic portals to the vascular and nerve structures of the arm, the instruments used to perform the portals must be blunt.

Not all portals are always needed, but be prepared whenever surgical difficulties show up.

Inflow pressure is not supposed to keep the joint expanded as in the shoulder: The use of retractors helps to maintain the arthroscopic pressure (20–30 mmHg) at low levels and allows the water to drain out of the portals.

Suction applied to the shaver can be dangerous every time it is used through the anterolateral joint capsule, close to the radial nerve, in particular in case of rheumatoid arthritis as the capsule is particularly weak and thin.

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Arthroscopic Treatment of Elbow Synovial Chondromatosis

55

Joseph Pooley

55.1 Diagnosis: Clinical

Synovial chondromatosis is a rare, essentially benign, affectation involving the synovial membrane of joints, bursae and tendon sheaths.

The condition was first described in 1558 in the knee joint [1], the joint most often affected. Involvement of the elbow joint was first reported in 1918 by Henderson [2], and since then, synovial chondromatosis has been reported to affect nearly all peripheral joints [3–9]. It is characterised histologically by the development of chondromatous nodules within synovial membrane which then calcify and/or ossify. In an intra-articular location, these nodules may then become detached and form loose bodies. Although much has been written about the condition, the aetiology remains unknown, and even the definition and diagnostic criteria remain unclear [10]. Furthermore, there is no agreed nomenclature, and the terms 'synovial chondromatosis', 'synovial osteochondromatosis' and even simply 'chondromatosis' [11] continue to be used to indicate the same condition. We prefer to use the term synovial chondromatosis as this most accurately describes the development and growth of cartilaginous bodies within synovial membrane, the fundamental pathological change which characterises this condition. Fisher in 1921 published his study of cartilaginous or osteocartilaginous loose bodies in joints in which he concluded that these developed from a proliferative disorder of sub-synovial soft tissues [12]. Henderson and Jones reviewed the literature and reported the Mayo Clinic experience in 1923 [13]. They concluded that primary synovial chondromatosis (PSC) is a separate entity from traumatic or degenerative loose body formation in that the loose bodies in PSC originated by metaplasia from a nidus in the synovial tissue.

More recently in 1977, Milgram [14] studied 30 cases of PSC clinically and pathologically and recognised three separate phases [14]. He described an initial phase of active intrasynovial disease only with no loose bodies, a transitional phase with active synovial proliferation and free loose bodies and an end phase in which there are multiple free osteochondral bodies but no demonstrable residual intrasynovial disease. For a diagnosis of PSC to be confirmed, a distinction must be made between this and other conditions in which inflammation of the synovial membrane and loose body formation occur. The commonest of these other conditions by far is osteoarthritis, but this also occurs as result of trauma or osteochondritis dissecans. The development of synovitis and loose bodies occurring in association with these other conditions is termed 'secondary synovial chondromatosis', which also perhaps adds to the lack of clarity. The essential histological distinction between PSC and secondary synovial

J. Pooley
Queen Elizabeth Hospital,
Gateshead, Tyne and Wear, UK
e-mail: pooleyjoseph@btconnect.com

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chondromatosis is that in PSC, relatively cellular cartilage nodules can be seen to form directly by metaplasia of subintimal synovial tissue, whereas in secondary synovial chondromatosis, hyaline cartilage is found embedded within loose bodies or in the synovial membrane [15]. A diagnosis of secondary synovial chondromatosis would be further confirmed by recognising the presence of an underlying condition likely to give rise to hyaline cartilage debris such as osteoarthritis. Milgram found that PSC is a self-limiting process which runs a rather predictable course corresponding to the pathological changes, usually beginning with pain on movement of the involved joint during the initial phase disease. Mechanical symptoms, locking or catching, then develop in the later phases as a result of loose body formation. The numbers of patients in the reported series of PSC involving the elbow joint are small [6, 8, 10, 14, 16–19], and consequently, it is not possible to identify clinical features normally present in a typical case which would then enable the diagnosis to be made on clinical grounds alone with confidence.

The largest reported series by far to date of histologically confirmed PSC involving the elbow is that of Mueller and his colleagues in 2000 who reported 12 cases [20].

Kamineni and colleagues in 2002 reported 12 cases of synovial 'osteochondromatosis' of the elbow, but of these, only 7 were considered on histological grounds to be primary, and 5 were secondary synovial chondromatosis [10].

Both series identified a male/female ratio of 5:1. In the series reported by Mueller et al., the average age at the time of the initial complaint was 29.6 years (range 19–50 years), the dominant arm was involved in every case, and in 90 % of this patient group, there was a history of strenuous activity involving the elbow joint. This led these authors to conclude that the typical patient was a young male manual worker with pain and locking symptoms in his dominant elbow. They also postulated that because the dominant elbow was involved in most cases, biomechanical stress might be a causal factor in PSC in the elbow. In the series reported by Kamineni et al., the mean age at the time of treatment was 39 years. They also identified a link between this condition and strenuous activity involving the elbow in that the majority of the patients were manual workers with a high-demand recreational lifestyle.

Although these authors noted that the dominant side was affected in only 6 of their 12 patients, it is evident from further analysis of their data that the dominant side was involved in five of their seven patients with primary synovial chondromatosis, whereas the dominant side was involved in only one of their five patients with secondary synovial chondromatosis. Both groups noted that patients had usually tolerated symptoms for some considerable time prior to seeking treatment. Mueller et al., all of whose patients had PSC, noted an average interval of 32 months. The published data therefore indicates that the symptoms of PSC, elbow stiffness, pain and locking, are entirely non-specific, and the range of movement is usually well preserved. However, the gradual development of these symptoms in the dominant arm of an active male in the 30–40 age range should arouse clinical suspicion.

55.2 Diagnosis: Radiological and Arthroscopic

55.2.1 Radiological

Whereas, the clinical features of PSC are entirely non-specific, plain x-ray examination may demonstrate characteristic appearances which enable the diagnosis to be made with a high degree of confidence on radiological grounds alone.

The characteristic radiological appearance of PSC in the elbow is of a 'nest-like' arrangement of round or oval radiopacities demonstrating a finally stippled appearance due to patchy calcification [21]. Pressure erosion of the adjacent bone cortex caused by the bulky synovium is seen in approximately 10 % of patients [18] (Fig. 55.1). Whereas in PSC loose bodies are more usually confined to the anterior compartment of the elbow joint [20], it has been found that in osteoarthritis, loose bodies are more frequently found in the posterior compartment [22]. This is therefore helpful in distinguishing PSC from

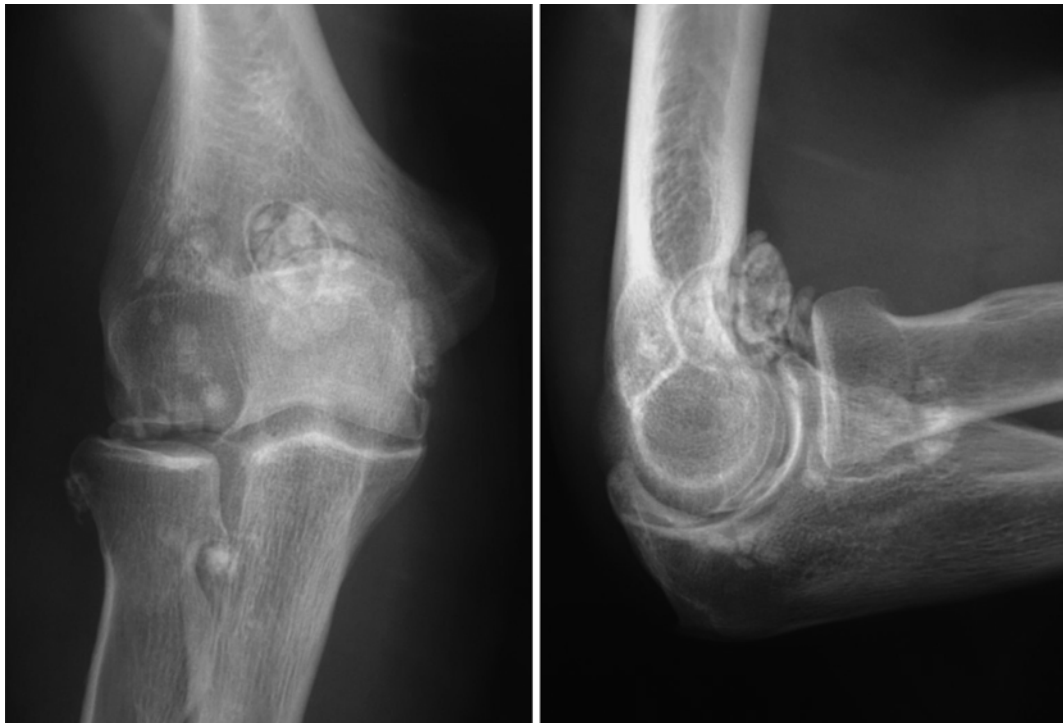

Fig. 55.1 AP and lateral radiographs of the right (dominant) elbow or a 37-year-old manual worker with an 18-month history of pain and locking demonstrating characteristic appearances of primary synovial chondromatosis (PSC). The 'loose bodies' are mainly confined to the anterior compartment. Pressure erosion of the anterior humeral cortex can be seen in the lateral projection

osteoarthritis occurring in association with loose body formation, which is the most common cause of secondary chondromatosis.

Plain x-ray examination also enables PSC to be differentiated from the conditions causing secondary synovial chondromatosis, osteoarthritis, traumatic osteochondral fragments and osteochondritis dissecans, as these have their own characteristic radiological appearances in addition to loose body formation.

It is of course not surprising, considering the initial pathology and subsequent evolution of PSC described by Milgram, that plain radiographs may be normal in patients in the early phases of the disease prior to the formation and subsequent calcification of loose bodies [14]. Whereas radiopaque bodies have been found in approximately 80 % of all cases, these are present in only 54 % of patients in phase 1, compared with 88 % in phase 2 and 100 % in phase 3 of the disease [18]. Nevertheless, plain x-ray examination alone can be expected to enable the diagnosis of PSC to be made in the majority patients and would usually enable this to be distinguished from secondary synovial chondromatosis. Ultrasonography has demonstrated lesions due to PSC which were not detected on plain radiographs [25], as has arthrography, CT and arthro-CT scanning [23] (Kamineni et al.).

It is now likely however that in cases in which there is doubt, these further imaging studies will be superseded by the rapidly increasing interest in elbow arthroscopy.

55.2.2 Arthroscopic Appearances of Primary Synovial Chondromatosis

The naked eye appearance of the synovial membrane excised in florid cases of synovial chondromatosis is well known, and numerous photographs

of excised tissue have been reproduced in the literature [24]. We have however found photographs of only two cases in the literature to date which illustrate the appearance of PSC of the elbow seen during arthroscopy [11, 25]. In one case, multiple loose bodies can be clearly seen, but there is no clear evidence of synovitis indicating that the disease had progressed to the end stage, phase 3 [11]. In the other case [25], the appearances are very similar to those we have found during arthroscopy in our own patients (Fig. 55.2a, b), and we consider therefore that these appearances may be considered to be typical of the transitional phase, phase 2, in which there is active synovial proliferation and free loose bodies. Mueller et al. described the intraoperative appearances as usually presenting a local nest-like arrangement of synovitis and a varying number of loose or adherent bodies which we consider accurately describe the appearances we have found during arthroscopy. We would also agree with these authors that general synovitis of the elbow joint is not a feature of PSC; the area of involved synovium is characteristically localised to one compartment, usually the anterior compartment. However, the area of synovitis may be quite extensive and involve the whole of the compartment, as in the patient whose x-ray is illustrated in Fig. 55.1.

55.2.3 Arthroscopic Appearances of Secondary Chondromatosis

The arthroscopic appearances of a patient with synovial chondromatosis secondary to primary osteoarthritis are illustrated in Fig. 55.3. This patient presented with symptoms of painful locking of the elbow x-ray examination that demonstrated multiple loose bodies in the posterior compartment together with evidence of degenerative change. Arthroscopic examination demonstrated appearances in the posterior compartment which we consider practically identical to those seen in patients with PSC, a nest-like arrangement of synovitis together with a number of loose or adherent bodies. Arthroscopic examination however also revealed full-thickness loss of the articular cartilage from the radiocapitellar joint surfaces together with synovitis in both the lateral and anterior compartments of the joint. This would therefore indicate that this is a patient with synovial chondromatosis secondary to osteoarthritis. We have identified no specific features of an area of synovial chondromatosis seen during an elbow arthroscopy which would enable PSC to be differentiated from secondary synovial chondromatosis.

Other intra-articular conditions can however be either confirmed or excluded by arthroscopy

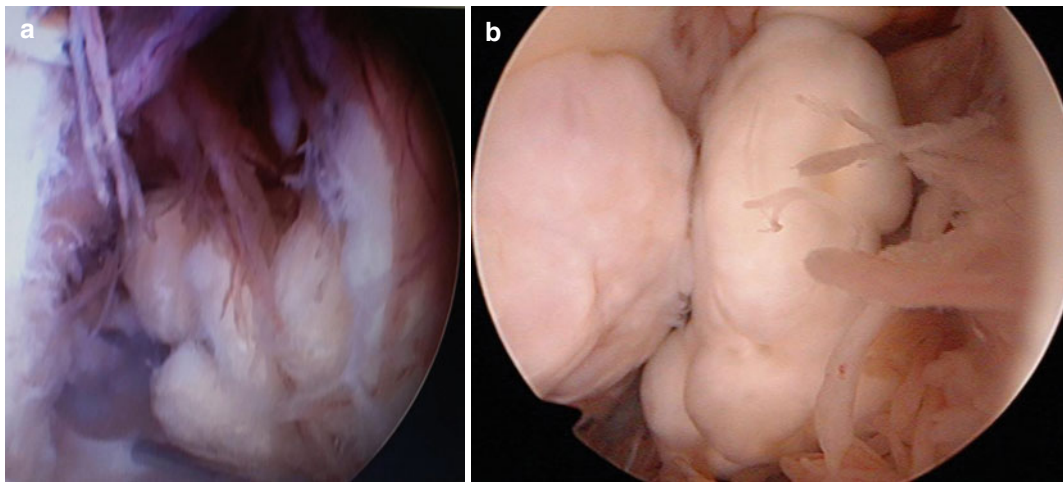

Fig. 55.2 (**a**, **b**) Arthroscopic appearances of primary synovial chondromatosis (PSC) in the anterior compartment of the elbow in two patients. Note the 'nest-like' appearance of multiple loose bodies and synovitis. (**a**) demonstrates the appearances seen during arthroscopy of the patient whose x-ray is shown in Fig. 55.1

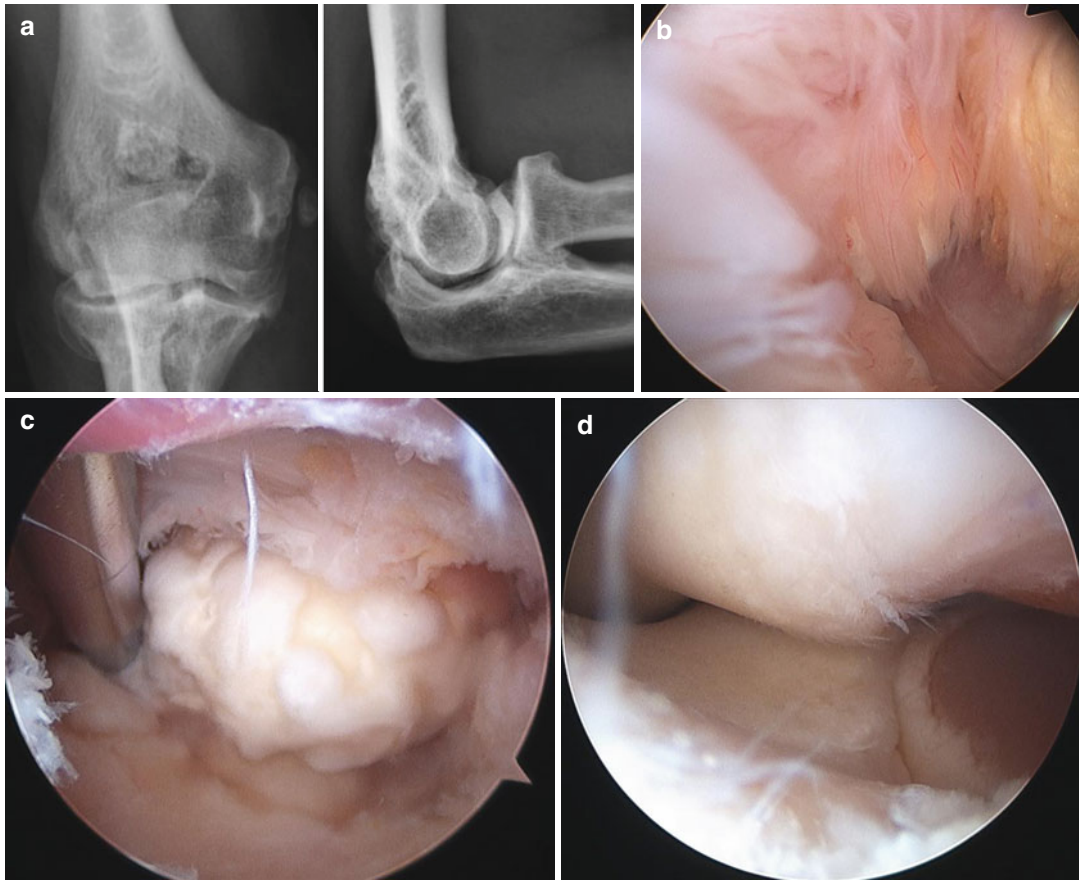

Fig. 55.3 (**a**–**c**) Secondary synovial chondromatosis. (**a**) AP and lateral radiographs of the right dominant elbow of a 49-year-old male patient. Multiple loose bodies can be seen in the posterior compartment more clearly on the AP projection. (**b**) Arthroscopy of the posterior compartment revealed a nest-like arrangement of multiple loose bodies and synovitis similar to the appearances of PSC. (**c**) Synovectomy of the posterior compartment is being performed prior to removal of the loose bodies. (**d**) The elbow joint viewed through a posterolateral portal revealed well-preserved humeroulnar joint surfaces but full-thickness loss of articular cartilage from the radiocapitellar joint, which is characteristic of osteoarthritis

which therefore enables the diagnosis to be established. A diagnosis of either PSC or secondary synovial chondromatosis can then be confirmed by histological examination of the synovial membrane excised during arthroscopy.

55.3 Indications for Treatment

We consider that symptoms of synovial chondromatosis can be grouped as inflammatory, mechanical and due to pressure effects. The development and progression of inflamed synovial membrane may cause joint swelling and restriction in the range of movement, particularly extension. Loose body formation then results in the development of mechanical symptoms, catching and locking. Episodes of locking can be extremely painful, and it is these symptoms which often result in patients presenting for treatment. The pressure effects of an increasing volume of synovium together with the development of loose bodies can by itself cause intrusive pain.

Neurological symptoms may also develop due to the effects of pressure on adjacent nerves, particularly the ulnar nerve [10], although lesions of the post-interosseous and median nerves have been reported [26, 27]. Malignant transformation

of synovial osteochondromatosis to chondrosarcoma has been reported [28]. This is however extremely rare, and the risk of malignant transformation would therefore not by itself constitute an indication for surgical treatment in patients with otherwise mild, tolerable symptoms. Although the symptoms of synovial osteochondromatosis may be relatively mild in its early phases, surgical treatment becomes indicated when symptoms become increasingly intrusive. Episodes of painful locking particularly when these compromise normal day-to-day activities, manual work or the ability to take part in active sports are a definite indication for surgical treatment.

Increasing limitation of elbow movement due to progression of associated degenerative changes is a relative indication for surgical treatment. The development of neurological symptoms would of course constitute a definite indication for surgical treatment, although this may require a combination of arthroscopic surgery and open surgical decompression of the involved nerve.

55.4 Surgical Technique

We routinely carry out the procedure under general anaesthetic. The patient is placed in the lateral decubitus position with the involved upper limb flexed over a padded arm support which allows access to both the anterior and posterior aspect of the elbow. A pneumatic tourniquet is applied; the upper limb is exsanguinated, prepared and draped. In addition to identifying the bony landmarks, the epicondyles, point of the olecranon and radial head, it is important to palpate the ulnar nerve and confirm that this has not been transposed. Anterior transposition of the ulnar nerve would preclude using a medial portal. We use the standard arthroscopic portals, midlateral, anterolateral, posterolateral and medial. We have also found an accessory lateral portal [29] to be very helpful for synovectomy and removal of loose bodies from the lateral compartment. It is important to distend the joint prior to making an entry portal as this both facilitates introduction of the arthroscope sheath and trocar through the capsule into the joint cavity and displaces adjacent neurovascular structures away from the surgical field.

We therefore inject saline through the midlateral portal which is located in the centre of the 'soft spot', a triangle formed by the lateral epicondyle, subcutaneous olecranon tip and radial head. Usually, the joint is filled by injecting 20–30 mL of fluid at which point the elbow can be seen to passively extend a few degrees (Fig. 55.4).

It is much easier (and safer) to introduce an arthroscope into the anterior compartment of elbow at the beginning of the procedure when the joint is fully distended with saline. We therefore establish an anterolateral portal as our initial portal and complete any surgery required in the anterior compartment before proceeding to carry out arthroscopy of the posterior and lateral compartments. It is helpful to verify the position of an anterolateral portal by inserting a hypodermic needle. The portal is then established by carefully incising the skin and subcutaneous tissues only before inserting the arthroscope sheath and trocar as this reduces the risk of injuring adjacent structures particularly the posterior interosseous nerve. An anteromedial portal is established by driving the arthroscope sheath and trocar across the joint until the tip of the trocar 'tents' the skin and presents subcutaneously. The skin is then incised over the tip of the trocar which is then withdrawn enabling instruments to be guided into the anterior compartment with the arthroscope sheath by using the 'railroad' technique. Although the osteochondral bodies seen on radiographs may appear to be free, this is not usually the case as they often have a synovial attachment (pedunculated) or are embedded within synovial tissue (Fig. 55.5). The procedure is therefore begun by performing synovectomy with a soft tissue resector which frees the osteochondral bodies from their synovial attachments and enables them to be readily removed with grasping forceps. It is occasionally useful to use a high-speed rotating burr in order to reduce the volume of larger loose bodies before extracting these. Complete removal of all of the involved synovium is advisable in patients with PSC as this is likely to reduce the risk of future recurrent

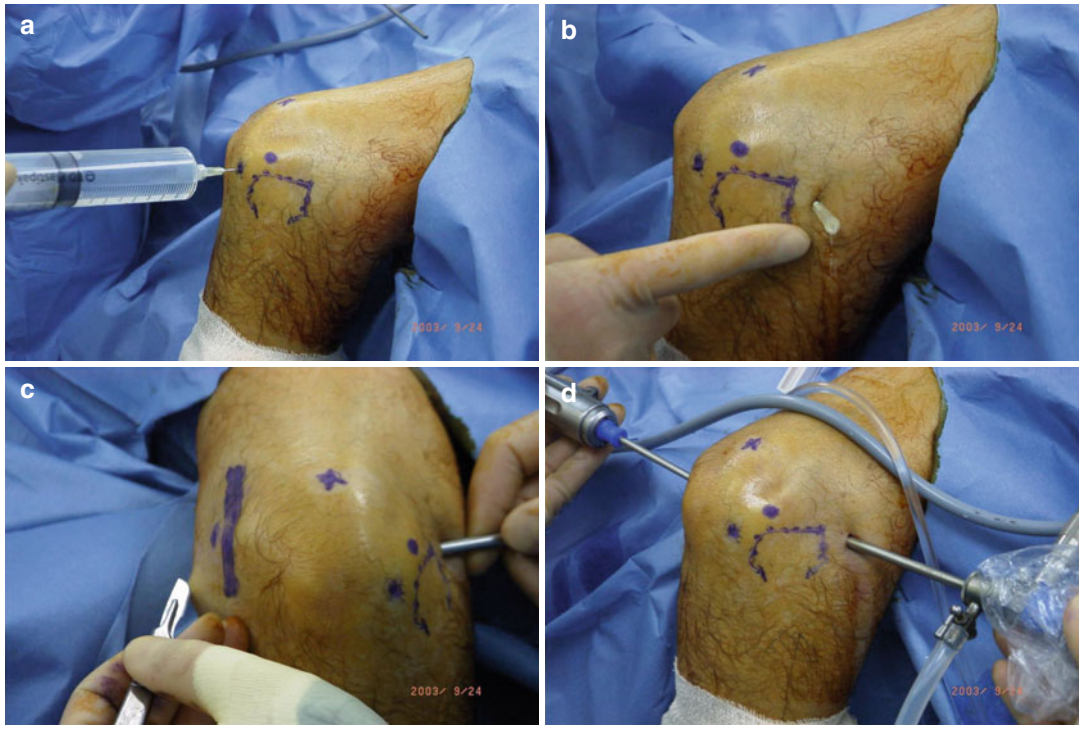

Fig. 55.4 (**a**–**d**) Insertion of an arthroscope and instruments prior to beginning of surgery on the anterior compartment of the elbow. (**a**) The elbow joint is being fully distended with saline injected through a mid-lateral portal. (**b**) Verification of placement of a lateral portal by insertion of a hypodermic needle and observing retrograde flow of a few drops of saline. (**c**) The arthroscope sheath and trocar have been introduced into the anterior compartment and advanced across to the medial side of the elbow joint until the tip of the trocar is in an immediate subcutaneous location. The medial portal is being established by incising the skin over the tip of the trocar. Note that the ulnar nerve has been confirmed to lie in its usual anatomical site posterior to the medial epicondyle, and its position has been clearly marked with a skin marking pen. (**d**) The arthroscope sheath has been used to guide a soft tissue resector into the anterior compartment using a 'railroad' technique; the arthroscope has been inserted and synovectomy is being performed

loose body formation. However, subtotal synovectomy only is required in patients with secondary synovial chondromatosis, sufficient to enable visualisation and removal of all the osteochondral bodies. Additional procedures including anterior capsulectomy, debridement of impinging osteophytes and cheilectomy of the olecranon and coronoid can then be performed in patients with osteoarthritis in order to improve the range of movement. At the end of the procedure, we close the portals with sutures and apply a padded bandage before removing the tourniquet. The bandage is removed 3–4 days post-operatively and supervised active exercises commenced within the limits of post-operative symptoms.

55.5 Complications

The potential advantages offered by the arthroscope for removal of loose bodies from the elbow joint was recognised early, and this in fact was the original indication for arthroscopic surgery of the elbow [30]. Kelly et al. (2001) reported the complications of elbow arthroscopy in 473 patients [31]. Four (0.8 %) developed a complication classified as major (septic arthritis). Minor complications occurred in 11 %, including prolonged portal drainage or superficial infection and transient nerve palsies. They found that rheumatoid arthritis, followed by joint contracture were the two most

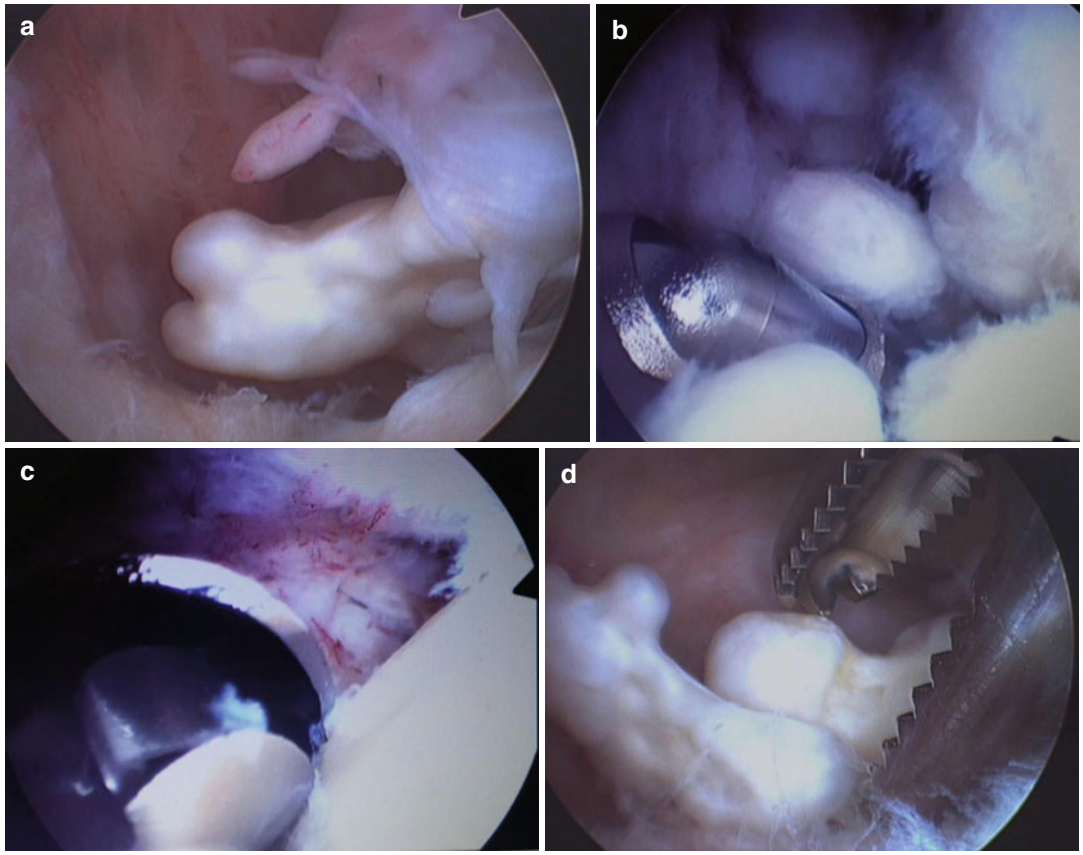

Fig. 55.5 (**a**–**d**) These photographs were taken during the surgical procedure carried out on the patient with PSC whose radiographs are shown in Fig. 55.1. (**a**) A view of the anterior compartment which demonstrates that the 'loose bodies' are often attached to the synovial membrane (pedunculated). (**b**) A soft tissue resector is being used to perform synovectomy and simultaneously 'liberate' the loose bodies prior to their extraction. (**c**) A high-speed burr is being used to reduce the volume of a large loose body. This enabled removal through a standard arthroscopic portal without the need to enlarge it. (**d**) Synovectomy has been completed, and the loose bodies are being removed with grasping forceps

significant risk factors for temporary nerve palsies. We reported the complications in an initial series of 397 patients on whom we had performed arthroscopic elbow surgery, which therefore included our 'learning curve' [32]. We found only one complication which we would regard as major, septic arthritis which responded to antibiotics and joint lavage. Two patients developed transient ulnar nerve neuritis, and one developed a superficial portal infection. One patient developed unexplained olecranon bursitis, but this then resolved spontaneously. No complications following arthroscopic treatment for synovial chondromatosis were reported by the authors of the three largest published series to date [10, 11, 20]. Although Flury and his colleagues had expected to find a larger number of complications, in patients treated by arthroscopy compared with those treated by open surgery, they found that this was not the case. Similarly, we have encountered no complications in our patient population who have undergone arthroscopic synovectomy and removal of loose bodies. We consider therefore that the original potential of elbow arthroscopy for diagnosis and loose body removal has now become established and that this is associated with a low risk of complications.

55.6 Results: Literature Review

Although there are numerous case reports in the literature of individual patients with synovial chondromatosis of the elbow, usually describing an unusual presentation or neurological complication of the condition, there are few reports of the results of arthroscopic surgery in a series of patients. Byrd in 2000 reported treating two patients with synovial chondromatosis of the elbow in whom he removed multiple loose bodies arthroscopically, with good results observed at 2 years follow-up [25]. Although he considered that there were classical manifestations of synovial chondromatosis in each patient, histological examination could not confirm whether this was primary or secondary. Associated degenerative changes were found in one patient, and it seems likely therefore that the condition was secondary in this case.

In the series of 12 patients with histologically proven primary synovial chondromatosis reported by Mueller and colleagues in 2000, eight were treated by arthrotomy with removal of loose bodies and partial synovectomy. In their four most recent cases however, surgery was performed using an arthroscopic technique. The average follow-up interval following surgery was 16 years 10 months (range, 15 months to 36.3 years). These authors reported overall good results with high patient satisfaction. Two patients were pain-free, eight had mild pain on exertion and two had moderate pain on exertion. They commented that primary synovial chondromatosis frequently leads to osteoarthritis which deteriorates with time but, in their patients, seemed to have little impact on activities of daily living. In the retrospective study of 12 patients reported by Kamineni et al. in 2002, the condition was primary in seven patients, four of whom were treated arthroscopically and three by open surgery. In their five patients with secondary chondromatosis, one was treated arthroscopically; the other four were treated by open surgery. These authors found that stiffness associated with primary and secondary synovial chondromatosis responded well to surgery especially with regard to restoring elbow extension. They noted that primary synovial chondromatosis can recur after subtotal synovectomy and that osteoarthritis secondary to synovial chondromatosis appears to progress. They observed a recurrence of symptoms in two of the seven patients with primary synovial chondromatosis and in three of the five patients with secondary synovial chondromatosis. Of the five patients who experienced a recurrence of symptoms, two declined further surgery. One patient in the primary group underwent open synovectomy and anterior capsular release. One patient in the secondary group underwent humeroulnar arthroplasty; the other patient underwent total elbow replacement. In their retrospective review in 2008, Flury and colleagues identified 24 patients who had undergone surgery between 1989 and 2003 following a diagnosis of synovial chondromatosis made on radiological grounds [11]. If there was a recognisable underlying disorder, osteoarthritis or osteochondritis dissecans, the chondromatosis was regarded as secondary. In the absence of an underlying disorder, a diagnosis of PSC was made. An open surgical procedure was carried out in five patients, and an arthroscopic procedure was performed in their more recent 14 patients. Nineteen patients were available for review after a mean follow-up of 56 months (range 11–177 months). These authors reported a good outcome on the whole of this patient group. Pain was significantly reduced and a preoperative extension deficit was remedied. They concluded that there were no true cases of recurrence as loose bodies could not be found on post-operative radiographs. Residual symptoms, pain, locking and swelling were noted in two patients, which they attributed to a moderate degree of osteoarthritis. They found no subsequent development of osteoarthritis in the patients with primary chondromatosis at the time of review; however, they noted a measurable increase in the size of osteophytes in 40 % of the patients with synovial chondromatosis secondary to osteoarthritis They concluded that a patient with secondary chondromatosis can expect relief of symptoms specific to the chondromatosis following surgery, but symptoms of the underlying disorder, osteoarthritis, would persist. They also concluded that contrary to their expectations at

the beginning of their study, they found no increase in the incidence of complications or residual loose bodies in patients who underwent arthroscopic surgery compared with those who had undergone an open procedure. On the contrary, they found that patient satisfaction following arthroscopic surgery was higher than that after open surgery. They postulated that this was probably due to shorter rehabilitation time and better cosmesis following arthroscopic surgery which the patients also perceived as modern and minimally invasive. Kamineni et al. pointed out in 2002 that the few published accounts of synovial osteochondromatosis in the elbow do little to clarify the condition beyond describing the clinical and operative findings [10]. Consequently, the condition affecting the elbow is based on little information. Since then, the only other publication to describe the outcome of arthroscopic treatment in the elbow in a series of patients is that of Flury and his colleagues in 2008 [11]. The conclusions we have drawn from our review of the literature is that there is a clear pathological distinction between primary synovial chondromatosis and secondary synovial chondromatosis. Primary synovial chondromatosis is a disease which begins in the synovial membrane with the development of cartilaginous plaques. These then calcify and/or ossify and cause mechanical symptoms due to interposition between the joint surfaces. Secondary synovial chondromatosis is an accompaniment of osteoarthritis (either primary or secondary) in which the articular cartilage debris (hyaline cartilage) becomes embedded in the synovial membrane causing synovitis and growth of osteocartilaginous bodies which similarly cause mechanical symptoms due to interposition between the joint surfaces. However, the arthroscopic appearances of both primary and secondary chondromatosis appear to be identical.

It is not possible to distinguish between PSC and secondary synovial chondromatosis on clinical grounds alone although the onset of elbow pain and stiffness in the dominant elbow of an active male in the 30–40 year age group is highly suggestive, and the presence of loose bodies particularly in the anterior compartment of the elbow would then practically confirm the diagnosis of PSC. These symptoms occurring in an active male patient over the age of 40 years together with an x-ray demonstrating loose bodies in the posterior compartment of the elbow would practically confirm a diagnosis of secondary chondromatosis. Arthroscopic synovectomy and removal of loose bodies are effective in relieving the mechanical symptoms, particularly painful locking, in both primary and secondary synovial chondromatosis. This does not however prevent the natural progression of established degenerative changes in either condition. Nevertheless, removal of loose bodies and partial synovectomy have been found to be effective in preventing the recurrence of PSC [11, 20]. The association between PSC and osteoarthritis has been reported in the past to be either nonexistent [15] or rare [33]. We however would agree with Mueller and his colleagues who noted that PSC of the elbow frequently leads to secondary osteoarthritis that deteriorates over time. We would also therefore agree with Kamineni and his colleagues who consider that although the histological distinction between PSC and secondary chondromatosis is of little clinical significance with regard to treatment, the development of loose bodies in both conditions does represent a common pathway as an aetiology of degenerative change. In other words, we consider PSC to be one of the causes of the development and progression of degenerative changes in the elbow joint. This is illustrated by our patient with PSC whose x-rays are shown in Fig. 55.1. He had satisfactory relief from symptoms for 5 years following arthroscopy and removal of loose bodies before developing symptoms, including rest pain, a characteristic of osteoarthritis. Arthroscopy then revealed complete loss of articular cartilage from the surfaces of the radiocapitellar joint with well-preserved articular cartilage in the humeroulnar joint, which is the usual pattern of articular cartilage loss in osteoarthritis [34, 35]. We have developed implants for resurfacing the lateral compartment of the elbow, the LRE arthroplasty (Biomet) [36], which we consider particularly appropriate for younger active patients with this pattern of

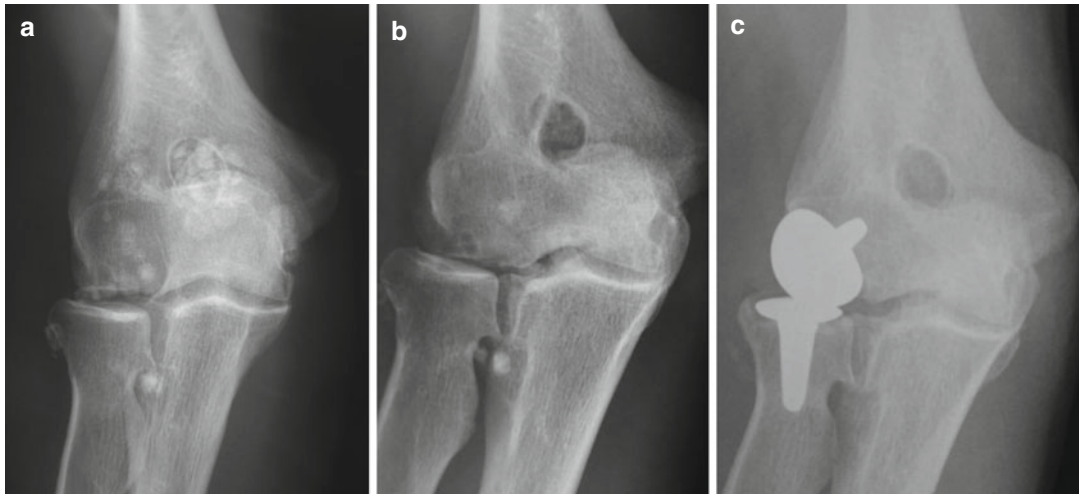

Fig. 55.6 (**a**–**c**) Serial radiographs demonstrating progression of degenerative changes (osteoarthritis) in the patient with PSC whose x-ray is shown in Fig. 55.1. (**a**) AP radiograph prior to arthroscopic synovectomy and removal of loose bodies shown in Fig. 55.5. (**b**) AP radiograph 5 years later during which the patient had been free of mechanical symptoms. He had developed rest pain which was becoming increasingly intrusive and radiological evidence of progression of degenerative changes in the lateral compartment. (**c**) AP radiograph following insertion of a lateral resurfacing elbow arthroplasty (LRE) which relieved his symptoms and enabled him to return to manual work

articular surface degeneration and used these in this case (Fig. 55.6). We have similarly treated two of our patients with secondary synovial chondromatosis due to osteoarthritis whose initial mechanical symptoms were relieved by arthroscopic removal of the loose bodies before they then developed arthritic symptoms, and these patients have subsequently returned to their manual work.

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Lateral Elbow Pain

56

Srinath Kamineni and Domingo Molina

56.1 Diagnosis

The diagnosis of lateral elbow pain can be challenging to the examiner, due to the large number of diagnoses that are geographically located in this region. The lateral elbow can be defined proximally by the lateral aspect of the distal third humerus, distally by the proximal radius (head, neck, and bicipital tuberosity), anteriorly by the lateral trochlea ridge, and posteriorly by the crista supinatoris of the ulna. Of the many pathologies that exist in this region, the common differential diagnoses include lateral epicondylitis, radial/posterior plica impingement, osteoarthritis, loose bodies, fractures, rheumatoid arthritis, instability, and radial nerve entrapment [2, 11].

A thorough history and physical examination is essential in determining the origin of lateral elbow pain. The interview aspect of the patient-doctor interaction is specifically targeted to decipher how a pathology began (acute versus chronic, or acute or chronic). The examiner should pay special attention to history of any unusual or out of the patient's normal routine activities, snapping, clicking, popping, and instability. Sometimes subtle and early pathologies are difficult for the patient to describe, with a more vague symptomatic complaint, e.g., "elbow feels weak and feels like falling when carrying a milk bottle" when lateral elbow instability is encountered early in the pathological progression. The vast majority of diagnoses are achieved in this phase of interaction with the patient, and the "devil is in the detail"! Patients often mention important facts as casual remarks, often overlooked by the nonobservant clinician, but prove to be valuable data. For example, a patient mentioning that the only unusual activity was taking a flight with pain felt when placing a bag in the overhead bin can be interpreted as posterior plica that was compressed in the posterior radiocapitellar articulation, while the elbow was loaded in compression by the bag and further by muscle contractions. Pain with daily activities and sports will give clues to particular pathologies of the lateral elbow. Once a detailed, targeted history is complete, and a differential diagnosis list is formulated, physical examination should be considered a means of corroborating one or more of the differentials. Rarely does a physical examination help to make a diagnosis; instead it helps to confirm and narrow a diagnosis, e.g., a clinical history can point to an elbow instability, and the physical examination will help differentiate between a valgus and posterolateral rotatory instability.

56.1.1 Inspection

Inspection should begin with a general inspection of body habitus, shoulder and elbow position,

S. Kamineni, MBBCh, FRCS-Orth (✉)
D. Molina, MD
Department of Orthopaedics and Sports Medicine, Elbow Shoulder Research Centre (ESRC), University of Kentucky, Lexington, KY, USA
e-mail: SrinathKamineni@gmail.com

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and any muscle wasting or trophic changes of the hand, aspects that are often forgotten and hence should be addressed early. In patients with a complaint of lateral elbow pain, all regions of the elbow should be inspected. Bruises, bumps (Fig. 56.1), scars, discolorations, muscle wasting, or fasciculations should all be considered, both with a static and a dynamically moving elbow. Inspection with the patient flexing and extending the elbow can reveal a loss of active motion, subluxing radial head, locking of the joint due to a loose body, and audible crepitus due to a degenerate articular surface. Special attention should be given to the lateral soft spot, a triangle formed by the radial head, olecranon, and capitellum. Swelling in the soft spot may be indicative of synovial proliferation or joint effusion [8].

56.1.2 Palpation

Every zone of the elbow and lateral elbow should be methodically felt for temperature, lightly palpated for structure identification and pain, and deep palpation only performed at the end of the examination if necessary or diagnostic doubts still exist. Tenderness to palpation over the anterior aspect of the distal lateral epicondyle is indicative of lateral epicondylitis due to ECRB (extensor carpi radialis brevis) involvement, while pain predominantly at the apex of the epicondyle is more likely to involve the EDC (extensor digitorum communis). Pain with palpation may help to differentiate certain geographically close etiologies such as lateral epicondylitis and radial tunnel syndrome or valgus extension overload syndrome from a posterolateral plica. Pain with palpation should also be noted when range of motion is performed, with a differentiation of mid-arc versus end-arc pains. The importance of the latter is that mid-arc pain indicates articular cartilage disintegrity while the latter may be due to abutment of the coronoid/radial head anteriorly in terminal flexion or the olecranon process posteriorly in terminal extension. Crepitus and tenderness to palpation of the radial head and radiocapitellar joint can indicate fracture, OCD, or articular fragmentation [8]. Loose bodies can occur from articular fragmentation in the young athlete with OCD or in older patients with loose bodies associated with arthritis [6].

When suspecting lateral epicondylitis, the extensor carpi radialis brevis (ERCB) must be tested, by direct palpation over the anterior aspect of the lateral epicondyle. Pain with palpation over the apex of the lateral epicondyle is more indicative of the EDC variant of tennis elbow. In lateral epicondylitis, pain will occur over the lateral epicondyle when the examiner tests resisted wrist extension [25]. Lateral epicondylitis can mimic other pathologies such as radial plica impingement or posterior interosseous nerve (PIN) entrapment [20, 24].

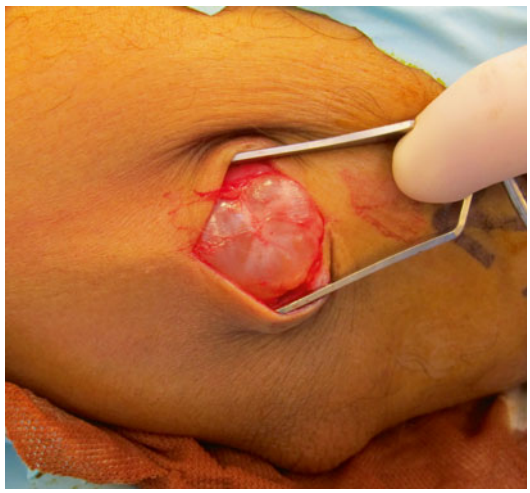

Fig. 56.1 Large lateral painful elbow ganglion, treated with a small open surgery

56.1.3 Arc of Motion

Assessing the arc of motion is critical in diagnosis of lateral elbow pain as well as determining the need for arthroscopic intervention. Flexion and extension of the elbow joint range from about 0° in extension (with the humerus and forearm linearly aligned) to 130–150° of flexion (with anterior soft-tissue contact between the arm and forearm). Longitudinal rotation of the forearm occurs between the proximal and distal radioulnar

joints with an arc of 85° of supination and 75° of pronation [15]. Functional range of axial rotatory motion of the elbow is 50° of supination and 50° of pronation. Loss of functional range of rotatory motion can be indicative of loose bodies, bony malunions, soft-tissue contractures, radiocapitellar osteochondritis, synovitis, and radial head fracture [3].

56.1.4 Stability

Lateral elbow pain can be indicative of joint instability; therefore, stability testing should be a key component during the examination. The most basic testing of instability is carried out with a simple valgus-varus stress test with the elbow in full extension and in 30° of flexion. The lateral ulnar collateral ligament (LUCL) is one of the many static soft-tissue stabilizers of the lateral elbow, in concert with the radial collateral ligament and the annular ligament. Some patients may have a feeling of instability as the elbow is brought from flexion to extension in supination [2]. The lateral pivot shift apprehension test as described by O'Driscoll can be used to assess posterolateral rotatory instability and LUCL incompetence [16]. The patient is placed supine with the arm held overhead. The forearm is supinated and stressed in a varus to valgus motion with axial compression, while the elbow is brought into flexion. If the patient has reproducible symptoms or apprehension, the test is considered positive. Posterolateral subluxation or dislocation of the radius and ulna from the humerus is indicative of posterolateral rotatory instability.

56.2 Exploration

Arthroscopy can be both a diagnostic and therapeutic modality. Imaging is used before instrumentation of the elbow to better assist in diagnosis of lateral elbow pain. Standard AP, lateral, and oblique radiographs can be used to look for bony abnormalities such as fractures, loose bodies, osteophytes, and malalignment. Stress views can be used to evaluate ligament laxity and assess need for further soft-tissue or dynamic imaging.

Magnetic resonance imaging (MRI) can be used to evaluate soft tissues and cartilage. MRI can assess tears of the lateral collateral ligament complex and the extensor carpi radialis brevis muscle. MRI may show a low signal in OCD lesions attached to subchondral bone and a high signal in lesions detached from underlying subchondral bone [23].

56.3 Rating Systems of Relevance

A classification system describes a particular pathology based on its characteristics and provides standardized objective data for diagnosis, treatment, and prognosis. Classification systems for disorders that mimic lateral elbow pain may be of benefit to arthroscopists during diagnosis and treatment.

Acute radial head fracture is an uncommon indication for elbow arthroscopy. Treatment of radial head fractures can be difficult and have potential complications such as pain and loss of elbow function. Classifying radial head fractures can aid in treatment and prognosis. Mason described three types of radial head fractures. Type I fractures are non-displaced fractures of the head or neck; type II fractures are displaced fractures (>2 mm) of the head or neck; and type III fractures are severely comminuted fractures of the radial head [12].

Articular injuries are encountered frequently during diagnostic arthroscopy as well as various imaging modalities. The ICRS developed a standardization system for cartilage injuries and the need for repair. ICRS OCD I lesions are stable with a continuous but softened area of intact cartilage. ICRS OCD II lesions have partial discontinuity but are still considered stable. ICRS OCD III lesions have complete discontinuity but are not yet dislocated (Fig. 56.2.) [7].

Lateral epicondylitis: Three types of pathologic changes in the ECRB tendon in lateral epicondylitis have been described in the literature. Inflammation and fraying of the tendon

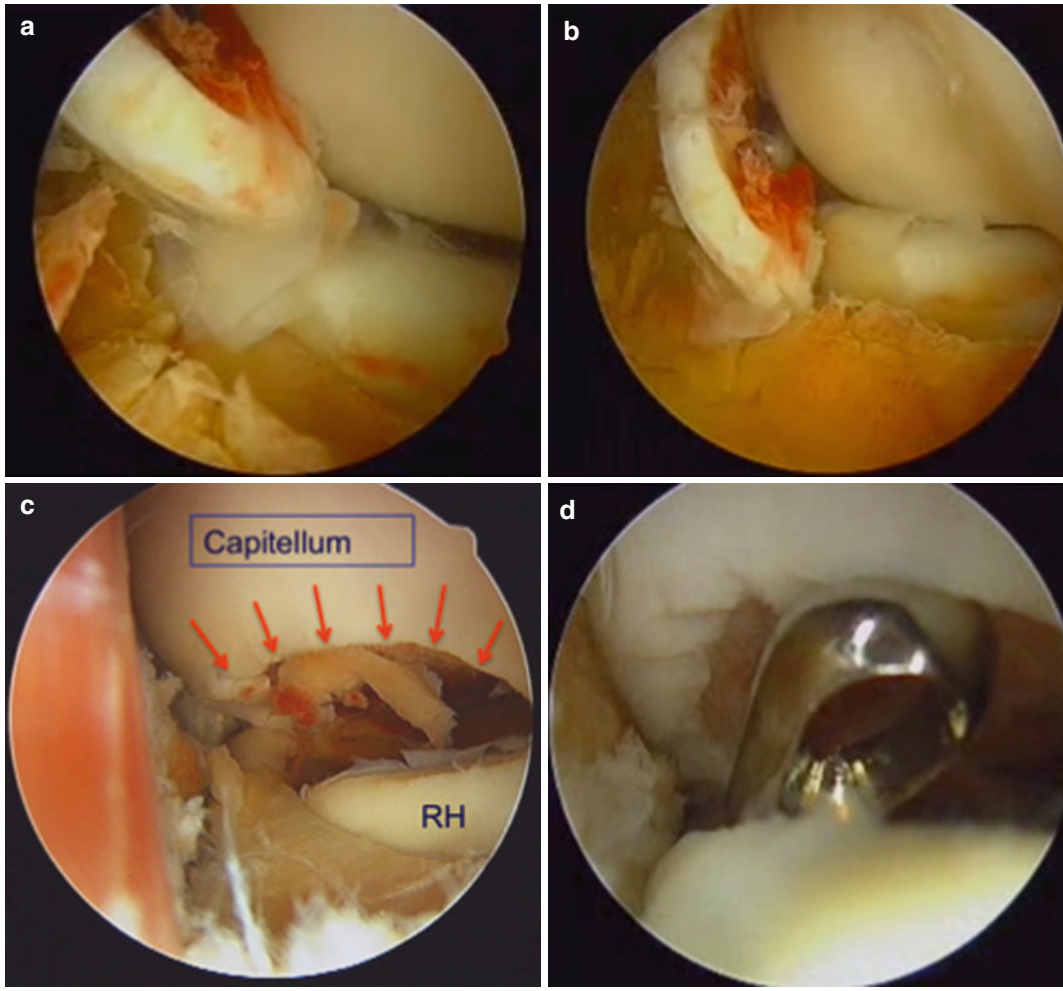

Fig. 56.2 (**a**) Large loose OCD lesion of the capitellum, (**b**) the loose body is removed by a grasper, (**c**) the defect on the inferior surface of the capitellum is well visualized with in situ fibrous debris, (**d**)

without frank tear are designated type I lesions; linear tears at the undersurface of the ECRB are designated type II lesions; partial or complete avulsions of the tendon are designated type III lesions (Fig. 56.3) [5].

Rettig et al. developed a method of classifying radiographic parameters in patients with *primary osteoarthritis* of the elbow. The absence of degenerative changes in the radiocapitellar joint is designated class I; class II primary OA exhibits mild joint space narrowing and mild ulnartrochlear arthrosis; class III is defined as the previously described radiographic changes plus radial head subluxation [19].

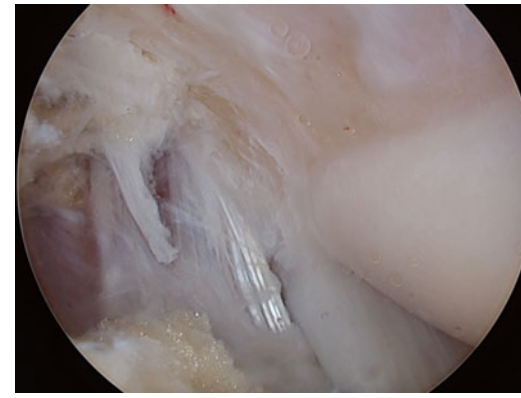

Fig. 56.3 Grade III frayed ECRB tendon with recalcitrant tennis elbow symptoms

56.4 Indications

Arthroscopy has become an effective modality in diagnosis and treatment of lateral elbow pain. Indications for arthroscopy in relation to lateral elbow pain include lateral epicondylitis, removal of loose bodies, posterolateral rotatory instability, acute radial head fracture, snapping plica excision, osteoarthritis, treatment of rheumatoid arthritis, joint contracture, and PIN entrapment [1]. However, few studies have compared outcomes of arthroscopy versus an open approach. In the treatment of lateral epicondylitis, arthroscopy has been shown to have similar functional outcomes as an open approach, with patients returning to work sooner and having less postoperative therapy needs [18].

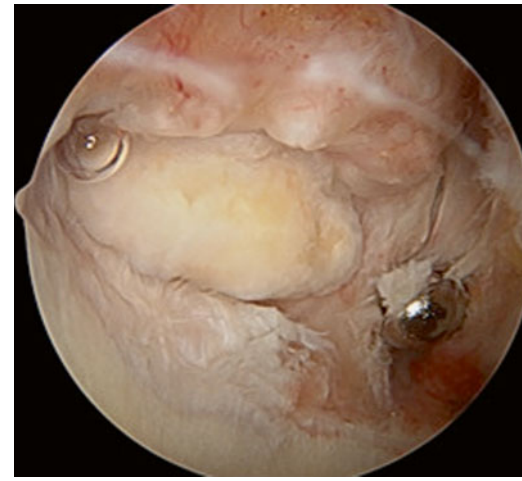

Fig. 56.4 Large radial head fossa loose body in situ, causing anterolateral impingement pain with elbow flexion

56.4.1 Loose Bodies

Arthroscopy has long been used for the removal of loose bodies and is one of the common indications for loose body-associated joint locking and clicking. A complete diagnostic arthroscopy is often needed due to the migration of loose bodies between compartments [8]. Loose bodies can be either completely free of soft-tissue attachments, allowing free migration about the joint ("joint mouse"); tethered by soft-tissue attachments, making them less mobile; or firmly attached. Patients who underwent removal of loose bodies with associated OCD lesions reported significant improvement in symptoms (Figs. 56.4 and 56.5) [17].

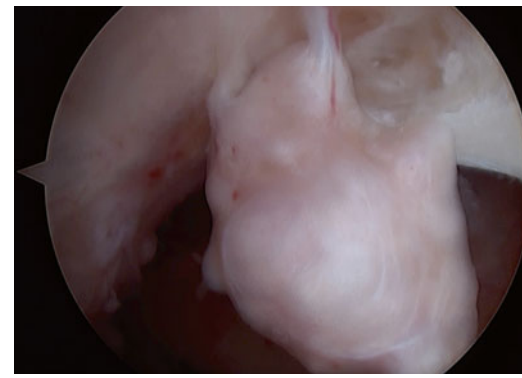

Fig. 56.5 Large loose body in the anterior elbow compartment

56.4.2 Posterolateral Rotatory Instability

Many patients with PLRI have lateral elbow pain and associated clicking, popping, or snapping when the elbow is brought from flexion to extension position in supination. Capsular repair can be accomplished with absorbable sutures with or without anchors [2]. Electrothermal shrinkage of the ligaments has been shown to reduce joint laxity on stress radiographs and eliminate instability [22]. Long-term results of such techniques of thermal shrinkage, which have been superceded in the shoulder, remain to be reported in the elbow.

56.4.3 Radial Head Fracture

Radial head fracture with severe comminution or delayed presentation may often be treated by excision of the radial head [26]. Arthroscopic excision of the radial head is preferred over an open approach in order to decrease chance of injury to the annular ligament, lateral stabilizers, and posterior interosseous nerve. Wijeratna et al.

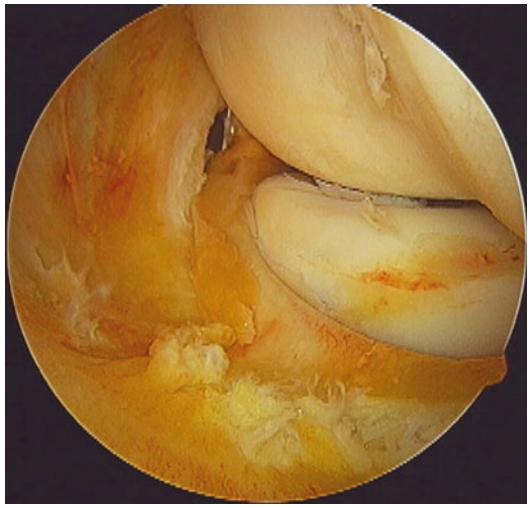

Fig. 56.6 Hemosiderin in elbow after an intra-articular fracture of the radial head

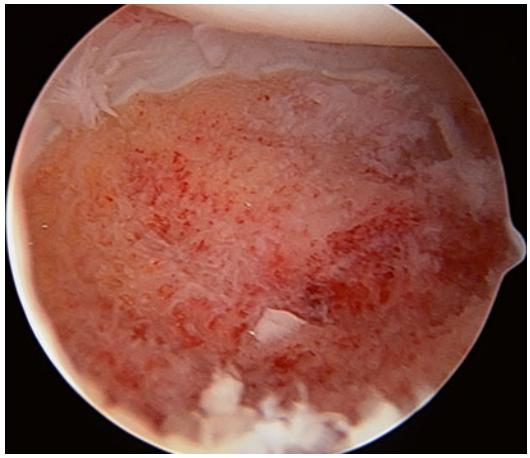

Fig. 56.7 Partially excised radial head

reported that arthroscopic excision of the radial head has comparable results to open excision (Figs. 56.6 and 56.7).

56.4.4 Lateral and Posterolateral Plica

The possibility of a posterolateral plica must be entertained when patient undergoes unsuccessful treatment for lateral epicondylitis (Fig. 56.8). Lateral elbow pain with snapping or popping during flexion and extension seen in plica must also be differentiated from loose bodies, PLRI, and medial subluxation of the triceps over the medial epicondyle [20]. Arthroscopy is indicated for the diagnosis of snapping plica as many of the aforementioned conditions can mimic similar symptoms (Fig. 56.9).

56.4.5 Osteoarthritis

A painful elbow with restricted motion that has failed nonoperative therapy, which includes physical therapy, arthritis medication, and splinting, might be an indication for arthroscopy. Synovectomy, debridement, capsular excision, osteophyte removal, olecranon fossa fenestration, and possible radial head excision have been used in the arthroscopic treatment of osteoarthritis [21]. Savoie et al. noticed a significant increase in range of motion after large loose bodies and bone spurs were removed. In comparison with open debridement, arthroscopy avoids the vast majority of iatrogenic injury to adjacent muscle-tendon complexes, which will also allow for increased motion in the acute postoperative period (Figs. 56.10, 56.11, and 56.12).

56.4.6 Lateral Epicondylitis (Tennis Elbow)

Arthroscopic release of the ECRB tendon is indicated when a patient has failed a conservative therapy program. Various results are reported due to difficulty in determining the origin of the ECRB through the arthroscope [1]. Baker et al. reported that 97 % were "much better" or "better" and 3 % were no better after arthroscopic surgery [5]. Proper patient selection, experience in elbow arthroscopy, and knowledge of surgical exposure are necessary for successful patient outcomes in the treatment of lateral epicondylitis (Fig. 56.3).

56.4.7 Rheumatoid Arthritis

Pain, restricted range of motion, and failed response to antirheumatic medications are indications for synovectomy in the rheumatic

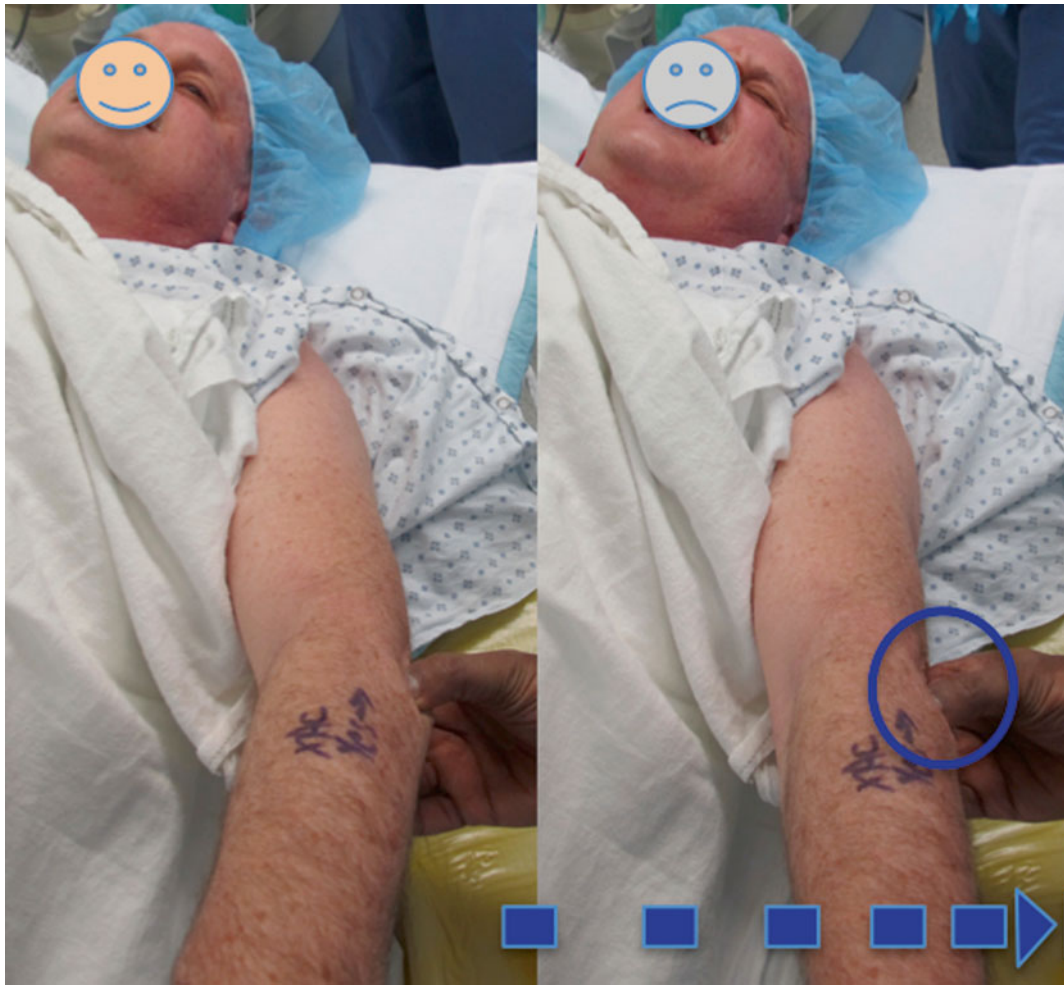

Fig. 56.8 Clinical test for a posterolateral symptomatic plica: demonstration of pain elicited when the posterolateral soft spot is compressed with the elbow moved into terminal extension

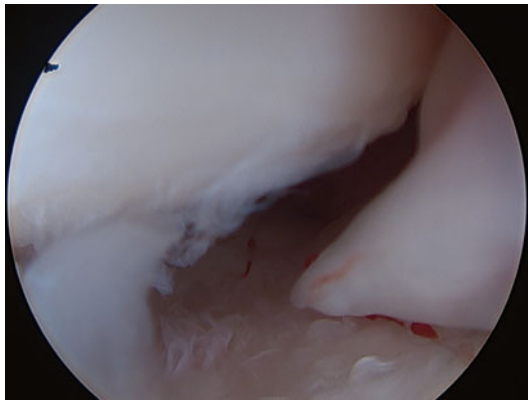

Fig. 56.9 Lateral elbow plica with central injection caused by mechanical irritation with an associated degenerate RCJ

elbow. Joint stiffness, infection, and wound breakdown have been associated with open synovectomy [9]. Kang et al. demonstrated positive outcome arthroscopic synovectomy in patients with arthritic elbows of Larsen grades 1, 2, and 3 [9]. Arthroscopic synovectomy can delay progression of arthritis in the elbow, improve functional scores, and reduce pain. It should be borne in mind that the aggressive pannus related to rheumatoid disease can often erode and perforate the joint capsules, with the potential for greater vulnerability to nerve and vessel injury during arthroscopic debridement procedures.

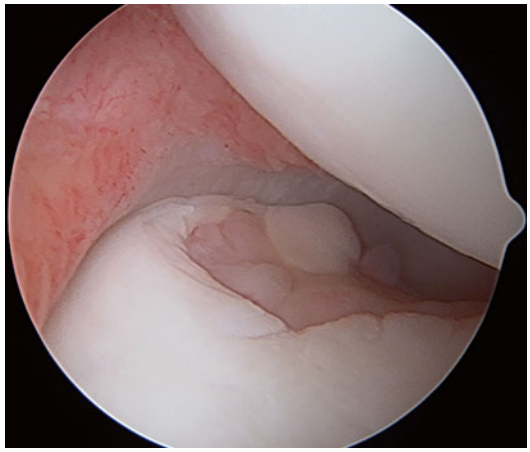

Fig. 56.10 Degenerate radial head with incongruity with pain and surrounding synovitis

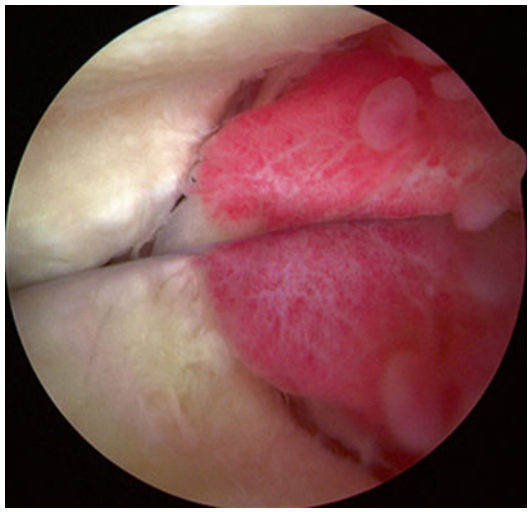

Fig. 56.11 Synovitis in relation to abnormal distal humeral bony erosion due to imperfectly implanted prosthetic radial head

56.4.8 Nerve Compression

Compression of the radial nerve along the elbow often is misdiagnosed as lateral epicondylitis or posterolateral plica. Fibrous bands at the radiocapitellar joint, the medial edge of the ECRB, the leash of Henry, the proximal fascia of the supinator, and the distal edge of the supinator are possible areas of radial nerve compression, specifically the posterior interosseous nerve (PIN). Diagnostic arthroscopy is indicated when a patient has continued pain and other sources of lateral elbow pain have been excluded. Nerve decompression via arthroscopy is only indicated when the PIN is compressed due to anatomical or mass structures and when the operator has a significant experience with arthroscopic nerve decompressions [14]. The common and safer route would be an open PIN release (Fig. 56.13).

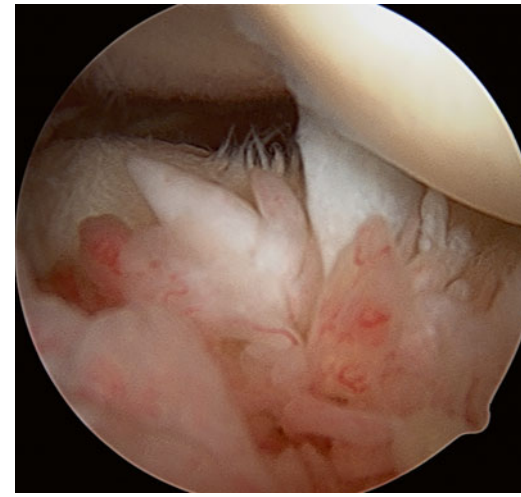

Fig. 56.12 Florid synovitis

56.5 Techniques

Although it is beyond the scope of this chapter to teach all the necessary arthroscopic skills, some helpful tips for arthroscopy are included.

1. When moving the arthroscope from medial to lateral, a time-saving technique is to pass a switching stick between the anteromedial and anterolateral portals, thereby allowing quick reintroduction of the cannula to the opposite portal.
2. To stop loose bodies being displaced away from the grasper to the fluid inflow/outflow, either turn off fluid while trying to grasp it or push the arthroscope onto the loose body, thereby trapping it against a periphery. The latter makes visualizing the gasping motion more tricky. An alternative would be to stabilize the loose body with a needle.

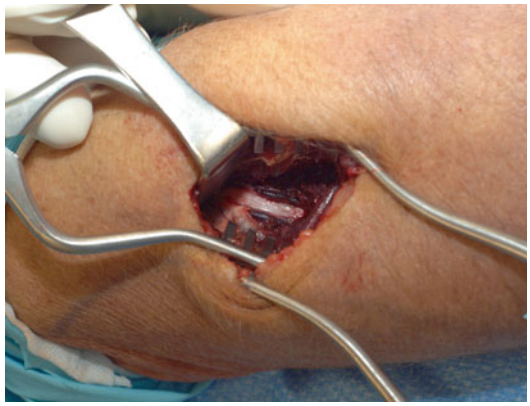

Fig. 56.13 PIN release through a small surgical open approach

3. When resecting synovitis, especially rheumatoid related to the anterolateral capsule, turn off suction, and orient the shaver blade away from the capsule, to minimize the danger of drawing the PIN and perineural fat into the shaver.
4. Do not use cannulas to prevent fluid from escaping the joint during an arthroscopic procedure. It is better not to retain fluid in the joint under pressure, which can lead to fluid extravasation into surrounding forearm soft tissues.
5. When using radio-frequency probes, do not use prolonged periods of cautery/coagulation. The fluid can heat up very quickly leading to articular cartilage injury. Always uses small focused pulses close to the target tissue, being aware of neurovascular anatomy.

56.6 Complications

Complications of elbow arthroscopy have been known to include superficial infection, contracture, temporary nerve palsy, and persistent drainage from portal sites [10]. Deep infection was noted to occur in about 0.8 % of elbow arthroscopies [10].

In the treatment of lateral epicondylitis, the most common complication is incomplete release of the ECRB [13]. During the excision of a snapping plica, the annular ligament as well as the articular surface to the radial head and capitellum can be damaged through a posterolateral portal [4]. Neurovascular damage is a known complication during radial head excision for acute fracture. Fracture may alter anatomy and pose potential risk of damage to the radial and posterior interosseous nerves during portal placement [26].

Nerve injuries occur frequently in elbow arthroscopy. Kelly et al. noted that the use of retractors and exploration of nerves reduced nerve injuries [10].

Complications from treatment of lateral elbow pathologies can be reduced by knowledge of three-dimensional anatomy, proper portal placement, and surgical experience.

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Elbow Stiffness

57

Bo Sanderhoff Olsen

Elbow joint stiffness is a significant problem after elbow trauma, in degenerative and arthritic elbow joint diseases, in congenital defects and following surgery on the elbow joint. The elbow joint is particularly prone to this condition, compared to other joints. The condition presents as lack of joint motion and may be accompanied by pain, locking, swelling and distorted anatomy [1–7]. Treatment of this disease can at times be difficult, and it requires a team with access to different conservative and surgical treatment options [1, 3–9].

Morrey et al. originally described the range of elbow joint motion (ROM) necessary for performing everyday activity [10]. The ROM defined by these authors became the goal of the treatment and prevention efforts. Today though a ROM of 100° in the elbow flexion axis and 100° in the forearm rotation axis is often insufficient, many individuals lead a much more active life, where work and sport place higher elbow demands than prior [2].

Anatomically the elbow joint is a complex trocho-ginglymoid joint. The joint consists of articulations between the humerus, the ulna and the radius.

B.S. Olsen, MD, PhD
Section for Surgery on the Shoulder and the Elbow, Orthopedic Department, Herlev/Gentofte Hospital, Copenhagen University, Herlev Ringvej 75, 2730 Herlev, Denmark
e-mail: bo.sanderhoff.olsen@regionh.dk

The humeroulnar joint is a functional hinge joint with a high congruency between the deep trochlea of the humerus and the greater sigmoid notch of the ulna, giving an inherent constraint due to the bony anatomy and further reinforced by strong lateral (LCL) and medial (MCL) ligaments. The thick anterior capsule has some stabilising effect in the extended joint position. The humeroulnar joint allows flexion and extension of the forearm relative to the humerus. The anterior tilt of the articular surface on the distal humerus allows, along with the fossa on the humerus, the ability to flex and extend the elbow joint. The humeroradial joint, the proximal radioulnar joint, the interosseous forearm membrane and the distal radioulnar joint cooperate to allow rotational movements of the forearm around the forearm axis. The top of the radial head, with its concavity, and the spherical capitellum articulate with concavity compression. The joint is further constrained by the annular ligament that surrounds the radial head (Fig. 57.1) [1, 2, 11–15].

Positioning of the hand is allowed by the arm. The shoulder motion allows hand positioning on a sphere around the body with the arm length as diameter. The elbow joint allows positioning of the hand inside this sphere, and the forearm rotation allows rotatory positioning of the hand. Therefore even minor elbow motion deficits can severely affect functionality of the arm (Fig. 57.2) [2, 13].

The lack of elbow joint extension is a common presentation of elbow joint stiffness and can be

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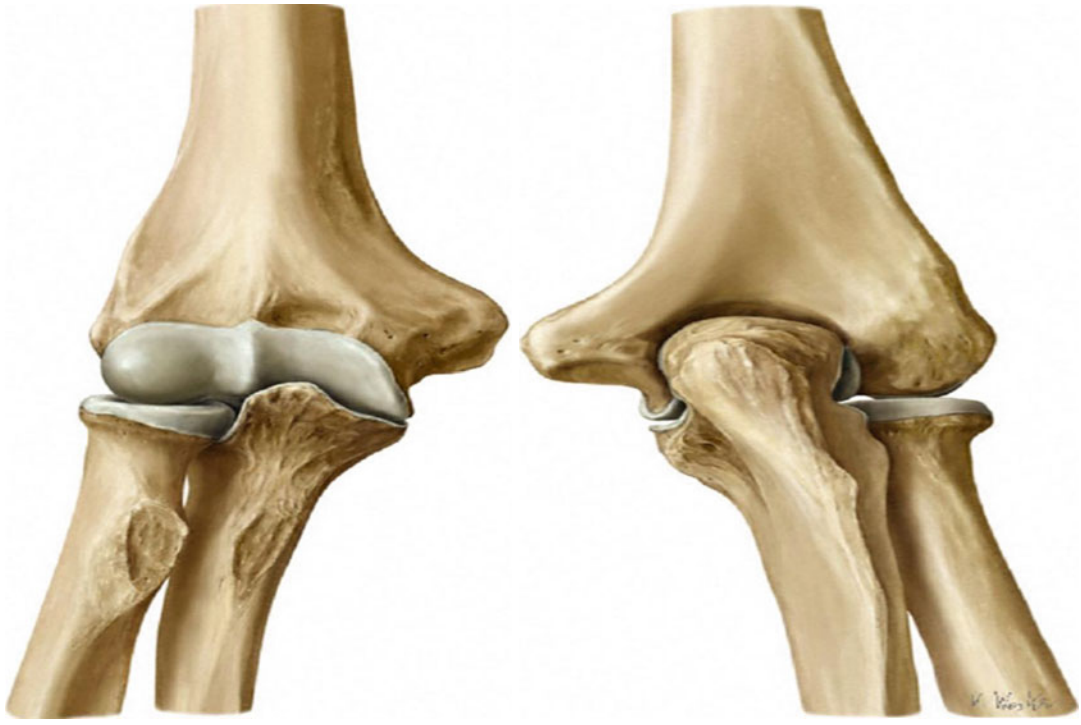

Fig. 57.1 Osseous anatomy of the elbow joint; note the intimate congruence and the fossa for olecranon and processus coronoideus at distal humerus (These are drawings that can be used for inspiration for a new drawing)

very troublesome. This condition is usually caused by either anterior capsular stiffness with or without calcifications and/or osteophytes on the olecranon, free bodies located in the olecranon fossa, distorted anatomy of the olecranon fossa or stiff synovial tissue filling the fossa [1, 2].

Lack of elbow joint flexion is usually caused by stiffness of the posterior and posterolateral joint capsule and/or osteophytes on the coronoid process, free bodies, distorted anatomy of the coronoid fossa or heterotopic/periarticular calcifications in the anterior compartment of the joint blocking flexion [1, 2].

These changes can often be dealt with through physiotherapy, manipulation, splinting or surgical resection and release [1, 3–9, 16–21].

Joint side changes that might cause impairment in the flexion axis can be radial head pathology that restricts motion (Fig. 57.3). Simple resection can be indicated accompanied by surgical joint release, though caution is required since resection fundamentally changes the load distribution in the joint and might lead to pain in

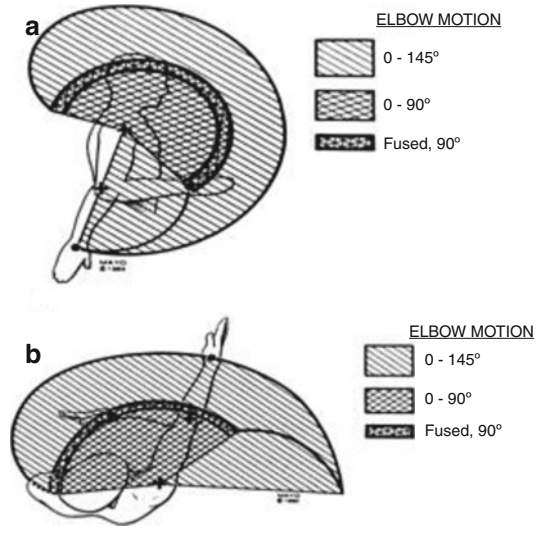

Fig. 57.2 The sphere around the body where hand positioning is allowed. Elbow motion allows positioning of the hand inside this sphere (These are drawings that can be used for inspiration for a new drawing)

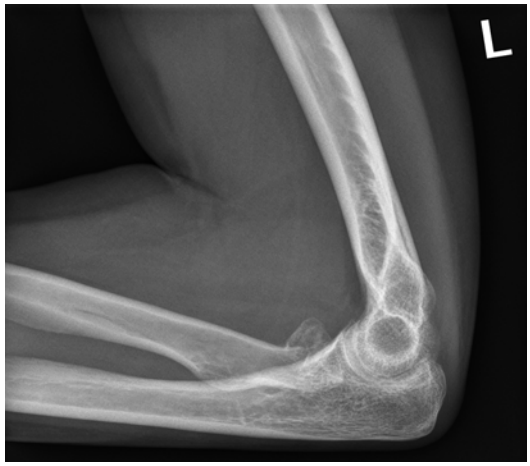

Fig. 57.3 Preoperative lateral x-ray of a young man with sequela of a radial head fracture with pain and severe restriction in ROM

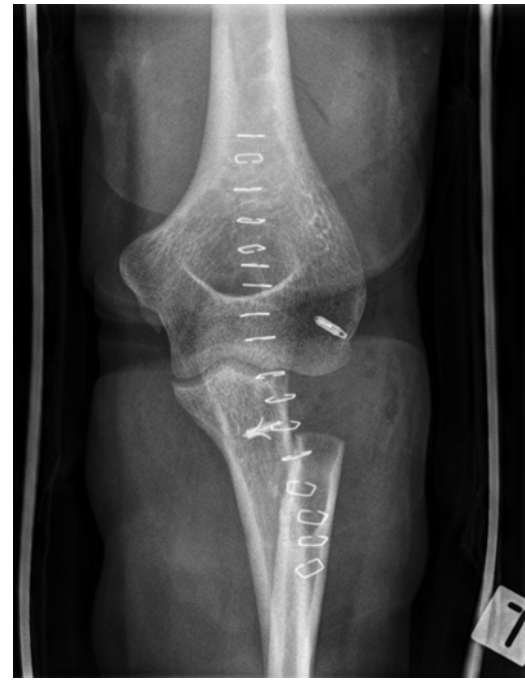

Fig. 57.4 Postoperative anterior x-ray of the same patient as seen in Fig. 57.3, following radial head resection and reinsertion of the annular and lateral collateral ligaments using Mitek GSII bone anchor

the elbow and/or the forearm complex (Fig. 57.4). Further the cause can be articular in-congruencey of the elbow following trauma and degenerative or inflammatory joint disease, leading secondarily to the above described soft tissue changes (Fig. 57.6) [1, 2]. The condition can be treated surgically; sometimes a total- or a hemi-elbow implant may be indicated [1, 3–9, 16–22].

Mal- or non-united supra- or intra-condylar fractures are rare causes of elbow stiffness (Fig. 57.5). In these cases the treatment can be ORIF or osteotomy [3].

Lack of forearm rotation is not infrequent, it can impose significant disability and it can be very difficult to treat. The condition can be caused by different pathologies. In the elbow joint, the condition is usually caused by radial head fractures with incongruence or adhesions between the annular ligament and the radial head following trauma and immobilisation (Fig. 57.3). Furthermore, degenerative or inflammatory joint disease in the radiohumeral joint can cause pain and stiffness (Fig. 57.6). Infrequently calcifications or synostosis in the interosseous membrane of the forearm can be caused by fracture dislocations or surgery for distal biceps tendon rupture (Fig. 57.7). Finally, antebrachium fractures and wrist problems can cause lack of forearm rotation [1, 6, 7].

Treatment can be radial head resection or surgical lysis of adhesions between the radial head

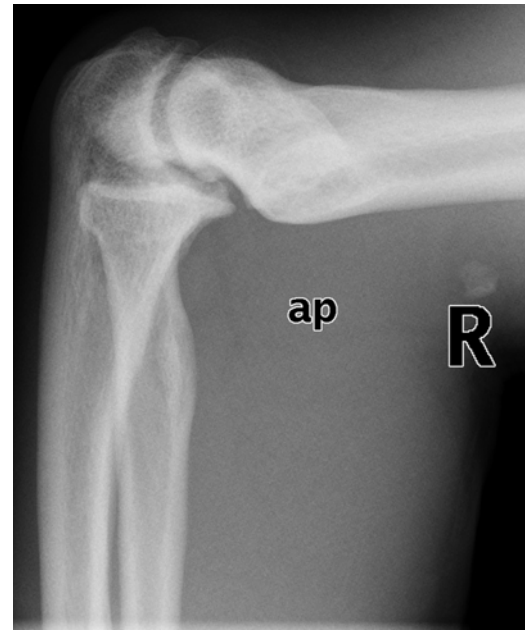

Fig. 57.5 Preoperative lateral x-ray of a young male with malunion 2 years after a supracondylar humeral fracture treated insufficiently with k-wire fixation. The patient had at presentation pain and a ROM of −20–85°. This patient was treated with open osteotomy and release and obtained ROM of 5–125°

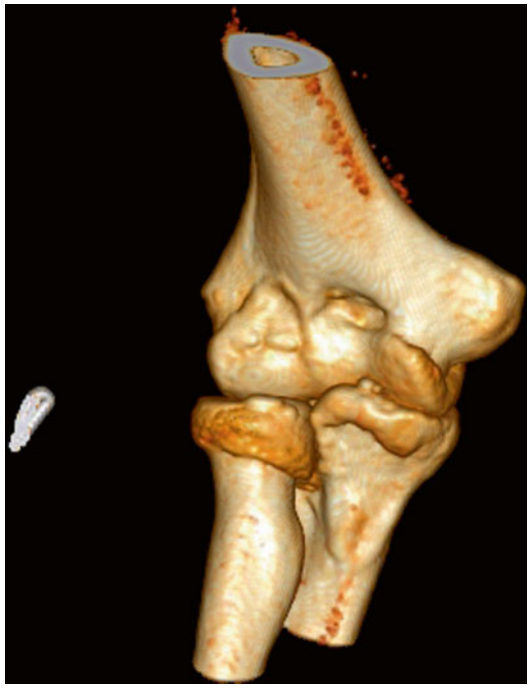

Fig. 57.6 A preoperative 3D CT scan of an elbow joint with arthrosis and severely restricted ROM and pain. This patient was treated with arthroscopic resection of the osteophytes, synovectomy and capsular release. He obtained a good result with a pain-free ROM increase of 36°

and the capsule (Fig. 57.4). With synostosis following distal biceps tendon insertion, resection of the mature bone may improve rotation. In other situations surgical release of forearm rotation can be difficult [1, 6].

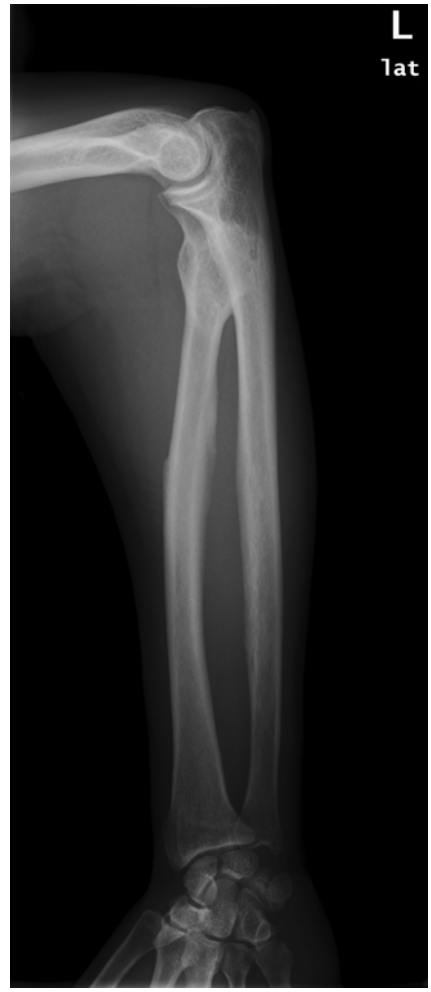

Fig. 57.7 A preoperative lateral x-ray of a middle-aged male with synostosis 1 year after treatment for a traumatic distal biceps tendon rupture. The synostosis was operatively resected with the application of a fascia lata graft

57.1 Diagnosis

Elbow joint stiffness can be classified differently [1, 2, 4, 5]. The clinical relevant systems relate to pathophysiology, clinical presentation, risk of complications and the consequent surgical procedure. We prefer the relatively simple classification described by Morrey [4]. This classification system deals with the following causes of elbow stiffness:

Extrinsic causes (located outside the joint surfaces): Capsular contractures are caused by immobilisation or lack of use due to pain. Often the anterior capsule is involved and presents as stiff and thick. Sometimes there are ossifications around the joint, situated in either the ligaments, capsule or muscles (Fig. 57.7). Furthermore, elbow contractures can be caused by the skin as in severe burns, or by extra-articular painful bony mal- or non-unions.

Intrinsic causes (located inside the joint surfaces): Can be articular mal- or non-unions, or joint side destructions due to elbow arthritis or elbow arthrosis (Figs. 57.3 and 57.5). Furthermore, intra-articular loose bodies can block the movement, and osteophytes seen in

arthrosis can cause impingement and lead to contracture (Fig. 57.6). Finally, adhesions between the joint surfaces can cause lack of motion.

Mixed contractures with involvement of intra- as well as extra-articular structures are most frequent, since capsular stiffness is almost always involved in the condition [1–4].

Jupiter et al. classify the contractures as either simple or complex. Simple contractures have mild to moderate contracture, no prior surgery, no ulnar nerve transposition and no heterotopic ossification and preserved anatomy [1, 2, 5].

Clinically the patients present with stiffness in the flexion axis and/or in the forearm rotation axis. The condition is often associated with pain and locking, though this is not always the case [1, 5–9, 16–19, 21, 22]. In posttraumatic cases, when present, pain is often reported in the extremes of motion, whereas in cases of degeneration or inflammatory joint disease, the condition is characterised by periodic painful joint effusions and generalised elbow joint pain.

The history of the patient is important with focus on debut of symptoms, trauma, occupation, age, hand dominance and night pain. We always perform a visual analogue scale (VAS) on pain in activity and at rest. Furthermore, we always observe the spontaneous use of the elbow during undressing and in the consultation in general, followed by measurements on the exact elbow ROM in flexion and rotation, specified for active and passive motion.

Palpation of pain and crepitus is important, and ulnar nerve symptoms, including mobility of the nerve during ROM, should be evaluated similar to the evaluation of the other upper extremity nerves. Finally, we always examine the stability of the elbow joint although instability is rarely present in elbow joint stiffness [6].

Functional elbow scores exist [23–25]. We use the Oxford Elbow Score routinely. This score do not require a physical follow-up, since it is patient administered [24]. Other scores do exist with a more or less correct validation for different diseases [23, 25]. Finally, when considering posttraumatic and postsurgical contractures, it is important to wait until a final ROM has been reached. In cases of heterotopic bone formation, maturation of the bone formation is important prior to surgery [1, 6, 16]. We often wait at least 0.5 year with stable ROM before the decision on release surgery is drawn. Though in postsurgical cases, an early closed brissement/manipulation may be indicated in order to preserve motion [26]. Improvements in elbow ROM during training or splinting can appear late following trauma or surgery [6, 8].

57.2 Radiographic Exploration

In all cases of elbow joint stiffness, we perform anteroposterior and lateral plain radiographs (Figs. 57.3 and 57.4). This allows identification of disturbances in joint architecture and all bony causes for contracture of the joint [1, 6, 7].

In selected cases we perform computed tomography (Fig. 57.6) in order to define the bony pathology that needs resection or correction during the surgery; this is especially the case in the rare cases of distal humeral mal- or non-union were osteotomy might be indicated. In these cases as well as in other elbow contracture causes, 3D-reconstruction techniques using CT have proven particularly useful (Fig. 57.6) [1, 3, 6, 7].

If traumatic articular cartilage defects are suspected and/or specific soft tissue pathology as fx. thick anterior capsule or pathology in contracted muscles is suspected, a magnetic resonance imaging (MRI) or ultrasound (US) examination can be indicated (Fig. 57.8). The latter examination has the advantage that it can be performed as a dynamic evaluation of the elbow joint [1, 3, 6, 7].

With ulnar neuropathy and ulnar nerve pain and other cases of nerve pathology in the forearm and hand, we occasionally do neurophysiologic testing (EMG) in order to evaluate the preoperative status of the nerves [6].

In cases with inflammatory disease or suspected infection, we do relevant blood counts, and with suspected joint infection, microbiological examination on articular fluid is performed routinely.

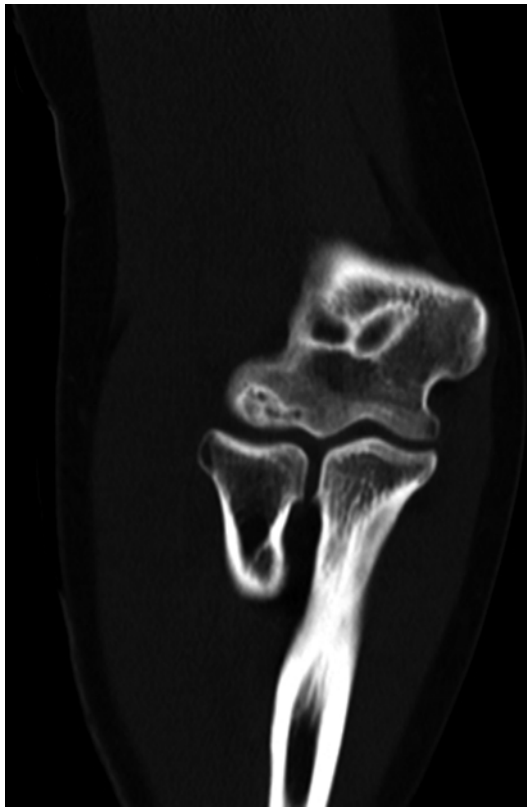

Fig. 57.8 MRI scan of a boy with pain, restricted ROM, radiohumeral crepitus and locking. Note the changes on the capitellum showing osteochondritic changes. This patient was treated initially conservative; at control after 2 years, he was successfully treated with arthroscopic murectomy, release and inforation of the defect

Early on arthroscopy was used for examination, but with the increase in techniques for radiographic examination, this is now only rarely the case [7].

57.3 Indication for Different Treatment Approaches to the Stiff Elbow

Generally the stiff elbow can be handled by more approaches [1]. Probably the most important measure is *prevention* following trauma or surgery [27, 28].

More reports have advocated early mobilisation following acute or surgical trauma. Mehlhoff reported worse results in patients following conservative treatment of acute elbow dislocation with immobilisation in more than 3 weeks [28]. Other authors have advocated even earlier mobilisation.

Following elbow joint fracture, stable ORIF is attempted to allow early mobilisation with reports on postoperative immobilisation as short as 8 days [29].

Physiotherapy or guided training following trauma or surgery of the elbow is generally recommended but poorly documented [6]. Most authors tend to recommend its use in order to avoid stiffness [1, 6]. Currently the use of active or passive stretching of the elbow is debated [6, 16]. Especially the use of CPM (continuous passive motion) devices in the treatment and prevention of elbow joint stiffness following surgery or trauma is discussed [8, 30]. Nevertheless, the majority of reports on surgical treatment of elbow stiffness using open techniques tend to advocate its use in the immediate postoperative period [1, 16, 30].

Bandages and splinting can be used as treatment as well as prevention in elbow joint stiffness [3, 8, 17, 26, 31]. Lindenhovius documents its use as a regular treatment for elbow joint stiffness [8]. The technique can be implemented using dynamic as well as static splinting, with reported results that might be comparable to results following surgical release of the elbow joint [8]. Other authors report its use in combination with *closed elbow manipulation* [17, 26]. This was prior used as monotherapy as "brissement of the elbow". A recent study reported the technique as an adjunct in the surgical release and as a possible treatment in the early postoperative period after a surgical elbow joint release with persistent stiffness [26]. Another study described its use early in posttraumatic cases [17]. With ulnar nerve paraesthesia, caution with brissement was advocated [26].

When all non-invasive means of treatment for elbow joint stiffness fail and in cases with articular destruction, different surgical techniques can be used to improve elbow ROM and relive pain. Different open approaches to elbow stiffness were reported [1, 3–6, 8, 9, 16, 17, 20, 22]. Though in the recent years, arthroscopic treatment

of the stiff elbow has gained increasing popularity and can now exhibit results comparable to the open techniques [1, 3, 5, 7, 9, 17–19, 21, 31–33].

In our clinic surgery is indicated when a stable condition of elbow stiffness with significant disability for the patient with or without pain is present despite intensive elbow training. For us the exact amount of elbow ROM restriction is less important than the actual handicap induced to the patient [1].

In acute trauma we introduce guided elbow mobilisation/physiotherapy as soon as possible in order to avoid or minimise the elbow stiffness induced by immobilisation. Generally we avoid long-time immobilisation of the elbow joint, and only rarely the joint is immobilised more than 2 weeks [27–29].

57.4 Technique

In minor intrinsic motion deficits, where an anterior or posterior capsule contracture is involved, no indication for release of the ulnar nerve, no indication for radial head resection, ROM >80° and extension deficit <40°, we tend to do an arthroscopic joint release. This is in our hands a joint side debridement of osteophytes, anterior and posterior capsule release and synovectomy [1, 7]. Over the years an increasing amount of procedures are performed arthroscopically [1]. Today this is our most common procedure in elbow joint stiffness with or without pain and locking.

For *arthroscopy* the patient can be placed supine or in the lateral position. We prefer the lateral position since movement of the arm is possible during the procedure, and this position allows us to progress immediately to open surgery when necessary (Fig. 57.9). We apply a tourniquet and place the mid-portion of the humerus on a padded flexible arm holder (Fig. 57.9). This allows easy access to the front as well as the posterior part of the joint, and multiple portals can be employed. With this set-up the surgery can be performed with only a nurse assistant.

We always draw bony landmarks, mark the ulnar nerve and the intended portals (Fig. 57.9). We insufflate the joint with 20 ml saline to protect the neurovascular structures. We use few different instruments: a standard 30°-angled, 4-mm scope (Karl Storz-Endoskope, Tuttlingen, Germany), radiofrequency ablation device and/or shaver and with the need of osseous resection, a bur as well (Fig. 57.10). Other authors describe

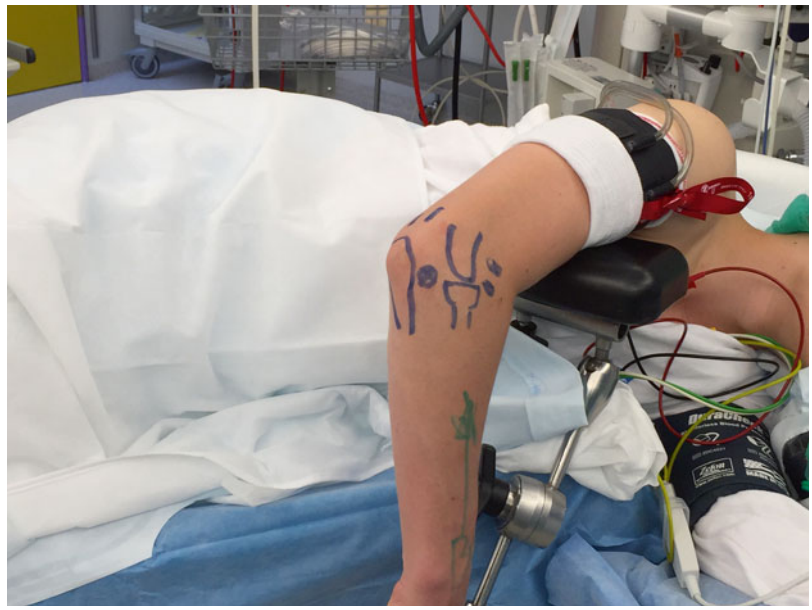

Fig. 57.9 Patient positioning for elbow arthroscopy. Note the padded rest under the mid-portion of the humerus, the tourniquet and the systematic drawing of bony landmarks and marking of portals and the ulnar nerve. Sometimes we also mark the radial nerve

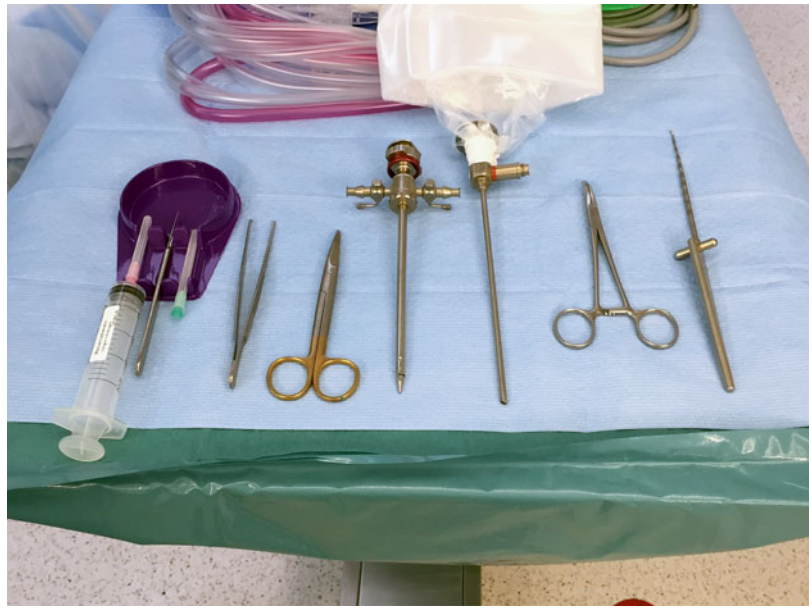

Fig. 57.10 This is our standard instruments for a simple standard scope of the elbow; occasionally, we supply with more advanced instruments for arthroscopic murectomy and direct resection of articular adhesions

the successful use of minor scopes and other angulations (between 30 and 70°) [7, 33]. We always use a pressure-controlled pump with relatively low inflow pressure.

Normally, we approach the joint from the anterolateral portal (Fig. 57.9). Other authors prefer to start their approach from the anteromedial side or the posterior side [21, 31, 33]. Only the skin is incised, followed by the use of blunt-tipped instruments. We apply an anteromedial portal with inside-out technique at the anterior side of the medial condyle, in order to protect the ulnar nerve. Instrumentation and scoping is allowed from both sides. We complete the anterior compartment release before we approach the posterior part of the joint. For the radial head and the centre of trochlea, we prefer to use the direct lateral or soft-spot portal (Fig. 57.9).

In the posterior elbow compartment, we normally apply two portals centred in the olecranon fossa, to facilitate the posterior compartment release and debridement (Fig. 57.11). Shaver and burr utilisation in this compartment are used with the back of the instruments towards the ulnar nerve and often without suction. In severe swelling or in cases with loss of overview of the posterior compartment, we do a mini-open posterior release through the extension of one of the posterior portals, usually the most lateral. In cases with severe motion restriction, we do mini-open ulnar nerve release as described by Blonna et al. [21].

In all other cases, we tend to do an *open elbow joint release*, performed as a staged procedure [1, 6, 16]. The first stage is a posterolateral approach with debridement of anterior and posterior compartment and capsular release, facilitated by LCL release that allows posterolateral joint subluxation. In the majority of cases, this procedure, along with a terminal brissement, will be sufficient to restore elbow joint motion. Then the LCL is reinserted to the undersurface of the lateral condyle, using a bone anchor (I prefer Mitek GSII) (Fig. 57.4). The triceps is closed with strong sutures, and the anconeus fascia is reinserted to the ulna.

If restriction of elbow ROM persists after this release, we continue the procedure with the second stage. The ulnar nerve is identified and protected without transposition, followed by posteromedial capsule and posterior MCL release, with preservation of the anterior band. Only rarely is release of the anterior MCL band indicated. In this situation we reinsert the ligament using a Mitek GSII anchor applied in the origin of the MCL at the medial humeral epicondyle. Radial head resection is reserved for special

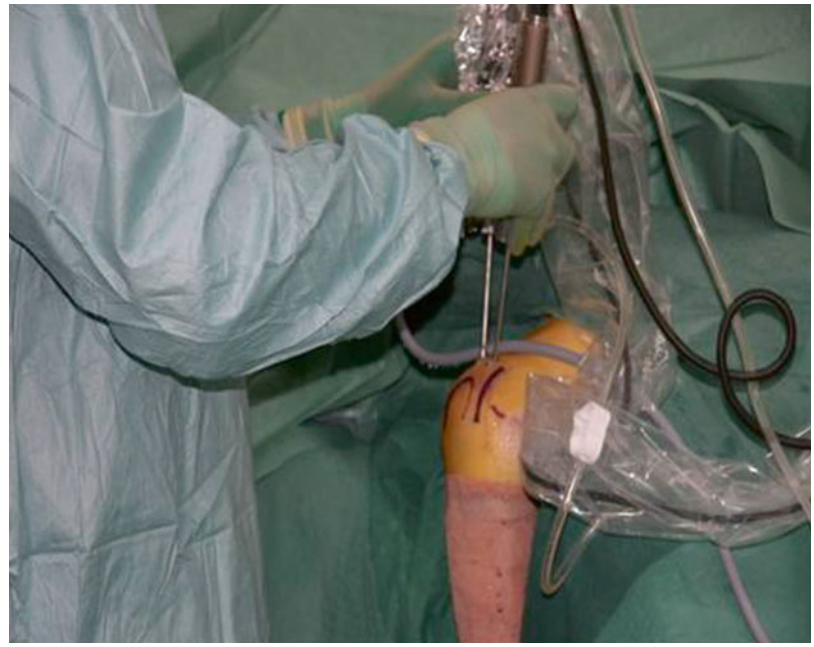

Fig. 57.11 This is the technique in the posterior compartment with the use of two portals. Note the marking of the ulnar nerve. With the need for open debridement, we use the most lateral portal for our approach, except in cases were a concomitant release of the ulnar nerve is required. In these cases we use the medial portal

indications where joint stiffness in flexion or rotation is mediated by the radial head (Fig. 57.4). In certain situations we do a capsular release or trim or resect bony osteophytes at or around the radial head in order to avoid resection [6].

Postoperative mobilisation is initiated immediately after the surgery using sufficient pain relief, usually by the use of an infraclavicular plexus block [34]. In severe cases we tend to use in-hospital CPM for 24–36 h under infraclavicular plexus block using indwelling catheter, followed by pain treatment and immediate and intensive physiotherapy using both passive and active stretching [1, 6, 8, 16, 30, 34]. The training sessions continue to the elbow ROM has been stabilised [1].

57.5 Complications

Initially complications to arthroscopic elbow surgery were feared and severe [35]. Later it was described that complications to elbow arthroscopy were relatively common but less severe occurring in more than 10 % of the procedures. The neuro-complications were reported to be mainly transient [36]. In the recent years, more publications on complications to arthroscopic surgery of the elbow in general and to arthroscopic and open elbow joint release in particular were published [1, 7, 9, 18, 19, 21, 31–33]. Generally complications are divided in major and minor. Major complications affect the final outcome, whereas minor complications are transient and without influence on the final outcome [31, 33].

Marti et al. in a single-surgeon series of the first 100 arthroscopic procedures reported no major complications and 6 minor complications in five patients (5 %). They observed two haematoma, two transient nerve palsies, one of the latter had a wound healing disorder as well and one case of CRPS (chronic regional pain syndrome) that resolved on conservative therapy. A relation between osteoarthritis and stiffness to occurrence of complications was observed [33].

In another recent single-surgeon series of 200 arthroscopic procedures, one major permanent ulnar nerve injury was observed; further 14 minor complications was reported, being 3 transient nerve palsy, 2 prolonged drainage and 2 superficial infections. Further six cases of persistent contracture and one increased contracture were noted as complications. All in all complications were observed in 7.5 % though only one was major [32].

A study from 2013 focused on neurological complications in a large single-surgeon series of 502 procedures with arthroscopic capsular release of the elbow. A 5 % incidence of only transient nerve injury was reported, all resolved within 24 h and 24 months. In 76 procedures a concomitant open decompression and transposition of the ulnar nerve were performed [21]. These authors recommended the use of retractors in arthroscopic procedures and found arthroscopic procedures to be safer than open procedures [21].

In 2014 the group from St. Louis USA reported complications from a single group series of arthroscopic elbow joint release performed from 1999 to 2012; all in all 417 of 510 procedures were analysed. The procedural complexity was noted. Complications were reported in 14 %. Major complications were in 20 cases or 4.8 % (deep infection most common with 2.2 %). No permanent nerve injury was observed. Minor complications were observed in 37 cases or 8.9 % (superficial infection most common with 6.7 %). Transient nerve injury was observed only in seven cases or 1.7 %. It was concluded that procedural complexity was without influence on complications. Intraoperative articular steroid increases the risk for infection and should be avoided. Nerve injuries are relatively uncommon [31].

Following open surgery for elbow joint stiffness, more complications were reported [6, 9, 16]. The incidence of complications was observed between 0 % and 50 % [6, 9]. In average complications were reported in 15 % of surgeries; the majority was observed to be minor, and ulnar neuritis and residual stiffness were reported as the most common complications [6].

A Dutch study from 2013, performed as a systematic review on treatment of posttraumatic elbow stiffness, with 30 articles describing the treatment of 798 patients, but without any randomised studies, observed arthroscopic studies to report significant fewer complications than studies on open elbow release. All in all 6 papers reported a mean of 5 % complications in arthroscopic release, and 21 papers reported a mean of 23 % complications in open contracture release. When external fixation or distraction was applied, the amount of complications increased significantly to well above 50 % [9].

In conclusion the arthroscopic release of elbow joint contracture appears safe with mostly minor complications. The majority of neurologic complications are transient. The use of arthroscopy might be safer than open elbow joint contracture release, though open releases tend to be used in major and arthroscopic releases in minor motion deficits [1, 7, 9]. The majority of papers published originate from high-volume specialised surgeons, indicating that the actual amount of complications to surgical elbow joint release might be higher.

57.6 Results

Reporting on results from release of the stiff elbow joint, the majority of papers state the improvements in the elbow flexion/extension axis, whereas the improvements in forearm rotation are only rarely reported [1, 6, 7, 9]. Therefore, in the following text, we will focus on elbow flexion and extension ROM.

The traditional open elbow joint release was observed to give significant improvements in elbow joint ROM [1, 3–6, 8, 16, 17, 22]. We observed a gain in ROM of 45° following surgery [1]. The same improvement was observed by Mansat using the column procedure [22]. Using the extensive open approach with different surgical techniques, increases in the elbow flexion axis between 23° and up to 60° were reported [6, 8, 9, 16].. In a few small series, external fixators were used to allow more aggressive release. One study further included distraction with the external fixator. These studies reported gains in elbow ROM between 56 and 89° [6, 9]. Though the addition of external fixator and ± distraction, it significantly increased the amount of complications to well above 50 % [9].

One study observed that the largest improvements following open elbow joint release were seen in the most stiff elbow joints [16].

Since the early 1990s, an increasing amount of studies reported on results from arthroscopic elbow joint release [1, 3, 5, 7, 9, 17–19, 21, 31–33, 36]. The majority reported improvements in pain [7].

Over the years a significant improvement in the reported gain in ROM following arthroscopic elbow contracture release was observed [5, 7, 9, 18, 19, 21, 33, 36]. We observed a more modest gain in ROM of 23°, compared to the open releases, but arthroscopic releases were used with less preoperative ROM restrictions, than the open procedures [1]. Other studies also observed relatively low increments in elbow ROM after arthroscopic contracture release [7, 9, 18]. More aggressive approaches with the use of intra-articular retractors, open ulnar nerve release and mini-open debridement of the olecranon fossa might increase the possible gain in elbow ROM to 40–74°, without increasing the amount of complications [7, 9, 21]. Understanding the results from arthroscopic elbow contracture releases, it is important to remember the lesson learned from open contracture releases: "the largest increments in ROM following surgery are seen in the stiffest elbows" [16].

Therefore, the future of elbow joint contracture releases might include a more aggressive approach to arthroscopic procedures, new developments in pain management, a combination of the different surgical procedures (arthroscopic and open) in order to avoid complications and secure early mobilisation postoperatively in order to increase the gain in ROM achieved by surgery.

In conclusion treatment of the stiff elbow can be done with different approaches. The first and most important step is probably patient selection and information. The patient should be left with a realistic interpretation of what he or she can achieve from the surgery. We inform the patient that the surgery tends to cure 50 % of the preoperative ROM deficit, and in the majority of cases, the pain is decreased and the locking is cured.

At our department we have observed a continuous trend towards more arthroscopic procedures, and with the evolvement of our technique, we observe that more advanced pathology can be handled arthroscopically, since this technique allows visualisation of areas of the elbow that can be difficult to approach with open procedures. We have seen that combining the procedures as advocated by other authors tends to improve our results without placing the patients at higher risks [7, 21].

Finally, handling this group of patients continues to be a team effort in order to secure proper preoperative treatment and evaluation, quality of the surgery performed, pre- and postoperative handling of pain and intensive and qualified postoperative training in order to preserve the gain in ROM achieved by the surgery. Expect increments in ROM to continue for up to 6 month, do close follow-up in order to supervise the improvements by training and with unexpected drawbacks consider doing closed elbow mobilisation.

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Elbow Fractures Treatment

58

André Thès and Philippe Hardy

58.1 Diagnosis: Clinical

Elbow fractures are rare but challenging conditions as they can affect simultaneously multiple bones and compromise elbow stability. They therefore need methodical evaluation. The physician has to look for the circumstances of the trauma: mechanism (direct or indirect), amount of energy, and elbow dislocation even self-reduced. Careful observation of the elbow researches deformity, bruises or hematoma, and even skin opening. Mobility and stability evaluation is most of the time limited because of the pain, which can be partially relieved by drainage of the hemarthrosis. One should not forget to check neurovascular status and to research associated injuries such as shoulder or wrist pain and distal radioulnar instability. Preoperative examination under general anesthesia assesses the stability of the joint.

A. Thès, MD (✉) • P. Hardy, MD, PhD
Service de Chirurgie Orthopédique et de Traumatologie, Hôpitaux Universitaires Paris Ile-de-France Ouest, Assistance Publique-Hôpitaux de Paris, Boulogne-Billancourt, France

Université de Versailles Saint-Quentin-en-Yvelines, Versailles, France
e-mail: andre.thes@gmail.com

58.2 Exploration: Instrumented, Radiological

The radiographs guide the diagnosis but might be limited due to the pain and the inability of mobilizing the limb. CT scan with three-dimensional reconstructions permits analysis of the fracture pattern and exposes small osteochondral fragments.

58.3 Rating: International Classifications

58.3.1 Capitellar Fractures

The Bryan and Morrey classification [1] describes capitellar fractures in four types. Type I is a complete fracture of the capitellum involving a large osseous piece with lateral part of the trochlea, also known as Hahn-Steinthal fracture. Type II (Kocher-Lorenz fracture) is a detached osteocartilaginous fragment in the frontal plane. This fractures result from shearing forces. Type III (Broberg-Morrey fracture) is a comminuted fracture of the capitellum. McKee described a type IV fracture involving both capitellum and trochlea in a frontal plane [2].

58.3.2 Radial Head Fractures

Radial head fractures are described by Mason modified by Hotchkiss classification [3]. Type I is a non-displaced or minimally displaced

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fracture of the head (<2 mm) or neck, type II is a displaced fracture (>2 mm) of the head or neck (angulated), and type III is a comminuted displaced fracture. A fourth type combines radial head fracture and elbow dislocation.

58.3.3 Coronoid Fractures

Coronoid fractures are pathognomonic of elbow instability. Associated injuries are therefore very common: posteromedial or posterolateral rotatory instability, terrible triad of the elbow. The Regan-Morrey classification is based on the fragment size. Type I is an avulsion of the tip of the coronoid process, type II is a fracture of 50 % or less of the height of the coronoid process, and type III involves more than 50 % of the coronoid process. O'Driscoll proposed a classification [4] based on the location of the fracture: the tip (subtype 1 involving less than 2 mm of coronoid height and subtype 2 involving more than 2 mm of coronoid height), the anteromedial facet (subtype 1 is a fracture of only the anteromedial rim, subtype 2 associates the rim and the tip, and subtype 3 associates anteromedial rim and sublime tubercle +/− the tip), and the Basal fractures (subtype 1 is a fracture of the coronoid body and base, subtype 2 is associated with an olecranon fracture). This classification recognizes the posteromedial instability associated with anteromedial facet fractures.

58.4 Indications

The arthroscopic treatment of elbow fractures is somewhat recent. The indications are therefore evolving as the surgeons' skills progress. Arthroscopy permits precise evaluation of associated lesions and precise articular fracture control. The aims of the treatment are as follows: having at least the same reduction of the fracture as open reduction and having a fixation strong enough to begin early mobilization and rehabilitation [5].

58.4.1 Capitellar Fractures

Very small osteochondral fragments can be resected. Resection of larger bony fragments even performed arthroscopically may induce posterolateral instability from the absence of the lateral column and secondary osteoarthritis. Open reduction might be associated with devascularization of the detached fragment and periarticular soft-tissue lesions that may lead to joint stiffness. Type I and some type II fractures are amenable to reduction and fixation with at least one cannulated/headless screw.

58.4.2 Radial Head Fractures

Reduction and fixation is indicated in Mason type II and some type III or IV fractures of low complexity. Radial head resection is indicated when the fracture is too comminuted for fixation, or in case of malunion or nonunion with associated pain and loss of motion after a period of rehabilitation. An open approach may lead to injuries of the lateral collateral ligament, the annular ligament, or the posterior interosseous nerve and is associated with postoperative stiffness and delayed recovery. Arthroscopic resection or fixation of the radial head is feasible. Arthroscopic fixation of the radial head is limited to the less comminuted fractures.

58.4.3 Coronoid Fractures

The coronoid is a major factor of elbow stability: it opposes posterior ulnar displacement, and it is where the anterior articular capsule inserts. Reduction and fixation of coronoid fractures is recommended in Regan-Morrey type III fractures and in case of associated elbow instability. Resection of small fragments is sometimes needed when it interferes with joint motion.

58.5 Techniques

58.5.1 Common Features

Arthroscopic treatment of the elbow fractures includes numerous challenging procedures that must be carefully planned. Preoperative CT scan is almost mandatory and gives information about the number and the size of the fracture fragments; it can also help for the size of the screws. The use of an interscalene block is controversial because it can delay postoperative neurologic examination but also helps early mobilization. One should not forget to mark bony landmarks of the skin as well as nerves and vessels location. Severe deformation of the elbow due to swelling or very displaced fractures contraindicates arthroscopy. Intra-articular hematoma is evacuated with repeated irrigations. Fracture debris and clots are removed with a 3.5 mm arthroscopic shaver; then a complete articular exploration with stress tests permits total lesions assessment. Low intra-articular pressure is needed to prevent compartment syndrome of the forearm. Using only lateral portals preserves medial structures and gives an excellent view to the fracture site, but some surgeons routinely use anteromedial portal for visualization or as instrumental portal. The patient then needs to be positioned in prone or lateral decubitus. Reduction and fixation is controlled by both arthroscopy and perioperative fluoroscopy.

58.5.2 Capitellar Fractures (Fig. 58.1)

The patient is placed in supine position with a tourniquet, and the elbow is flexed to 90°. Only lateral portals can be used. Joint is distended by a posterolateral approach (at the center of a triangle formed by the radial head, the lateral aspect of the olecranon, and the lateral epicondyle). The scope is placed in a proximal anterolateral portal (3 cm above the lateral epicondyle, slightly anterior to the humerus). An anterolateral approach 3 cm distal and 2 cm anterior to the lateral epicondyle is made for instrumentation. Joint inspection usually shows a unique fragment attached to the humerus by a lateral periosteal flap. Reduction is performed with a probe or a small punch coming from the anterolateral portal. Varus stress and traction to the axis at 30° elbow flexion can help the reduction. A temporary K-wire is placed to maintain reduction, and a (2.5 mm to 3.5 mm) cannulated screw/headless screw achieves fixation. The head of the screw has to be buried in the cartilage. If the fragment is large enough, a second screw can be placed either from anterior to posterior by the anterolateral portal or from posterior to anterior by the posterolateral portal.

58.5.3 Radial Head Fractures (Fig. 58.2)

Patient is placed either in supine or prone/lateral decubitus position, the elbow flexed to 90° with a tourniquet. A dislocated elbow must be reduced before the procedure. The fracture is visualized through anteromedial or posterolateral portals. Mobilization and reduction with a probe of the fragments is done through anterolateral portals. Temporary fixation is performed percutaneously with K-wire from lateral to medial, and then headless cannulated screws are placed after fluoroscopic control. K-wires as definitive fixation are associated with painful postoperative mobilization and more stiffness. Each time possible one should prefer to put a buried fixation to prevent those particular complications. In very comminuted fractures of the radial head or in case of delayed presentation, excision of the radial head gives excellent results in a stable elbow. This intervention can be performed arthroscopically with a 3.5 mm shaver and a 5.5 mm burr using alternatively posterior, anterolateral, and posterolateral portals. The annular ligament is left intact to preserve proximal radioulnar joint stability. The shaver/burr should be oriented posteriorly to preserve posterior interosseous nerve.

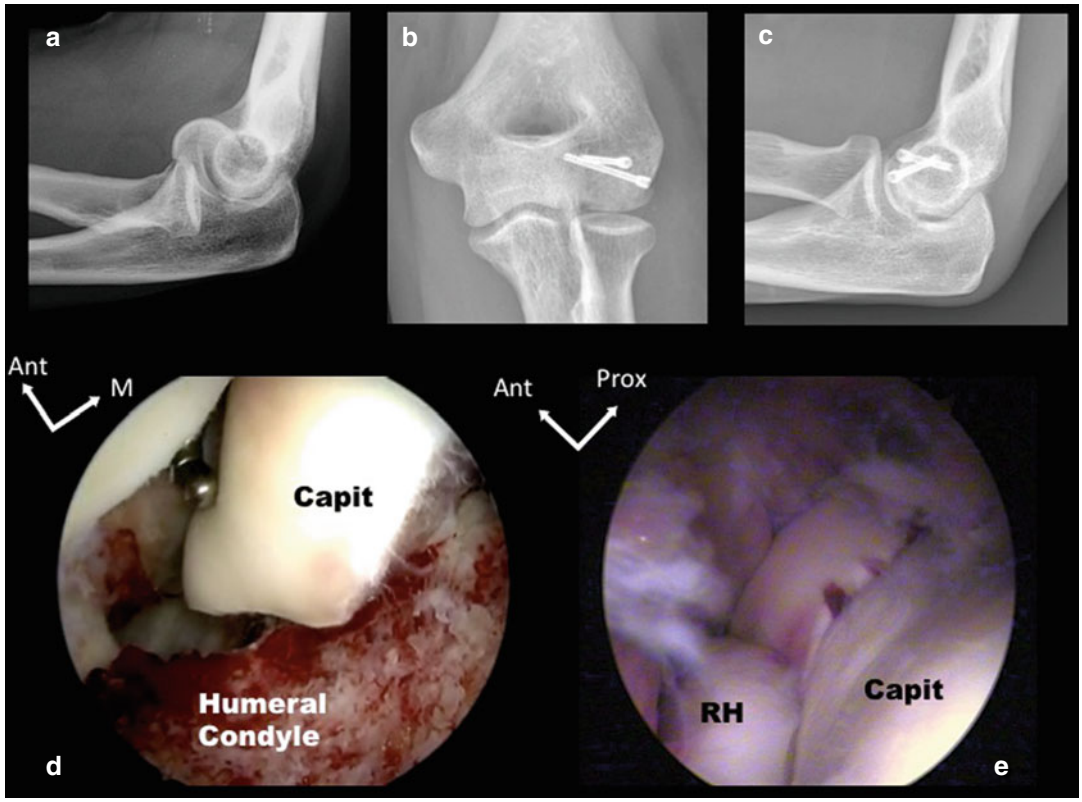

Fig. 58.1 Displaced Hahn-Steinthal fracture before (**a**) and after (**b**, **c**) reduction using a probe (**d**) and fixation. Arthroscopic view of the reduction from the anterolateral portal (**e**); (*Ant* anterior, *M* medial, *Prox* proximal, *RH* radial head, *Capit* capitellum)

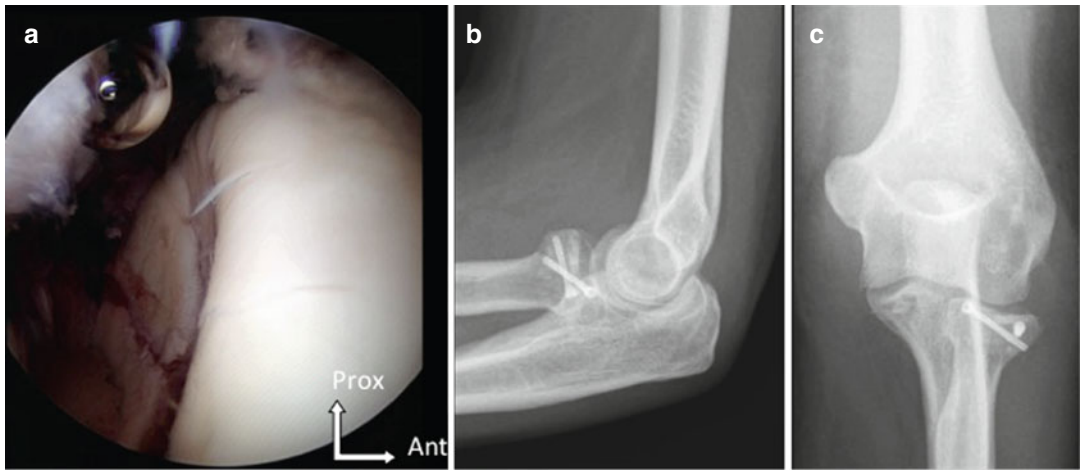

Fig. 58.2 Arthroscopic view of a reduced Mason type III fracture (**a**) with screw fixation (**b**, **c**) (Courtesy of N. Pujol)

58.5.4 Coronoid Fractures

Patient is placed in prone or lateral decubitus; the elbow is flexed to 90°, and a tourniquet is inflated after exsanguination. Lateral portals are used to preserve medial structures. In case of a small fragment or comminuted fracture, an osteosuture of the anterior capsule with associated bone fragment is performed. Large fragments can be reduced and fixed with retrograde screw insertion.

58.6 Osteosuture of Small Fragments (Fig. 58.3)

Arthroscope is in the anterolateral portal, just anterior to the lateral epicondyle. A second lateral portal is created 2 cm more proximal under arthroscopic control. Free intra-articular bone fragments are resected. The continuity between bone fragment and anterior capsule is assessed. A suture anchor is placed through the proximal lateral portal at the fracture margin. Pulling on the anchor tests good hold of it and this movement can reduce humeroulnar partial dislocation. After switching of the portals, capsular osteosuture is performed. The wires are passed just at the interface of the bone and capsule to prevent vascular or nervous lesions, and knots are tied under arthroscopic control. Elbow stability is then assessed under arthroscopic visualization.

58.7 Reduction and Fixation of Large Fragments

The same portals are used. The scope is in the proximal anterolateral portal. An anterior cruciate ligament drill guide system is inserted through the anterolateral portal and placed at the fracture margin. A small incision is made over the posterior aspect of the proximal ulna. Using the drill guide, one or two guide wires are advanced from the posterior ulna to the basis of the coronoid. Reduction of the fracture is done with an arthroscopic grasper through the anterolateral portal after removal of the drill guide. The guide wires are pushed through the coronoid fragment. Then 4 mm cannulated screws are placed after measurement of their lengths. The reduction of the fracture and the stability of the joint are controlled by arthroscopic and fluoroscopic examinations. Care must be taken to prevent guide wires to advance too far anteriorly as they can damage vascular and nervous structures.

58.7.1 Olecranon Fractures

Some non-comminuted olecranon fractures can be reduced, and percutaneous fixation is done under arthroscopic control. The patient is placed in lateral decubitus, elbow flexed at 90°. Direct posterior portal is used to infuse joint, and the arthroscope is placed through it. A second

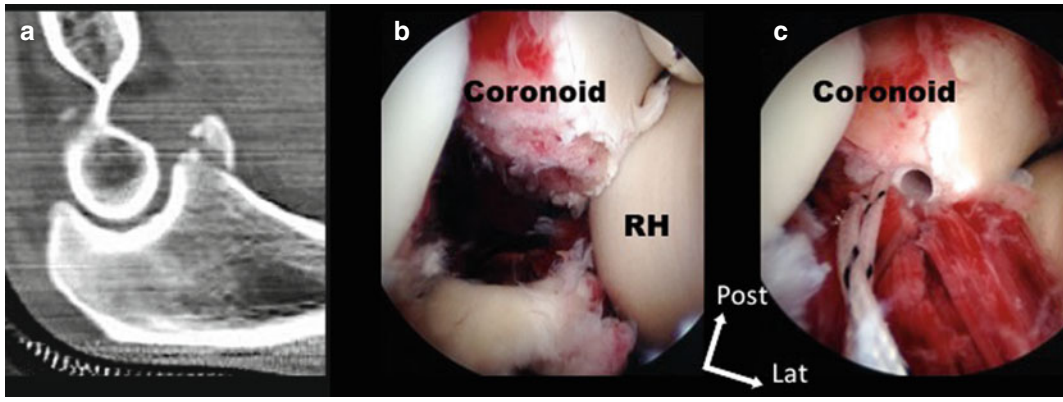

Fig. 58.3 Displaced type I coronoid fracture (**a**, **b**) and capsular osteosuture using a suture anchor (**c**) (Courtesy of N. Pujol)

posterior portal is done at the lateral aspect of the triceps tendon, 2 cm proximal to the top of the olecranon. This second portal shows the olecranon tip and fossa. Reduction is performed with a sharp peak through the skin and controlled under arthroscopic examination. The fixation is achieved with one intramedullary screw or two large K-wires.

58.7.2 Distal Humerus Fractures

Savoie et al. [6] propose arthroscopic reduction and percutaneous fixation of AO (Arbeitsgemeinschaft fur Osteosynthesefragen) C1 distal humerus fractures in selected patients with bone quality sufficient to receive only one column screw fixation. This technique needs further evaluation.

58.7.3 Pediatric Fractures

Little literature is available about arthroscopic management of pediatric fractures. The instrumentation is the same as adult's one except for younger children that may need small wrist arthroscope and dedicated instrumentation. Fractures of the lateral condyle are frequent fractures in children that are treated with ORIF if displaced. Arthroscopic-assisted reduction and fixation technique is described for children from 2 to 11 years old [7, 8]. The patient is placed in supine position; the scope is in an anteromedial portal and instrumentation in an anterolateral portal. Fracture fragment is manipulated to reduce the fracture. Putting the elbow in flexion and the forearm in pronation locks the reduction if needed. Then two extra-articular K-wires are placed percutaneously from the lateral side of the distal humerus to medial and proximal side. Hausman et al. added a third horizontal K-wire [7] coming from lateral to medial through the capitellum and the trochlea. This technique permits an anatomic reduction and a solid fixation with good clinical results. It also allows the diagnostic and the treatment of associated intra-articular injuries. It may lessen the radiation dose, the risk of avascular necrosis of the lateral humeral condyle, or malunion. Dawson and Inostroza proposed an arthroscopic reduction and percutaneous fixation with one K-wire of a displaced radial neck fracture in an 11-year-old girl [9]. The scope was placed in the anteromedial portal and instrumentation in anterolateral portal. This technique permitted precise fracture reduction with excellent clinical results.

58.8 Complications

Few complications are reported in arthroscopic elbow fractures treatment, whereas elbow arthroscopy has the highest rate of post-arthroscopy complications. First of all it is an emerging technique, and little literature is available. Then these procedures are most performed by highly experienced surgeons. Training in cadaver lab is mandatory, and the first procedures in living patients must be time bounded to limit fluid extravasation and tourniquet time if the elbow must be opened. In elbow fractures there is a modification of the surface anatomy due to swelling and deformation and that may lead to miss correct position of the nervous or vascular structures with catastrophic consequences. Finally, fixation devices such as K-wire, suture passer tool, may cause injuries to periarticular structures if inappropriately manipulated.

58.9 Results Literature Review

58.9.1 Capitellum Fractures

These fractures are rare, and a few case reports are available. Feldman et al. [10] described in 1997 arthroscopic excision of type II capitellar fractures in two patients. After 1 year and a half, both regained full extension. One patient had persistent pain in heavy lifting or pulling. Arthroscopic reduction and fixation of Hahn-Steinthal fractures [11–13] seems to give good results with a pain-free and stable elbow. Two patients out of four had minimal extension deficit after a minimum 1-year follow-up (5° and 15°, respectively).

58.9.2 Radial Head Fractures

Michels et al. [14] reported a retrospective study on 14 patients with Mason type II fractures with arthroscopic reduction and fixation. Mean follow-up was 5.5 years. Functional results (evaluated with the Broberg and Morrey functional rating score) were good in 3 cases and excellent in 11. Worst results are associated with chondral lesions of the capitellum. No complication was noted. Rolla et al. [15] treated six patients with arthroscopic reduction and fixation of type II ($n=3$), III ($n=2$), and type IV ($n=1$) radial head fractures. Mean follow-up was 12 months (6–18), and all patients regain preoperative activities at a mean time of 3.5 months. Mayo score was good to excellent for all six cases. Arthroscopic excision of the radial head gives similar results to open excision when the elbow is stable as the primary treatment of highly comminuted fractures or when there is secondary arthritis, malunion, or nonunion of the fractures [16, 17].

58.9.3 Coronoid Fractures

Four Regan and Morrey types I and II fractures were treated arthroscopically by Hausman et al. [18]. They reported no recurrence of instability, the range of motion was 2.5–140° with full pronation and supination. No loss of reduction was noted and the fracture healed in all cases at 1-year follow-up. Adams et al. [19] reported the arthroscopic treatment of four type II and three type III fractures. Mayo elbow performance score was 100% in five patients. All of the seven patients were pain-free. One patient had secondary ulnar neuropathy requiring nerve transposition 5 weeks after. Another patient had lateral capsular imbrication at 8 weeks because of persistent posterolateral rotatory instability.

Conclusion

Arthroscopic treatment of elbow fractures is a challenging but yet developing procedure. Indications of this technique concern acute treatments with good functional outcome. Arthroscopy has the advantage of lessening damages to soft periarticular structures and to permit a complete assessment of the intra-articular lesions. It may lead to fewer complications such as avascular necrosis of the capitellum in coronal shear fractures, less infections, faster rehabilitation, and recovery. Using lateral portals permits to treat most of the lesions while preserving median structures. Further assessment is needed as the technique spreads to prove superiority of arthroscopic techniques over open techniques in selected cases.

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Osteochondritis Dissecans of the Capitellum

59

Miguel Trigueiros

Osteochondritis dissecans (OCD) is a musculoskeletal condition that occurs primarily during the maturation of the skeleton. It is a cause of elbow pain and disability in the adolescent athlete, and it is an uncommon disorder in the general population [1]. OCD typically affects adolescent athletes engaged in repetitive overhead or upper extremity weight-bearing activities (e.g., baseball, tennis, volleyball, and gymnastics).

59.1 Etiology

OCD is currently recognized as an acquired lesion of the subchondral bone and is *characterized by degrees of osseous resorption*, *collapse*, *and sequestrum formation with possible involvement of the articular cartilage through delamination unrelated to an acute osteochondral fracture of the normal cartilage* [2–13].

Although many etiologies of OCD have been postulated, including trauma, inflammation, genetics, vascular abnormalities, and constitutional factors, the true cause of this condition remains unknown [14, 15].

M. Trigueiros
Hand Surgery Unit, Hospital de Santo António - ICBAS, Universidade do Porto, Porto, Portugal

Hand Surgery Unit, Hospital de Santa Maria - ICBAS, Universidade do Porto, Porto, Portugal

Sports Medicine, Universidade do Porto, Porto, Portugal
e-mail: mtrigueiros@gmail.com

The most accepted theory for its development is the effect of the repetitive microtrauma and overuse that result from the valgus elbow stress. This commonly happens in athletes who need to throw or in athletes who deal with forceful weight bearing in the upper extremities like gymnastics. *This high-shear and impact force across the elbow joint has a tenuous blood supply. The immature capitellum is supplied by one or two end vessels that enter the chondroepiphysis posteriorly which leads to the development of the lesion or the perpetuation of an established one*. Jackson et al. [7] *and* Singer et al. [16] *believed that OCD resulted from compressive insults*, *responsible for causing vascular insufficiency*, *to a developing stressed chondroepiphysis*.

When this condition occurs, the subchondral bone softens and leads to a loss of the solid foundation for the overlying articular cartilage. The cartilage fissures, by exposing the bone to synovial fluid, allow further bone injury and deterioration as the synovial and inflammatory fluid tracks beneath the subchondral bone. This situation lessens the chance for bone healing and increases the odds of bone fragmentation and the consequent progeny bone formation within the capitellar OCD crater. Ultimately, as the disease progresses, the nonhealing progeny bone becomes a loose fragment leading to the locking of the elbow, as was seen in the knee when the disease was described for the first time [9, 17].

Osteochondritis dissecans must be distinguished from osteochondrosis of the capitellum

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or Panner disease, which is typically seen in children between 7 and 12 years old. Panner disease is a self-limiting disorder that usually resolves with rest and is characterized by ischemia and necrosis of the capitellar epiphysis, followed by regeneration and recalcification. However, it has been suggested that osteochondrosis and osteochondritis of the capitellum are different stages of a single condition affecting the maturation of the capitellar epiphysis and that Panner disease can develop into OCD when not treated with adequate rest [4, 6, 18–20].

Radiographs are commonly used for diagnosis of OCD of the humeral capitellum. However, early stages could be missed. Computed tomography (CT) may also be indicated to depict osseous details and to determine the size of the lesion. Nevertheless, as research into OCD continues and grows, classification systems for disease progression and OCD management, based on findings obtained from physical examination, radiographs, MRI, and arthroscopy, shall be established.

59.2 Diagnosis: Clinical

Young athletes, around 10 and 17 years old, with a medical history of capitellar OCD often show diffuse, nonspecific complaints of elbow pain during their sports activity, which are relieved by rest. As patients may not feel pain in this phase (or only mild enough so they remain capable of throwing), they usually do not seek for medical attention [1, 21]. In later stages, the complaints become localized on the lateral aspect of the elbow and are concomitant with a loss of motion that is suggestive of intra-articular loose bodies. The physical examination shows tenderness and swelling over the lateral aspect of the elbow with crepitation during pronosupination. These symptoms become increasingly pronounced as the disease progresses.

59.3 Epidemiology

Not much is known about the prevalence of OCD of the humeral capitellum [22]. In 1933, Nielsen [23] reported that OCD of the humeral capitellum affected the elbow of 1 out of 139 office workers and 40 out of 861 manual workers. A study by Gugenheim et al. [24] that included 595 Little League Baseball players demonstrated that elbow pain with restricted range of motion happened in 17 % of players without any evidence of OCD of the humeral capitellum. Larson et al. [25] in their Little League survey of a total of 166 players, elbow pain and restricted range of motion were apparent in 20 %, and abnormalities of the humeral capitellum were seen in 5 %. Another study of Little League Baseball players, conducted by Matsuura et al. [26] and that included 6,677 players aged 8–12 years, the prevalence of OCD of the humeral capitellum was 1.6 %. In this case, both clinical and radiological evaluation were obtained. In a 2004 study, Hang et al. [27] researched 343 adolescent baseball players in Taiwan. Although morphologic abnormalities of the medial epicondyle were common among pitchers and catchers, there was only one case of OCD of the humeral capitellum. Concerning the study of Kida et al. [22], the prevalence of OCD of the humeral capitellum was 3.4 %.

59.4 Exploration: Instrumented and Radiological

Imaging of OCD includes standard anteroposterior (AP) and lateral radiographs of the elbow. AP view in 45° of flexion is crucial. Conventional anteroposterior radiographs of the elbow often lead to an underestimation of the lesion size and extent. Early findings, such as radiolucency or flattening of the articular surface, may be noted in these exams (Fig. 59.1).

Advanced lesions demonstrate sclerosis, fragmentation, and loose body formation (Fig. 59.2). Late findings include degenerative changes and radial head enlargement. Although conventional radiographs can usually diagnose the osteochondral lesions, they do not show the breaches of the articular cartilage and cannot evaluate whether the lesions are stable or not.

Additional imaging modalities are often required for full lesion characterization and stability. MRI (Fig. 59.3) can detect the earliest

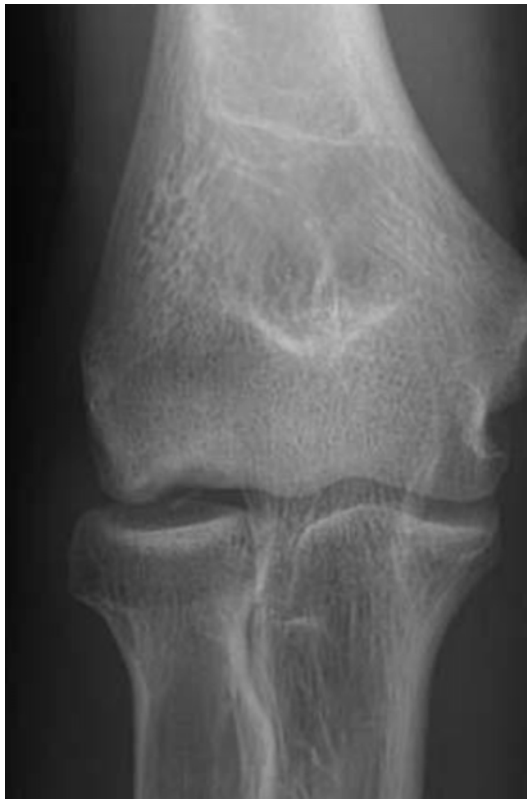

Fig. 59.1 Localized flattening and radiolucency

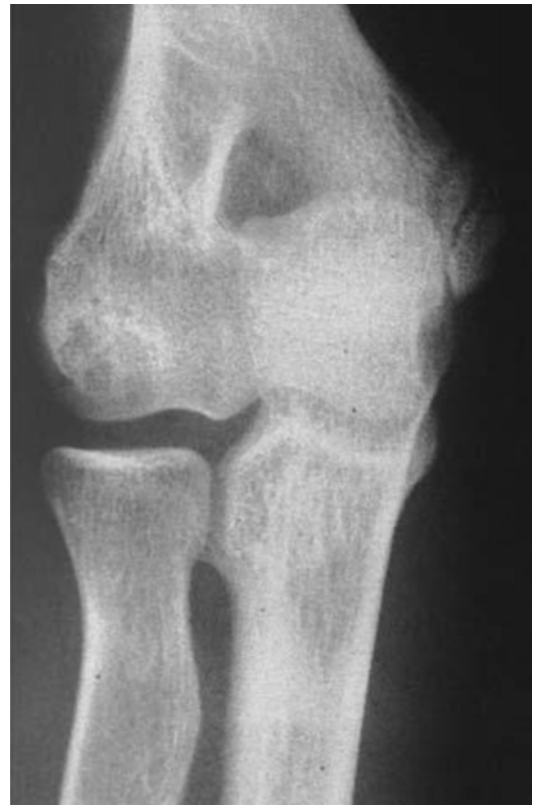

Fig. 59.2 Displaced fragment

changes of OCD (even when radiographs are normal), identify the presence of loose bodies, and provide valuable information regarding the integrity of the articular cartilage cap and assessment of the underlying subchondral bone. The determination of the lesion stability, based on findings on T2-weighted images, is crucial to establish the prognosis and the type of treatment. The presence of a high-signal line or cyst behind the lesion on the T2-weighted image may indicate the presence of fluid and is suggestive of an unstable lesion [1, 8]. On the other hand, this high signal may just represent vascular granulation tissue as response of a healing reaction.

Kijowski et al. [28] and De Smet et al. [29] showed similar characteristics on MRI in a small series of patients with capitellar OCD lesions.

A high-signal line behind the fragment is predictive of an unstable lesion. While the exact etiology

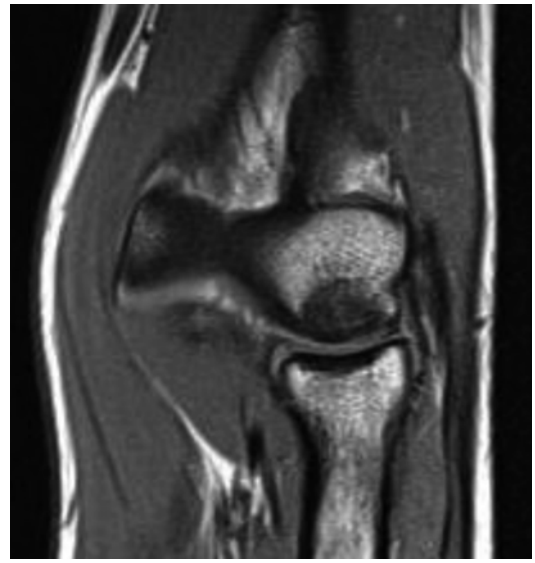

Fig. 59.3 MRI

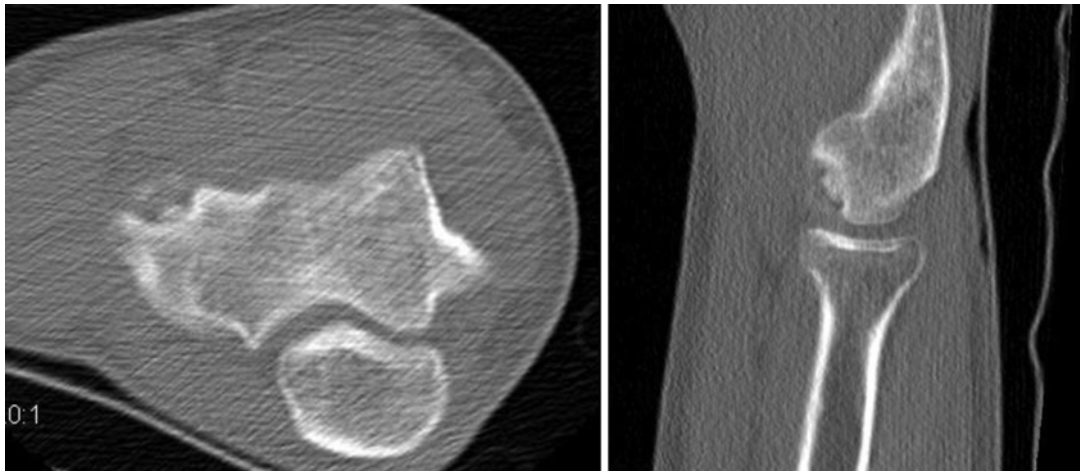

Fig. 59.4 CT

of the high-signal line remains controversial, it may represent a violation in the integrity of the articular cartilage surface that allows for communication of synovial fluid and granulation tissue formation below the OCD lesion. Since 3D sequences can provide higher-resolution and multiplanar reformatted images, the cartilage sequence may help in differentiating fluid from granulation tissue and provide a more accurate staging of OCD. Compared with helical CT (Fig. 59.4), the true extent of the OCD may be obscured by concomitant bone marrow edema on the MRI scan [30]. The diameter of the lesions measured on MRI can exceed diameters measured on conventional radiographs.

59.5 Rating: International Classification

The Minami classification describes the appearance of the capitellum on plain radiographs [31]. In Minami type 1 OCD lesions, there is flattening of the capitellum or cystic changes in the capitellum. In Minami type 2 OCD lesions, there is a clear subchondral detachment or a splitted fragment in the capitellum.

Four MRI criteria predict the stability of OCD lesions in the knee [32, 33]:

1. A line of high-signal intensity at least 5 mm in length between the OCD lesion and the underlying bone
2. An area of increased homogeneous signal at least 5 mm in diameter beneath the lesion
3. A focal defect of 5 mm or more in the articular surface
4. A high-signal line traversing the subchondral plate into the lesion

Nelson et al. [34] classified MRI findings according to five grades:

Grade 0	Normal
Grade 1	Intact cartilage with signal change
Grade 2	A high-signal breach of the cartilage
Grade 3	A thin, high-signal rim extending behind the osteochondral fragment, indicating synovial fluid around the fragment
Grade 4	Mixed- or low-signal loose body, either in the center of the lesion or free within the joint

The International Cartilage Repair Society (ICRS) has suggested the following arthroscopic classification systems for OCD lesions [35]:

ICRS OCD I indicates a stable lesion with a continuous but softened area covered by intact cartilage.

ICRS OCD II indicates a lesion with partial discontinuity that is stable when probed.

ICRS OCD III indicates a lesion with a complete discontinuity that is not yet dislocated.

ICRS OCD IV indicates an empty defect, as well as a defect with a dislocated fragment or a loose fragment lying within the bed.

Stable lesions corresponding to the ICRS OCD I stage should heal completely with elbow rest. Stable osteochondritis dissecans lesions all show the following findings at the time of initial presentation: an immature capitellum with an open growth plate, flattening, or radiolucency of the subchondral bone (a grade I radiological lesion) and almost normal elbow motion. In other unstable osteochondritis dissecans lesions, it is likely to find the following features: a mature capitellum with a closed growth plate, fragmentation (a grade II or III radiological lesion), or a restriction of elbow motion of ≥20°. The choice of surgical treatment should be determined according to the ICRS classification.

59.6 Indications

The treatment of OCD of the elbow remains controversial. The following factors are considered very important for the appropriate management of this condition: lesion stability, overlying cartilage integrity, and open or closed capitellar physis.

59.6.1 Nonoperative Treatment

Stable lesions (Fig. 59.5) are those with an intact cartilage surface as well as nondisplaced lesions with cartilage compromise. Positive prognostic factors for successful nonoperative management are:

- Open capitellar physis
- Relatively preserved elbow range of motion (less than 20° of motion loss)
- Localized flattening or radiolucency on radiographs without evidence of defect fragmentation or instability

The treatment of stable OCD lesions typically include rest and activity modification. Sports and aggravating activities are ceased until symptoms resolve (usually between 3 and 12 weeks). Protecting the elbow with a hinged brace helps correct natural elbow valgus and off-load the capitellum [11].

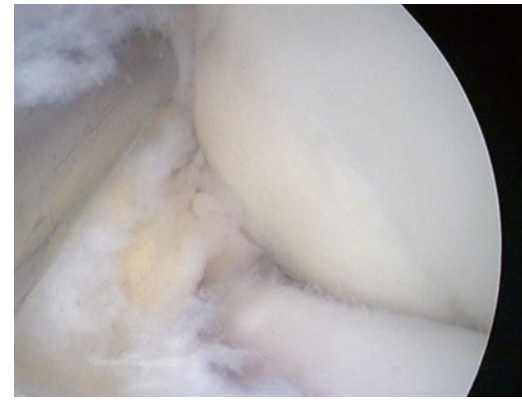

Fig. 59.5 Stable lesion

With the symptoms improve, active and passive range-of-motion exercises are initiated. Return to sports should be considered after 3–6 months, considering clinical and radiological improvement. Patients must be informed of potential long-term sequelae. Radiological, progressive ossification or narrowing of the lesion is observed. Repair processes begin initially in the lateral area of the lesion and progress medially. Patients with continued stress of the affected elbow clinically show persistent pain with worse radiographic findings with formation of loose bodies.

Osteochondritis dissecans lesions with an open physis that are managed with elbow rest show better healing and a better outcome with respect to pain, return to sports, and radiographic findings. Osteochondritis dissecans lesions with a closed physis show no differences in the outcome between the resting and the active groups regarding pain and repair. These findings indicate that lesions with a closed physis are unstable and that should be managed surgically [8, 11, 36–38].

59.6.2 Operative Treatment

Operative management has indication for elbow OCD lesions that fail the conservative treatment or persist with mechanical symptoms with unstable fragment and/or an episode of locking and/or MRI evidence of fragment instability.

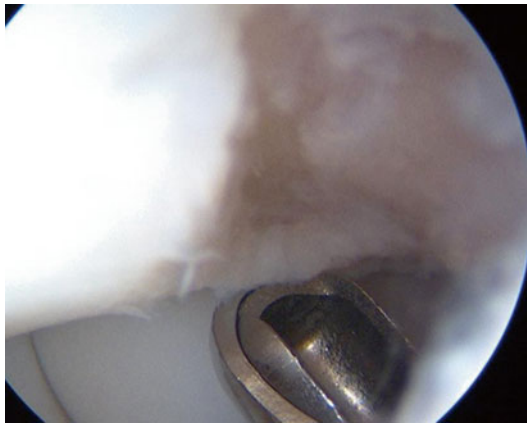

Fig. 59.6 Debridement

Management is primarily based on the integrity and stability of the overlying cartilage and the size and location of the lesion (Byram et al. [39]). The ultimate goals of surgical treatment are to prevent the development of arthritis and allow a return to the pre-injury levels of activity.

Capitellar OCD is a relatively uncommon condition. Most research on surgical management are retrospective, and outcome measures are inconsistent. This makes it difficult to compare between the different operative options [8, 33]. Varieties of surgical techniques described in literature include fragment removal with or without marrow stimulation, drilling of the defect, fragment fixation, osteochondral autograft, autologous chondrocyte implantation, and lateral humeral closing-wedge osteotomy.

59.7 Techniques

59.7.1 Arthroscopy

Arthroscopic treatment of OCD is performed in the lateral or prone position, but the supine position may be better because of the easy conversion to an open procedure if needed. Standard anterior medial and lateral portals are used for inspection of the anterior compartment. The anterior capitellum is often normal as the pathological lesion resides out of view on the more posterior aspect [39].

Posterior standard portals are used for inspection of the posterior compartment. Posterolateral portal is made slightly more distal at the level of the olecranon tip. The detached OCD fragments are often located in the olecranon fossa.

For direct assessment of the OCD lesion, a soft-spot portal is created to probe and debride. A second direct lateral portal should be placed ulnarly to the first to avoid an injury to the lateral ligament complex. The "distal ulnar portal," a viewing portal at 3–4 cm distal to the posterior aspect of the radiocapitellar joint and just lateral to the posterior border of the ulna, has also been described for better visualization and easier hand-eye coordination.

59.7.2 Fragment Removal and Drilling of the Defect

Arthroscopic debridement (Fig. 59.6) for osteochondritis dissecans is a common and minimally invasive procedure [40]. Arthroscopy is performed as previously described. After evaluation of the lesion, unstable areas and bone fragments already detached were removed. Drilling (Fig. 59.7) was also performed using a 1.2-mm K-wire if bleeding was poor after focal excision. If an empty crater is found in the capitellum, a careful search for loose body is performed in both compartments. A range of motion exercises are started on the day after surgery, and permission to return to sports is allowed after physical conditioning and training [10, 32, 33, 40].

Open or arthroscopic fragment excision has been shown to decrease pain and improve radiologic parameters in patients with OCD lesions measuring less than 50 % of the capitellar. A total of 81 % of the treated patients were able to return to sports activities after treatment. Returning to sports was not found to be related to radiographic findings, but it was significantly related to pain [10, 32, 40].

Several small studies have reported clinical outcomes of arthroscopic debridement for osteochondritis dissecans of the humeral capitellum. Ruch et al. [41] reported that remodeling was confirmed in all 12 patients followed up for

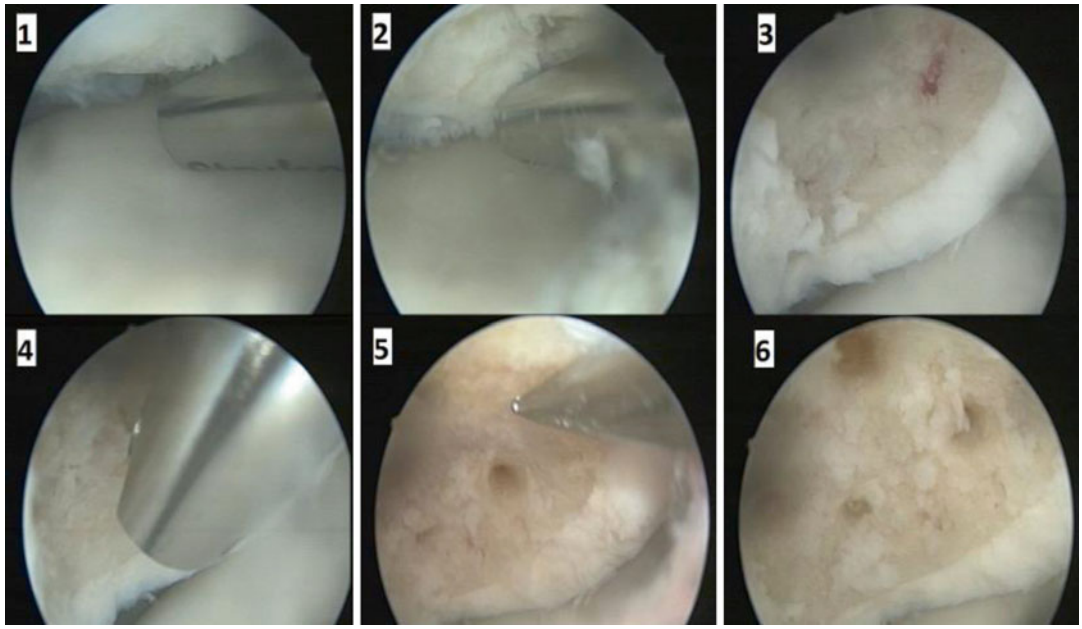

Fig. 59.7 Sequential views of a typical arthroscopic debridement and microfracture procedure. This is the right (dominant) elbow in a 17-year-old male tennis player whose chief complaint was pain. *1* Osteochondral lesion visualized through direct lateral portal with the shaver in the adjacent direct lateral portal; *2* debridement of osteochondral lesion with shaver; *3* debrided and cleaned defect with nearly modeled border at the interface with the surrounding healthy cartilage; *4* removal of calcified cartilage from base of defect using shaver; *5* piercing the subchondral bone using a microfracture awl; *6* the lesion site after completion of procedure, the holes being 2–4 mm deep and 3 mm apart (Courtesy of Professor Ivan Bojaniw. Department of Orthopedics at University Hospital Zagreb)

2–5 years and that satisfactory results were obtained in 92 % of cases. Baumgarten et al. cited by Rahusen et al. [42] reported that 82 % of the 17 patients followed up for an average of 4 years returned to their sports activity at the pre-injury level and that osteoarthritic lesions were not observed in any cases.

Jones et al. [43] also reported that 86 % of the 21 patients returned to participate in their sports activity at their pre- injury level. In contrast, Byrd et al. [10] found that although clinical outcome was evaluated as excellent in all of the ten patients who were followed up for 2–5 years, plain radiographs showed osteoarthritic lesions in two of the cases. Moreover, only four patients were able to return to their sports activity at the same level as before their injuries.

For Miyake et al. [40], 105 of 106 patients were able to return to their sports after an average of 2.4 months. Ninety patients (85 %) returned to their sport at their pre-injury levels. Prognosis, thus, varies in different reports. Radial head enlargement might have resulted from the absent capitellar articular surface in patients with remaining growth potential of the radial head, and this can lead to early osteoarthritis of the radiohumeral joint after the procedure.

59.7.3 Fragment Fixation

Occasionally, a surgeon may encounter a large and viable OCD fragment. In this situation, the fragment is gently "hinged" open, and the defect base is debrided with a shaver. The fragment is then replaced within its bed and stabilized. Many fixation techniques have been described, including Kirschner wires, Herbert screws, retrograde sutures, cancellous screws, bioabsorbable implants, bone-peg graft, and pullout wiring [44]. Some studies reported that the rate of healing of the lesion in these cases was 94–100 %, and the

rate of return to previous sports was 91–100 % [45]. Mihara et al. [33] reported on 27 male patients, with a mean age of 13 years old, who had undergone drilling, fragment fixation, pull-out wiring, or osteochondral autografting of a capitellar OCD defect. A retrospective chart review was performed with a mean follow-up period of 37 months. Nobuta et al. [46] reported on 28 male patients with a mean age of 22 years. They performed fragment fixation with a double soft wire technique on the capitellar OCD site. A retrospective chart review was performed with a mean follow-up period of 17 months. Rahusen et al. [42] reported findings of a prospective cohort study of 15 patients (6 males and 9 females) with OCD of the elbow who underwent arthroscopic debridement of the defect. The mean age of the included patients was 28 years. The follow-up period was 45 months and none of the patients was lost to follow-up. Takeda et al. [47] performed fragment fixation using pullout wiring in 11 male patients with a capitellar OCD defect. The mean age at the time of surgery was 15 years. A retrospective chart review was performed with a mean follow-up period of 57 months.

59.7.4 Osteochondral Autograft

Iwasaki et al. [48] reported on 19 male patients, with a mean age of 14 years, who had undergone osteochondral autografting of a capitellar OCD defect. A retrospective chart review was performed with a mean follow-up period of 44 months. Because of the retrospective design primarily used, loss to follow-up was not applicable.

Yamamoto et al. [49] reported on 18 male patients, with a mean age of 14 years, who had undergone an osteochondral autograft transfer to the capitellar OCD defect. A retrospective chart review was performed with a mean follow-up period of 42 months.

In the rare late-stage OCD defect that compromises the lateral capitellum, open or arthroscopic osteochondral grafting can be considered to bolster the lateral joint and prevent instability. The knee, rib, and proximal olecranon are potential osteochondral autograft sites. Alternatively, one can use allograft or synthetic implants.

59.7.5 Lateral Humeral Closing-Wedge Osteotomy

In 1983, Yoshizu described closed-wedge osteotomy to treat osteochondritis dissecans of the capitellum in order to reduce compression and allow revascularization and remodeling in the area of the lesion. The technique describes exposure of the elbow joint anteriorly and subperiosteally between the extensor carpi radialis longus and the extensor carpi radialis brevis muscles, protecting the deep radial nerve. The origin of the annular ligament is cut protecting. The ulnar part of the lateral collateral ligament was kept intact to maintain the stability of the elbow joint.

A laterally based wedge osteotomy with an intervening angle of 10° at 2 cm proximal to the lateral epicondyle, with its apex just medial to the capitellum. The posterior aspect of the capitellum is not exposed as to prevent damage to its blood supply. The articular surface of the apex was kept intact. The defect and stability are obtained by use of a screw. According to Kiyoshige et al. [50], the carrying angle was little changed after remodeling of the capitellum occurred without severe degenerative change of the joint because the intact ulnar part of the lateral collateral ligament maintained its stability.

59.8 Complications

Most authors agree that the best short-term results are obtained with simple excisions of the loose body, and complex procedures involving open excision of the capitellum, bone grafting, and internal fixation of the loose fragment are usually worst [13].

Due to the minimal invasiveness of arthroscopic techniques, scarring is smaller, recovery is quicker, and complications are less common [51]. Arthroscopic techniques using standard 4-mm instruments were shown to be

effective in evaluating and treating elbow disorders such as osteochondritis dissecans [13]. Nevertheless, because of the small size and compartmentalization of the elbow joint, lack of surgeon familiarity, and proximity of portals to neurovascular structures, elbow arthroscopic surgery is technically demanding [39].

In a study conducted in 50 patients with chronic osteochondral lesions of the talus, who underwent arthroscopic treatment, the outcomes were good in the majority of the patients. However, pain and functional limitation may persist in some patients, especially those noted to have unstable osteochondral defects at the time of arthroscopy [52]. On the other hand, in another research, led by Schoch et al. [32], all 13 patients, diagnosed with osteochondritis dissecans of the capitellum, who underwent surgical intervention with arthroscopic debridement, due to failed conservative treatment or because of the presence of an unstable lesion or loose bodies on the initial presentation, revealed no surgical complications.

Kiyoshige et al. [50] followed up patients submitted to closed-wedge osteotomy for osteochondritis dissecans of the capitellum during 7–12 years. The results show that none of the patients experienced any complications such as infection or screw irritation. The pain was relieved in all patients except one, who continued to have mild elbow pain only during throwing. The lesion of the capitellum was revascularized and remodeled within a half year in all of the patients.

Concerning the osteochondral autograft, some problems related with pain at the donor site have been described. However, the same was not true for other authors, who had no complications at the donor site. The only complication found by Yamamoto et al. [49] in his 2-year follow-up of juvenile baseball players after being submitted to osteochondral autograft transplantation for osteochondritis dissecans was an ectopic callus at the approach site of the elbow joint recognized in one patient with no observer must be removed. No infection or neurologic deficit developed postoperatively in any case. However, despite the fact that all operated elbows were stable after surgery and the patients continued to be highly satisfied with the procedure [33], the authors suggest that longer follow-ups are needed in order to determine late complications such as degenerative [49].

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Arthroscopic Synovectomy for Rheumatoid Elbow

60

Mehmet Derviş Güner and Mehmet Demirtaş

60.1 Diagnosis: Clinical

The most common cause of elbow arthritis is rheumatoid arthritis, followed by posttraumatic arthritis and primary osteoarthritis. Rheumatoid arthritis is an inflammatory disease characterized by synovial hypertrophy that can affect multiple joints. Within 5 years of the onset of disease, 20–65 % of patients with rheumatoid arthritis develop elbow involvement [1, 2]. Furthermore, 50–75 % of rheumatoid arthritis patients present with elbow and wrist symptoms [3–5]. Pain throughout the arc of motion is the most common complaint associated with rheumatoid elbow; however, swelling and stiffness can also occur. Although patients may exhibit limited forearm rotation, ulnotrochlear articulation involvement usually occurs primarily [6]. Synovitis and pannus invasion cause loss of articular cartilage and destruction of subchondral bone [7]. Loss of bone congruency and destruction of soft tissue stabilizers, in most cases, result in instability. Joint incongruity can lead to elbow instability during extreme motion in the coronal plane [8].

M.D. Güner
Orthopaedics and Traumatology, Medicana International Ankara Hospital, Ankara, Turkey

M. Demirtaş (✉)
Orthopaedics and Traumatology Hand Surgery, Ankara Memorial Hospital, Ankara, Turkey
e-mail: demirmeh@yahoo.com

The skin should be inspected to identify any previous surgical incisions and healed wounds. Limitation of elbow flexion and extension should be carefully measured using a goniometer and recorded. Forearm rotation should also be assessed to determine if there is radiocapitellar joint involvement. Flexion-extension and pronation-supination range of motion measurements must be obtained, both actively and passively. Palpation of the soft spot is important to identify possible joint effusion. Neurovascular examination is also very important, especially for evaluating ulnar nerve irritation. Physical examination must include the varus-valgus stress test for coronal plane instability and O'Driscoll's test for posterolateral instability. Lastly, the ulnar nerve should be examined for signs of irritation.

60.2 Exploration: Instrumented, Radiological

Initial radiological evaluation of the rheumatoid elbow should begin with plain X-rays. Anteroposterior, lateral with the elbow flexed at 90°, and radiocapitellar oblique views are essential. Rheumatoid arthritis has typical radiographic findings, including symmetric joint space narrowing, periarticular erosions, and disuse osteopenia, and radiographic findings are, in most cases, adequate for diagnosis. Ultrasonography (US) is a useful diagnostic tool for soft tissue assessment. The thin soft tissue layer surrounding the elbow joint permits

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visualization of even bony structures. US can detect minimal erosions of the cortical area, especially during the early stages of the disease. Synovial inflammatory status can be assessed using color US [9], although magnetic resonance imaging (MRI) can be useful for detecting synovial hypertrophy and cartilage erosions (Fig. 60.1). In general, for the majority of patients, additional radiological imaging is not necessary. Measurement of rheumatoid factor, the complete blood cell count, the erythrocyte sedimentation rate, and the C-reactive protein level are important for diagnosis.

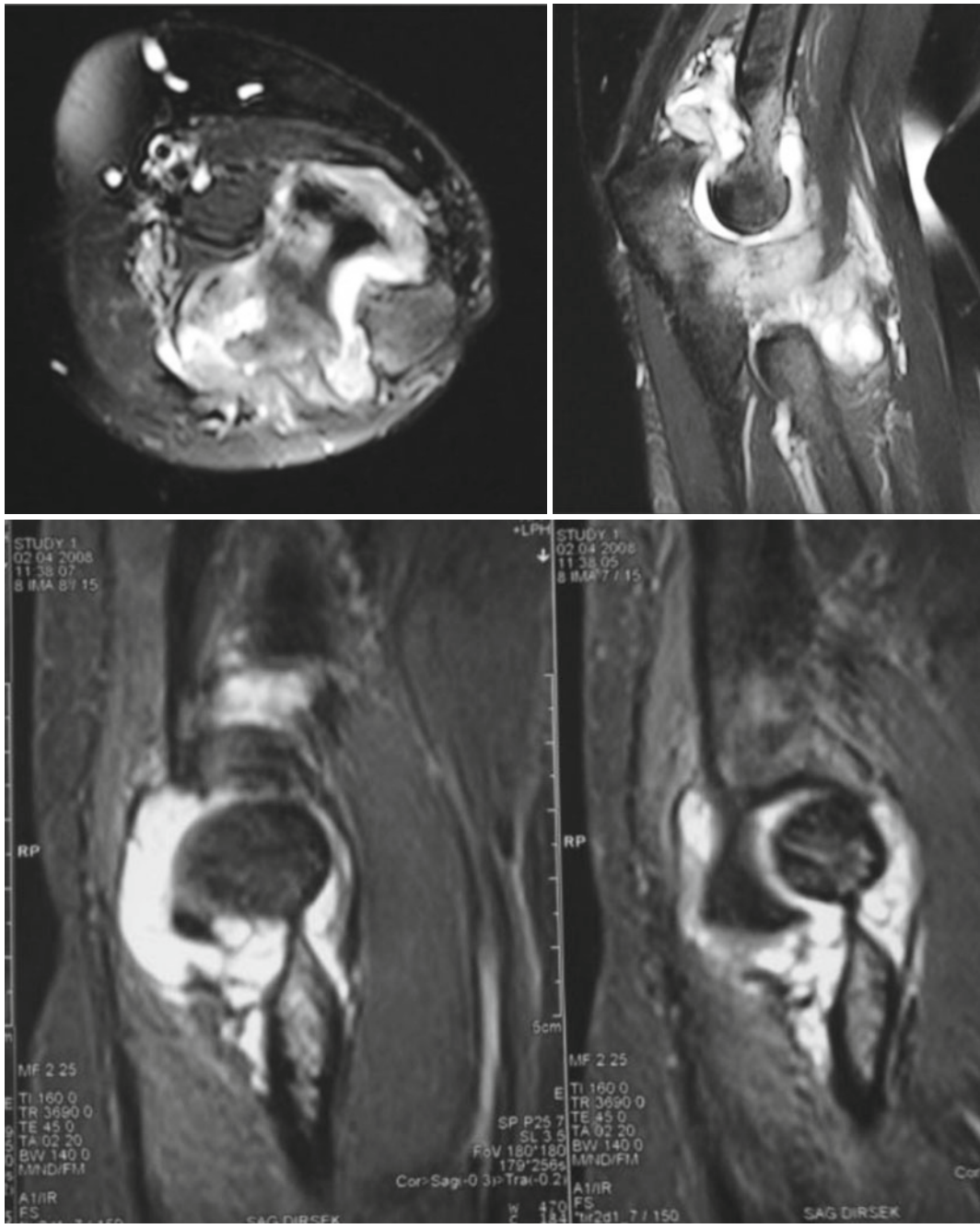

Fig. 60.1 Synovial hypertrophy capsular enlargement, cartilage lesions of the elbow joint in rheumatoid arthritis

60.3 Rating: International Classification

In 1974 Larsen [10] developed a classification system for rheumatoid arthritis based on standard radiography that was subsequently modified several times (1977, 1978, 1984, 1985, 1987, and 1995) [11]. Grade 0 means normal radiographic findings. The presence of minor abnormalities (periarticular soft tissue swelling, periarticular osteoporosis, and slight joint space narrowing) is considered grade 1. Grade 2 disease is characterized by mild to moderate joint space narrowing. Grade 3 denotes architectural alteration, such as thinning of the olecranon, or resorption of the trochlea or capitellum (capitulum). Variable joint space narrowing, with or without cyst formation, can also be seen in patients with grade 3 disease. Grade 4 disease presents severe articular damage, gross destruction, and instability. Grade 5 is diagnosed based on mutilating abnormalities; in addition, the ulnohumeral joint is not identifiable, and ankylosis can be seen in grade 5 patients. The wrist is considered as one unit, and the score is multiplied by 5. Joints assessed include five distal interphalangeals (DIPs), four PIPs, five MCPs, the wrist as one unit for each hand and wrist, ten MTPs, and two IPs for the feet. Total score ranges from 0 to 250 [11, 12].

Mayo classification is useful as it radiographically describes rheumatoid disease of the elbow. Mayo classification grade I is based on synovitis without articular destruction; radiographs of grade I disease show soft tissue swelling and osteopenia. Grade II disease denotes mild to moderate joint space narrowing. In patients with grade III disease, they show significant arthrosis and architectural changes, with a variable degree of joint space narrowing. Grade IV disease is characterized by gross articular destruction, with extensive loss of subchondral bone [13].

In 2010 Hashizume et al. [14] described a functional classification system for elbow joint destruction in patients with rheumatoid arthritis. In their study two new radiographic parameters – the humeral surface height ratio (HHR) and ulnar surface height ratio (UHR) – were used to sensitively evaluate changes in the bony structure of rheumatoid elbows. Rheumatoid elbows were classified in two forms and four types, based on radiographically observed structural changes. They classified 101 X-rays of rheumatoid elbows as follows:

1. Osteoarthritis type: joint space narrowing without bone destruction
2. Ankylosis type: bony ankylosis
3. Erosive type: joint space narrowing, joint surface irregularity, and bone erosion
4. Resorptive type: massive bone destruction

The osteoarthritis and ankylosis types were combined and denoted as the stable form. Similarly, the erosive and resorptive types were combined as the unstable form. Following this classification, they measured the HHR in the anteroposterior view and the UHR in the lateral view, reporting that both HHR in anteroposterior view radiographs and UHR in lateral view radiographs differed significantly between the stable and unstable forms. Moreover, significant differences were noted between the osteoarthritis and erosive types and between the osteoarthritis and resorptive types [14].

60.4 Indications

If conservative treatment of rheumatoid elbow fails and pain becomes intolerable, then surgery is indicated. Lysosomal enzymes in the synovial fluid cause cartilage destruction and ligament elongation which leads to instability. Synovectomy is an effective surgical treatment option for patients with rheumatoid elbow to prevent cartilage destruction and instability (Figs. 60.2 and 60.3). Arthroscopy provides better access to the elbow joint; in addition, capsulectomy, radial head resection, osteophyte debridement, and removal of loose bodies can be performed with less morbidity. Arthroscopy is highly efficacious for removing hypertrophic and inflamed synovial tissue that causes pain and cartilage destruction in patients without severe joint cartilage erosion. If radiocapitellar joint involvement is a source of pain, arthroscopic radial head resection can also be performed.

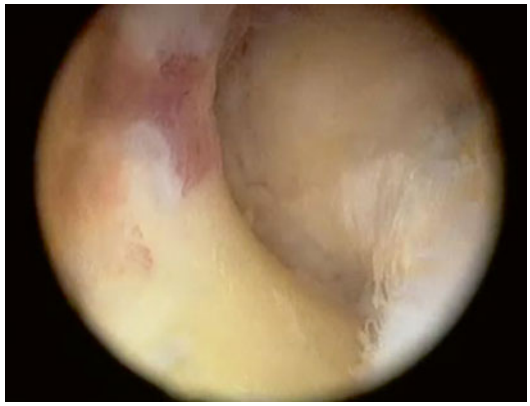

Fig. 60.2 Synovitis over the cartilage, damage of the cartilage surface

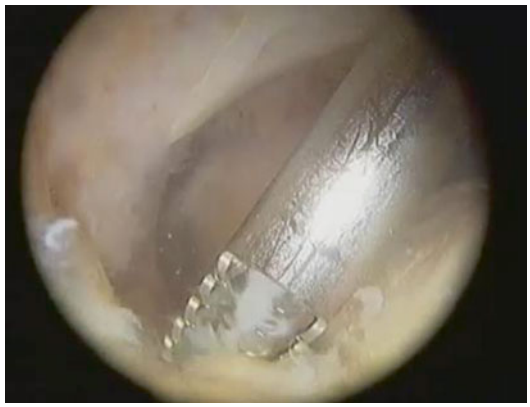

Fig. 60.3 Arthroscopic synovectomy

The advantages of arthroscopic synovectomy are improved intraoperative visualization, lower risk of infection, smaller incisions, lower risk of problematic wound healing, and easy rehabilitation [2]. Moreover, arthroscopic synovectomy can facilitate access to difficult to reach parts of the elbow through multiple portals [15]. Ankylosis or severe arthrofibrosis and significant capsular contracture are contraindications for elbow arthroscopy. A history of serious elbow trauma, such as distal humerus fracture, is a relative contraindication for elbow arthroscopy. Anatomical changes in the elbow due to trauma increase the risk of injury to adjacent neurovascular structures during arthroscopic synovectomy [16, 17].

60.5 Techniques

There are three options for positioning patients for elbow arthroscopy: supine, prone, and lateral decubitus. The supine position offers more flexibility and allows for visualization of the elbow joint in the upright position, with full access to the airway [18]. The use of the supine position for elbow arthroscopy was first described by Poehling et al. [19]. The prone position facilitates better access to the posterior part of the elbow joint, and traction is not necessary. The prone position allows for visualization of the joint space in the upside-down position. As the prone position is associated with poor airway control, general anesthesia is essential [18]. The lateral decubitus position has advantages similar to those of the prone position, and it is easy to control the airway in this position. Although the lateral decubitus position facilitates better access to the elbow's posterior compartment, access to the anterior compartment is difficult [18].

A tourniquet should be placed on the proximal part of the arm, regardless of patient's position. After patient positioning and tourniquet placement, the soft spot formed by the borders of the lateral epicondyle, radial head, and olecranon should be palpated. Then, 20–30 mL of sterile saline should be injected into the joint using an 18-gauge needle. Free backflow of fluid confirms intra-articular location. Distention of the joint reduces the risk of injury to neurovascular structures by positioning them away from the bone [17].

There are some key points to consider regarding portal placement. Bony landmarks of the elbow should be palpated and marked before establishing portals. Stability of the ulnar nerve should be carefully evaluated before making medial portal incisions. Portals should be made by incising only the skin. Subcutaneous tissues should be bluntly dissected using a hemostat, so as to avoid superficial nerve damage. Anterior portals should be created with the elbow in flexion. Adjacent neurovascular structures can be positioned away from the bony landmarks by flexing the elbow [17].

The elbow joint has three major arthroscopic compartments: anterior, posterior, and posterolateral. The anterior ulnohumeral, radiocapitellar, and proximal radioulnar joints and the coronoid process, anterior trochlea, radial head, capitellum, and medial and lateral condyles can be evaluated during anterior arthroscopy. Posterior compartment arthroscopy can be used to assess posterior ulnohumeral articulation, the olecranon fossa, posterior trochlea, medial, and lateral gutters. The posterior aspect of the radiocapitellar joint and the radial head, olecranon, lateral gutter, and capitellum can be visualized via posterolateral arthroscopy [20].

Although multiple portal sites have been described, anterolateral, midlateral soft spot, anteromedial, proximal anteromedial, proximal anterolateral, posterolateral, and straight posterior portals are most commonly used for elbow arthroscopy [18]. The proximal anterolateral portal is located 1–2 cm proximal to the lateral epicondyle and about one fingerbreadth anterior to the distal humerus. The anterolateral portal is located 2 cm anterior and 3 cm distal to the lateral epicondyle. The anteromedial portal is located 2 cm distal and 2 cm anterior to the medial epicondyle. The direct posterior portal is located centrally 3 cm proximal to the tip of the olecranon. The proximal posterolateral portal is also located 3 cm proximal to the olecranon tip, but lateral to the border of the triceps tendon [18].

An arthroscopy system 4 mm in diameter with a 30° angle is necessary for visualization of the elbow joint. Other equipment for arthroscopic synovectomy, including a motorized shaver, radio-frequency ablation system, a probe, and cutting forceps, should be set up and ready to use in the operating room. Additionally, a pump system may be useful for maintaining intra-articular pressure.

60.6 Complications

Recurrence of synovitis is the most frequent complication of elbow arthroscopy, followed by nerve transection, compartment syndrome, and joint space infection. Prolonged drainage from or superficial infection of a portal site, persistent minor contracture <20°, and transient nerve palsies (ulnar, superficial radial palsies, posterior interosseous palsy, medial antebrachial cutaneous palsy, and anterior interosseous palsy) are minor complications of elbow arthroscopy. Synovial fistula is a complication specific to arthroscopic surgery that can be avoided by closing arthroscopy portals with sutures [2].

Nerve injury is among the most catastrophic complications of elbow arthroscopy. An underlying diagnosis of rheumatoid arthritis is the most significant risk factor for the development of temporary nerve palsy postsurgery [21]. Careful performance of elbow arthroscopy, which is a safe technique, and avoiding patients with a history of elbow fracture can reduce the risk of nerve injury. The infection rate following elbow arthroscopy is reported to be 0.8–2 %. Synovial fistula is a complication specific to arthroscopic surgery that can be avoided by closing arthroscopy portals with sutures [2]. Despite the potential complications associated with elbow arthroscopy, the technique has been demonstrated to be safe and effective when performed by experienced surgeons [22].

60.7 Results and Literature Review

The literature includes numerous studies on synovectomy for the treatment of rheumatoid elbow. Lee and Morrey [1] reported excellent and good short-term outcomes with arthroscopic synovectomy in 57 % and 36 % of patients with rheumatoid elbow, respectively. They also reported that the surgical results tended to deteriorate more rapidly following arthroscopic synovectomy, as compared to open synovectomy; at a mean follow-up of 42 months, only 57 % of their patients treated via arthroscopic synovectomy were evaluated as good-excellent. Horiuchi et al. [23] reported good-excellent outcomes at the 2-year follow-up in 71 % of 20 patients following subtotal arthroscopic synovectomy; however, only 43 % of the elbows were evaluated as good-excellent at the 8-year follow-up. Nemoto et al.

[24] reported satisfactory functional results even in advanced cases with Larsen grade 4. Tanaka et al. [25] compared arthroscopic versus open synovectomy: 48 % of patients in the arthroscopy group had mild or no pain, a mean 13 years post-surgery, versus 70 % of patients in the open synovectomy group. They reported that outcomes were better in patients with early stage disease and preoperative flexion arc >90°. Kang et al. [26] reported that 73 % of patients had good excellent results during a mean follow-up period of 33.9 months and that the recurrence rate was 15 %. More recently, Chalmers et al. [7] reported that patients with rheumatoid elbow undergoing arthroscopic or open synovectomy were equally likely to require subsequent arthroplasty. In 2012 Chung et al. [3] reported excellent results following arthroscopic synovectomy in 13 patients with rheumatoid elbow at a mean follow-up of 34 months and a recurrence rate of 8 %.

Arthroscopic synovectomy of the elbow joint is a reliable procedure for reducing pain in patients with both early- and late-stage rheumatoid elbow (Fig. 60.3). Because of the close proximity of neurovascular structures, arthroscopy of the elbow joint should be performed only by surgeons that have experience performing this procedure in other joints.

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Elbow Instability

61

John T. Heffernan, Michael O'Brien,
and Felix H. Savoie III

61.1 Elbow Instability

61.1.1 Diagnosis: Clinical

61.1.1.1 Introduction

Posterolateral rotatory instability (PLRI) is a pathologic condition of the elbow resulting in the entire forearm rotating on the humerus, producing both radiocapitellar and ulnohumeral instability. As first described by O'Driscoll et al. in 1991, PLRI is a spectrum of injury due to an incompetent radial ulnohumeral ligament (RUHL) complex, including the RUHL, the lateral collateral ligament, and the annular ligament [1]. The patient's history of injury is usually variable, ranging from an acute dislocation, repetitive microtrauma, and after surgical and nonsurgical treatment of lateral elbow pathology. They will complain of recurrent lateral elbow pain and mechanical symptoms of locking, snapping, and clicking. Unlike medial instability, which usually only affects sports participation, patients with PLRI of any degree will have problems in everyday life. Surgical repair or reconstruction, both open and arthroscopic as described by O'Driscoll and by Savoie, respectively, has provided satisfactory restoration of function in a majority of patients.

Medial, or valgus, instability is most often the result of overuse in overhead throwing athletes resulting in repetitive strain and insufficiency of the medial collateral ligament (MCL). During the late cocking and early acceleration phases of the throwing motion, the anterior bundle of the MCL provides the valgus restraint to the elbow. With repetitive strain, the anterior bundle degenerates or traumatically ruptures, leading to medial elbow pain at rest and instability with throwing. While PLRI is poorly tolerated in performing daily activities, MCL insufficiency is rarely problematic for patients other than overhead throwing athletes, frequently baseball pitchers. In this select population, repair or reconstruction of the MCL is required.

Surgical reconstruction of the MUCL in athletes was initially described by Jobe et al. [2]. His initial technique described autologous palmaris graft reconstruction, tied in a figure-of-eight fashion through multiple bone tunnels, as well as detachment of the flexor-pronator mass and submuscular transposition of the ulnar nerve. Jobe's original technique has been modified multiple times since its inception. Variations by Altchek, Andrews, ElAttrache, and many others have

J.T. Heffernan, MD
Orthopaedic Surgery, Tulane University School of Medicine, New Orleans, LA, USA

M. O'Brien
Division of Sports Medicine, Tulane University School of Medicine, New Orleans, LA, USA

F.H. Savoie III, MD (✉)
Department of Orthopaedics, Tulane University School of Medicine,
1430 Tulane Avenue 8632, Room 2070, New Orleans, LA 70112, USA
e-mail: fsavoie@tulane.edu

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included muscle-splitting approaches to the MUCL, subcutaneous ulnar nerve transposition, docking techniques, interference screws, and hybrid techniques [3–5]. Direct repair of proximal or distal injury to an otherwise normal ligament in nonprofessional athletes has also shown to be effective in return to sport [6].

61.1.1.2 Posterolateral Rotatory Instability

Anatomy

The elbow is a complex hinged joint whose stability is determined by the static and dynamic constraints of bony articulations, ligaments, and muscles. The lateral ligament complex of the elbow consists of the radial ulnohumeral ligament (RUHL) also known as the lateral ulnar collateral ligament, the radial collateral ligament (RCL), the annular ligament, and the accessory collateral ligament (Figure 61.1, anatomical dissection of the RUHL complex). The LCL complex originates on the posterior lateral aspect of the lateral epicondyle and inserts on the crista supinatoris of the ulna [7]. The LCL complex is the key ligamentous stabilizer of the elbow to varus stress and posterolateral instability [8]. O'Driscoll et al. originally described PLRI in 1991 as recurrent instability of the elbow due to insufficiency of the radial ulnohumeral ligament (RUHL). Subsequently, multiple studies attempted to more precisely define the disrupted tissue in PLRI. Dunning et al. demonstrated that sectioning of either the RUHL or RCL alone was insufficient to induce PLRI [9]. Seki et al. demonstrated that the LCL has a Y-shaped configuration and functions as a complex [10]. Sectioning of just the anterior band of the LCL was enough to produce PLRI.

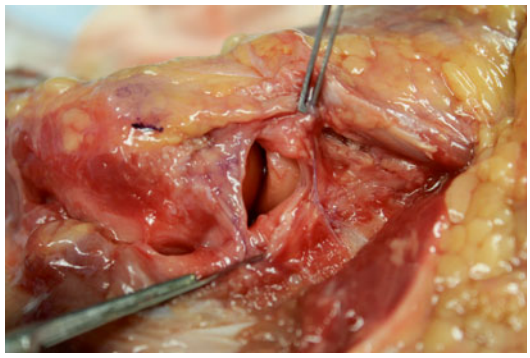

Fig. 61.1 The anatomy of the ligamentous complex on the lateral side of the elbow is delineated in this cadaveric dissection

History

PLRI has a varied etiology, occurring only rarely after acute dislocation but more commonly after repetitive stress injuries and after treatment of lateral tendinopathy. After traumatic elbow dislocation, PLRI can result if the proximally avulsed LCL fails to heal back into position. Other patterns of injury in PLRI include midsubstance tears of the LCL, distal ligamentous avulsions, or bony avulsions from the humeral epicondyle or crista supinatoris. PLRI can also be induced through iatrogenic injury by steroid injections or arthroscopic or open surgery in lateral epicondylitis [11]. Patients with underlying chronic lateral epicondylitis may be at higher risk of concomitant PLRI or the induction of PLRI after fall and injury [12]. Other initiating factors of PLRI include chronic cubitus varus deformity and radial head resection. The differential diagnosis for chronic lateral elbow pain should include lateral epicondylitis, PLRI, radiocapitellar arthritis, radial tunnel syndrome, and posterolateral plica syndrome. Patients with PLRI will complain of lateral elbow pain and mechanical symptoms of clicking, locking, and catching. Classically patients with PLRI will report a history of traumatic dislocation of the elbow or fall onto outstretched hands leading to the elbow sustaining axial compressive and valgus forces with the forearm in supination. O'Driscoll created a classification scheme for staging of PLRI [13] (Table 61.1). Often the patient will report certain activities that exacerbate their symptoms, such as opening doors, starting a car, or pushing up from a seated position. In common with these activities are forearm supination, valgus force, and axial loading of the elbow that cause the entire forearm to rotate away from the humerus, most easily seen by the radial head subluxating posterolaterally. Symptoms worsen as the elbow is extended until the bony architecture causes a spontaneous reduction of the posterolateral radial head subluxation.

Physical Examination

The *lateral pivot-shift test* as described by O'Driscoll et al. can be performed in the supine or prone position. The forearm is fully supinated and axial and valgus loading is applied to the patient's elbow by the examiner. As the elbow is slowly brought from extension to full flexion, the displacement is maximized at 40° and a dimpling of the skin is visible proximal to the radial head. Further flexion spontaneously reduces the radiohumeral and ulnohumeral joints with a palpable and sudden "clunk." The test is considered positive with the findings of either gross instability or simply pain or apprehension. The exam is most sensitive with the patient fully sedated and is difficult to perform while the patient is awake. At our institution we perform a modified O'Driscoll test with the patient in the prone position. The humerus is stabilized by the exam table and the radiocapitellar joint is palpated with one hand while the examiner's other hand holds the patient's wrist to pronate the arm and flex the elbow while providing a gentle valgus and axial load. Posterior lateral subluxation of the radial head is palpable as the elbow is flexed beyond 90°. Regan and Lapney described two further tests, the *prone push-up test* and the *chair push-up test*, to evaluate PLRI more easily in an awake patient [14]. Both of the tests place the patient's forearms in maximal supination while the elbow is extending against an axial load. Arvind and Hargreaves described the *table-top relocation test* which is performed by having the patient push up against a table or wall with the arm in full pronation and then repeated in full supination [15]. Positive signs for these tests are apprehension, pain, or palpable instability.

61.1.1.3 Valgus Elbow Instability

Anatomy

Ligamentous restraint of the medial elbow is provided by the medial collateral ligament (MUCL). The MUCL consists of an anterior bundle, the posterior bundle, and the transverse ligament (Figure 61.2, anatomy of the medial ligament complex). The anterior bundle originates on the anteroinferior surface of the medial epicondyle and inserts onto the base of the coronoid. The posterior bundle originates on the posteroinferior medial epicondyle and inserts slightly posterior to the anterior bundle on the coronoid [7]. The primary restraint to valgus stress of the elbow is the anterior bundle of the MUCL, which can withstand tensile forces up to 260 N [16]. The act of throwing a baseball generates a valgus force across the elbow estimated at 290 N and an angular velocity in excess of 3000°/s [17]. During the late cocking and early acceleration phase of the throwing motion, the valgus stress to the elbow exceeds the strength of the anterior bundle of the MUCL. Dynamic stabilization by the surrounding musculature and stability from bony constraints compensates for this deficiency in valgus stability. With repetitive overuse and/or poor mechanics in throwing athletes, degeneration or acute tears of the MUCL can result. Reconstruction of the anterior bundle of the MUCL has been shown to restore radiocapitellar articular pressures under valgus force to nearly normal values, demonstrating the importance of anterior bundle of the MUCL and the effectiveness of surgery [18].

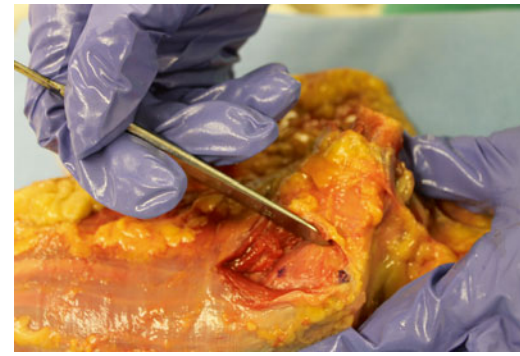

Fig. 61.2 The anatomy of the ligamentous complex on the medial side of the elbow is delineated in this cadaveric dissection

History

Injuries to the MUCL typically present with chronic medial-sided elbow pain that is worsened by activity in overhead throwing athletes. Occasionally, patients will report symptoms consistent with acute injury such as sharp, acute pain or popping in their medial elbow when throwing. Pitchers will complain of decreased velocity and

accuracy and arm fatigue. Patients complaining of pain in their posterior elbow may have symptoms resulting from valgus extension overload and posteromedial osteophytes. The patient may also report symptoms of ulnar nerve irritation.

Physical Examination

Examination of the patient begins with palpation of the medial elbow. Tenderness to palpation may be appreciated over the inferior medial epicondyle and the flexor-pronator mass or along the posteromedial olecranon if concomitant valgus extension overload is present. Medial instability is best demonstrated by the *moving valgus stress test* described by O'Driscoll [19]. The patient is positioned with the arm abducted to 90° and the humerus in full external rotation. The examiner applies a constant valgus load to the elbow and extends the elbow from full flexion to full extension. Pain on the medial elbow and apprehension by the patient are considered a positive test, particularly in the range from 70 to 120° of elbow flexion. The *valgus stress test* is performed with the patient seated and the elbow flexed to 30° to unlock the olecranon from the olecranon fossa. As the patient's arm is grasped and a valgus load applied to the elbow, the medial ulnohumeral joint is palpated for either increased opening or no definitive end point. The milk test is performed with the patient's arm elevated forward and maximally externally rotated while the examiner grasps the patient's thumb and pulls downward to load the MUCL. Pain at the medial elbow or apprehension by the patient is considered a positive test. The ulnar nerve should be examined as well for neuritis symptoms elicited by a positive Tinel's sign or palpable subluxation of the nerve. If MUCL reconstruction is planned, palpation for the presence of an ipsilateral palmaris longus tendon should be performed for use as possible autograft.

61.2 Exploration: Radiological, Instrumented

While PLRI is a clinical diagnosis, imaging studies of the elbow are often useful. Radiographic evaluation of PLRI should begin with radiographs of the elbow, which are frequently normal. Signs consistent with PLRI on radiographs of the elbow include bony avulsions, coronoid or radial head fractures, or widening of the ulnohumeral joint or posterior displacement of the radial head [20]. Stress radiographs or fluoroscopy while performing the pivot-shift test may reveal subluxation and posterolateral rotation of the radial head and ulnohumeral joint. Magnetic resonance imaging (MRI) of the elbow has been shown to be effective in identifying lesions of the RUHL [21]. Formal MRI arthrogram (MRA) is the most sensitive nonsurgical test for evaluation of the LCL pathology (Fig. 61.3).

Arthroscopic surgery provides the advantage of direct visualization of the elbow joint. In posterolateral instability, as viewed from the anteromedial portal, the annular ligament often appears lax, displaced from the radial neck. The normal humeral attachment of the radial capsule may also appear loose (Fig. 61.4). When viewing from posterior portals, there will be an arthroscopic "drive-through" sign in which the arthroscope may be moved completely through the ulnohumeral articulation from the lateral gutter to the medial side of the elbow.

Medial instability: Diagnosis of valgus instability of the elbow is primarily a clinical diagnosis reliant upon history and physical examination of the patient. Imaging for medial instability is helpful in some instances and begins with plain radiographs of

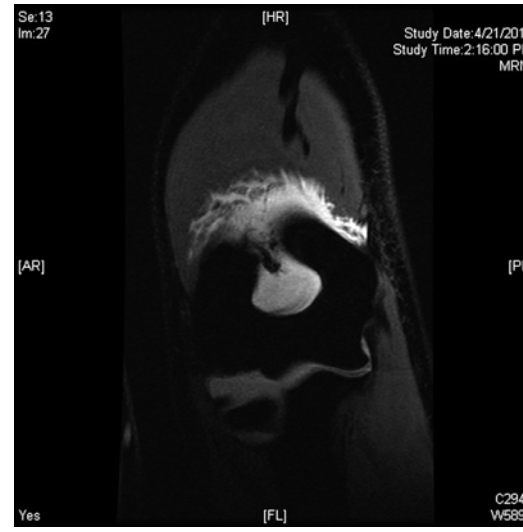

Fig. 61.3 A magnetic resonance imaging study with dye provides the most accurate imaging of the ligaments of the elbow

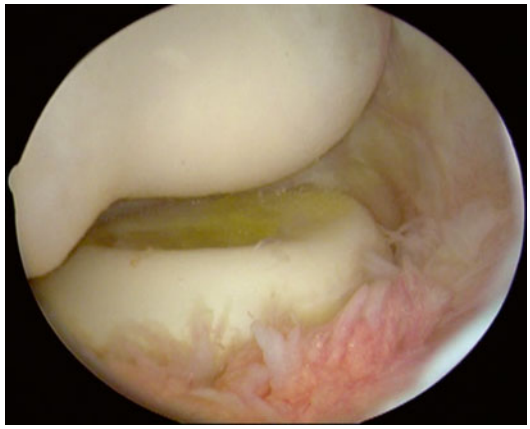

Fig. 61.4 A view from the posterior portal showing an avulsion of the humeral attachment of the radial ulnohumeral ligament

the elbow. Although frequently negative, avulsions from either the humeral or ulnar attachment of the tendon may be visible. Posteromedial osteophytes will be present in patients with chronic valgus extension overload. MRI is the most useful imaging modality for evaluation of the MUCL and may demonstrate partial- or full-thickness tears, thickening, proximal or distal avulsions, or general insufficiency. In younger athletes (age <20), it is important to evaluate the structural quality of the ligament to determine if the patient is a candidate for repair vs. reconstruction. Arthroscopy in medial instability will show opening of the ulnohumeral articulation when visualized from the lateral portal.

61.3 Rating: International Classification

Table 61.1 Classification of elbow instability

Stage	Definition
1	Posterolateral subluxation of the elbow
2	Subluxation of the elbow with the coronoid perched under the trochlea
3	Complete dislocation of the elbow with coronoid resting behind the trochlea
3a	Complete dislocation with disruption of only posterior band of MUCL
3b	Complete dislocation with disruption of anterior and posterior bands of MUCL
3c	Distal aspect of humerus stripped of all soft tissue. Unstable after reduction and immobilization

61.4 Indications

Indications for surgery for PLRI are pain and limitations of function despite adequate nonoperative treatment. In some cases of limited instability, conservative treatment with rest, limitation of supination and external rotation motion with a hinged brace or sugar-tong cast, physical therapy, strengthening of the extensors, and pain control may be effective. Conservative treatment is unlikely to be effective in chronic PLRI as the avulsed or torn RUHL will not heal in its anatomic location with immobilization alone. Arthroscopic repair of the RUHL is performed utilizing small multi-suture anchors that allow both plication and repair for primary cases of PLRI [22]. For certain high-demand patients such as elite athletes or professionals who rely on their hands, we have found acute or subacute arthroscopic repair of the RUHL after elbow dislocation leading to PLRI to be a safe and effective procedure [23]. The treating surgeon should always be prepared to either harvest a palmaris tendon graft or have allograft tissue available for reconstruction in the situation of inadequate tissue for repair.

Surgery is indicated for MUCL injuries in the athlete who has failed conservative treatment and is unable to perform at their previous level of play due to symptoms in their elbow. Patients who are recreational athletes and do not wish to continue competing or pursue further opportunities in their sport can often forego surgery. MUCL injuries are tolerated well in activities of daily life.

61.5 Techniques

61.5.1 PLRI

61.5.1.1 Arthroscopic Repair

Arthroscopic repair for surgery begins with the patient in the prone position. Diagnostic arthroscopy of the anterior compartment is performed via the proximal anteromedial portal and the proximal anterolateral portal. With insertion of the arthroscope through the anteromedial portal, it is easy to identify fractures of the radial head

and coronoid and tears in the anterior capsule. Further assessment of the stability of the elbow is made by applying varus stress with pronation and supination and seeing abnormal movement of the radial head on the capitellum. Posterolateral subluxation of the radial head off the capitellum is indicative of an insufficient RUHL and PLRI. With laxity in the LCL complex, it is possible to drive the arthroscope "around the corner" of the capitellum. An arthroscopic valgus stress test is performed at this time to test for competence of the MUCL. Attention is turned from the anterior to the posterior compartment. The arthroscope is placed into the posterolateral portal. If the arthroscope is driven easily down the posterolateral gutter and across the ulnohumeral articulation into the medial gutter, this is known as the "drive-through sign of the elbow" and is consistent with laxity of the LCL. The elimination of the "drive-through sign" is consistent with adequate tightening and repair of the complex. Last, the origin of the LCL complex on the posterolateral aspect of the lateral epicondyle is visualized, and avulsion of the ligament will be evident by a bare area of the humerus.

After completing the diagnostic arthroscopy, repair begins with placing a double-loaded suture anchor into the humerus at the site of origin of the RUHL on the posterolateral epicondyle (Fig. 61.5). The sutures are retrieved through a lateral "soft-spot" portal via a percutaneous suture passer. The sutures are drawn through the uninjured part of the ligament and tensioned to create two horizontal mattress sutures. If there is a bony avulsion, one set of sutures is placed around the fragment itself. As the sutures are tensioned, the LCL complex is brought back to its anatomic position. If the tension on the repair is adequate, the arthroscope will be driven out of its position in the lateral gutter. The elbow is extended to 30° and the sutures are tied beneath the anconeus muscle. The arthroscope is positioned back into the anterior compartment and motion and stability of the joint evaluated in order to assess restoration of tension to the annular ligament.

For chronic PLRI, repair is performed via arthroscopic plication and repair of the complex

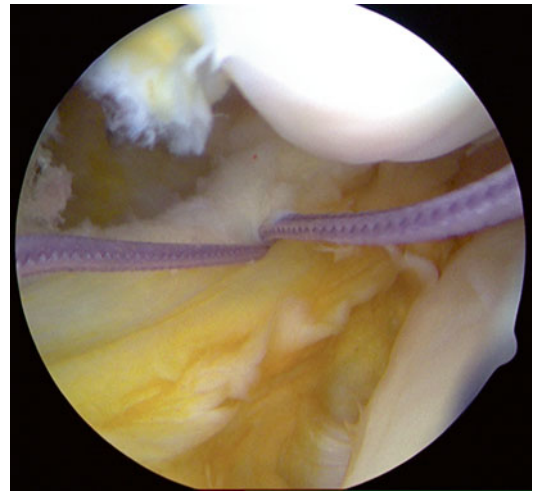

Fig. 61.5 This view from the posterior portal shows the sutures in place as the radial ligament complex is repaired arthroscopically

to the humerus [24]. Adequacy of the lateral tissue is assessed preoperatively and is determined by palpation of the lateral elbow, history of previous procedures, and tissue present on MRI arthrography. Absorbable sutures are placed from proximal to distal beginning at the most distal attachment of the RUHL on the ulna. The first suture is placed into the joint through the midportion of the annular ligament. The suture will be aligned from distal posterior to proximal anterior, to plicate the LCL complex. The subsequent sutures are delivered moving from distal to proximal and retrieved via a retrograde retriever passed under the RUHL near its proximal attachment to the humerus. The sutures are tightened and the plication is evaluated. As with the technique of tensioning in acute repairs, the arthroscope will be driven out of the lateral gutter if repair is adequate. Residual laxity of the complex can be corrected by placing a suture anchor at the isometric point of the lateral epicondyle. One limb of the anchor is passed under the plicated ligament complex and tied to pull the entire complex back to the humerus. Care is taken during suture retrieval to avoid inadvertent damage to the radial nerve or lateral antebrachial cutaneous nerve. Sutures are retrieved posterior to the most anterior aspect of the lateral epicondyle and proximal to the radial head.

61.5.1.2 Open Technique

The preferred open technique for plication and repair is similar to the procedure described by O'Driscoll and colleagues in 1991. A diagnostic arthroscopy may be performed first to identify instability, osteochondral defects, and loose bodies in the joint. The posterolateral approach is used and the anconeus is split and retracted anteriorly. If adequate tissue is present for repair, the ligaments are plicated and repaired back to the humerus as described in the arthroscopic section. For patients with either inadequate tissue for repair or in revision surgery, a palmaris autograft or gracilis allograft may be used. The insertion site on the supinator crest of the ulna is identified and dissected free. A bone tunnel is created at the ulnar attachment of the RUHL on the supinator crest using a 4.0 mm drill. The graft is drawn through the tunnel and the midportion is secured using an interference screw technique. The two free ends of the graft are brought back, passing one limb under the annular ligament, and attached to the isometric point on the posterior lateral epicondyle. The elbow is ranged and the graft should be tight with flexion and slightly lax in extension.

61.5.2 Postoperative Care

Immediately upon completion of surgery, patients are placed into a splint or hinged elbow brace in 30° of extension to decrease tension on the repair. At this time the reduction of the joint is verified with fluoroscopy or radiographs, as additional flexion may be needed reduce the joint. The patient returns to clinic 3–5 days after surgery for wound evaluation and is placed in a hinged elbow brace set from 0 to 45° that allows limited comfortable movement. Gentle shoulder, wrist, and hand exercises are permitted as long as they do not produce pain in the elbow. The patient is followed up regularly in clinic at 2-week intervals and motion is increased through the brace as swelling and pain allows. Physical therapy is initiated at 6–8 weeks postoperatively. Patients must be able to perform all strengthening exercises pain-free in the brace before gradually progressing out of the brace.

61.5.3 MUCL Injuries

61.5.3.1 Repair: Fig. 61.6

We prefer direct repair of the MUCL versus reconstruction for symptomatic injury as it allows a faster return to play. Appropriate patients for repair are those with injuries of the proximal or distal end of the MUCL and athletes at the college level or younger with good ligamentous tissue. The procedure begins with the patient in the standard prone arthroscopic position and the arm flexed to 90° over a small bump. A standard diagnostic arthroscopy is performed, with attention paid to possible cartilage damage, capsular thickenings, loose bodies, and posteromedial osteophytes. The arthroscopic stress test as described by Field and Altchek is performed for confirmation of valgus instability [25]. Next the arm is rotated internally and placed on an arm board to access the medial elbow. A 5 cm skin incision is made from the medial epicondyle distally, in a path 1 cm anterior to the course of the ulnar nerve. The medial antebrachial nerve and ulnar nerve are identified and retracted for protection. Exposure to the MUCL is through the muscle-splitting approach as described by Smith et al., leaving the flexor-pronator origin intact [26]. Next an incision is made along the most anterior surface of the MUCL and it is retracted to visualize the ligament. Simple tears of the proximal portion of the ligament are repaired with a double-loaded absorbable suture anchor placed at the junction of the trochlea and the distal medial epicondyle. The first set of sutures are placed just distal to the tear site and tied in horizontal mattress fashion. The procedure is repeated for the next set of sutures, placed 5–8 mm distal to the first. Distal tears are repaired in similar fashion, with the suture anchor placed directly into the sublime tubercle and angled distally to avoid inadvertent penetration of the ulnohumeral joint. Great care should be taken to protect the ulnar nerve during placement in the procedure as it lies close to the posterior aspect of the MUCL. Finally, the midportion of the tendon is plicated with absorbable suture, and the elbow is ranged to confirm an anatomic repair.

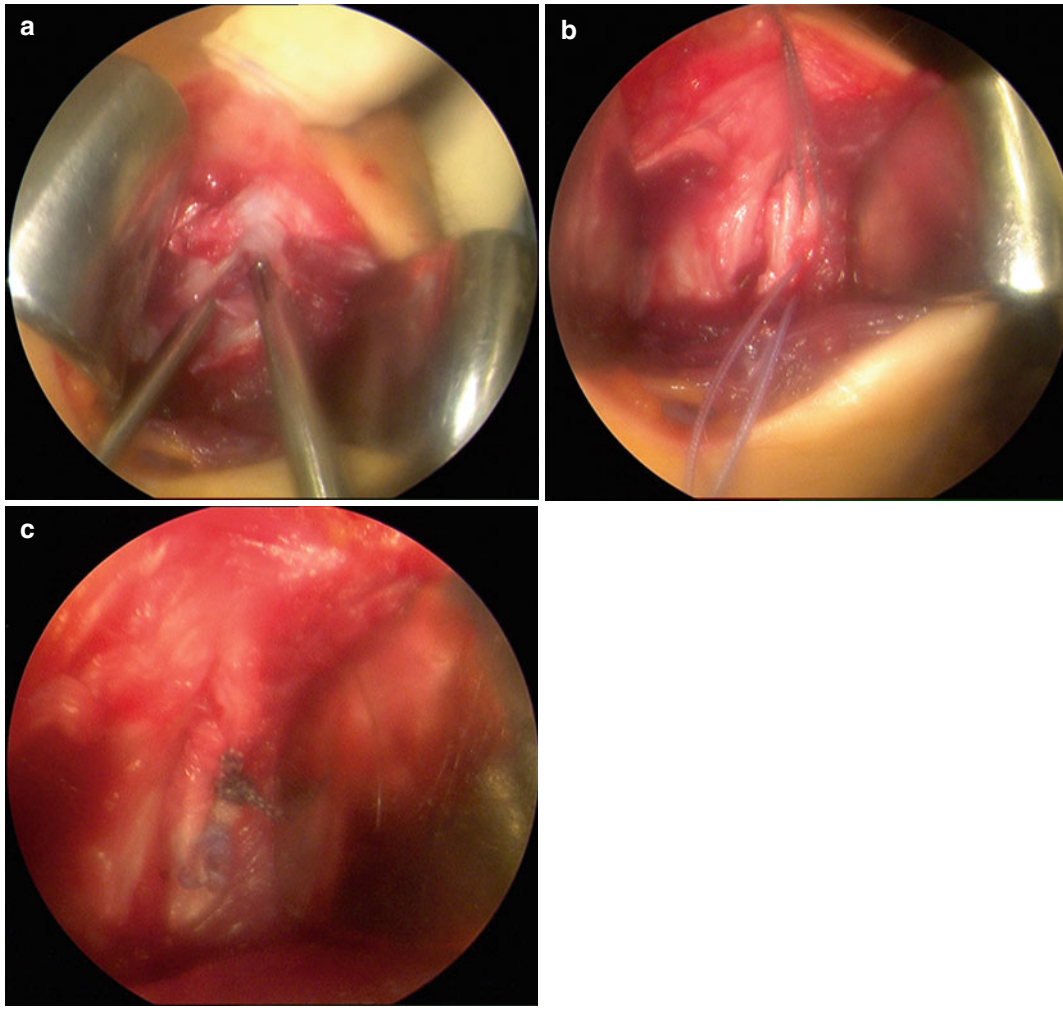

Fig. 61.6 (**a**–**c**) The steps in the repair of the medial ulnar collateral ligament are shown in this series

61.5.3.2 Reconstruction: Fig. 61.7

The Smith approach to the elbow is again utilized as with MUCL repair. Direct visualization of the ulnar nerve is achieved by splitting the fascial sheath. Again as with the repair procedure, the MUCL is exposed and both surfaces of the ligament are carefully inspected. Graft choice traditionally is ipsilateral or contralateral palmaris longus, gracilis tendon, or autograft. A recent study we conducted demonstrated outcomes with hamstring allograft similar to autograft tissue after 24 months of follow-up [27]. A longitudinal incision is made on the anterior surface of the MUCL and the ligament reflected to free away the native footprint on the ulna and humerus. Either converging tunnels on the sublime tubercle are made in the classic Jobe technique or a single tunnel is centered on the sublime tubercle and drilled laterally toward the supinator crest. In the latter technique, the graft is placed into the tunnel and fixated with an absorbable interference screw. The humeral reconstruction is performed either with a standard Jobe technique through Y-type drill holes and the graft limbs crossed and sutured together or with a docking technique. The elbow is flexed to 70° and forearm supinated while a valgus load is applied as the graft is tensioned. The residual native ligament is sutured to the graft, and the flexor-pronator fascia repaired.

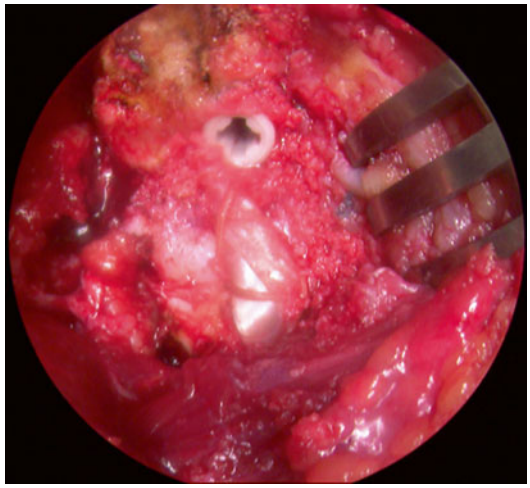

Fig. 61.7 The view of an MUCL reconstruction showing the graft in place after fixation of the ulnar and humeral attachments

61.5.4 Postoperative Care

For both repair and reconstruction of the MUCL, the patient is placed into a posterior-slab protective plaster splint and sling at 70° of flexion. At the first postoperative visit, the splint is removed and the arm is placed in a hinged elbow brace. Gentle active range of motion in the elbow and forearm is allowed. Scapular rehabilitation is initiated at the first postoperative visit, and core, shoulder, and leg strengthening exercises are started soon after in therapy. For repaired elbows, the hinged brace is removed at 12 weeks and the patient is progressed gradually back into play.

The rehabilitation of the reconstructed elbow follows a similar but gentler course due to the need for graft incorporation. A throwing program with the brace in place is initiated at week 12 if there is no pain or edema in the elbow and the range of motion in the elbow is the same as preoperatively. The majority of athletes will be able to remove the brace by 6 months and slowly resume throwing according to normal return-to-throwing protocols.

61.6 Complications

The most common complication of arthroscopic or open PLRI surgery is recurrent instability. Other complications include wound infection, nerve transection or neuritis, or development of arthritis. Complications specific to repair or reconstruction of the MUCL are ulnar nerve paresthesias or neuropraxia and arthrofibrosis.

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Endoscopic Approach to Cubital Tunnel Syndrome

62

Fabrizio Campi, Giovanni Merolla, Paolo Paladini, and Giuseppe Porcellini

62.1 Introduction

Cubital tunnel syndrome is a well-known neuropathy of the upper limb caused by ulnar nerve entrapment at the elbow [1]. The cubital tunnel [2] is an osteofibrous structure with a bony pavement, delimited medially by the medial epicondyle and laterally by the olecranon. The roof is formed by Osborne's arcuate ligament or Osborne's band [3]. The ulnar nerve can be compressed in the osteofibrous tunnel by the bone structures, Osborne's ligament, and the fascia of the ulnar flexor muscle of the carpus or of the aponeurosis of the deep flexor of the fingers. The reduction in volume of the cubital tunnel is associated with a limited ulnar nerve flow during dynamic maneuvers and an increase in intra- and extraneural pressure [2, 4–6]. A rise in pressure values up to double or triple the norm (>50 mmHg) causes blocking of the intraneural circulation [7] with electrodiagnostic modifications and clinical symptoms [8]. Histological studies [7, 9–11] have shown pathological changes in the segment of the ulnar nerve in patients with clinical signs of neuropathy of the ulnar nerve without evidence, on electronic microscopy, of lesions in the segments located 5 cm proximal and distal to opening of the cubital tunnel; severe demyelinization was observed in the section of the nerve just proximal to the cubital tunnel. Surgery is essential when rehabilitation and physical therapy have failed. Various surgical techniques have been reported in the literature for the treatment of the ulnar neuropathy at the elbow [12–19].

In this chapter we will describe our endoscopic approach to the problem.

62.2 Diagnosis

Patients with ulnar nerve compression at any level have altered sensation in the little and ring fingers. Indeed, in most patients, sensory loss is the first symptom to be reported. As the condition progresses, they may also notice clumsiness in the hand, as the ulnar nerve is the principal motor supply to the intrinsic muscles of the hand. In well-established cases, there may be marked wasting of the small muscles of the hand and the ulnar-sided muscles of the forearm.

Intrinsic muscle weakness, as well as weakness of flexor digitorum profundus of small and ring fingers, can be seen in more advanced disease, which presents as clawing. Sparing of flexor digitorum profundus is seen with more distal compression, such as seen at Guyon's canal, and can help with differential diagnosis.

On physical exam there is a positive Tinel's sign over the cubital tunnel. Tinel's sign should

F. Campi
Orthopedic Department, San Marino Hospital, San Marino, San Marino
e-mail: fcampi@me.com

G. Merolla (✉) • P. Paladini • G. Porcellini
Unit of Shoulder and Elbow Surgery, Cervesi Hospital, Cattolica (RN), Italy

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be positive over the cubital tunnel itself, although some surgeons find it easier to elicit Tinel's sign over the medial side of the humerus. Froment's sign [20] is noted due to weakness of adductor pollicis muscle. Froment's sign is positive when a patient is given a piece of paper and holds it together between the thumb and index finger with flexion of the thumb IP joint.

Inspection of the elbow in extension may show a valgus deformity, possibly secondary to a previous fracture around the elbow. Malunion after supracondylar fracture of the humerus can result in an adult cubitus valgus deformity, which in turn predisposes to a tardy ulnar nerve palsy. Always examine if the nerve does/does not subluxate over the medial epicondyle.

Positive flexion sign at the elbow with supination and wrist extension reproducing the symptoms up to 60 s and ulnar nerve subluxation with elbow flexion can also be seen, although a variation of this test, the shoulder internal rotation elbow flexion test, seems to be more accurate [21–23].

62.3 Exploration

The cubital tunnel syndrome is essentially a clinical diagnosis that is confirmed with nerve conduction studies. In mild cases, nerve conduction studies may be normal. Electrodiagnostic tests must, however, be interpreted as part of the overall clinical picture. Nathan et al. [24] compared preoperative and postoperative nerve conduction studies and observed that in some patients, although the objective finding of nerve conduction improved markedly, the patients described little or no improvement in symptoms. Anyway neurophysiological studies should be done if surgery is planned, in order to document preoperative baseline. Ulnar nerve velocity of <50 m/s at the elbow is considered positive for cubital tunnel syndrome [25].

Standard radiological study around the elbow may show osteoarthritis, cubitus valgus, or calcification in the medial collateral ligament and should be taken if there is a history of preexisting trauma or when the symptoms do not fit in with the clinical examination [26]. Magnetic resonance imaging and ultrasound are useful in showing lesions such as ganglions, neuromas, or aneurysms of the ulnar artery in Guyon's canal causing compression neuropathy. In clinical practice it is unusual to request MRI, while the ultrasonography is useful to evaluate the dynamics of the ulnar nerve during elbow movement, the morphology of the ulnar nerve, and the ulnar nerve groove [27, 28].

62.4 Rating

The classification of the progression of the symptoms and neural deficits is still controversial.

The Dellon classification [9, 10] (Table 62.1) takes into consideration objective and subjective clinical parameters in order to identify three stages of deficit of the ulnar nerve at the elbow.

A study about the conduction speed of the ulnar nerve (ENG) and on action potentials at the level of the muscle fibers (EMG) allow to single out five stages based on the Akahori classifica-

Table 62.1 Dellon stages for ulnar nerve compression syndrome at the elbow

	Mild	Moderate	Severe
Sensitivity	Paresthesias come and go; increase in vibratory perception	Paresthesias come and go; normal or decreased vibratory perception	Persistent paresthesias; vibratory sense decreased; abnormal 2 points discrimination
Motility	Subjective weakness, dysesthesias, or lack of coordination	Weakness can be measured in reduced grip strength	Weakness measurable in reduced grip strength plus muscle atrophy
Tests	Elbow flexion test or Tinel's sign could be positive	Positive elbow flexion test or Tinel's sign; finger crossing may be abnormal	Positive elbow flexion test or Tinel's sign; finger crossing abnormal

tion [29], wherein each is related to a specific symptomatology (Table 62.2).

On the basis of these classifications, Gu in 2011 proposed a classification that includes neurophysiological tests as a diagnostic quantitative index for cubital tunnel syndrome [30]. Compared with other clinical classifications and treatment programs, Gu's system adopts electromyography (EMG), an internationally recognized diagnostic index for cubital tunnel syndrome. The system is based on quantitative neurophysiological indicators, as shown in Table 62.3. According to Gu's classification, patients with cubital tunnel syndrome may be divided into three types: mild, moderate, and severe. Patients classified as moderate are recommended to receive neurolysis decompression surgery, whereas patients classified as severe should be treated with anterior transposition. However, clinical diagnosis and treatment efficacy when using this classification system may be unsatisfactory in certain patients with elbow osteoarthritis, elbow deformity, or cubital tunnel mass oppressors. In these selected patients, treatment should not be based only on the previous classification as it lacks radiographic evaluation of the elbow structures; in this case we can use another classification proposed by Qing et al. in 2014 that adopts a CT imaging evaluation index [31]. This classification seems simple and practical, and therapies based on this classification are more targeted than those based on previous classifications.

62.5 Indications

Mild cases with a recent history can be treated conservatively at first. Nocturnal elbow splinting can markedly improve symptoms, although there is no consensus regarding the optimal type or duration of splinting [32]. Surgery should be performed before the development of muscle atrophy, which is largely irreversible, in particular endoscopic neurolysis of the ulnar nerve can be performed when specific inclusion criteria are respected: mild or moderate osteoarthritis, Akahori classification stage 1 and 2, Dellon classification moderate stage, and age under 50 years.

62.6 Techniques [33, 34]

Patient's Position Surgery is carried out under general anesthesia or regional block of the brachial plexus using lidocaine and bupivacaine. The patient is placed in lateral decubitus with shoulder abducted at 90° and elbow flexed at 90° (Fig. 62.1); in this position an excellent access to the elbow joint is permitted. A pneumoischemic tourniquet at the root of the upper limb is applied for a mean time of 45 min (minimum 35, maximum 70). The arm is positioned in a padded arm holder attached to the side of the table. The elbow is placed slightly higher than the shoulder to guarantee a complete (360°) exposure of the elbow joint, freedom of movement during surgery

Table 62.2 Comparison between speed of conduction of the ulnar nerve and the clinical symptoms (Akahori classification, modified 1986)

	Speed of conduction			Clinical symptoms		
	Motor nerve	Sensory nerve	Sensitivity		Motor	
Stage				Atrophy	Weakness	"Claw"
I	Normal	Normal	Normal or mild paresthesia	±	±	–
II	Normal	Slowed down	Hypoesthesia +	+	±	±
III	Normal or slowed down	Slowed down or not measurable	Hypoesthesia +	+	+	±/+
IV	Slowed down	Not measurable	Hypoesthesia ++	++	++	++
V	Slowed down or not measurable	Not measurable	Hypoesthesia or analgesia ++	++	++	++

– absent, ± mild, + present, ++ severe

Table 62.3 Classification and treatment selection for cubital tunnel syndrome from Gu (2011)

Types	Sensation	Movement	EMG	Imaging (X-ray, CT, or MRI)	Cubital tunnel index[a]	Treatment
Type I	Ring and little finger numb, Tinel's (+)	Conscious weakness, with or without action, uncoordination	Normal	Normal	Normal	Movement control, rest, physiotherapy
Type II	Ring and little finger numb, Tinel's (+)	Poor grip strength, decreased interosseous muscle strength, or muscle atrophy	Motor and/or sensory nerve conduction velocity reduced	Normal	Normal	Ulnar neurolysis
Type III	Ring and little finger numb, Tinel's (+)	Poor grip strength, decreased interosseous muscle strength, or muscle atrophy	Motor and/or sensory nerve conduction velocity reduced	Osteoarthritis	Increased or decreased	Cubital tunnel or expansion, ulnar decreased nerve anterior transposition
Type IV	Ring and little finger numb, Tinel's (+)	Conscious weakness, decreased interosseous muscle strength, or muscle atrophy	Motor and/or sensory nerve conduction velocity reduced	Tumor, cysts, elbow deformity, posttraumatic change	Normal	Targeted surgical treatment

EMG electromyography, *CT* computed tomography, *MRI* magnetic resonance imaging
[a]Depth/width ratio when the cross section rotates 30° forward through the Hueter line (normal range, 0.273 ± 0.055)

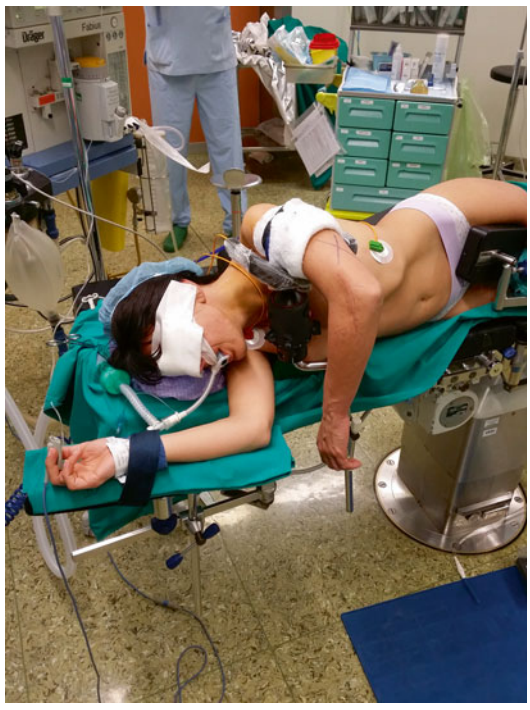

Fig. 62.1 Patient in lateral decubitus with the arm in a padded arm holder

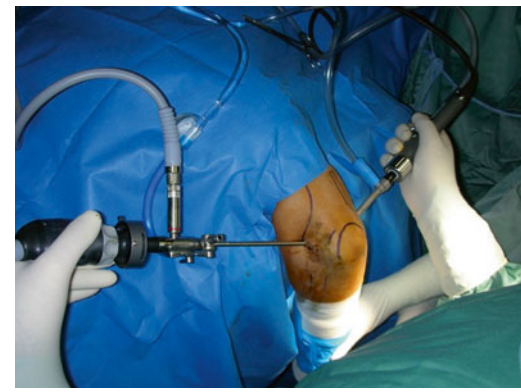

Fig. 62.2 Surgeon position during surgery (note the freedom of movement during surgery)

(Fig. 62.2), and easy access to the posterior elbow and facilitate anterior joint visualization by gravity [35, 36].

Anatomical Landmarks The anatomical surface landmarks must be drawn on all patients including the lateral epicondyle, medial epicondyle, radial head, "capitulum humeri," and olecranon. The

location of the ulnar nerve should be checked and marked (Fig. 62.3), excluding its potential subluxation from the cubital canal which is a formal contraindication for this procedure. On the guide of the surface landmarks, the authors identify the triangle delimitated by the lateral epicondyle, radial head, and olecranon to introduce an 18-gauge needle and distend the elbow joint with 20–30 mL of saline solution 0.9 % (Fig. 62.4). The distension permits easier entry with trocar into the joint reducing the risk on nerve and vessels that are kept farther away from the portal site.

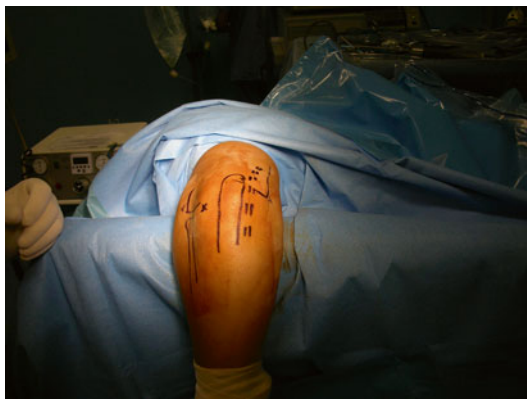

Fig. 62.3 Anatomical landmarks. The *dotted line* indicates the location of the ulnar nerve

Endoscopic Portals The arthroscopic technique adopted includes, at first, an articular phase through two portals: anterolateral and anteromedial. The radial nerve is the structure at risk in the creation of the anterolateral portal. To reduce that risk it is essential to establish the portal as soon as the joint is distended before the fluid extravasation makes it difficult to see and touch the landmark [35]. The anterolateral portal (Fig. 62.5) is established just anterior to the space between the capitulum humeri and radial head. An alternative midlateral portal ("soft-spot portal"), for an excellent view of the posterior compartment, can be created in the center of the triangle between the olecranon, lateral epicondyle, and radial head. The authors used an arthroscopy system, 4.0 mm in diameter, with a 30° angle. The intra-articular pressure is maintained about 140 mmHg by a pump system. The view from the anterolateral portal shows the coronoid process, the posterior surface of capitulum humeri, the radial head, and the radioulnar articulation. Sometimes the restricted articular space for working can require a 2.7 mm arthroscope [37]. The anteromedial portal (Fig. 62.5) is located 2 cm distal and 2 cm anterior to the medial epicondyle, and it is created under direct visualization with an arthroscope with an out-in technique using a spinal

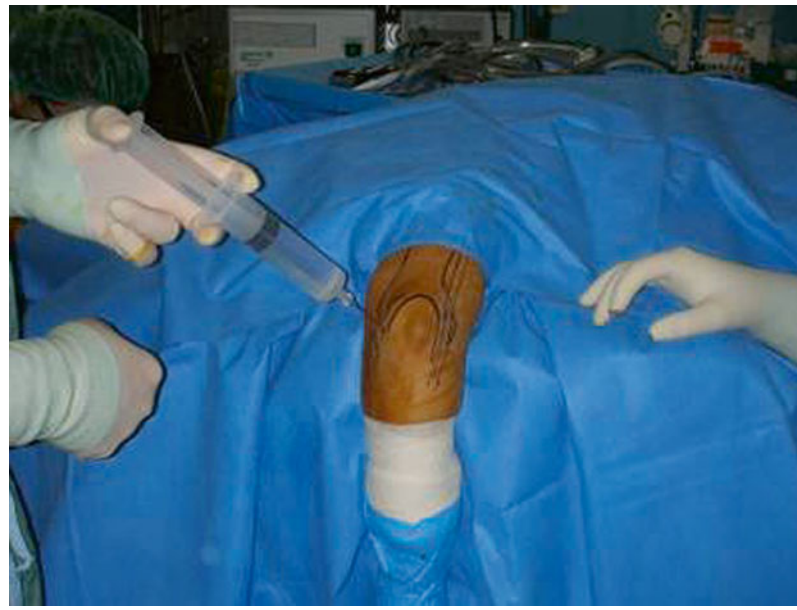

Fig. 62.4 Elbow joint is distended with saline solution to allow easier entry with trocar reducing the risk on nerve and vessels

guide needle and a 5 mm non-flexible cannula. The medial antebrachial cutaneous nerve is at risk with the creation of this portal. The median nerve is quite safe with an average distance of 7 mm [38]. In the second step the ulnar nerve course is approached through the posterior portals which are necessary to visualize the posterior aspect of the elbow joint. The posterolateral portal (Fig. 62.6) is built level with the tip of the olecranon just laterally to the joint line. The trocar should be introduced at the center of the olecranon fossa. The direct posterior portal (Fig. 62.6) is created 2 cm proximal to the tip of the olecranon.

Cubital Tunnel Decompression and Ulnar Nerve Neurolysis Once the anterior joint portion has been visualized to perform the arthrolysis, endoscopic view is switched going to the retro-olecranon space using the posterolateral portal previously described. Then, maintaining the view on the posterolateral portal, a direct, posterior transtricipital portal is established. In this second phase the authors evaluate the space bounded superiorly by the triceps tendon and inferiorly by the olecranon fossa and by the olecranon itself. With the endoscopy in the posterolateral portal, a debridement of the olecranon fossa can be performed. If the tendon and the olecranon are medially followed, we arrive at the cubital tunnel, the site of ulnar nerve compression. Once the cubital tunnel has been found, perineural scarring adherences are examined (Fig. 62.7). The instrument used to release the ulnar nerve is an arthroscopic shaver with its

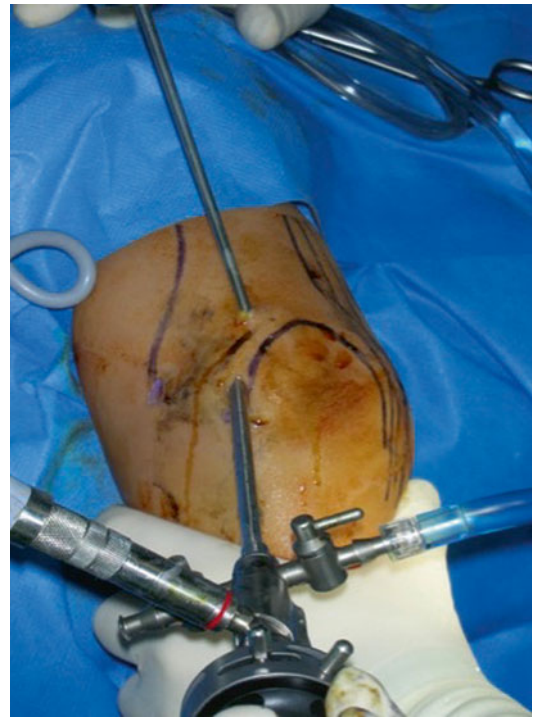

Fig. 62.6 Arthroscope in the posterolateral portal and arthroscopic shaver direct in the posterior transtricipital portal during endoscopic neurolysis of the ulnar nerve

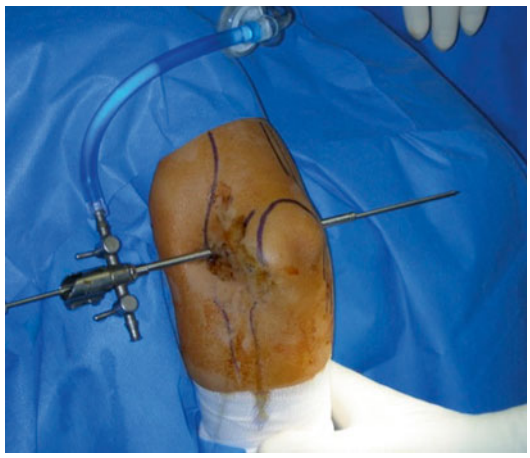

Fig. 62.5 Anterolateral and anteromedial portals with the trocar inside

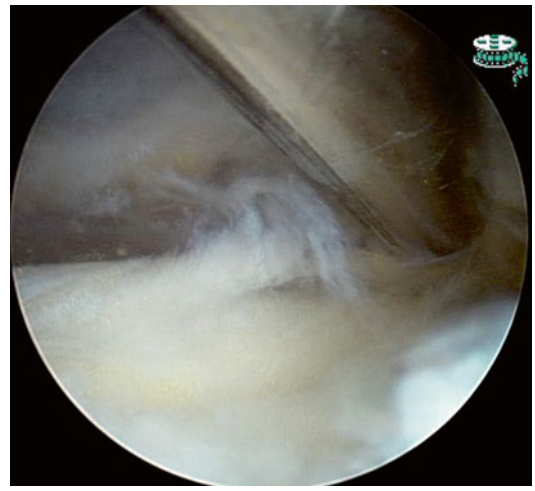

Fig. 62.7 Perineural scarring adherences around the ulnar nerve in the cubital tunnel

blade turned away from the nerve, against the bone, with aspiration at minimum. The operation proceeds with the help of blunt retractors to release the nerve on all its aspects (Fig. 62.8). An important step is to identify Osborne's ligament (Osborne's band); this structure is about 4 mm thick and it runs transverse from the medial epicondyle to the apex of the olecranon. Four variations of Osborne's band have been described [6]. When the band is thick (types Ib and II), the risk of ulnar nerve compression is higher. A straight basket is used to incise Osborne's ligament, taking care to completely isolate the ulnar nerve and to protect it with blunt retractors, introduced percutaneously. A little artery get across Osborne's ligament and must be identified before proceeding to cut the arcade. At the end of the procedure, evaluate the nerve running during passive flexion and extension of the elbow after Osborne's ligament has been cut and opened.

Postoperative Care and Rehabilitation The patient is medicated with compressive bandage which is removed the day after surgery. A caution assisted passive mobilization is allowed from the first day after surgery. From the 15 days begin passive complete physiotherapy and self-aided exercises. After 3 weeks begin a complete active program of rehabilitation in water pool. At 60 days after surgery, continue with strength and isometric exercises.

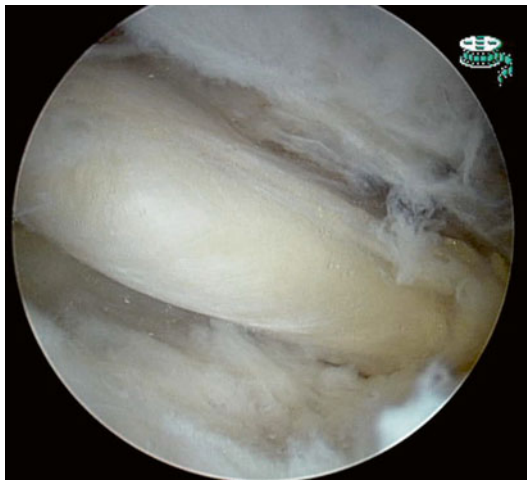

Fig. 62.8 Ulnar nerve released in all its aspects

62.7 Complications

During this procedure some complications may occur [39, 40]. Endoscopic approach to ulnar neuropathy has the advantage to allow immediate recovery well-being of the patient, lesser invasiveness, and minimum vascular and neurologic complications [41]. The posterior branch of the medial antebrachial cutaneous nerve is a common complication during endoscopic procedures [42]. The restriction of the procedure to the distal portion of Struthers' arcade avoids the risk of injury in the distal motor portion of the ulnar nerve but has an evident limit to treat acute and chronic pathologies located distally to Struthers' arcade. Among complications let us recall subdislocation in the original position, fascial residues caused by new sites of entrapment, injuries of the motor branch of the FUC, and post-immobilization contracture. The most feared complication is, however, devascularization of the ulnar nerve related to the segmental nature of the vascularization that places it at risk especially in anterior transposition surgery [15, 43].

62.8 Results and Literature Review

In our previous paper we described an initial case series of 12 endoscopic decompressions of the ulnar nerve [33]. A clinical evaluation was based on two different scales of evaluation: VAS (visual analogue scale) and Bishop's score [44]. These evaluations were carried out immediately presurgery and 6 months and 1 year after surgery. We recorded two minor complications: postoperative hematoma solved in a few days and presence of a phlyctena caused by tourniquet, solved within 3 days. In one case we had to perform anterior transposition of the nerve to treat entrapment of the same in Struthers' arcade and persistence of pain and paresthesia symptoms more than 6 months after arthroscopy. On evaluation with the VAS, 91 % of patients reported a satisfaction. Bishop's scale was on the average 7 points with a minimum of 5 and a maximum of 9. Postoperative evaluation after 6 months and 1 year did not reveal statistically different values.

Furthermore we know that a muscle atrophy of more than 1 year's duration is generally only partly reversible, if at all, and the rate of recurrence of cubital tunnel syndrome after endoscopic or open decompression is 12.2% [45].

Multiple meta-analyses and systematic reviews have not revealed any statistically significant difference between the outcomes of simple decompression and anterior transposition (whether subcutaneous or submuscular). The transposition procedures had more frequent complications. For milder cases, the findings of a randomized controlled trial suggest that conservative treatment is the best treatment.

Calliandro et al. [46] have concluded: "The available evidence is not sufficient to identify the best treatment for idiopathic ulnar neuropathy at the elbow on the basis of clinical, neurophysiological and imaging characteristics. We do not know when to treat a patient conservatively or surgically. However, the results of our meta-analysis suggest that simple decompression and decompression with transposition are equally effective in idiopathic ulnar neuropathy at the elbow, including when the nerve impairment is severe. In mild cases, evidence from one small randomised controlled trial of conservative treatment showed that information on movements or positions to avoid may reduce subjective discomfort."

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Elbow Arthroscopy: Difficult Cases and Ulnar Nerve Preservation

63

L.A. Pederzini, F. Di Palma, F. Nicoletta, and E. Tripoli

63.1 Introduction

Arthroscopy has been increasingly used to diagnose and treat elbow pathologies, even though the elbow has always been considered a difficult joint to be arthroscopically explored [20, 27, 32, 33, 37, 40]. An increase in arthroscopy knowledge and skills as well as technological advances in the last few years has allowed a standardization of techniques and a better definition of indications.

In the 1980s Andrews and Carson, Hempfling and Lindenfeld published the first indications, techniques and notions on elbow arthroscopy [3, 16, 22].

Elbow arthroscopy becomes a very difficult technique when an alteration of the anatomy can determine vessel and nerve displacement. This can happen in contracted elbow joint. Furthermore because the contracted joint cannot distend normally with inflow, neurovascular structures around the elbow may not be safely displaced after saline injection.

In 1981, Morrey et al. determined that the elbow functional motion ranged from 30 to 130° of flexion [20, 25, 26]. However, many daily activities performed at work or while doing physical exercise require extension past 30° [20, 25, 26]. As a matter of fact, for sportsmen and manual workers even a small decrease in ROM, together with slight symptoms of pain and inability to perform specific tasks, can be unacceptable and, hence, interfere with their daily work or sporting activities. For these reasons, there has been an extension of indications for treatment of stiff elbows. In 1992 O'Driscoll and Morrey presented 72 cases of elbow arthroscopy, and in 2001 they published a review of 473 cases in which they analysed the complications related to this procedure [29]. The previous year, Reddy et al. published a review of 172 cases in which patients had undergone arthroscopic elbow surgery with a 7-year follow-up [35].

The indications for elbow arthroscopy has grown over the past years and today includes osteochondritis dissecans (OCD), plica syndrome, synovitis, lateral epicondylitis, loose body removal, osteoid osteoma and stiff elbows related to degenerative or post-traumatic causes [2, 10, 14, 23, 27, 30, 32, 44, 45, 47]. Recently, Conso et al., Schubert et al. and Salini et al. published results comparing elbow pathology (including stiffness) treated by either arthroscopic or open procedures [8, 38, 42].

Stiff elbow, presence of osteoid osteoma into the olecranon fossa and osteochondral autologous transplantation are complex pathologies and procedures that can be treated arthroscopically.

L.A. Pederzini (✉) • F. Di Palma • F. Nicoletta
E. Tripoli
Orthopaedic – Traumatologic Department, New Sassuolo Hospital, Via Ruini 2, Sassuolo 41049, Italy
e-mail: gigiped@hotmail.com

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63.2 Stiff Elbow

In this cases indications for arthroscopic surgery include failure of at least 6 months of conservative treatment (mobilization, splinting and physical therapy) [24, 29, 30, 43], absence of important anatomical deformity, reduction in ROM, disability or inability to perform sport or occupation.

Relative contraindications are cerebral palsy, muscle spasticity, burns, previous surgery with anatomical deformity, heterotopic ossification, myositis ossificans, chronic regional pain syndrome (CRPS), articular instability and sepsis-related stiffness.

63.3 Surgical Procedures

The main arthroscopic procedures in our department have been:

- Isolated removal of loose bodies
- Anterior and posterior capsulectomy
- Anterior and posterior osteophytes removal
- Radial head resection
- Partial or total synovectomy
- Mosaicplasty from homolateral knee to elbow for osteochondritis dissecans

All these arthroscopic surgeries have increased the range of motion.

63.4 Surgical Technique

The anaesthetic procedure begins with the identifications of the appropriate nerve trunks with electrostimulation, and a catheter is placed without injecting anaesthetic. Patients then receive general anaesthesia. After waking up a neurological evaluation is performed, and a peripheral block is done.

After the induction of anaesthesia, ROM is carefully assessed and a complete assessment of ligamentous stability is performed. A well-padded tourniquet is placed proximally around the arm. The limb is exsanguinated and the tourniquet insufflated to approximately 250 mmHg. The patient is then placed prone but can also be placed in the lateral or supine position depending on the surgeon's preference and experience, with the shoulder abducted 90°, the elbow flexed to 90° and the arm held up by an arm holder secured to the operating table. A sterile field is set up and posterior, superior anteromedial and superior anterolateral arthroscopic portals are marked.

The risk of nerve injury, including posterior interosseous nerve and ulnar nerve injury, is real in these stiff elbows and should be considered by the operative surgeon before undertaking arthroscopic management.

Because the contracted joint does not distend normally with inflow, neurovascular structures about the elbow may not be safely displaced after N saline injection.

Except in cases with full ROM, an ulnar nerve neurolysis is always performed through a 2 cm skin incision. Ulnar nerve intraneural pressure increases as the elbow proceeds from full extension to full flexion. Beyond 90° of flexion, the intraneural pressure raises more than the extraneural pressure. In fact, at 130° of elbow flexion, the intraneural pressure is 45 % greater than the extraneural pressure [13, 39].

So if ROM is less than 100° of flexion, a neurolysis of the ulnar nerve is necessary before any arthroscopic procedures.

An 18-gauge needle is then inserted into the elbow through the "soft spot" in the middle of the triangular area demarcated by the lateral epicondyle, the radial head and the olecranon. The contracted joint does not distend normally with inflow (15 %, less fluid 3–9 ml at 85°). The joint is then distended as possible by injecting N saline solution. This aids in shifting neurovascular anterior structures away while introducing the trocar. Five portals (three posterior and two anterior) are always used. Posterior compartment arthroscopy is performed first by introducing a 4.5 mm 30° arthroscope through the posterolateral portal (soft spot). A second portal is then established 1.5 cm proximal to the first portal. These two portals allow the use of the scope and the shaver at the same level of the posterior portion of the radial head. Joint distension is maintained with a pump set at 35–50 mmHg.

Once a complete view of the proximal radioulnar joint (posteriorly) is obtained, a third posterior portal is placed in the olecranon fossa, close to the medial border of the triceps and 2–3 cm proximal to the olecranon tip. A complete debridement of the olecranon fossa and its lateral wall can be performed. If present, removal of loose bodies from the lateral side of the olecranon and humerus may be performed to allow better gliding of the articular surfaces.

In stiff elbows despite of anatomical changes, the medial epicondyle and medial intramuscular septum in most cases are used as a guide for anterior portal placement.

The proximal anteromedial portal is generally made in an outside-in manner and kept superiorly and also posterior to the brachialis muscle.

We use different approaches on the posteromedial side depending on the size of the osteophytes and because of the proximity of the ulnar nerve. After inserting the arthroscope through the most proximal portal, we evaluate the size of the osteophytes. If they are small, we protect the ulnar nerve by positioning a retractor in an accessory portal slightly posterior to the ulnar nerve, and we resect the osteophytes arthroscopically. If they are large, we prefer to remove the osteophytes by performing a small arthrotomy at the end of the procedure, thus avoiding fluid extravasation during arthroscopy. The medial approach is always used after ulnar nerve neurolysis, which is the first surgical step of the procedure. This is necessary to prevent overstretching of the nerve during flexion and extension testing in surgery.

Hypertrophy or contractures may have bound the posterior interosseous nerve, increasing the risk of a damage while performing a lateral portal. Using an inside-out technique with an anterior superior lateral portal decreases the risk of injury to this structure. Unlike a normal elbow, portal establishment in a contracted elbow joint requires careful placement of a cannula, not only through the skin but during joint entrance to prevent misdirection by the hypertrophied tissue with resultant soft tissue injury. In severe cases, it may be necessary to develop the tissue plane between the brachialis muscle and the capsule and secondarily incise and then excise the capsule.

The anterolateral portal is so created using an inside-out technique and placing a Wissinger rod 2 cm proximal and 1 cm anterior to the lateral epicondyle. A plastic cannula is introduced over the rod. The rod is then removed and a shaver inserted through the cannula and the anterior debridement carried out (removal of loose bodies, anterior osteophytes and synovectomy).

During the capsular release and excision, the surgeon must remember the relationship of the capsule to the neurovascular structures.

In the anterior compartment, the brachialis muscle lies between the capsule and the anterior neurovascular structures (median nerve, radial nerve and brachial artery). Thus, arthroscopic capsular release and excision should be continued from within the joint until brachialis muscle fibres are visible but no further. Shaver blades and cutting instruments must be kept in close proximity to the humerus at all times to avoid being too far anteriorly and potentially into the neurovascular structures by brachialis muscle penetration. Using accessory anterior portals to place protective retractors to hold the brachialis muscle and anterior neurovascular structures away from the operative field is helpful in preventing potential complications.

On the lateral aspect of the elbow, the radial nerve courses between the brachioradialis and brachialis muscles. It divides into the superficial radial nerve and the posterior interosseous nerve at the level of the elbow joint. The posterior interosseous nerve runs distally and laterally to the brachialis muscle and becomes immediately adjacent to the anterior joint capsule in the distal half of the elbow. Scar tissue and hypertrophied joint capsule from injury to this area may tether the posterior interosseous nerve and allow damage to it during release. In these cases, the nerve should be identified and retracted before continuing the excision distally.

Until the location of the nerve is identified, extension of the capsular excision should remain proximal to the radial head.

Posteriorly, the ulnar nerve should be identified and protected throughout the procedure.

In several cases, due to the presence of a thick capsule (post-traumatic causes), an anterior cap-

sulectomy may be required. We start by trimming the proximal humeral capsule with a shaver, but a complete anterior capsulectomy is performed with a basket device, at about 1 cm proximal to the apex of the coronoid, firstly in a lateral to medial direction and then in a medial to lateral direction.

After capsulectomy is performed just anterior to the radial head, it is possible to palpate the branch of the radial nerve. This can be useful in order to avoid neurological complications particularly if we are treating radial head problems.

After arthroscopy, ROM is assessed. One or two suction drains are positioned in the joint, arthroscopic portals are sutured and a splint holding the joint in full extension is applied.

On day 1 after surgery, our rehabilitation protocol begins with very slow continuous passive motion (CPM), four times a day for 40 min with the help of two suction drains and a perinervous anaesthetic catheter. On day 2, CPM is performed four times a day for 40 min, plus 60 min of physiokinesiotherapy and self-active movements four times a day for 30 min. The third day the neurocatheter is removed and CPM is continued, together with physiokinesiotherapy and self-active movements. On day 4, the drains are removed and CPM, physiokinesiotherapy and self-active movements continue. On day 5, once discharged, the patient goes back home with a 20 day re-educational programme combined with indomethacin for 15 days. The splint is removed after 20 days. After 1 month patients attend their first follow-up visit. The rehabilitative programme continues for 3–5 months [32, 33].

63.5 Technical Tricks

From the technical point of view, we believe it is mandatory to have a perfect view of both the compartments; the lack of range of motion can lead to anatomo-pathological changes both anteriorly and posteriorly in the long run. The use of retractors is important in every stage of the surgery because it minimizes any risk of damage to vascular and nervous structures. During posterior debridement, the medial olecranon osteophyte removal should be carefully considered: a retractor can help, but in some cases due to big osteophytes close to the ulnar nerve, arthroscopic surgery is not recommended. The previous isolation of the ulnar nerve enables open surgery, avoiding risks. Posterior debridement and olecranon osteophyte removal allow an extension improvement that, together with the surgical procedures above-mentioned, increases total ROM. Also anterior capsulectomy allows an extension improvement. On the contrary, flexion is favoured by posterior capsulectomy and removal of anterior hypertrophic coronoid or humeral osteophytes. During anterior capsulectomy, it is important to pay attention to the brachialis muscle which is visible once the capsule is removed. This is necessary not only because of the proximity of the humeral artery but also to avoid muscle bleeding, which can lead to possible calcifications. We have found that brachialis muscle in stiff elbows is frequently thinner than in normal elbows, due to muscle's atrophy.

63.6 Osteoid Osteoma

Osteoid osteoma (OO) is a benign neoplasm that is generally smaller than 1 cm in diameter. Osteoid osteoma at the elbow is rare [48].

Clinical symptoms include nocturnal pain that is relieved by nonsteroidal anti-inflammatory drugs (NSAIDs) [21], as well as limited motion caused by pain or synovitis [48]. Diagnosis can be made on plain radiography (Fig. 63.1a), but a computed tomography (CT) scan (Fig. 63.1b) and/or MRI is usually helpful [17]. Optimal surgical treatment comprises complete excision of the OO.

Percutaneous destruction with the use of a laser or radiofrequency is reportedly effective, with a 91 % rate of success [19]. Thermocoagulation is responsible for a spherical bone necrosis of about 1 cm around the area on which it is placed. With thermocoagulation it is not always possible to conduct a pathologic examination so it is not indicated in patients with unprecise diagnosis. Rosenthal [36] reported nondiagnostic findings in 27 % after

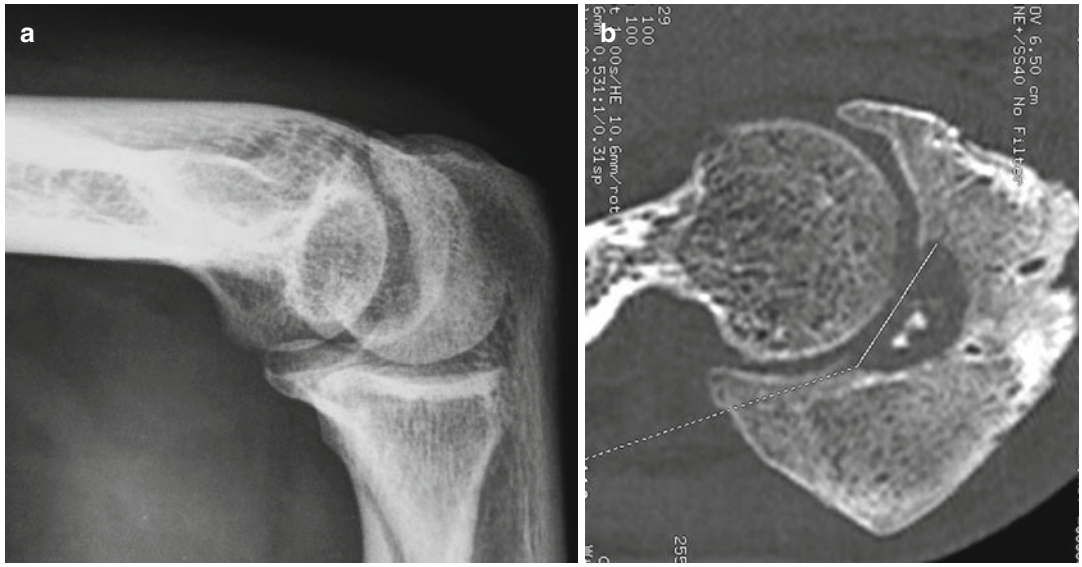

Fig. 63.1 (**a**) Diagnosis can be made on plain radiography (**a**), but a computed tomography (CT) scan (**b**) and/or MRI is usually helpful. (**b**) Diagnosis can be made on plain radiography (**a**), but a computed tomography (CT) scan (**b**) and/or MRI is usually helpful

needle biopsy. The electrode must be at least 1 cm away from a main nerve to prevent nerve injury. This technique may be dangerous for patients with specific localization as near nerve structures or cartilage.

Operative excision (i.e. en bloc resection and curettage) is the recommended treatment for patients with OO of the elbow [48]. Excision of the lesion usually permits complete elbow motion recovery and pain relief.

In our experience the most frequent difficult localization to treat is along the trochlear notch (Fig. 63.2) and coronoid fossa or olecranon fossa. In trochlear notch localization, arthroscopic treatment is performed with the patient under general anaesthesia and in a lateral decubitus position. A direct lateral approach through the soft point (or proximal) is used for the scope. The lesion is removed with a curette through a medial approach after ulnar nerve neurolysis. The hyperemic aspect is identified and totally removed. Excision is performed under arthroscopic visual control. The bony fragment is sent for pathologic testing (Fig. 63.3a, b).

Use of shavers can make pathologic diagnosis difficult because of mechanical artefacts [18]. So before using a shaver, a bony biopsy must be performed first.

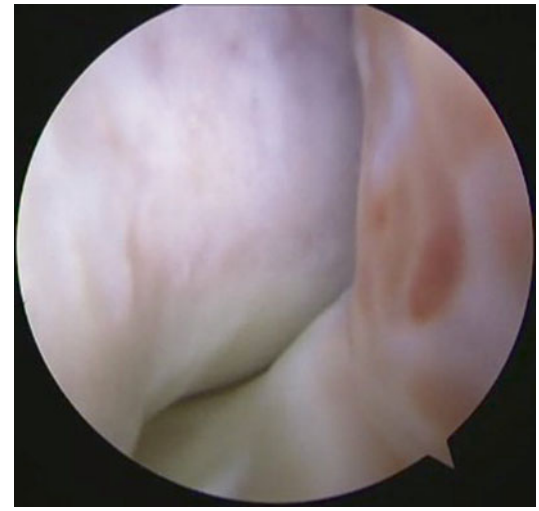

Fig. 63.2 Arthroscopic view of osteoid osteoma along olecranon trochlear notch

With CT scan post-op, we can check the complete resection of the OO (Fig. 63.4).

Patients report total pain relief and complete elbow motion. After 6–8-months follow-up,

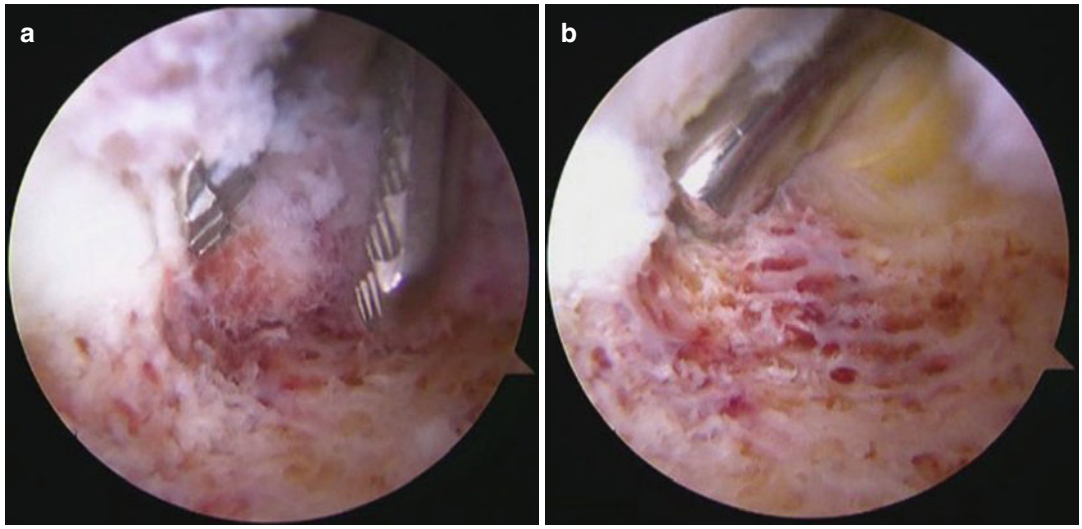

Fig. 63.3 (**a**, **b**) The lesion is removed with a curette through a medial approach after ulnar nerve neurolysis. The hyperemic aspect is identified and totally removed. Excision is performed under arthroscopic visual control. The bony fragment is sent for pathologic testing

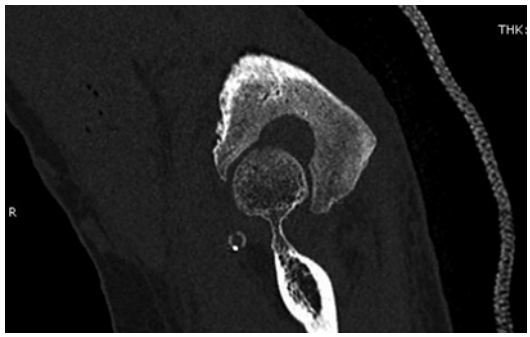

Fig. 63.4 CT scan post osteoid osteoma resection

patients generally have no recurrence of elbow limitation or pain.

In coronoid or olecranon fossa localization, arthroscopic treatment is performed with the patient in the same position. We perform arthroscopic OK procedure by drilling the lesion up to healthy bone.

Advantages of arthroscopy include reduced post-operative pain related to minimal incisions, few wound problems, wider intraoperative vision, less invasive surgery without peripheral muscle and ligament damage, outpatient surgery and early return to full activity [46].

63.7 Osteochondritis Dissecans (OCD)

OCD is an osteochondral focal lesion that generally involves the capitellum, characterized by recurring pain, progressive functional impotence with secondary contracture in flexion of the elbow of approximately 15°, joint swelling and clinical improvement after a resting period.

The causes are vascular deficiency of unknown origin or secondary to direct joint trauma with consequent local vascular lesion and secondary bone necrosis [5, 9, 12].

Osteochondritis dissecans occurs most commonly in overhead-throwing athletes and in gymnasts between the ages of 13 and 16 years [6, 31–33]. It typically affects the young adolescent athlete involved in high-demand, repetitive overhead or weight-bearing activities. The most commonly associated sports are baseball, gymnastics, racquet sports, football and weightlifting [5, 9, 12, 33].

OCD can be a cause of painful elbow with limited ROM. These young patients, usually athletes complaining pain and dysfunction, limit their activity becoming unable to participate in sport. Although lesions have been reported in the

trochlea, radial head and olecranon, the most common site of OCD of the elbow is in the capitellum [3, 5, 9, 12, 34].

Radiographs reveal radiolucency or fragmentation of the anterolateral capitellum. MRI has become the standard imaging for identifying OCD, and it can provide an accurate assessment of the size, extent and stability of the lesion.

Determination of lesion stability and integrity of the articular cartilage cap is really important regarding the decision to prescribe nonoperative treatment or proceed with the surgery [8, 32–34].

Panner's disease, most common between 4 and 8 years of age, should not be confused with true OCD because it involves the entire ossification centre, while only the anterolateral capitellum is involved in osteochondritis dissecans of capitellum [5, 6, 31].

Treatment for stable, early-stage OCD lesions consists in avoiding repetitive stress of the elbow and observation. If the lesion has not resolved in 3–6 months, then consideration of surgical management is made.

Surgical management is the treatment of choice for unstable lesions, lesions that have failed nonoperative management and loose bodies. Lesions that are unstable have a tendency to remain symptomatic even if no loose body is present, therefore leading to surgery [5, 6].

Multiple operative procedures have been described for treating OCD. Surgical treatments include drilling of the lesion, fragment removal with or without curettage of the residual defect, fragment fixation by a variety of methods (pull-out wiring, Herbert's screw, bone peg grafting, etc.), reconstruction with osteochondral autograft and autologous chondrocyte implantation [5, 32].

Several studies report different results with open procedure, but more recently arthroscopy has been employed with encouraging scores in the treatment of capitellar OCD [5, 6, 9, 15].

Baumgarten and colleagues report excellent results in a group of 17 patients whose elbows were treated with arthroscopic debridement with a complete return to sport activities at the pre-injury level in 82 % of cases [6].

Reports of arthroscopic treatment of OCD of the capitellum with removal of loose bodies, debridement and abrasion chondroplasty describe overall improvements in pain and range of motions with variable return to pre-injury level of sporting activity [6, 31, 32].

A grading system based on absence, partial or total detachment of the bone plug has been developed by Baumgarten et al. [6] to aid in decision-making during elbow arthroscopy. The recommendation presented for grade 1 lesions is either observation or arthroscopic drilling of the lesion. Grade 2 lesions were treated with debridement of the cartilage to healthy tissue. Grade 3 lesions were treated with loosening of the fragment to create a grade 4 lesion, which was then resected. Grade 5 lesions were treated with a diligent search for the loose bodies [6].

We prefer arthroscopic evaluation and treatment for lesions requiring operative management.

Removal of the bone plug and microfracture is mandatory in order to eliminate catching and popping while the possibility to bone graft the lesion is still controversial [15, 32, 33].

In some cases we have performed an arthroscopic mosaicplasty taking the graft from the homolateral knee putting the patient in lateral decubitus and extrarotating the hip performing knee arthroscopy (Fig. 63.5). The 6.5 mm cylinder graft token from the lateral knee trochlea was inserted in the elbow lesioned area carefully checking the angle of the drilling and of the insertion of the bony cartilaginous cylinder (Fig. 63.6). Arthroscopically the perpendicular insertion of the cylinder allows a complete coverage of the OCD area. A 4-month post-operative MRI shows a nice bone incorporation of the graft (Fig. 63.7). Post-operatively CPM is started the second day post-op and passive exercises in day 4 post-op. Patients are back to normal activity in 4 months [32, 33].

63.8 Ulnar Nerve-Associated Treatment

Taking into account the outcomes, we can assert that the ulnar nerve-associated treatment has always been studied carefully. So far neurolysis has been performed in case of stiffness, with or without neurological disorders.

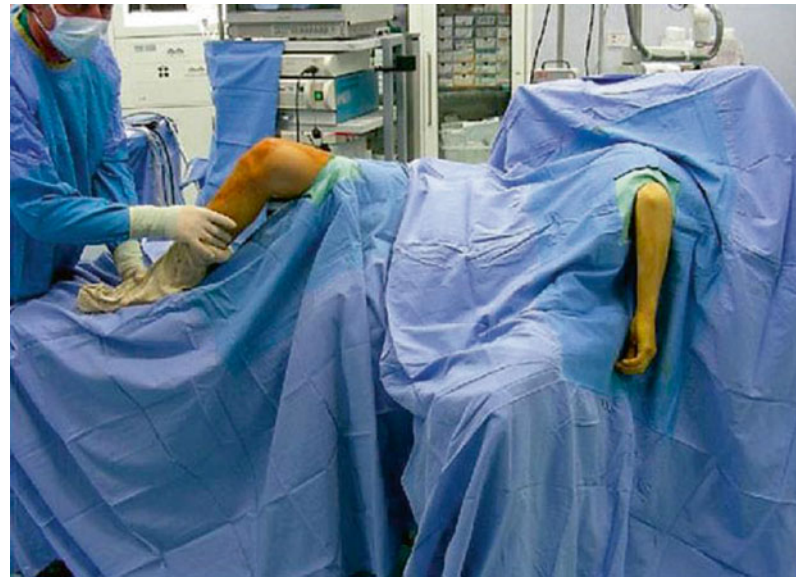

Fig. 63.5 The mosaicplasty from the knee to the elbow is performed on lateral decubitus positioning the hip in extra-rotation to allow knee arthroscopy for taking the graft from the lateral trochlea

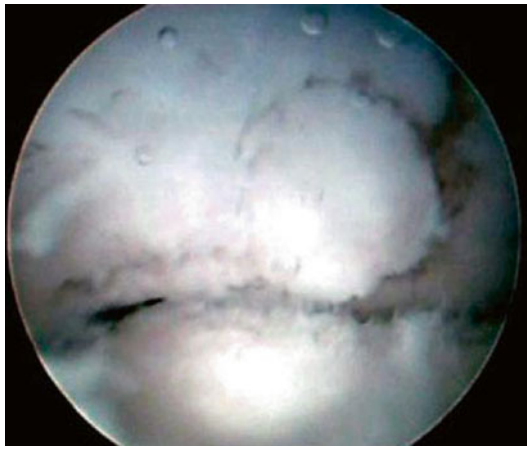

Fig. 63.6 The graft is positioned on the lateral humeral condyle to fill the OCD gap

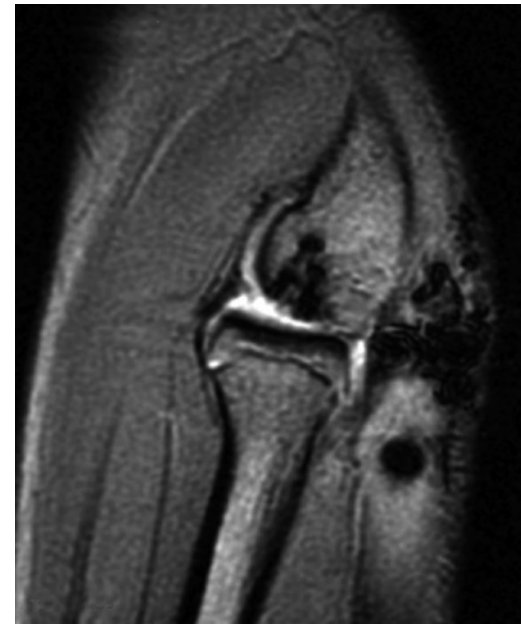

Fig. 63.7 Four months control MRI shows a good bone incorporation of the osteochondral cylinder

Only when ROM is almost complete and neurological disorders nearly absent, neurolysis is not performed (removal of one to two loose bodies). The case study shows a good pain resolution or improvement. On the contrary, failures are related to a scar around the nerve. Ulnar nerve transposition has never been carried out, except for one case in which the residual scar made it necessary. Neurolysis of the ulnar nerve is nearly always recommended in cases of severe stiffness and where there is a marked ROM recovery. Once isolated, the nerve can be fixed anteriorly in cases of major stiffness, in severe valgus elbow or where a previous surgery prevents the proper positioning in the epitrochlear sulcus. In this study, the release of the ulnar nerve has been performed in more than 90 % of cases.

63.9 Complications

Elbow arthroscopy is a safe and effective technique for the surgical management of a variety of intra- and extra-articular pathologies, but potential complications exist. The most common complications associated with elbow arthroscopy are neurologic injury, heterotopic ossification, infection and post-operative contracture [21, 29, 32, 33].

One of the most serious complications is nerve injury, which has been reported in all forms from neuropraxic to neurotmetic damage. Nerve injury can occur secondary to compression or direct injury from instruments, excessive joint distension, aggressive manipulation or post-operative CPM [21, 32].

Nerves majorly involved in complications are the posterior branch of the radial nerve, the median and the ulnar nerve.

More significant partial or complete nerve damage can also occur and may be caused by direct trauma from portal creation or as a consequence of mechanical or thermal injury from arthroscopic instruments [21, 29, 41].

During arthroscopy of the anterior compartment of the elbow, the posterior interosseous branch of the radial nerve and median nerve are at risk and may be as close as 6 mm to the capsule. The elbow should be insufflated with fluid to distend the capsule and displace the neurovascular structures away from the articulation [21, 32, 40].

Damage to the ulnar nerve can occur in a variety of situations. It is imperative that the surgeon be aware of ulnar nerve hypermobility and subluxation, which can predispose to contusion or laceration when creating anteromedial portals. The ulnar nerve is most at risk during debridement of the medial gutter when performing posterior compartment arthroscopy [21, 41]. It is mandatory during these procedures to identify before the ulnar nerve and use the retractors in order to protect it from the other instruments.

Another risk with elbow arthroscopy is the development of heterotopic ossifications post-operatively.

This can present as a spectrum, from scattered asymptomatic deposition in the surrounding soft tissues to disabling ankylosis requiring open resection. Reported risk factors for the development of heterotopic ossification include recent prior surgery, associated burns and trauma, diffuse skeletal hyperostosis and abnormalities of metabolism.

In high-risk patients, a dose of radiation therapy may be considered as also the use of indomethacin (700 mg a single dose) for 3 weeks [21, 32, 33, 40].

Like all surgery, there exists a risk for superficial and deep infection with elbow arthroscopy. The authors routinely administer a single dose of intravenous antibiotics prior to arthroscopic elbow surgery.

Finally recalcitrant elbow stiffness can occur after arthroscopy. The risk seems highest with surgery for post-traumatic disorders of the elbow, including arthroscopic contracture release and arthroscopic-assisted intervention for fracture [21, 33, 41].

63.10 Discussion

The use of different portals, the ulnar nerve isolation, the use of arthroscopic retractors and the avoidance of an excessive intra-articular joint pressure, are all fundamental elements for an accurate elbow arthroscopy. Post-traumatic and degenerative arthroscopic cases have different features. In post-traumatic cases the articular space is smaller, fibrosis is higher and capsule consistency, when removed by basket forceps, is stronger. In degenerative cases, articular space is larger, fibrosis is lower and capsule consistency weaker. Indications for stiffness arthroscopic treatment are still, in many cases, surgeon dependant. A more advanced learning curve guarantees a wider possibility to address post-traumatic pathologies and degenerative cases.

In 2000 Reddy et al. [35] presented a review of a large number of patients operated by several different surgeons, in different decubitus and by different techniques reporting low rate of minor complications but a complete lesion of the ulnar nerve. As Reddy described [35], we obtain the same low rate of complications using the tech-

nique we presented, peculiarly the use of a fine haemostat (after only skin incision) to turn away superficial and deep neurovascular structures.

In 2001 Morrey et al. reported extensive case studies in which they analysed complications following arthroscopic surgery [25]. In some cases, other authors report limited case studies where they compare the outcomes achieved by open techniques with arthroscopic ones [1, 4, 7, 8, 11, 13, 26, 28, 38]. We agree with Reddy [35] that it is impossible to review any large series of elbow arthroscopy without report neurological complications. Despite this we consider that 1.8 % of nervous complications can be defined as a low rate. We also think that 10.8 % of minor complications (synovial leakage through the portals, superficial portal infections) are connected to our aggressive rehabilitative protocol. We still use this protocol because it allows us to obtain a better ROM and result. In case of articular congruence damage, post-traumatic anatomical alterations or previous surgical outcome, arthroscopic indication is not common, while open surgery can be useful and decisive. On the other hand, arthroscopy is used in case of hypertrophy of the olecranon caused by long-standing instability, radial head osteophytes connected to a previous fracture and hypertrophy of the coronoid caused by an intense physical or manual activity.

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Part V

HIP

General Aspects on Hip Arthroscopy

64

Filippo Randelli, Fabrizio Pace, Daniela Maglione, Sara Favilla, Paolo Capitani, and Marco Brioschi

64.1 Diagnosis: Clinical and Radiological Diagnosis

Sometimes, hip pain is difficult to investigate. This is especially true in pathologies at their first stages, which are exactly those stages where a hip arthroscopy may be indicated. Pain felt around the hip may be due to intra-articular or extra-articular diseases [1] or to elsewhere-located pathological entities: spine, visceral, or neurological disorders.

64.1.1 History

A comprehensive history is paramount. Pain location, onset, kind, severity, duration, and responsiveness to drugs are some of the answers physician should know before any diagnostic approach. Familiarity for hip pathologies and specific sport and lifestyle behaviors are also investigated [2].

64.1.2 Physical Examination

First inspection: Stance, gait, and any asymmetry at the lower limb. Leg lengths should be measured.

F. Randelli (✉) • F. Pace • D. Maglione • S. Favilla
P. Capitani • M. Brioschi
Centro di Chirurgia dell'Anca e Traumatologia,
IRCCS Policlinico San Donato, Milano, Italy
e-mail: filippo.randelli@fastwebnet.it

Palpation is useful to highlight peritrochanteric space disorder and rule out extra-articular sources of pain such as those coming from the lumbar spine, sacroiliac joints, or pubic symphysis.

One therefore has to assess hip active and passive range of motion quantifying the degree of pain-free movements. It should also be tested the muscular strength, especially in abduction, as fascia lata overtensioning.

To establish that pain is coming from the hip joint, some provocative tests are normally used.

Unfortunately, most, if not all, tests present a just moderate sensitivity and a very low specificity [3].

The FADDIR test (flexion, adduction, and internal rotation) and the FABER or Patrick test [4] (flexion, abduction, and external rotation) are the most used in clinical diagnosis of femoroacetabular impingement (FAI).

Different maneuvers are used to recreate snapping, clicking, or popping described by some patients. Those noises or patient's sensations may be referred to extra-articular or intra-articular sources as an impinging psoas, loose bodies, and an unstable labral, chondral, or ligamentum teres tears.

Recently, O'Donnel et al. [5] have proposed a diagnostic test for ligamentum teres lesions with a sensitivity and specificity of 90 % and 85 %. With the knee flexed at 90°, the clinician first passively flexes hip fully and then extends for

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30°, leaving the hip at about 70° flexion, the hip is then abducted fully and then adducted 30°, typically leaving it at about 30° abduction; the leg is then passively internally and externally rotated to available end range; the test is positive when there is reproduction of concordant pain with either internal or external rotation [6].

An internal snapping hip is mostly due to a rapid iliopsoas tendon stepping on the anterior aspect of the femoral head or the iliopectineal eminence [7]. The snap is often reproducible, usually bringing the hip from flexion, abduction, and external rotation into extension and internal rotation [1].

An external snap is caused by a retracted iliotibial band (ITB) or anterior gluteus maximus border over the greater trochanter [7]. The patient is usually able to reproduce the snap that can be painful and even audible by the examiner [8].

Rarely, pain is stimulated by the extension and contemporary adduction as in case of ischiofemoral impingement (an abnormal contact between the ischium and the lesser trochanter) [9].

64.1.3 Imaging

Standardized X-ray views are still the best and essential way to have a diagnosis in most of the cases with bone abnormalities where all other diagnostic tools serve to refine the diagnosis.

An anteroposterior view of the pelvis (anteroposterior pelvic view), a cross-table lateral view, a 45° or 90° Dunn view, a frog-leg lateral view, and a false-profile view are the ones indicated [10].

Different angles, indexes, and signs (Table 64.1) are used to assess morphologic parameters either for the acetabular, such as

Table 64.1 Angles and signs for hip bone morphology

		Angles and signs	Normal range
Acetabular	Femoral head coverage	Sharp angle: it is formed by the horizontal line passing through the tear drop and the line that connects the tear drop with the anterior border of the acetabulum	38 ± 4°
		Wiberg angle: it is formed by the perpendicular passing through the femoral center of rotation and the line connecting the center of rotation with the lateral acetabular rim	32 ± 6°
		Tönnis angle: it is formed by the horizontal line passing through the medial acetabular rim tangent to the femoral head and the line that connects medial and lateral acetabular rim	10°
		Extrusion acetabular index: Acetabular medial profile is on a line passing from the medial border of the ischium body to medial profile of the ilium. If the acetabular profile is lateral to this line, it comes to coxa profunda	
	Acetabular retroversion	Crossover sign: the anterior and posterior acetabular wall lines cross before the lateral acetabular rim	
		Posterior wall sign: the posterior wall is medial to the femoral head center of rotation	
		Ischial spine sign: ischial spine is visible inside the pelvic cavity	
Femoral	Femoral head sphericity	Alpha angle: formed by a line from the center of the femoral head through the femoral neck axis and a line from the center of the femoral head to the head-neck junction	50–55°
		Beta angle: centered on the femoral head and drawn between the femoral head-neck junction and the acetabular rim	*38°*
		Head-neck ratio: ratio between the diameter of femoral head and neck	0.64–0.80

Tönnis, Wiberg, and Sharp angle, extrusion/acetabular index, crossover signs (Fig. 64.1), posterior wall sign, etc., or for the femoral side, such as alpha angle (Fig. 64.2) and beta angle [11].

Once abnormal morphologies have been underlined, degenerative changes have to be checked.

Although Tönnis [12] and Kellgren and Lawrence [13] classifications are dated, they are still widely used for grading hip joint degenerative changes through an X-ray, but they are not enough, alone, to indicate a conservative surgery. Furthermore, some pathology is radiographically undetectable.

Computed tomography (CT) allows better evaluating of bone morphology. It is more and more used in preoperative planning of FAI [14].

MRI, excluding 3.0 T MRI, has the ability to evaluate bone and soft tissue pathologies [15–17] but has a low sensibility on articular cartilage and labrum where is frequently preferred an MR arthrography [18–20]. MR arthrography with dedicated traction may be used, especially in the evaluation of ligamentum teres pathology [21]. 3.0 T MRI and 3.0 T MR arthrography are shown to have a better sensitivity in labral tear detection, while MR arthrography seems to be more sensitive in detection of chondral defect [22].

Local anesthetic joint injection may be useful in differentiating intra-articular from extra-articular source of pain; although a good preoperative response to injection is not a strong predictor of a good short-term outcome following hip arthroscopy, a negative response may predict a negative result from surgery [23].

64.2 Instruments: Basic and Advanced

The hip presents a challenging arthroscopic approach. Due to the thickness of soft tissue that surround the hip, it was necessary to develop instruments with an increased length and solidity. Furthermore, the restricted round-shaped anatomy has led to the creation of curved or bendable as needed instruments. In some instance, there is no need for longer instruments, at least at the beginning of the procedure.

Hip arthroscopy sets may be divided into basic, designed to allow an accurate, reproducible, and safe hip joint access, and advanced, designed to completely satisfy the wide range of surgical procedures.

Basic sets are composed of cannulated instruments inserted in the joint trough flexible guidewires [24].

Basic instruments for a diagnostic hip arthroscopy are as follows (Fig. 64.3):

- 30° and 70° arthroscopes [25, 26]
- Dedicated long arthroscope sheath with a cannulated obturator

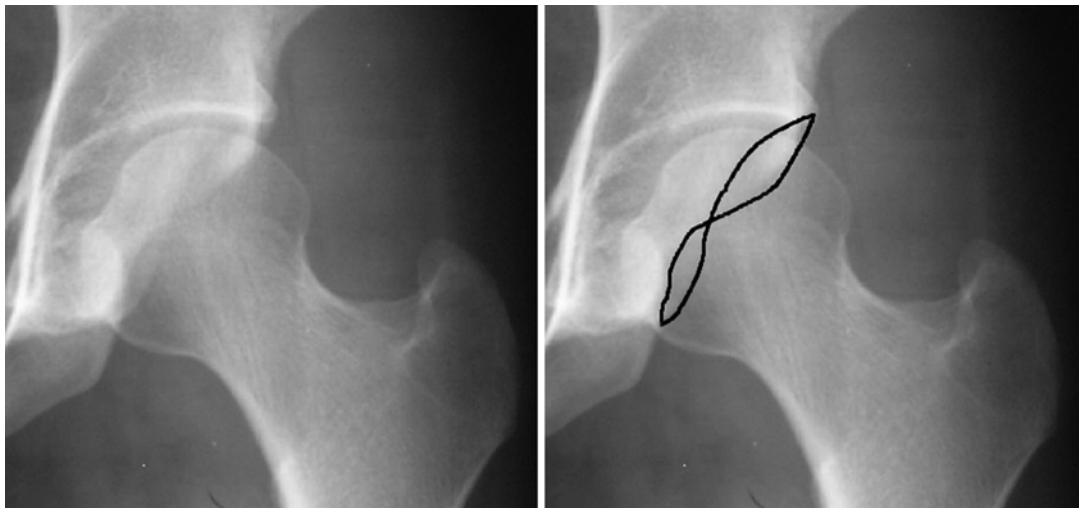

Fig. 64.1 Drawing of a crossover sign on an anteroposterior pelvic view in a PINCER-type impingement [11]

- 17-gauge long needles to gain access to hip joint
- 30–60mL disposable syringes, for capsular distension
- Extra-long nitinol guidewires [27], used to switch from spinal needles to obturators
- Two cannulated or not switching sticks (changing rods) to easily exchange portals

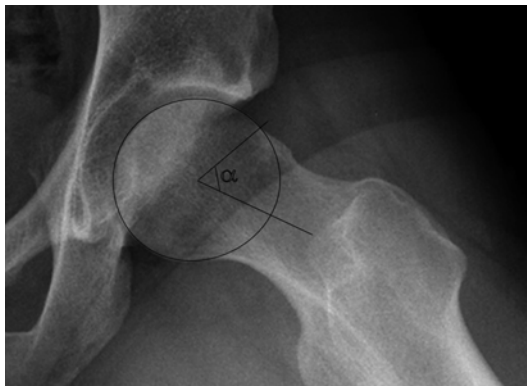

Fig. 64.2 Drawing of an abnormal alpha angle (normal range: 50–55°) in a CAM-type impingement [11]

- Extra-long cannulas (4.5–8.25 mm diameter) with cannulated obturators
- Extra-long probe, straight or curved, with a working length of at least 18 cm

The advanced non-disposable instruments for an operative hip arthroscopy are (Fig. 64.4):

- A handled slotted cannula [28] to switch wider instruments without the need of a cannula
- Long dedicated punch, curve and straight shaft
- Arthroscopic blades, different shapes, long length
- Suture retriever/tissue grasper, short and long length
- Loose body retriever, long length
- Dedicated and curved open curettes, tissue elevators, rasps
- Long chondro picks (90°, 40° curved tips mainly) for microfracture
- Long drill guides with dedicated cannulated obturator and drill for anchor placement

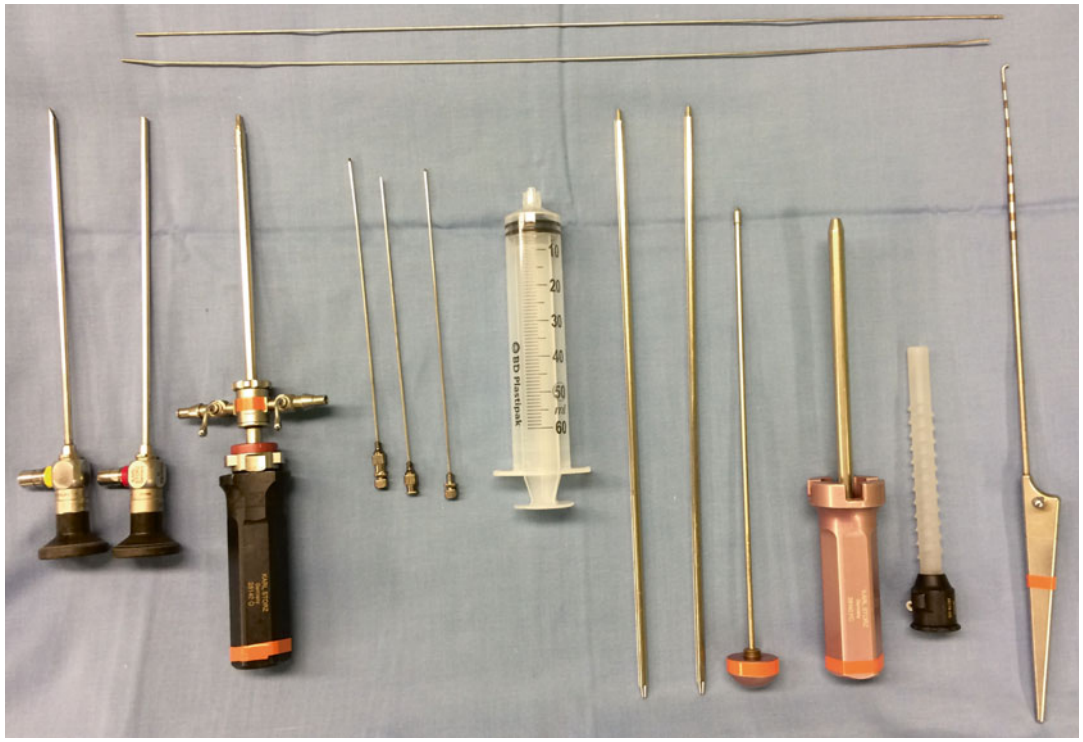

Fig. 64.3 Basic instruments

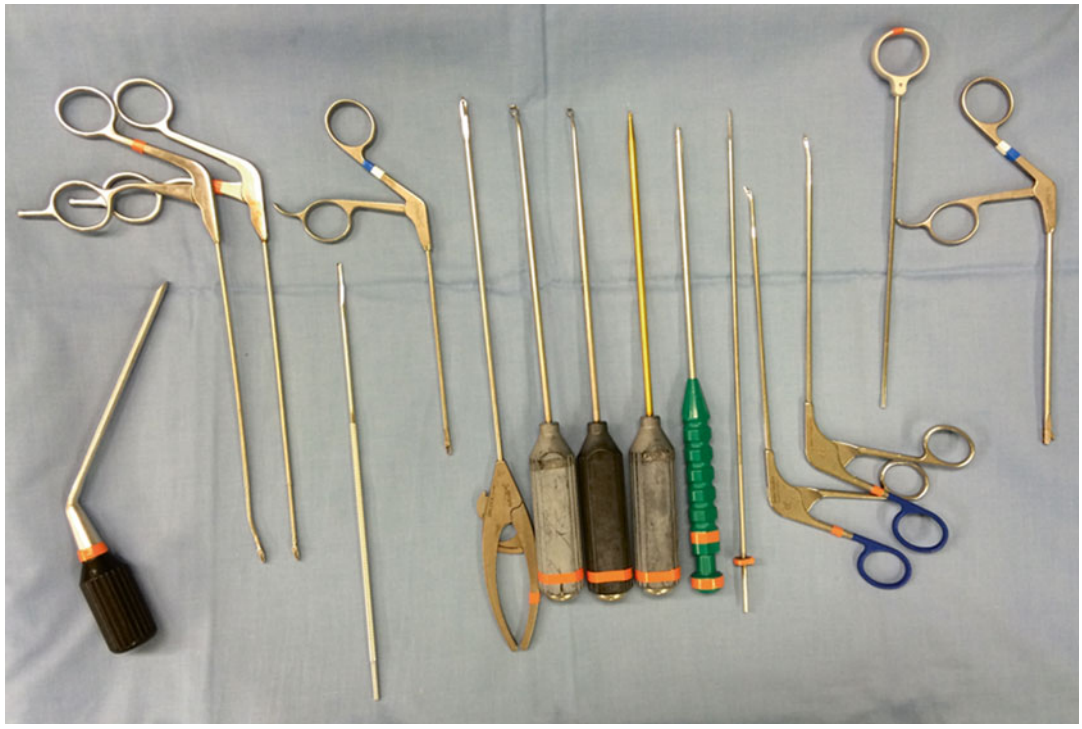

Fig. 64.4 Example of advanced non-disposable instruments

- Suture passing with different curvatures (different options)
- Knot pusher, long
- Suture cutting, long length

The advanced disposable instruments for an operative hip arthroscopy usually are (Fig. 64.5):

- Long shaver burrs (with an extruded cutting spherical or oval tip)
- Standard or long straight shaver blades
- Long full radius convex or concave shaver blades
- Long bendable shaver blades
- Hip ablation probes:
  - Straight, long, powerful (better with suction)
  - Hip-specific flexible tip [29]
- Bioabsorbable or nonabsorbable, suture or knotless anchors (specific long handle)

64.3 Classification of Injuries/Diseases

Different pathologies may affect the hip (Table 64.2). Many of them have been shown in literature to be possible of an arthroscopic or endoscopic approach. They are academically divided in intra-articular and extra-articular pathologies.

64.3.1 FAI

Femoroacetabular impingement (FAI) [30] is today, numerically, the first indication for hip arthroscopy. This does not mean that all FAI should be treated arthroscopically.

Different congenital or acquired pathologies may lead to FAI that, academically, is divided in three different pathogenetic mechanisms: CAM, PINCER, or mixed [31].

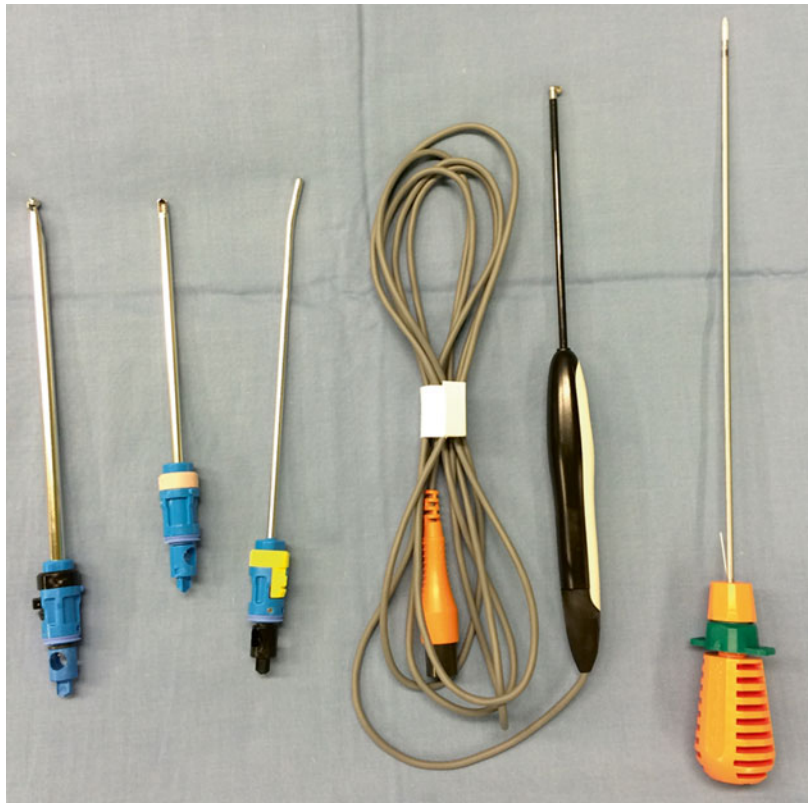

Fig. 64.5 Example of advanced disposable instruments

Table 64.2 Hip: main differential diagnosis

Intra-articular	Extra-articular
Femoroacetabular impingement	Greater trochanteric pain syndrome
Isolated labral tears	External snapping hip
Loose bodies	Internal snapping hip
Chondral damage	Bursitis
Ligamentum teres tears	Osteoid osteoma
Capsular laxity	Bone marrow edema syndrome
Development dysplasia of the hip	Avascular necrosis of the femoral head
Slipped capital femoral epiphysis	Stress fractures
Post-Perthes disease	Bone and soft tissues neoplasms
Septic arthritis	Ischiofemoral impingement
Inflammatory arthritis and synovitis	

CAM impingement is mainly caused by pathological changes at the femoral head-neck junction with more or less localized bone excess (bump) and decrease of the femoral offset (Fig. 64.1) [32]. The result is an aspherical junction with progressive early chondral damage since the beginning of symptoms [31].

PINCER impingement is caused by pathological changes leading to a constriction of the acetabulum over the femoral head and neck [33]. It may occur in case of localized or generalized acetabular retroversion (Fig. 64.2), deep acetabulum, or protrusio acetabuli. The femoral neck comes into a pathological contact with the acetabular edge. The result is an initial labral damage followed by chondral damage starting from the posterior part of the acetabulum (counteract lesion) [31].

Finally, patients may present different combinations of these two mechanisms [31, 34].

Diagnosis is done through standardized radiological exams [35–38].

Second-level imaging tools, such as CT scan, MRI, and the MR arthrography, are used to refine the diagnosis, set a plausible indication and relative prognosis, and prepare for surgical intervention. MRI and MR arthrography should also be used to exclude an arthroscopic indication, for example, in case of widened chondral pathology, subchondral cysts, and edema [26, 39, 40]. Unfortunately, arthroscopy remains the most accurate method of assessing chondral lesions in the hip joint [41].

64.3.2 Cartilage Injuries

Over the Outerbridge [42], cartilage injuries of the hip have specific classification systems [31, 43, 44]. These take into account peculiar pathological mechanisms and anatomy of the hip. This is the case of the "carpet phenomenon" [31], also called "wave sign," very often seen in CAM and MIXED-type impingement. It is the detachment of part of the acetabulum chondral layer from the underlying bone. The wave sign is the first stage of a detrimental degenerative cascade. The involved area progressively detaches from the underlying layer forming first a chondral flap and then a full-thickness lesion. Labrocartilage junction may also be involved.

A more rare but specific cartilage injury is a vertical chondral fissure located on the posterior femoral head in mixed-type impingement, the "Crevasse" lesion [45].

64.3.3 Osteochondral Defects and Loose Bodies

Osteochondral lesions [46] of the femoral head are uncommon and usually happen after posttraumatic dislocation. Different surgical techniques have been reported in literature for osteochondral lesion treatment and mainly through an open approach as Ganz surgical dislocation [47]. Mosaicplasty [48], osteochondral autograft (OATS) from the ipsilateral knee [49], osteochondral allograft [50], and partial resurfacing [51] have been described. Arthroscopy is rarely used and only as an aid to these procedures [52, 53].

Hip arthroscopy has an indisputable role in removing loose bodies. Different loose bodies [54–56] have been described affecting the hip joint. Synovial chondromatosis [57] remains the more frequent etiology.

64.3.4 Labral Lesions

Acetabular labral tears rarely occur in the absence of bony abnormalities [58]. Acetabular labrum is a well-vascularized and innervated structure and often represents a cause of hip pain [59, 60]. Labral pathologies are classified upon localization [61], morphology, consistency [62], MRI appearance, and integrity [63, 64].

64.4 General Setup, Positioning, Traction Table, and Anesthesia

Hip arthroscopy is performed with the patient in supine [65] or lateral decubitus [66]. Both have pros and cons. The lateral decubitus offers some advantages in obese patients and in gaining more access to the inferior and posterior aspects of the joint [66]. Disadvantages include a longer time needed to position the patient and the necessity to use special traction devices instead of a common fracture table [67].

Different kinds of anesthesia have been used for hip surgery [68]: general alone, spinal alone, or combined spinal-epidural with IV sedation or general anesthesia. Lumbar plexus blockade has been also proposed as an aid for postoperative pain, but its risk/benefit ratio is not clear yet [69, 70]. Neuromuscular blockade is necessary to guarantee complete muscle relaxation [71], fundamental for a safe exploration and treatment of hip central compartment.

In supine position, the patient may be placed on a common fluoroscopic fracture table, but dedicated distraction devices are commercially available.

By our experience, patient's upper limbs should not be fixed to the fracture table avoiding unnecessary tractions or hindrance during the procedure. Thus, the operative-sided upper limb is crossed over the thorax, while the opposite upper limb is positioned along the body. The perineal zone is most exposed to traction complications and must be protected. A well-padded and oversized post should be used. A too large post may complicate dynamic maneuvers during hip impingement tests. The post should be fixed as lateral as possible against the medial side of the operative thigh [65] protecting perineum and genitals from excessive pressure forces and supplies an optimal moment arm to traction [72]. Both feet are well wrapped and firmly secured inside distraction boots [73].

The surgeon and the assistant stay on the surgical field side, with the scrub nurse behind them. The arthroscopic tower and C-arm are placed on the opposite side. The C-arm should be easily placed and removed from the field in a sterile manner. The anesthesiologist and anesthesiological nurse work at the head of the patient. The fluoroscopic monitor and orthopedic nurse, responsible for traction maneuvers, are at the foot of the patient. The anesthesiological nurse helps the traction nurse during traction maneuvers checking especially for eventual genitalia compression (Fig. 64.6).

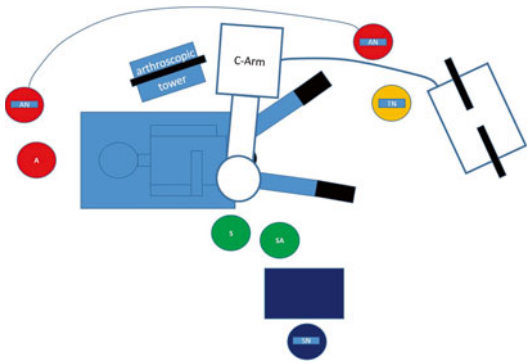

Fig. 64.6 OR setup: *A* anesthesiologist, *AN* anesthesiological nurse, *S* surgeon, *SA* surgeon assistant, *SN* surgeon nurse, *TN* traction nurse

A sufficient hip distraction, obtained without an excessive traction, is a key point of the procedure. Traction should start with the operative hip at approximately 25° of abduction and 10–20° of flexion. The contralateral limb should have been already abducted and softly tractioned. Approximately 20–30 kg should be needed to distract the joint, but this may vary upon different parameters [74, 75]. The hip is then carefully adducted and internally rotated until the femoral neck becomes parallel to the floor [76]. Image intensifier is used to confirm at least 10–12 mm of distraction [77]. If distraction is still unsatisfactory after some attempts, in asepsis and under fluoroscopy, a 17-gauge spinal needle should be inserted to release the vacuum [78] and distend the joint [79] with 30–60 mL of saline fluid. Uninterrupted traction time should be limited to 2 h, better if less. However, maximum traction weight, more than total traction time, seems the greatest risk factor for sciatic nerve dysfunction during hip arthroscopy [75].

Only after an optimal hip distraction, the sterile operative field should be draped.

64.5 Portals

Hip arthroscopic portals are limited posteriorly by the sciatic nerve, anteriorly by the femoral nerve and vessels and proximally by the superior gluteal nerve. Between these structures lies a relative safe zone. The lateral femoral cutaneous nerve (LFCN) and the ascending branch of the lateral circumflex femoral artery (LCFA) remain at risk for iatrogenic injury [80].

Central compartment of the hip joint is accessible through the anterior, anterolateral, mid-anterior, and posterolateral portals, with limitations in the posteromedial corner. A more medial portal did not offer substantial advantages regarding accessibility but decreased the safety distance to the femoral nerve. With regard to the peripheral compartment, the combination of the anterolateral, mid-anterior, proximal mid-anterior, and posterolateral portals allows visualization of most of the joint [81].

64.5.1 Anterolateral Portal

Its location is around 2 cm anterior and 2 cm superior to the tip of the greater trochanter; it penetrates the gluteus medius first and then the lateral aspect of the capsule with an angle of 15° cephalad and 15° posterior from axial and coronal planes, respectively. This is the portal that we establish first for introduction of the arthroscope. Positioning of the other portals is then facilitated by direct visualization and using triangulation technique. Labral and chondral lesions should be carefully avoided [80–82]. Using an AL portal, without traction, with the hip in flexion, it's also possible to get access to the peripheral compartment. In this case, instruments are directed to the transition zone between the anterior aspect of the femoral head and neck under the capsule [83].

64.5.2 Anterior Portal

It's placed along a line from ASIS to the lateral patella margin at the level of AL portal. Some authors prefer to create the portal 1 cm lateral to the ASIS to reduce the risk of injuring the LFCN [80].

64.5.3 Mid-anterior Portal

Creating an imaginary equilateral triangle, open medially, using a line from ASIS to AL as a side and the AL as the apex, the MAP is located on the other side at 2/3 of the distance [80].

We routinely use the anterolateral and mid-anterior portal as standard portals for hip arthroscopy (Fig. 64.7).

64.5.4 Proximal Mid-anterior

Using the same process we already used distally, we can use the proximal side of the triangle. The new point is the entry location of the proximal mid-anterior portal (PMAP) [80] (Fig. 64.8).

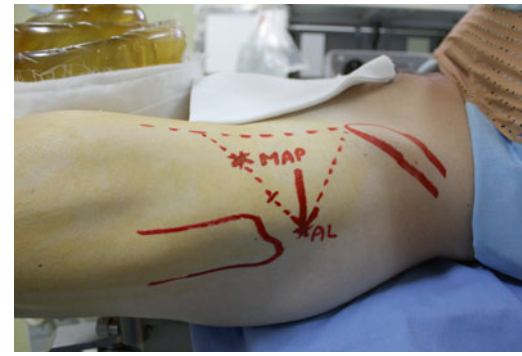

Fig. 64.7 MAP is obtained on the distal side of an equilateral triangle open medially and pointed on the AL portal; the length of each side is the same of the distance between AL portal and ASIS (anterior superior iliac spine). The MAP lies at 2/3 of the distal side of the triangle

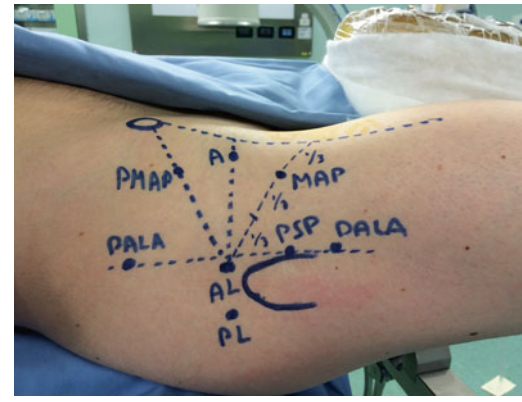

Fig. 64.8 A complete iconographic description of hip arthroscopic portals. See text for further description on how to obtain them

64.5.5 Posterolateral Portal

It is located around 1 cm posterior and 1 cm superior to the tip of the greater trochanter. Its angle is 5° cephalic and 5° anterior in axial and coronal planes, respectively; in this way, it should be 3 cm anterior to the sciatic nerve [80]. It penetrates both the gluteus medius and minimus before entering the lateral capsule at its posterior margin. It is important to recognize that flexion of the hip, to detent capsule and facilitate distraction, might place the sciatic nerve at an increased risk during this portal [82]. Similarly, external rotation moves the greater trochanter more posteriorly and closed to the sciatic nerve (Fig. 64.8).

64.5.6 Accessory Portals (Fig. 64.8)

Accessory portals are established, as needed, for acetabular anchor insertion, peripheral compartment arthroscopy, or perithrocantheric endoscopy [84]. They may vary upon surgical request.

The three more known and utilized accessory portals are:

- Proximal anterolateral accessory portal (PALA)
- Peritrochanteric space portal (PSP)
- Distal anterolateral accessory portal (DALA)

All three of these portals are located in line with the anterior border of the femur. The PALA is located directly posterior to the PMAP. The PSP lies at the level of the MAP. The third portal, DALA, is located more distally [80].

The PALA and PSP portals are useful for the management of the endoscopic gluteus medius repair. The DALA portal is useful to place a shaver to initiate a trochanteric bursectomy and visualize the lateral compartment [85]. We use DALA for safe anchor placement at the level of the acetabulum.

64.6 Complications and How to Avoid Them

The incidences of complications after hip arthroscopy, reported in literature, are extremely variable [74, 86–89]. The long learning curve and the relatively recent introduction of this technique seem to be the major cause of these complications. Interestingly, some authors correlate complications with the learning curve [89, 90], while others do not [74].

Traction-related injuries are the most frequently reported in the literature [87, 88, 90]. They are caused by prolonged traction time and, especially, application of excessive forces [90]. They may affect neurological structures as well as other soft tissues. Generally, sciatic or femoral palsies, in the form of neurapraxia, tend to resolve within few hours after surgery [74, 86]. Lateral femoral cutaneous nerve (LFCN) neurapraxia has been reported due to direct injury during anterior portal execution or indirect stretching during the procedure [91]. Griffin and Villar proposed the "trial of traction" in which traction is initially applied to ensure a successful joint distraction, and then it is released during surgical field preparation to be reapplied only when the arthroscopy is to begin [74]. We always try to intersperse traction periods, as much as we can, with other phases of the procedures.

Compression-type injuries are also associated with the use of the perineal post to obtain an adequate countertraction. The most affected in this case is the pudendal nerve [92]. Perineum soft tissues may also be affected ranging from small areas of edema-hematoma to pressure necrosis of the scrotum or labral/vaginal tears [74, 86, 89]. In order to minimize this type of injuries, the perineal post should be padded, with a large diameter and positioned on the medial aspect of the thigh rather than on the genitals, protecting and visualizing the soft tissues of the perineum during periods of traction [90]. Other possible complications related to traction could be hypoesthesia of the ankle or foot due to boot compression.

Iatrogenic lesions of the labrum or cartilage are relatively frequent, but underreported in literature [45, 93]. The most affected structures are the anterosuperior portion of the labrum or the femoral head cartilage. This type of injury usually occurs during the execution of portals or the introduction of instruments into the joint. To prevent these injuries is important to adequately distract the joint, sometimes starting with the peripheral compartment [94], and exchange frequently portals with the camera during the procedure to verify the condition of labrum and cartilage. A radiological sign, Byrd's sign, of initial labral penetration by the first AL spinal needle has been described and should be always kept in mind [95]. Another potential but rare complication is instrument breakage that might occur in constrained joints and due to long-lever arm typical of hip arthroscopy devices.

Abdominal fluid extravasation is a rare (0.16%) but potentially lethal complication after hip arthroscopy [96, 97]. Predisposing factors seem to be fresh acetabular fractures, long opera-

tive times, higher arthroscopic fluid pump pressure, and iliopsoas tendon release. To prevent this condition, it is important to monitor closely the abdomen, fluid balance, and core body temperature [90, 98, 99].

As in all surgical procedures in the lower limbs, risk of DVT or PE must be considered [100, 101]. To prevent the onset of these complications it is important to follow the general rules of prevention, with early mobilization, pharmacological prophylaxis, and assessment of individual risk factors. Among these, the use of oral contraceptives is the more frequent risk factor associated in hip arthroscopy [102, 103].

Infection, superficial or deep, is an extremely rare complication after hip arthroscopy [77]. Given the possible consequences of septic arthritis, it is important to administer a dose of broad-spectrum antibiotic as prophylaxis [90].

Adhesions between the capsule and the labrum are a possible cause of pain after hip arthroscopy [104]. Continuous postoperative passive movement and circumduction are considered the best prevention [105].

Avascular necrosis of the femoral head is a theoretical complication after hip arthroscopy [93] with some case report in literature [106]. Implicated factors are traction, capsulectomy, and injury of the medial circumflex artery [107]. In order to minimize this risk, it is important to avoid capsular dissection or bony resection at the level of the lateral synovial fold [90].

An excessive bone resection may predispose some patients to femoral fracture [89, 108]. Bone quality and age of the patient may be important factors in increasing this risk. Mardones et al. [109] claim that a resection until 30 % of the femoral neck can be safe. After, a decrease of bone resistance must be expected.

Heterotopic ossification (HO) after hip arthroscopy has an extremely variable incidence and has been underestimated for long time. The incidence reported in literature varies between 1.6 % and 33 % [110, 111]. The use of NSAIDs after arthroscopic FAI treatment seems to be an effective prevention [110, 111]. Bedi et al. in 2012 [110] reported an incidence with and without indomethacin as prophylaxis of 1.8 % and 8.3 %, respectively, while Randelli et al. in 2010 [111] reported a high incidence of HO in patients without NSAIDs prophylaxis.

Instability, subluxations and dislocations are possible catastrophic complications of hip arthroscopy [112–114]. Instability may be due to impairment of static stabilizers [114]. Other risk factors are dysplasia and laxity. In patients suffering from laxity, particular attention should be given either to resuturing the labrum and the capsule or avoiding an excessive rim trimming and a too liberal postoperative protocol [112].

Hip arthroscopy should be considered a major surgery with a steep learning curve that cannot be escaped. A careful evaluation of patient individual risk factors, intraoperative monitoring, accurate follow-up, and observance of prophylaxis are vital in order to avoid the onset of complications.

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Hip Arthroscopy: Diagnostic Techniques

65

Ivan Dzaja, Harman Chaudhry,
and Olufemi R. Ayeni

65.1 Indications

65.1.1 Femoroacetabular Impingement

Femoroacetabular impingement (FAI) is a condition where the femoral head and acetabulum are incongruous, resulting in abnormal contact between the proximal femur and acetabulum during ranges of motion. This leads to cartilage delamination and labral tearing [1]. Ganz described two forms of impingement: CAM and Pincer [2]. CAM-type impingement results from an abnormally shaped nonspherical femoral head with decreased head-neck offset, which abuts against the acetabulum (Fig. 65.1) [2]. Pincer-type impingement is an abnormally overcovered acetabular rim (Fig. 65.2). This overcoverage can be a global overcoverage (coxa profunda) or a more focal overcoverage (anterosuperior overcoverage due to acetabular retroversion) [2].

For symptomatic patients that fail nonoperative management, surgical treatment options are

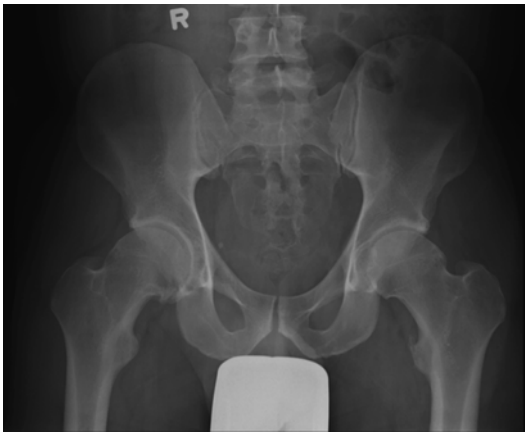

Fig. 65.1 AP pelvis radiograph demonstrating bilateral joint space narrowing with bilateral CAM deformity- pistol grip deformity and decreased head-neck offset

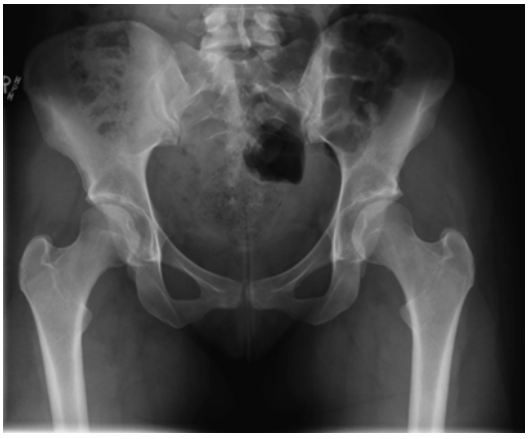

Fig. 65.2 AP pelvis radiograph demonstrating Pincer impingement with crossover sign on both left and right hips indicating acetabular retroversion

I. Dzaja, MD, FRCSC (✉)
Clinical Fellow Orthopaedic Surgery, McMaster University, Milano, Italy

H. Chaudhry, MD, MSc
Resident Orthopaedic Surgery, McMaster University, Milano, Italy

O.R. Ayeni, MD, MSc, FRCSC
Associate Professor Orthopaedic Surgery, McMaster University, Milano, Italy
e-mail: ayenif@mcmaster.ca

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available. Arthroscopic and open surgical dislocations have both been described as treatment for FAI. The goal of surgery is to treat any labral pathology and chondral damage, as well as to remove sites of bony impingement and restore femoral head-neck offset. Both arthroscopic and open surgical dislocation appear to be safe and effective options for treatment of adolescent FAI in patients with persistent pain after failure of nonoperative management [3]. Compared to open surgical dislocation, hip arthroscopy showed greater improvement in hip outcome score sport-specific subscale and a higher absolute non-arthritic hip score [4]. However, both open and arthroscopic techniques are generally accepted as capable at treating FAI in "experts' hands."

65.1.2 Labral Tears

Labral pathology represents one of the most common diagnoses among adolescent and adult patients who present with hip pain [5, 6]. The estimated prevalence of labral pathology in patients with clinical symptoms ranges in the literature from 22 % to 55 % [5, 7, 8]. The labrum is a fibrocartilaginous structure that surrounds the rim of the acetabulum and inserts on the transverse acetabular ligament (Fig. 65.3). The periphery of the labrum is more vascularized than the central portion, which has implications for healing potential [9, 10]. Its blood supply, primarily by radial branches of a periacetabular vascular ring, receives contributions from the superior and inferior gluteal arteries and the medial and lateral circumflex femoral arteries [11].

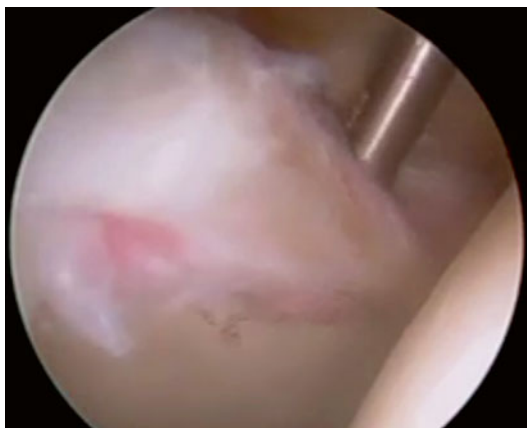

Fig. 65.3 Arthroscopic view of the hip joint. Femoral head at bottom right, acetabulum at *bottom right*, with arthroscopic instrument probing the labrum from above. Pathology at the chondrolabral junction is visible in this image

The labrum functions to increase stability of the hip joint and to provide a suction seal preventing the escape of synovial fluid [12–16]. Partial labral resection in a cadaveric model resulted in loss of fluid pressurization and change in the hip suction seal [13]. With loss of this suction effect and loss of joint fluid, there is increased contact pressure between the femoral head and acetabulum [9]. This is believed to have a role in development of degenerative disease [7]. In addition, patients with labral tears can present with groin pain and mechanical symptoms. Pain can be positional with symptoms increasing with sitting, driving, or putting on shoes.

For patients that have maximized nonoperative management and are still symptomatic, arthroscopy can play a role in definitive treatment. Surgical options available include labral debridement, labral repair, or labral reconstruction. Evidence exists to suggest that patients report better clinical outcomes with labral repair compared to labral debridement [17]. Labral reconstruction has been described to maximize hip preservation in the setting of a deficient labrum. Current evidence shows short-term improvement in patient-reported outcomes and functional scores after reconstruction [18].

65.1.3 Rupture of Ligamentum Teres

The ligamentum teres is a round ligament that connects the femoral head with the acetabulum. While it contributes to the blood supply of the femoral head during childhood, it is considered to be a vestigial structure in the adult [19]. More recently, rupture of the ligamentum teres is increasingly being recognized as a source of persistent hip pain [20]. In patients undergoing arthroscopy, the incidence of rupture of the ligamentum teres ranges from 4 % to 15 % [20–22]. An index of suspicion should be maintained in the presence of mechanical symptoms and a history of significant trauma.

Rupture may also occur simply from a twisting injury in the absence of major trauma [20].

In patients that fail nonoperative management (including medication, rest, and physical therapy), surgical treatment is warranted. Arthroscopic ligamentum teres debridement is indicated for short-term relief of hip pain caused by partial-thickness tears that fail nonoperative management [23]. Arthroscopic debridement alone of isolated ligamentum teres ruptures has been shown to have a short-term beneficial result in more than 80 % of cases [24]. Reconstruction with autografts, allografts, or synthetic grafts may be indicated in full-thickness ligamentum teres tears that are deemed "reparable," cause instability, have failed previous debridement, or a combination of these conditions [23].

65.1.4 Snapping Hip Syndrome

Internal snapping hip syndrome is due to snapping of the iliopsoas tendon over the femoral head, a prominent iliopectineal eminence, or an exostoses off the lesser trochanter. Patients that fail nonoperative management can be considered for surgical treatment. Open surgical release of the iliopsoas tendon is an invasive procedure involving extensive dissection. In contrast, arthroscopy allows for access to the iliopsoas tendon in a less invasive way. In comparison to open management, arthroscopic treatment of internal snapping shows a decreased failure rate, lower complication rate, and decreased postoperative pain [25].

65.1.5 Synovial Chondromatosis

Synovial chondromatosis is a benign monoarticular disorder characterized by synovial metaplasia and proliferation resulting in multiple intra-articular cartilaginous loose bodies. These loose bodies may also become ossified. Removal of these loose bodies is indicated in symptomatic patients. In the hip, arthroscopic removal of osteochondral fragments with synovectomy is both safe and effective with a mean recurrence rate of 7.1 % [26].

65.1.6 Joint Sepsis

Septic arthritis involves inflammation of a joint caused by infection. Treatment involves urgent thorough irrigation and debridement along with appropriate antibiotic therapy. In comparison to open treatment, arthroscopic irrigation and debridement of native hip septic arthritis is a safe and effective treatment option for patients with no significant bony deformity and who are not immunocompromised [27]. This use of hip arthroscopy is promising due to the reduced morbidity to the patient and potential for a quicker recovery.

65.2 Techniques

Hip arthroscopy is a challenging and technically demanding procedure. This is due to the spherical shape of the femoral head and the significant amount of surrounding musculature, making access to the joint difficult. Arthroscopy does have advantages in that pathology can be addressed in a less invasive way compared to open procedures. Hip arthroscopy gives access to both central and peripheral compartments. The central compartment includes the articular surface of the femoral head, the acetabulum, labrum, and ligamentum teres. The peripheral compartment includes the femoral neck, capsule, and synovium.

65.2.1 Patient Setup and Positioning

General anesthetic is preferred as complete relaxation is required for joint distraction. Both lateral and supine positioning have been described, with each having specific benefits. Advantages with supine position include ease of positioning, surgeon familiarity, and the ability to use a standard fracture table. The main advantage with lateral positioning is easier access with obese patients as well as access to posterior joint pathology. Both positions require the leg to be placed in traction to gain access to the joint. Roughly 10 mm of distraction is required to adequately visualize intra-articular structures. Traction time

Fig. 65.4 Perineal foam post to minimize pudendal nerve injury

should be limited to 2 h to minimize the chance of traction-related neuropraxias [28]. A well-padded, oversized perineal post is used to help prevent injury to the perineal soft tissues and the pudendal nerve. The post is lateralized against the medial thigh of the operative leg (Fig. 65.4).

Prior to applying traction, the patient is placed supine on the traction table. The perineal post is then applied. The operative leg is positioned in neutral flexion/extension, abduction (45°), and neutral rotation. Although flexion can relax the anterior capsule making distraction easier, it also brings the sciatic nerve closer to the joint thus making it potentially vulnerable to injury with a posterior portal. The contralateral nonoperative extremity should be positioned in 45° abduction. Traction should begin on the nonoperative leg. This serves as counter traction for the operative extremity. Traction is then applied to the operative leg with the leg abducted. Slowly, by bringing the leg from abduction to neutral while maintaining neutral extension/flexion joint, distraction is established. Leg is adducted 10–15° at a time with sequential fluoroscopic imaging confirming progressive joint distraction. Fluoroscopy should be used to verify joint distraction (Fig. 65.5). Typically, a 70° arthroscope should be made available to allow for adequate visualization. Instruments used for hip arthroscopy are typically longer than standard arthroscopic equipment.

65.2.2 Portal Placement

Once distraction is verified with fluoroscopy, the hip and leg are prepped and draped in usual sterile fashion. Be sure to maintain access to all potential accessory portals when draping the patient. Anatomic landmarks can then be drawn out mapping out bony structures and potential portal sites (Fig. 65.6). A vertical line can be drawn distal from the anterior superior iliac spine (ASIS) as a visual reminder to the surgeon. Care should be taken while making any portals medial to this line, as the femoral neurovascular structures reside in this area and can be damaged.

Traditionally, three portals are commonly used: anterolateral, anterior/mid-anterior, and posterolateral portals. The majority of central compartment procedures can be completed through the anterolateral and anterior/mid-anterior portals, with the posterolateral portal serving mainly as an outflow portal.

Establish the anterolateral portal first using fluoroscopy to ensure appropriate positioning.

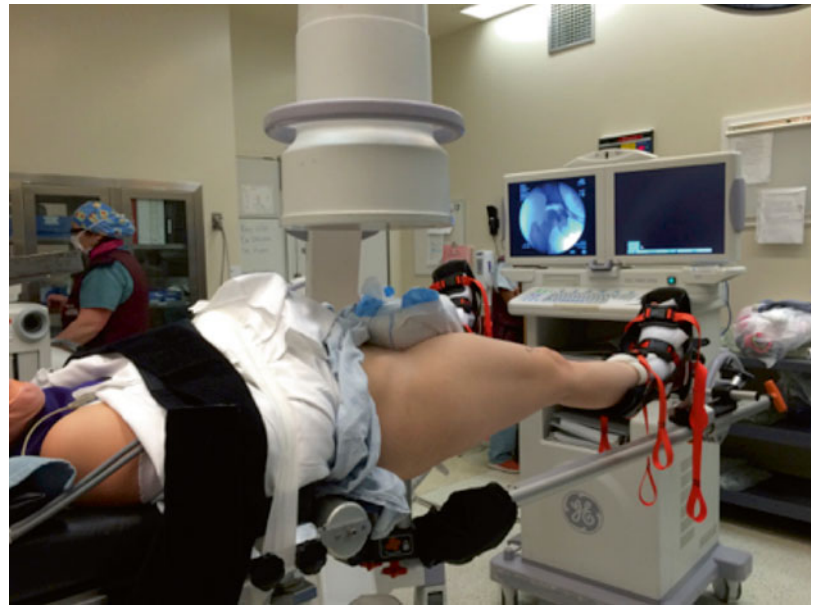

Fig. 65.5 Perineal post positioned against the medial thigh of the operative leg. Fluoroscopy positioned over the operative leg to ensure joint distraction

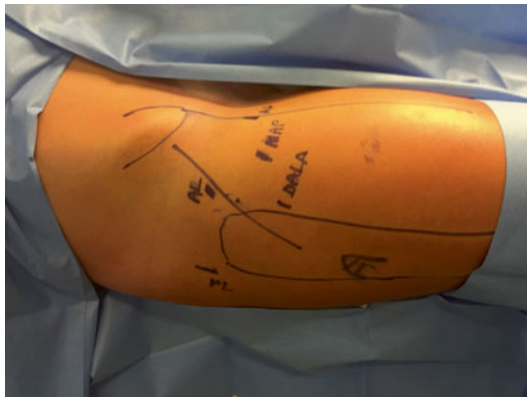

Fig. 65.6 Anatomy and possible portal sites marked. ASIS indicated at *top left* with a *vertical line* extending distal from ASIS. Greater trochanter and femoral shaft drawn inferiorly. *AP* anterior portal, *AL* anterolateral portal, *PL* posterolateral portal, *MAP* mid-anterior portal, *DALA* distal anterolateral accessory portal

Typically, the entry point for the anterolateral portal will be roughly 1 cm superior and anterior to the anterior edge of the greater trochanter. This portal pierces the gluteus medius muscle before reaching the hip capsule. The nearest neurovascular structure is the superior gluteal nerve, which resides a mean distance of 4 cm superior to the anterolateral portal [29].

The anterolateral portal is created using the Seldinger technique. A skin incision is made roughly 1 cm anterior and superior to the tip of the greater trochanter. Next, a spinal needle is inserted and directed toward the joint. The trajectory of the spinal needle is 15° cephalad and 15° posterior. The muscle interval used is the tensor fascia lata/gluteus maximus and rectus femoris/hip flexors. Once the spinal needle penetrates the joint capsule, a loss of resistance can be appreciated. Excessive resistance suggests that the surgeon is about to penetrate through the labrum rather than the capsule. In this case, the needle should be redirected.

Once satisfied with the fluoroscopic position of the spinal needle, the inserter is withdrawn from the needle, and fluoroscopy is used to visualize an air arthrogram. This indicates that the needle is in fact within the joint. Next, approximately 5–10 cc of normal saline is injected intra-articularly, and flashback of fluid is visualized (confirming intra-articular placement). This provides a secondary check that the needle is within the joint. A long guide wire is then inserted through the cannulated spinal needle and advanced to the acetabular fossa as verified by fluoroscopy. This provides the third check to appropriate spinal needle position. The scope trochar is advanced

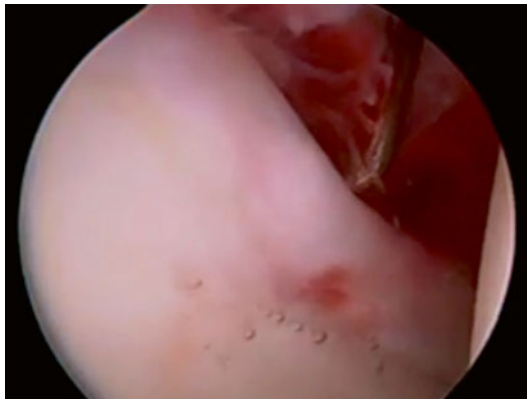

Fig. 65.7 Arthroscopic view of the hip joint: the femoral head is seen on the *right* with acetabulum on the *bottom*. Arthroscopic probe entering through an injected inflamed capsule probing the labrum

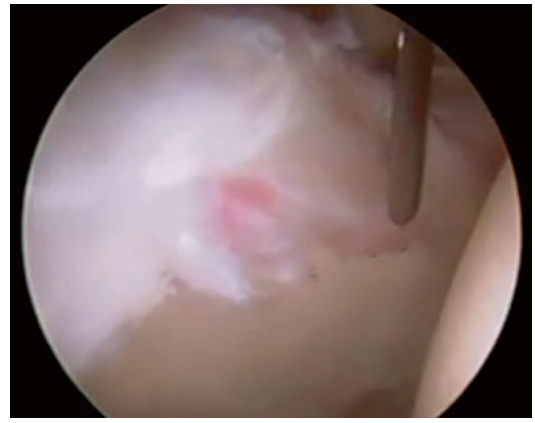

Fig. 65.8 Arthroscopic view of the hip: femoral head on the *right* with acetabulum toward the *bottom*. Capsulotomy blade is visible performing a capsulotomy connecting the two portals

over the guide wire and through the capsule, with caution taken to ensure the guide wire does not bend or break when removing it.

The 70-degree arthroscope is inserted, and the anterior/mid-anterior portal is made under direct visualization with fluoroscopic guidance as needed. We prefer the mid-anterior portal rather than the anterior portal as there is decreased risk of injury to the lateral femoral cutaneous nerve. Landmark for this incision is approximately 2 cm distal and 2 cm anterior to the anterolateral portal. The portal passes through the sartorius and rectus femoris muscles before reaching the hip capsule. The spinal needle trajectory is 45° cephalad and 10–15° posterior. This is done under direct visualization, observing the spinal needle as it enters the joint. The capsular triangle formed by the femoral head and acetabulum is the target for the spinal needle insertion (Fig. 65.7).

The posterolateral portal can then be made. Typically we utilize this portal as an outflow portal when visualization is suboptimal. The posterolateral portal is made 1 cm posterior and superior to the greater trochanter and is also made under direct visualization. The portal passes through the gluteus medius and minimus muscles before reaching the joint capsule. The closest neurovascular structure is the sciatic nerve, which resides a mean distance of 2.9 cm posterior to the portal [29].

The abovementioned three portals are typically sufficient to complete most central compartment procedures. After completing central compartment work, traction is removed and the hip can be flexed. This relaxes the anterior capsule and gives greater access to the peripheral compartment. Numerous accessory portals have been described, and their use will depend on the procedure being performed and the location of pathology (Fig. 65.6 above).

The distal anterolateral accessory portal is commonly used for osteochondroplasty associated with CAM impingement. The distal anterolateral accessory portal is made 3–5 cm distal to the anterolateral portal, using a similar trajectory and technique as that for the creation of the anterolateral portal.

65.2.3 Visualization

Once the anterolateral and mid-anterior portals are established, an anterior interportal capsular release is made from 3 to 11 o'clock connecting the two portals using a beaver blade (Fig. 65.8). This capsulotomy is essential for instrument mobility, anchor placement, and arthroscopic knot tying and can help visualization with suboptimally placed portals. This capsulotomy typically starts approximately

5–8 mm from the labrum and measures 12–15 mm in total length [30]. Care should be taken not to overextend this capsulotomy in patients with hypermobility syndromes or connective tissue disorders to minimize the risk of iatrogenic hip instability [31].

Diagnostic arthroscopy can then be completed first examining the labrum, looking for signs of injection and associated pathology. The chondrolabral junction is also examined, and areas of detachment and tearing are identified. The femoral head and acetabulum are both examined with special attention being made toward cartilage quality. The ligamentum teres is examined, as is the capsule also looking for tearing or signs of injection. The capsular recess should be examined for presence of loose bodies.

65.2.4 Osteochondroplasty

After central compartment pathology has been addressed, the peripheral compartment can then be entered. Femoral neck osteochondroplasty is commonly done to address CAM deformities. A distal anterolateral portal is created again using the Seldinger technique. Once the portal is created, the initial capsulotomy is extended. A T-capsulotomy is performed to allow adequate exposure to the anterolateral femoral neck. The lateral portion of the CAM is excised with the leg extended and while under traction using a 5.5 mm burr. Suction is used to evacuate bony debris to minimize the chance for heterotopic ossification [32]. After completion of the lateral neck debridement, traction is removed and the hip is flexed 45°. Internal and external rotation gives a 180° view of the (typical) anterior component of the CAM lesion. Osteochondroplasty is completed under dynamic visualization with hip rotation at 45° and 90° of flexion to ensure full decompression. The zona orbicularis represents the distal most extent of the decompression. It marks the terminal branch of the lateral femoral circumflex artery and also is an important structure for hip stability. A compromised zona orbicularis can lead to hip instability and loss of the suction seal and therefore should be retained by surgeons [33]. Capsular repair is indicated in documented cases of preoperative ligamentous laxity or connective tissue disorders to minimize the risk of hip instability [31].

65.3 Tips and Pearls

Hip arthroscopy can be a challenging procedure if the surgeon is not experienced in the nuances involved with this procedure. Strategies that can be utilized to improve operative success include the following:

- Patient selection is of utmost importance. History and physical examination should correspond with advanced imaging in defining pathology that can be addressed with arthroscopy. Patients with evidence of osteoarthritis should be made aware of the higher likelihood of short-term failure at pain resolution [34, 35].
- Obtaining joint distraction in a safe manner by working closely with anesthesia to ensure full muscle paralysis helps with visualization. Ensuring good padding of the perineal post also minimizes risk of nerve trauma.
- Use of accessory portals as described above. It is our preference to start with an anterolateral portal using fluoroscopy to help with portal placement, followed by mid-anterior portal. Having knowledge of accessory portals is useful in cases of large deformities that limit access to the joint.
- Once the above two portals are established, an anterior interportal capsulotomy is performed using a beaver blade. This allows for greater visualization and exposure and also allows some forgiveness for portal placement that is slightly less than ideal. This capsulotomy should be completed with some caution as it can lead to hip instability [30, 31].
- When establishing portals, ensure labrum is not violated. If excessive resistance is felt during needle placement, redirect slightly away from the acetabulum as you are likely directing your instrument toward or through the labrum.

- Once the initial trochar enters the joint through the anterolateral portal, you can verify its position within the joint using three "checks":
  - Remove the guidewire from the needle and use fluoroscopy to check for an air arthrogram.
  - After visualizing an air arthrogram, distend joint with 5–10 cc of normal saline. Flash back of fluid helps to verify that the needle has been placed within the hip joint.
  - At this point, a guidewire can be advanced fully until resistance is met. Fluoroscopy can then be used to verify that the guidewire is at the fovea.

65.4 Complications

As with any invasive surgical procedure, performing hip arthroscopy is associated with a risk of complications. Kowalczuk et al. performed a systematic review of 66 studies comprising a total of 6,962 hip arthroscopy cases. They found an overall mean incidence of complications of 4.0 % [36].

The most immediate complications occur intraoperatively. Iatrogenic joint damage, such as chondral scuffing and labral puncture, has been reported to occur in up to 20 % of cases [37]; however, the true incidence is likely underreported. Iatrogenic damage may be unavoidable even in experienced hands given the relatively blind nature of portal entry. However, as the natural history of these lesions is unknown, every effort should be made to avoid any further damage once intra-articular visualization is established.

Direct trauma to the neurovascular structures can be devastating but is consistently avoided with diligent adherence to established landmarks and appreciation of the surrounding anatomy. The femoral nerve, artery, and vein pass a mean 3.7 cm medial to the anterior portal; the sciatic nerve lies a mean 2.9 cm posterior to the posterolateral portal; the superior gluteal nerve lies a mean 4.4 cm superior to lateral portals [29]. Avoiding the lateral femoral cutaneous nerve (which lies a mean of 0.3 cm lateral to the anterior portal) may be unavoidable and has been reported to occur in 0.5 % of cases [38].

Traction-related neuropraxias are relatively common and usually recover spontaneously [39–41]. The most common of these involve the pudendal nerve, either through traction neuropraxia or direct compression at the groin traction post. Traction neuropraxia of the sciatic and common peroneal nerves may also occur. Other theoretical risks of traction involve injuries to skin, bones, and soft tissues, as well as the genitals; therefore, a well-padded setup is imperative. Heterotopic ossification (HO) may occasionally occur, and the risk increases in cases where an osteoplasty is performed.

Major complications after hip arthroscopy are rare, with a cumulative incidence of 0.2 % [36]. However, a high index of suspicion must be maintained as these complications can lead to devastating outcomes. Postoperative hip dislocation, femoral neck fracture, or avascular necrosis of the femoral head may occur with overresection of the acetabular rim or femoral head-neck. Fluid extravasation from the hip joint into the abdominal cavity can lead to an abdominal compartment syndrome, which is a surgical emergency. Surgical trauma, pain, and relative immobility of the operative limb can lead to deep vein thrombosis. Finally, septic arthritis may result from iatrogenic introduction of pathogens into the hip joint [36].

Precautions can help minimize complications in patients that are at increased risk. Limiting traction time to 2 h can minimize the risk of traction-related injuries [42, 43]. Resection of CAM lesions is necessary for complete treatment of FAI. To avoid instability, resection should not extend to the level of the zona orbicularis [33]. To minimize risk of femoral neck fracture, the burr should be handled gently during osteochondroplasty to avoid notching. Up to 30 % of the femoral head-neck can be resected safely [44]. Weight bearing should also be restricted with the use of gait aides to minimize risk of femoral neck fracture. To minimize risk of HO, the joint should be irrigated at the end of procedures that generate bony debris. Pharmacologic prophylaxis or radiation can be considered in patients at high

risk for developing HO. If HO appears on a postoperative radiograph, follow-up (both range of motion and imaging) should be continued for a minimum of 12 months.

65.5 Summary/Literature Overview

There has been increasing interest in FAI in recent literature. Between 2005 and 2010, the number of publications related to FAI has dramatically increased [45, 46]. Despite this, high-quality studies are still lacking. Botser et al. compared clinical results of open versus arthroscopic management of FAI. While both open surgical dislocation and arthroscopy are viable options for treatment, the arthroscopic group did trend toward faster recovery and quicker return to sports [47]. Philippon et al. studied outcomes following hip arthroscopy for FAI with one of the longest follow-ups currently reported. One hundred and twelve patients were included in their cohort with a minimum of 24-month follow-up. Hip arthroscopy for FAI along with suitable rehabilitation provided a good short-term outcome and high patient satisfaction [48]. Predictors of a better outcome included the preoperative modified Harris hip score, joint space narrowing >= 2 mm, and repair of labral pathology instead of debridement [48]. Despite the increase in interest and publications on FAI, higher-quality studies are still needed. Hetamish et al. performed a systematic review and found significant variation in the reported clinical and radiographic outcomes after arthroscopic treatment of FAI [49]. This highlights the need for consistent outcome reporting after arthroscopic FAI surgery.

Labral pathology and treatment has also been studied extensively in recent literature. Labral debridement for symptomatic labral tears has been performed for some time with good success. Byrd et al. reported 10-year follow-up of patients with labral lesions treated with arthroscopic debridement. Hips with no arthritis had a significant increase in Harris hip scores, and this improvement remained significant throughout the 10-year follow-up period [50]. Clinical findings of arthritis at the time of index procedure were found to be a poor prognostic indicator with poor results noted at 10 years [50]. Despite the success with labral debridement, evidence suggests that patients report better clinical outcomes with labral repair compared to labral debridement [18]. Further, labral reconstruction has been described to maximize hip preservation in the setting of a deficient labrum. Current evidence shows short-term improvement in patient-reported outcomes and functional scores after reconstruction [18].

Recent studies have demonstrated encouraging results for patients suffering from ligamentum teres ruptures treated with arthroscopy. Debridement of the ligamentum teres has been shown to have a short-term beneficial result in more than 80 % of cases [46]. Similarly, recent literature on internal snapping hip syndrome has demonstrated that compared to open management, arthroscopic treatment has shown a decreased failure rate, lower complication rate, and decreased postoperative pain [25].

65.6 Future Directions

Hip arthroscopy has traditionally been thought of as a hip preservation procedure. Recent publications have described its role in arthroplasty patients. Indications for arthroscopy after hip replacement include iliopsoas tendinopathy, symptomatic hips with no clear diagnosis despite extensive investigation, periprosthetic infection, and intra-articular loose bodies. Hip arthroscopy can be a safe and effective method of treating hip arthroplasty patients with iliopsoas tendinopathy [51]. It also has utility in patients with symptomatic hip arthroplasty after exhaustion of other diagnostic avenues [51].

Extra-articular sources of impingement have recently been recognized as a source of hip pain. It can be the result of psoas impingement, subspine impingement, ischiofemoral impingement, and greater trochanteric/pelvic impingement. A recent literature review suggests that there is some early evidence to support arthroscopic

treatment for psoas impingement and subspine impingement and open surgical treatment for ischiofemoral impingement and greater trochanteric/pelvic impingement [52].

Labral tears are known to cause symptomatic hip pain. There has been substantial literature comparing labral debridement versus repair. Hip labrum reconstruction has recently been described to optimize hip preservation when the labrum is deficient. Based on current available evidence, hip labrum reconstruction shows short-term improvement in patient-reported outcomes and functional outcome scores postoperatively in young patients with no significant arthritis [18].

Well-conducted long-term studies will be needed to fully understand the role of hip arthroscopy in treating intra- and extra-articular causes of hip pathology. As technology continues to develop, hip arthroscopy will likely play a role in arthroscopically assisted biologic therapy for cartilage pathology.

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Arthroscopic Treatment of Femoroacetabular Cam Impingement

66

Mohammad Masoud and Michael Dienst

66.1 Patient Selection

66.1.1 Cam FAI

Cam femoroacetabular impingement (FAI) is the femoral-sided component of FAI. It results from either local deformities of the head-neck transition or global orientation pathologies:

Local deformities:	Asphericity of the head-neck-transition
	Thickening of the femoral neck/loss of head-neck-waist
	Coxa magna (s/p Perthes disease)
	Local deformity from nonanatomically healed fractures
Global malorientation:	Retrotorsion (developmental)
	Retrotilt (s/p slipped capital epiphysis, femoral neck fracture)

Cam FAI typically leads to *outside-in shearing forces* exerted on the anterolateral acetabular rim cartilage with flexion and internal rotation of the hip resulting in *variable degrees of cartilage damage at the rim* ranging from cracking of the chondrolabral junction to different degrees of cartilage delamination. The labrum, in pure cam cases, tends to be later involved. While the hyaline cartilage cannot escape from the pathologic contact with the head-neck transition, the elastic acetabular labrum can be pushed away as the femoral head is flexed and rotated. As a result, the body and free edge of the labrum stay intact long. However, this does not implicate that the labrum does not need to be repaired in pure cam cases. The "extruding force" on the labrum and outside-in force on the adjacent cartilage lead to high "separating forces" at the chondrolabral junction not only resulting in hyaline cartilage flaps but also to deep chondrolabral separations with separation and instability of the acetabular labrum itself. Thus, also in pure cam cases, labral repair is frequently needed. In reality, FAI is often combined. In a recent epidemiological multicenter study, pure cam FAI was found in 47.6 % of the hips, 44.5 % had combined cam/pincer FAI, and 7.9 % had a pure pincer [1].

The *etiology and pathogenesis of cam FAI* are under current evaluation and not yet completely understood. However, there are strong indicators that the typical aspherical deformity of the head-neck transition is a result from a growth plate disturbance during adolescence [2]. The causes are likely high level sports activities and extremes of range of motion during the maturation age leading to physical injury and abnormal growth patterns [3]. This is supported by several studies demonstrating the higher prevalence of radiological cam deformity and positive clinical symptoms

M. Masoud, MD • M. Dienst, MD (✉)
OCM Klinik GmbH, Steinerstr. 6, München 81369, Germany
e-mail: mohammadmasoudortho@yahoo.com; Michael_Dienst@yahoo.de

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among professional athletes in comparison to amateurs. In addition, the development of a cam deformity after closure of the growth plate has not been observed [4–7].

The relation of such pathologic growth patterns to a slip of the femoral head epiphysis (SCFE) is obvious. The resulting retrotilt of the femoral head and prominent head-neck asphericities after medium and severe SCFEs are frequently resulting in early joint degeneration. This observation was one of the hints that were leading to the development of FAI [8].

There are cam cases where the classic femoral neck-head asphericity with relation to the growth plate is missing. A loss of femoral head-neck offset caused by pathologic thickening of the femoral neck is not rare and needs to be considered. Here, the pathomechanism is usually a combination of higher stresses on the anterolateral rim cartilage and squeezing of the labrum at the neck (pincer). After femoral neck fractures with displacement and impaction, both the anatomic sphericity and offset can be significantly changed.

The complex deformity resulting from Perthes disease can lead to cam patterns. Those may be compensated by the frequently concomitant dysplasia of the acetabulum, but may be relevant in cases where the acetabulum is not dysplastic and when acetabular reorientation is indicated. Here, the big head (coxa magna) can lead to high stresses at the anterolateral rim cartilage.

66.1.2 Patient Selection

A precise diagnostic workup and patient selection are crucial in order to avoid unnecessary operative procedures as well to achieve a successful surgical outcome. The diagnosis of FAI is a combined clinical and radiological one where the correlation of clinical findings with the morphological bony deformities and collateral damage visible on radiographs and MR imaging is of a high importance. Surgical corrections based on radiological findings only in asymptomatic patients as a prophylactic procedure to avoid further deterioration of the joint are not yet justified. While the direct causative relation between FAI and chondrolabral damage has been proven by multiple studies, data indicating a prophylactic effect of surgery are still missing.

Patient selection is a complex and important process. Patient symptoms and their duration, clinical examination findings including joint functional status, radiographic findings, patient expectations, and surgeon's experience must all be taken into consideration during the decision process. Poor patient selection is associated with unhappy patients, persistent complaints, higher failure, and total hip conversion rates.

The *most important questions during the decision process* that need to be addressed are:

- At what extent are the patient's complaints caused by the hip?
- Is hip preservation surgery still justified or is total hip arthroplasty the better solution?
- Which pain level justifies operative joint-preserving treatment?
- Can the hip pathology be treated adequately by arthroscopy or should an open procedure be considered?

The question if and *how much of the patient complaints is caused by the hip* is sometimes difficult to answer, despite a detailed assessment of the patient's complaints and physical and radiologic examination. Hip pain may be mimicked by pathologies originating from the lumbar spine, sacroiliac joints, and urogenital, gastrointestinal, and inguinal pathologies. In addition, even if the hip is the primary cause of problems, pain may come from periarticular collateral problems that are the sequelae of a reduced hip function. So, an osteitis pubis, sacroiliac joint problems, and adductor- and iliopsoas-related symptoms may primarily result from a limited hip range of motion. Moreover, it needs to be considered that the cam (and the pincer) deformity itself does not cause pain. The patient's complaints are the result from the collateral damage at the chondrolabral complex and periarticular changes from the pathologic joint function. In unclear cases, the easiest test to find out how much pain is directly coming from the joint is an intra-articular injection with local anesthetic and cortisone. With respect to its sig-

nificance for the decision process, the injection should be guided by fluoroscopy or ultrasound to confirm intra-articular administration of the fluid.

Frequently, patients with FAI present with advanced collateral damage where joint-preserving surgery is critical. Particularly in those patients, the *decision between joint preservation surgery and nonoperative therapy with later joint replacement* is often more difficult because of the young age and relatively high expectations. The decision is always individual, but there are some criteria indicating that the point between joint preservation and joint replacement is likely passed:

- Patient history:
  - Symptoms and pain progressive over many years
  - Signs of limited joint range of motion
  - Increasing pain with longer activities, persistent during rest and night
- Physical examination:
  - Limp caused by muscle contractures
  - Flexion and external rotation contractures
- Radiographs:
  - Incongruent joint space/eccentric head position
  - Big or multiple subchondral bone cysts
  - Big central and/or head-neck osteophytes, double floor of acetabular fossa
  - Deformation of the head
- MR imaging:
  - Advanced subchondral edema of the anterolateral acetabulum
  - Big or multiple subchondral bone cysts
  - Big joint effusion without evidence of primary synovial disease

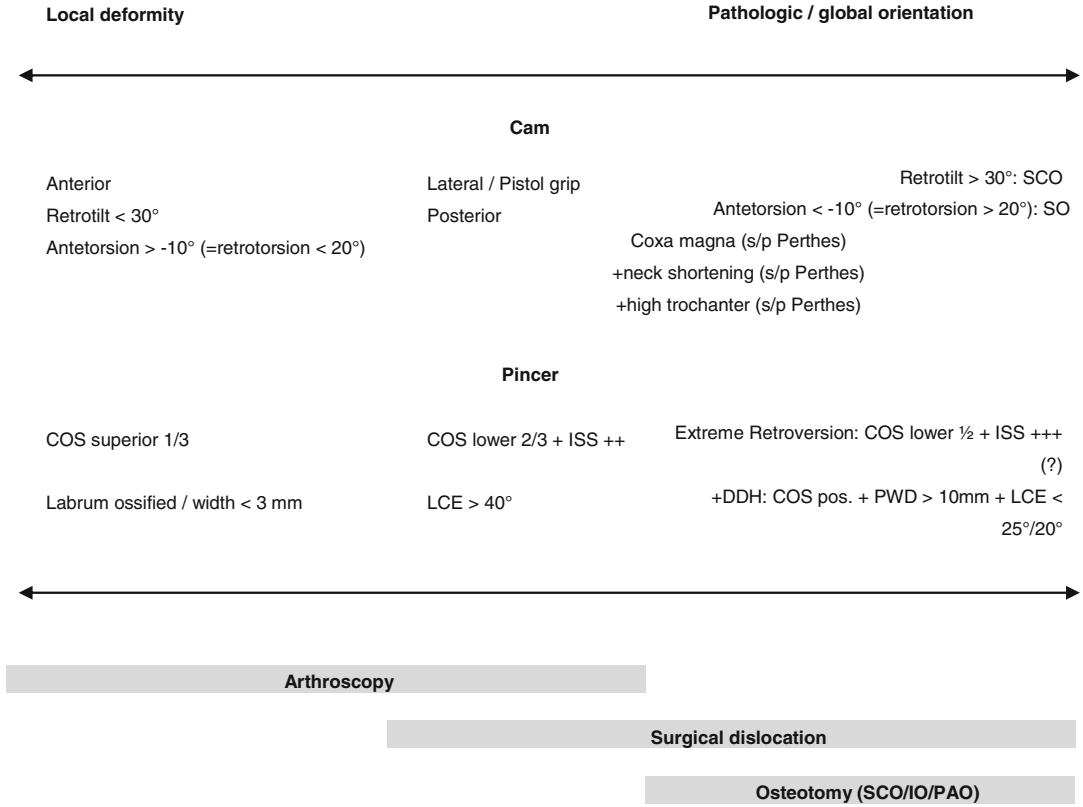
Along with the abovementioned discussion about prophylactic surgery goes the question *which pain level justifies the indication for joint-preserving surgery*. For this discussion, it needs to be considered that the FAI deformity itself is usually not causing pain. The patient's symptoms and complaints are the result from the collateral damage at the anterolateral rim cartilage and, in cam FAI, later also at the anterolateral acetabular labrum. In addition, it needs to be stated that, also in young patients, the damage can be already advanced even if the pain level is low. Thus, from our experience, surgical intervention should be considered early even in patients where the pain is minimal and only with sports activities. As an alternative, impingement sports should be terminated and the patient scanned with MR imaging regularly. If the follow-up MR images show progression of joint deterioration, surgery should be recommended.

66.1.3 Operative Treatment

Cam FAI can be treated by *different operative techniques*. Historically, FAI was first observed and treated by Ganz and coworkers via open surgical dislocation [9]. Within the past decade, less invasive mini-open anterior and anterolateral approaches with or without arthroscopy assistance and arthroscopic techniques were developed. Meanwhile, most FAI cases are being treated by arthroscopy. However, the *decision which technique should be used to treat FAI*, adequately, depends on various factors (Table 66.1):

- FAI type and severity of deformity: The more severe the cam and pincer deformity, the more difficult is a minimally invasive technique for adequate treatment of both the bony deformity and collateral damage. In other words, global deformities and pathologic orientation may be better treated by surgical dislocation where full exposure of both the proximal femur and acetabulum is possible and combined corrective osteotomy optional.
- Condition of the acetabular labrum: If the labrum is of bad quality or mostly ossified, detachment and/or repair of the labrum is usually not indicated. In those cases, treatment of FAI is technically less demanding and feasible via minimally invasive techniques.
- Grade of arthritis: When joint degeneration is more advanced, the more questionable is the balance between surgical risk, postoperative rehabilitation, and benefit. Here, mini-open solutions and arthroscopy may be preferable with smaller risks and less demanding postoperative rehabilitation.

Table 66.1 Authors' algorithm for operative treatment of FAI



SCO **subcapital osteotomy**, *SO* **subtrochanteric osteotomy**, *COS* **crossover sign**, *LCE* **lateral center edge angle**, *ISS* **ischial spine sign**, *PWD* **posterior wall distance to center of rotation**, *DDH* **developmental dysplasia of the hip**

- Experience of the surgeon: Besides FAI type and deformity, the training and experience of the surgeon is probably the most important factor. Experienced hip arthroscopists can manage even more global combined FAI cases, while hip arthroscopy beginners may even not be able to treat mild FAI types. It needs to be considered that not only the deformity needs to be corrected but also the collateral damage at the cartilage and labrum treated.

The most important goal is an adequate and successful treatment of FAI and its collateral damage. Thus, the decision which technique is used should be based on the abovementioned aspects and not on the current trend to prefer minimally invasive techniques such as arthroscopy. In addition, advantages and disadvantages of the different operative techniques should be considered:

- Surgical dislocation: The classic open technique offers full and safe exposure to both the proximal femur and the acetabulum. Even severe global deformities can be addressed, with the option of corrective osteotomy particularly at the proximal femur. The disadvantages of this technique are higher perioperative complication rate including the risks of the trochanteric osteotomy, adhesions and heterotopic bone formation, and a longer rehabilitation period.
- Mini-anterior approach (supine position, Hueter): The anterior approach uses a true intermuscular and internervous plane without

the need of muscle detachment. Rehabilitation is fast and similar to arthroscopy. For exposure of the socket, the use of a traction device is mandatory. Access to the posterolateral structures is however limited if no arthroscopic assistance is used. In comparison to the anterolateral approach and arthroscopy, there is a higher risk of heterotopic bone formation and injury to the lateral femoral cutaneous nerve.

- Mini-anterolateral approach (lateral position): The advantages and disadvantages of the anterolateral approach are similar to those of the anterior approach. In addition, there is a risk of injury to the motor branch of the superior gluteal nerve innervating the tensor fasciae latae.
- Arthroscopy: Arthroscopy for treatment of FAI is technically the most demanding surgical option. While hip arthroscopy itself is one of the most difficult arthroscopies in the human body, its use in FAI is listed top on a difficulty ranking. However, the arthroscopic technique has been fast evolving over the past decade. Meanwhile, experienced hip arthroscopists can handle even more severe combined FAI pathologies and their collateral sequelae. Here, the operative risks are small, but significantly higher in case of less experienced arthroscopists. The benefits of arthroscopy are its minimally invasive nature, its precise imaging of joint structures, and its pathologic changes and faster postoperative rehabilitation. Disadvantageous are its technical difficulty with a flat learning curve and longer operation time and limited three-dimensional viewing during bony corrections.

From the authors' experience, most local and moderate global cam deformities can be handled arthroscopically. For treatment of the more lateral and posterolateral cam deformities (pistol grip), more experience is needed. In those cases, less experience arthroscopic surgeons should consider exposure and treatment via a surgical dislocation. Moderate global cam pathology, such as the status post slipped capital epiphysis (SCFE) up to a posterior slip of about 30°, reduced antetorsion of the femoral neck up to a retrotorsion of about 20°, and moderate coxa magna after a Perthes disease can be treated via arthroscopy. More significant global pathologies may be better treated by surgical dislocations in combination with subcapital or intertrochanteric osteotomies, head reduction osteotomy, neck lengthening, and/or distalization of the greater trochanter. The cutoff and decision whether to prefer a less aggressive treatment or going for the osteotomy need to be further studied.

66.2 Arthroscopic Technique of Cam Resection

66.2.1 Cam Resection: Principles and General Considerations

The *goal of cam resection* is to recreate the physiologic convex-concave transition between the femoral head and neck without losing the normal roundness of the femoral head, not to distort the labral seal, with a smooth cartilage-bone transition proximally, creating adequate offset to the femoral neck without causing stress risers at the femoral neck.

There are *different technical problems* that need to be addressed during arthroscopy for the treatment of cam FAI:

- Limited overview and visibility: In order to assess the extent of the cam deformity and control its resection process, an adequate overview is crucial. However, particularly at the maximum of the cam deformity at about 1 o'clock (right hip), the iliofemoral ligament is thick and tight. In order to relax the ligament and increase and improve the working space, the hip needs to be flexed and, in addition, depending on the thickness and rigidity of the ligament, incised and partially removed.
- Two-dimensional arthroscopy vs. three-dimensional deformity and operative treatment: Particularly for beginners, the three-dimensional cam resection is difficult, for both viewing and instrumentation. Intensive dry and wet lab training as well as in vivo teaching is obligatory.

- Limited orientation by landmarks: Orientation around a ball-in-socket joint is demanding. Clear landmarks for the cam resection are rare. In addition, orientation depends significantly on the joint position, particularly on flexion and rotation, and coverage of the head by the acetabulum. Thus, soft tissue landmarks as the medial and posterolateral folds must be preserved. The joint position needs to be monitored and kept in mind during the decision where to start and stop the resection and during the resection process itself.
- Influence by acetabular coverage: The grade of acetabular coverage has a significant impact on the distance of the proximal border of cam resection to the acetabular labrum. In dysplastic sockets, where the coverage is reduced, the proximal border of cam resection needs to be further away from the acetabular labrum. That however may be compensated by a hypertrophic labrum. In a profound socket or in the rare situation where a hypertrophic labrum is attached to a normal acetabulum, the superior border of the cam resection needs to be closer to the free edge of the labrum. Here, especially when the cam deformity extends laterally or posterolaterally (pistol grip), the head needs to be distracted from the socket in order to pull the posterolateral cam away from the posterolateral labrum and bony rim. Otherwise, the posterolateral cam is covered by labrum and rim and cannot be addressed.
- Bleeding from bone, synovial tissue, and capsule: Visibility can be significantly reduced by persistent bleeding from the exposed bony surface, synovectomy area, and partially resected capsular surface. Probably the most important tip avoiding bleeding is to keep the systolic blood pressure low. Because of the supine position of the patient with head flat on the table, the risk of reduced perfusion of the brain is low. Thus, the systolic blood pressure should be ideally between 80 and 90 mmHg. More significant bleeders from the synovium and capsule should be coagulated with radiofrequency. Usually, such a device is part of the basic hip arthroscopy instrumentation used in every case. Another trick is to use a suction control device within the tube between the burr (hand piece) and the suction pump. Here, a various portion of air can be sucked into the tube to reduce the suction force at the burr.
- Fluoroscopic guidance: Even more experienced arthroscopists use fluoroscopy to image the borders and depth of the cam resection. Thus, if the surgeon is not sure where to stop or how deeply to resect, the C-arm should be brought in.

66.2.2 Strategies for Access and Operative FAI Treatment

Different strategies how to access the hip and handle FAI have been developed:

- *Central first*: This is the technique that has been developed first and is being used worldwide most often. Under traction and fluoroscopy control, the central compartment is accessed. After a variable extent of capsular work and diagnostic round, rim trimming and chondrolabral pathology are treated first; before the peripheral compartment is accessed and after additional variable capsular work, the bony cam deformity is handled.
- *Peripheral first*: After "detection" of the peripheral compartment, Dorfman and Boyer and the senior author developed the peripheral first technique. Here, the peripheral compartment is accessed under fluoroscopic control without traction. After a variable degree of capsular work, the cam deformity and potential labral ossifications are resected or trimming of an overhanging acetabular rim in coxa profunda is performed. Under traction, portals to the central compartment are placed under arthroscopic control. After additional capsular work of variable extent, rim trimming is performed and potential chondrolabral pathology is treated.
- *Extracapsular first*: This is the latest technique that has been developed during the past years. With or without fluoroscopy, and without traction, the instruments are brought to the space anterior to the joint capsule. The anterolateral capsule is longitudinally incised and

parallel to the acetabular labrum in a T-shape fashion ("endoscopic Hueter approach") [10]. Depending on the surgeon's preference, the peripheral compartment or central compartment is accessed and treated first.

Each strategy has *advantages and disadvantages*:

Central first:	⊕	Direct detection of collateral damage at anterolateral rim
	⊖	Risk of iatrogenic damage to cartilage and labrum
	⊖	Reduced visibility in the peripheral compartment caused by capsular flaps
	⊖	Difficult/impossible in coxa profunda/ossified labrum
Peripheral first:	⊕	Safe access with less risk to cartilage and labrum
	⊕	Good visibility in the peripheral compartment
	⊕	No need of capsular repair
	⊕	Easier central access
	⊖	Detection of collateral damage after central access
Extra-articular first:	⊕	Safe access with less risk to cartilage and labrum
	⊕	Good visibility in the peripheral compartment
	⊕	Easier central access
	⊕	Detection of collateral damage after central access
	⊖	Capsular repair needed to avoid postoperative instability
	⊖	Fluid extravasation into soft tissues

The peripheral compartment first technique is the authors' preferred technique and described below.

It needs to be considered that *most cam pathologies cannot be adequately resected without traction*. Only the rare "easy" more anterior than lateral cams can be handled without traction. If the AP radiograph indicates lateral and likely posterolateral extension of the cam, the head needs to be distracted from the posterolateral labrum and acetabular rim to expose the otherwise covered deformity. In addition, the central compartment needs to be checked for collateral chondrolabral damage. Thus, a traction device has to be used in all cases.

The anterolateral part of the cam can be resected from the peripheral compartment without traction, whereas the lateral part is often addressed under traction. The posterior and posterolateral extension of the cam is better addressed from the central compartment under traction.

66.2.3 Portals

The authors prefer a 3-portal technique for arthroscopy of the peripheral compartment (PC) and a 2–4 portal technique for arthroscopy of the central compartment (CC). For resection of the anterolateral cam in the peripheral compartment, the scope is introduced via the proximal anterolateral portal; instrumentation is done via the anterior and classic anterolateral portals. For exposure and instrumentation of the posterior and posterolateral pistol grip, the scope is inserted via the anterior portal to the central compartment; the burr is working via the anterolateral or lateral portal.

Proximal anterolateral portal to PC (*PALP*^{PC}): The skin is incised at the soft spot between anterior border of gluteus medius and the lateral border of the tensor fascia lata on the junction between upper one third and lower two thirds of a line connecting the anterior superior iliac spine (ASIS) and tip of the greater trochanter. The needle is directed under fluoroscopic guidance perpendicular to the neck axis closer to the head than to the neck and penetrating the capsule at 1 o'clock position (right hip). This penetration point is of most importance as it will allow the lens to wind around the anterolateral head-neck junction falling into the lateral aspect of the joint allowing visualization of the anterior, lateral, and partly also posterolateral cam deformity. This is the viewing portal where the lens is kept during the whole cam resection procedure within the PC.

Anterior portal to PC (*AP*^{PC}): The skin incision is about 3 cm lateral to the line connecting the ASIS and patella, about two fingerbreadths anterodistal to the PAL^{PC}. The needle is perforating the capsule proximal to zona orbicularis between 2 and 3 o'clock (right hip) in order to have better access to the anterolateral part of

the head-neck junction. This is the main working portal for resection of the anterolateral cam deformity.

Anterolateral portal to PC (*ALP^{PC}*): The skin incision is the same as the anterolateral portal to the CC. The direction of the portal is more horizontal, so that the capsular perforation is further distal at the most lateral part of the femoral head curvature. This portal is used for lateral and posterolateral cam resection with and without traction.

Anterior portal to CC (AP^{CC}): Using the same skin incision of *AP^{PC}*, the needle is redirected into the central compartment at about 3 o'clock anteriorly (right hip).

Anterolateral portal to CC (ALP^{CC}): Using the same skin incision of *ALP^{PC}*, the needle is redirected into the central compartment at about 12 o'clock superiorly (right hip). This is usually our first CC-Portal, done under direct vision from PC. The second portal into CC (AP^{CC}) is then placed under visualization via ALP^{CC}.

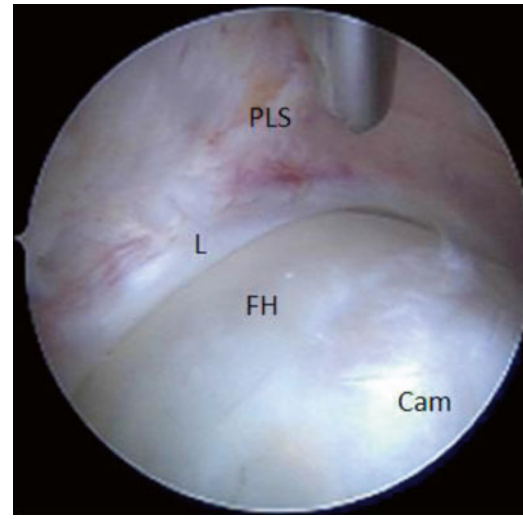


Fig. 66.1 Arthroscopic view of the peripheral compartment. The lens is in the PAL^{PC} and directed proximally. The shaver lies in the AP^{PC} and proximal to the lens to allow proximal synovectomy and opening of the paralabral sulcus (*PLS* perilabral sulcus, *L* acetabular labrum, *FH* femoral head) (Courtesy of Michael Dienst)

66.2.4 Steps of Cam Resection

66.2.4.1 Exposure of the Cam Deformity (PC)

In cases of symptomatic FAI, a variable degree of synovitis and capsular thickening is almost always encountered. Absence of such synovitis may even question the correct surgical indication. The first steps include partial synovectomy as well as a selective capsular release. This will allow an adequate arthroscopic overview and maneuverability of scope and instruments. It has also a therapeutic postoperative effect of increased range of hip motion.

With the scope in the PALP^{PC} and an aggressive shaver introduced via the AP^{PC}, the hip is flexed to about 30–40° in order to relax the anterior structures giving more room for working anterior to the head-neck junction and hide the femoral head cartilage under the acetabulum. Synovectomy and capsular thinning start by opening the perilabral sulcus anteriorly (Fig. 66.1). The scope is located anterior to the femoral head-neck junction with the lens rotated proximally. The work is started using the shaver proximal to the scope. The recommended shaver has a standard length, has a diameter of 4.5 mm, and should be aggressive. The shaver is moved along the perilabral sulcus from anterior toward lateral. The thin anteromedial capsule should not be touched in order to avoid connecting the hip joint with the psoas tendon sheath. The anterolateral and lateral parts of the iliofemoral ligament need to be thinned out from the articular side.

The lens is rotated distally to view the anterolateral zona orbicularis; the shaver is moved distal to the scope into the viewing field. Release of the circular fibers of zona orbicularis again starts anteriorly moving laterally. Bringing the scope in a more vertical position, the lateral and posterolateral part of the zona can be viewed and addressed with shaver from anterior. Moving back and forth with the shaver either proximally or distally, release of the circular fibers of the zona orbicularis is advanced until a complete overview of the peripheral part of the cam deformity is achieved (Fig. 66.2).

A radiofrequency (RF) probe is introduced for hemostasis and shrinkage of the friable capsular

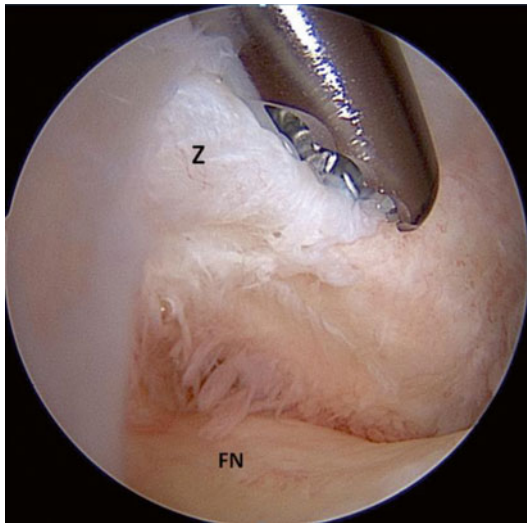


Fig. 66.2 Arthroscopic view of the peripheral compartment of the left hip. The lens is in the PAL^{PC} and directed distally. The shaver lies in the AP^{PC} and distal to the lens to allow distal synovectomy and release of the circular fibers of zona orbicularis (*Z* zona orbicularis, *FN* femoral neck) (Courtesy of Michael Dienst)

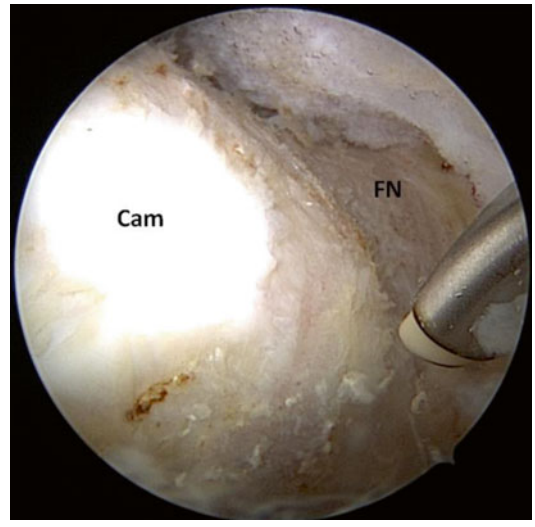


Fig. 66.3 Arthroscopic view of the peripheral compartment of the right hip. The lens is in the PAL^{PC} and directed distally. The radiofrequency probe lies in the AP^{PC} and distal to the lens. Here, the bony cam lesion was exposed after removing the overlying soft tissues using the shaver and radiofrequency probe. This is important for comprehending the extents of the lesion and for sound planning of extent and depth of resection (*FN* femoral neck) (Courtesy of Michael Dienst)

tissues. The anterolateral soft tissue and periosteum overlying the femoral head-neck junction are removed and the bony surface of the femoral neck exposed (Fig. 66.3). The medial and posterolateral synovial folds must be preserved as important landmarks for the following cam resection.

66.2.4.2 Identification of Landmarks and Delineation of the Cam (PC)

Before the cam resection is initiated, the joint position needs to be monitored, the radiographs viewed, the landmarks identified, and possibly also the borders of cam resection marked.

Monitoring the joint position: The position of the joint has a significant impact on the relation between the head-neck junction and the acetabular labrum/rim. From our experience, it is beneficial to start the anterior cam resection in a hip flexion of about 30°. For the lateral cam resection, the hip is progressively brought into extension.

Correlation with radiographs: The radiographs need to be visible during the whole case. The surgeon needs to correlate the arthroscopic image with the radiographic pictures. Here, especially the relation between the proximal extension of the cam and the anterior and lateral rim needs to be analyzed. In adolescents, where the epiphysis it not closed yet, knowledge of the relation between the cam and the physis is very helpful. Usually, the physis needs to be exposed during the cam resection.

Identification of landmarks: The following landmarks need to be identified before and during the resection process, the medial and posterolateral folds, the acetabular labrum, and the femoral neck.

- Medial synovial fold: Its attachment at the anteromedial head-neck junction at about 4:30–5:30 o'clock represents a stable landmark. The cam resection is started just proximal to its attachment.
- Posterolateral synovial fold: This fold lies most often between 11:20 and 00:40 o'clock [11]. The fold covers the posterolateral

retinacular vessels which must be protected to avoid avascular necrosis of the head. In this area, osteoplasty is limited to the femoral head and must not be extended to the neck.

- Acetabular labrum: The proximal border of the cam resection forms a straight line connecting the aforementioned point proximal to attachment of medial synovial fold with a point close or underneath the acetabular labrum laterally at the 12 o'clock position. The distance between this line and the labrum is determined by two variables; the degree of acetabular coverage and degree of hip flexion and rotation. In cases with focal or global retroversion, the line and border of resection needs to be closer to the labrum anteriorly. Lateral and posterolateral, the resection needs to be advanced underneath the labrum so that the head has to be distracted for exposure. As an alternative, the rim may be reduced first before the cam is addressed.
- Femoral neck level: The level of the neck needs to be assessed on both the anteroposterior and lateral radiographs and correlated with the intraoperative picture. In many cases, the neck is thickened so that an adequate offset correction will require a thinning out of the femoral neck. Frequently, the anteromedial neck contour is physiological, so that this contour can be used as a template for the offset correction of the anterior and lateral neck. In most cases, the resection needs to be advanced distally, almost down to the level of the intertrochanteric line. The very distal portion should be maintained during the resection process in order to keep this part as a stable level and reference if further correction is needed.
- Prominent cam deformity: Sometimes the cam is very prominent and presents with a step off at the distal end of the bump toward the neck (Fig. 66.4). Correlation with the preoperative radiographs gives very valuable information for arthroscopic orientation and resection.
- Herniation cysts: Herniation pits are usually not seen before the resection process is started. However, location and size of the cysts are very helpful when the cysts are exposed during the cam resection. Correlating the cysts with preoperative radiographs and MR images give important information about depth and location of resection. It needs to be considered that the floor of big cysts can exceed the depth of the cam resection level and must not be completely incorporated in the cam resection. In those cases, the soft tissue of the cyst should be curetted and the floor perforated with a microfracture awl in order to stimulate bony healing. In the rare case of huge cysts, longer periods of partial weight bearing should be considered. Bone grafting is usually not needed (Fig. 66.5).
- Epiphyseal growth plate in adolescents: Similar to the herniation pits, the epiphysis is not seen before the cam resection is started. During the resection, the growth plate needs to be included in the cam resection. Location of growth plate and correlation with the radiographs provide important information about proximal level of resection.

Delineation of the cam resection: It may be beneficial to mark the proximal borders of resection with a RF device or with the burr before the resection process is started and anatomy may be distorted (Fig. 66.6). This step is helpful especially in the beginning of the learning curve not to lose orientation later during osteoplasty.

66.2.4.3 Anterolateral Cam Resection (PC)

For cam resection, a long 5.5 mm acromionizer or round burr is used. The authors prefer the acromionizer type of barrel burr, which allows easier and safer burring to the side. No matter which type is used, the protection sleeve should be shortened in order to allow working when the abrader is perpendicular to bony surface.

Cam resection is initiated proximal to the origin of the medial synovial fold. The scope is introduced via the PAL^{PC}, lying anterior to the femoral neck and looking proximally in order to get an overview of the anteromedial head-neck junction including the anteromedial labrum and origin of the medial synovial fold. With the hip

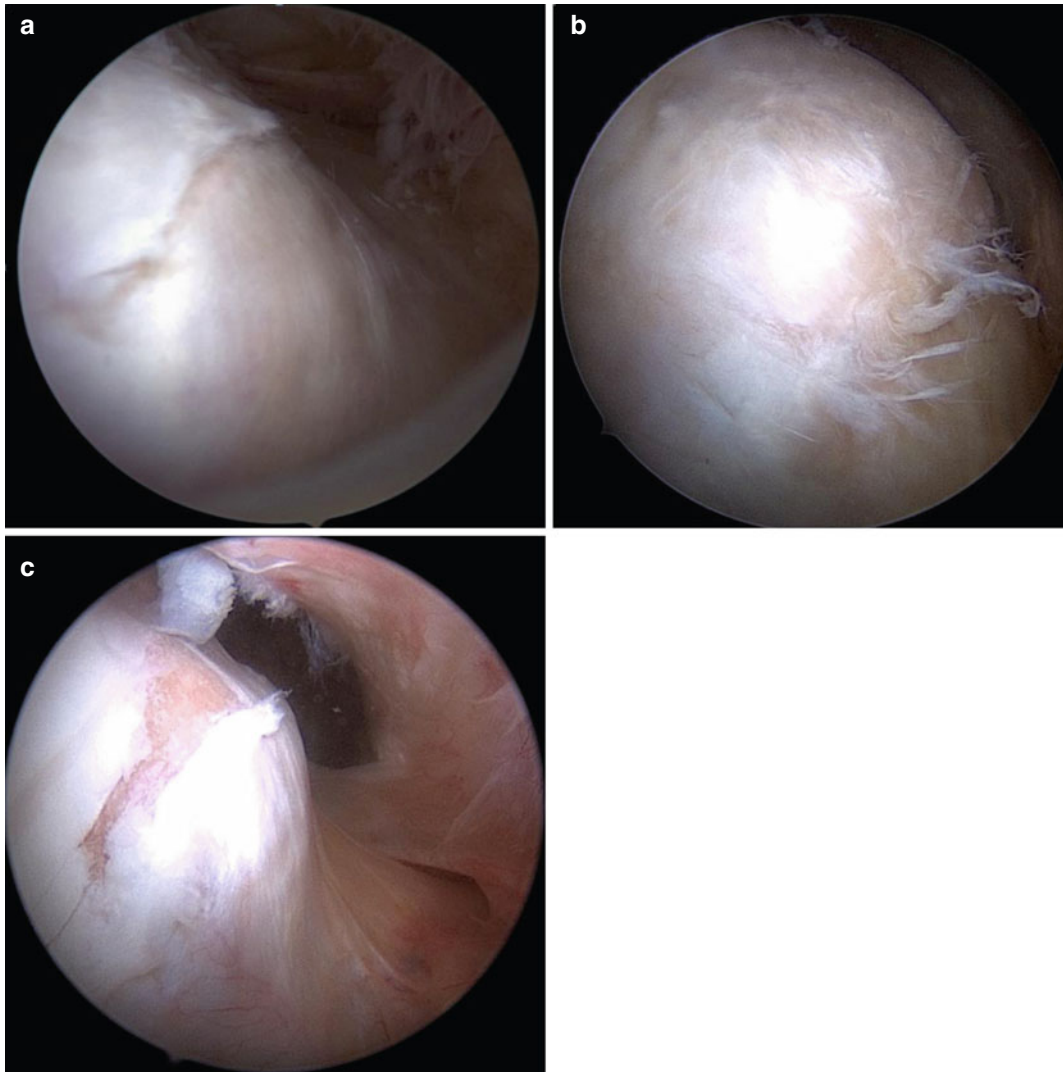


Fig. 66.4 (**a**–**c**) Different cam types (**a** flat type cam, **b** big cam, **c** cam with step off). Arthroscopic view of the peripheral compartment of the right hip. The lens is in the PAL^{PC}. Correlation between the arthroscopic cam morphology and the radiographic appearance is very helpful for estimation of extent and depth of resection (Courtesy of Michael Dienst)

flexed to about 30° and in neutral rotation, the burr is introduced via the AP^{PC}. The anteromedial extension of the cam starting just proximal to the medial synovial fold is resected (Fig. 66.7).

The scope is moved toward the head and rotated distally so that the anteromedial neck is viewed, while the burr is shifted distally toward the neck. The proximal resection is advanced toward the anteromedial neck underneath the medial synovial fold where the contour and offset are mostly normal. Starting from here, the physiological neck waist is developed toward the anterior and lateral neck. From our experience, it is beneficial to move the burr in a circular fashion around the axis of the femoral neck. This minimizes the risk of over-resection.

The arthroscope is again moved back to the neck, retracted as far as possible to the capsule, and rotated proximally for viewing of the anterolateral head. With the burr still in the AP^{PC}, the

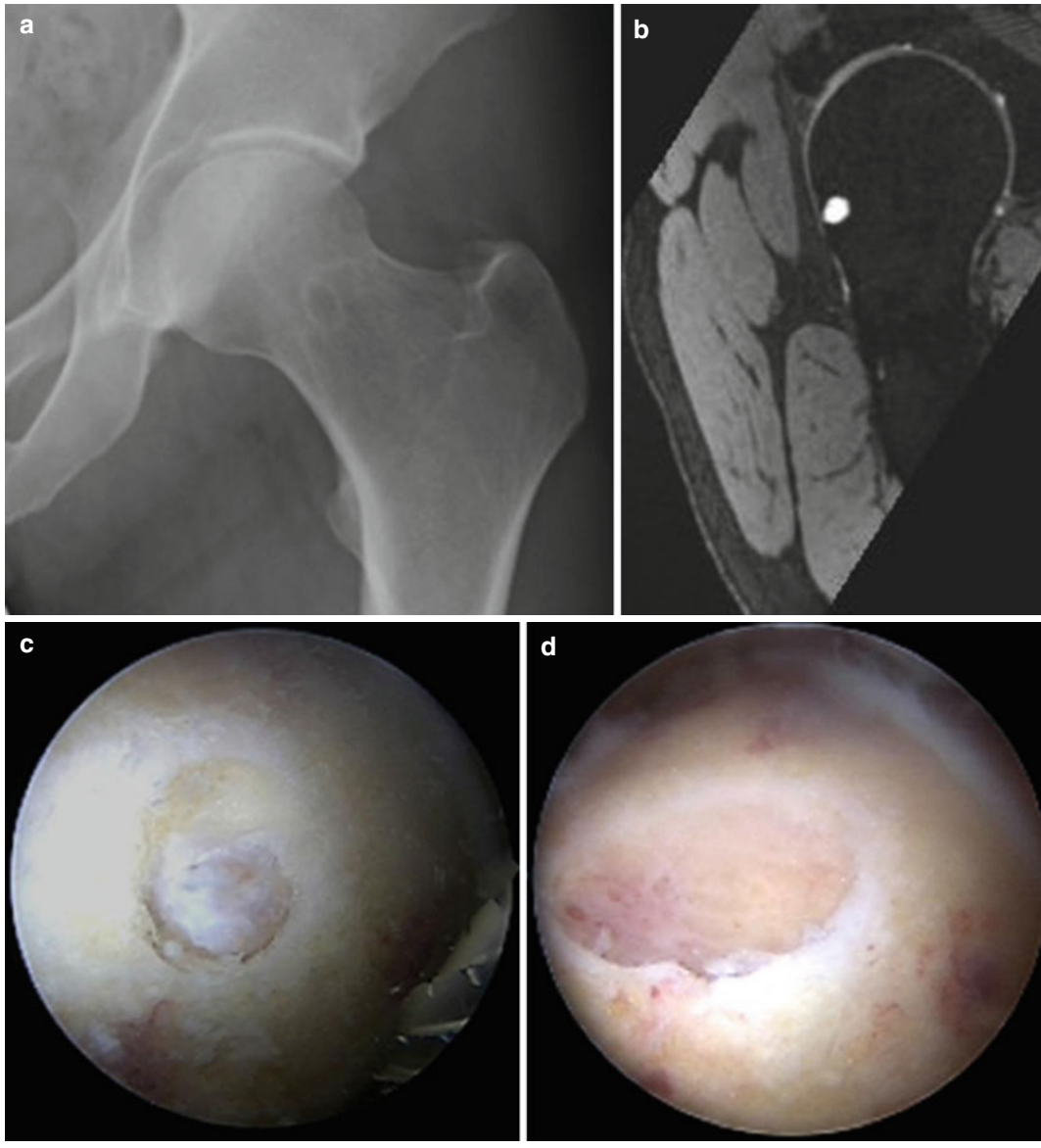


Fig. 66.5 (**a**–**d**) Showing a herniation cyst in a case of FAI. Correlating the relative position of the cyst as seen on radiograph and MRI with the arthroscopic finding gives valuable information about extent and depth of bony resection (Courtesy of Michael Dienst)

proximal border of the anteromedial cam resection is developed laterally toward the labrum at 12 o'clock.

The following work is the connection of the proximal border with the neo-waist at the antero-lateral neck. The arthroscope needs to be changed multiple times between the more distal position and upward viewing and the more proximal position and downward viewing in order to change the perspective and achieve an optimal convex-concave shape and adequate depth of the head-neck reshaping (Fig. 66.8).

66.2.4.4 Lateral Cam Resection (PC)

For resection of the lateral extension of the cam, the hip is gradually brought into full extension and

variable degrees of internal rotation. With the burr still introduced via the AP[PC], internal rotation brings the more lateral part of the femoral head-neck junction into the working range of burr from the AP[PC].

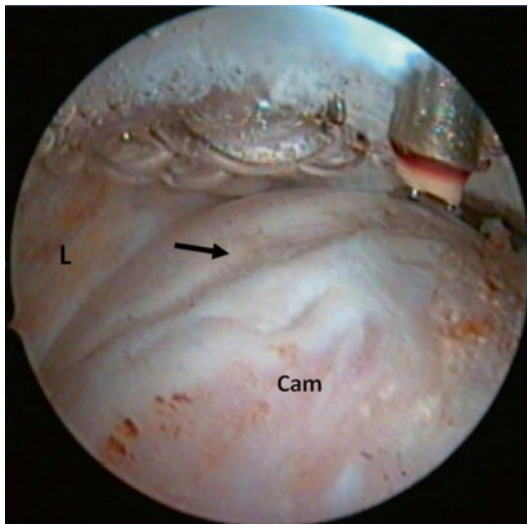


Fig. 66.6 Arthroscopic view of the peripheral compartment of a right hip. The lens is in the PAL[PC] and directed proximally; the RF probe is in the AP[PC] and lies proximal to the lens. Using the RF probe, a demarcation (*black arrow*) of the proximal end of resection was performed (*L* labrum) (Courtesy of Michael Dienst)

Most often, for a complete resection of a lateral cam deformity, the burr needs to be moved to the ALP[PC]. At the capsular perforation site, the strong lateral iliofemoral ligament has to be incised parallel to the labrum over a length of about 10 mm to allow sufficient maneuverability of the instrument. If the incision is limited, a later repair is not necessary. With the arthroscope still in the PALP[PC], the burr is advancing the anterolateral border of cam resection posterolaterally (Fig. 66.9). In most cases, the head needs to be distracted from the labrum in order to create a few millimeters space between the femoral head and the labrum, allowing extension of the resection posteriorly underneath the labrum. From this position, the proximal posterolateral resection is again connected with the neo-waist at the lateral femoral neck. The posterolateral resection with the burr inserted via ALP[PC] must be restricted to the femoral head and not be extended to the femoral neck in order to avoid injury of the end vessels of the medial circumflex femoral artery (MCFA). The posterolateral synovial fold as the landmark indicating proximity of the vessels can be touched and slightly peeled off from the bone but must not be deeply injured. If the fluid pressure is decreased, arterial pulsation can

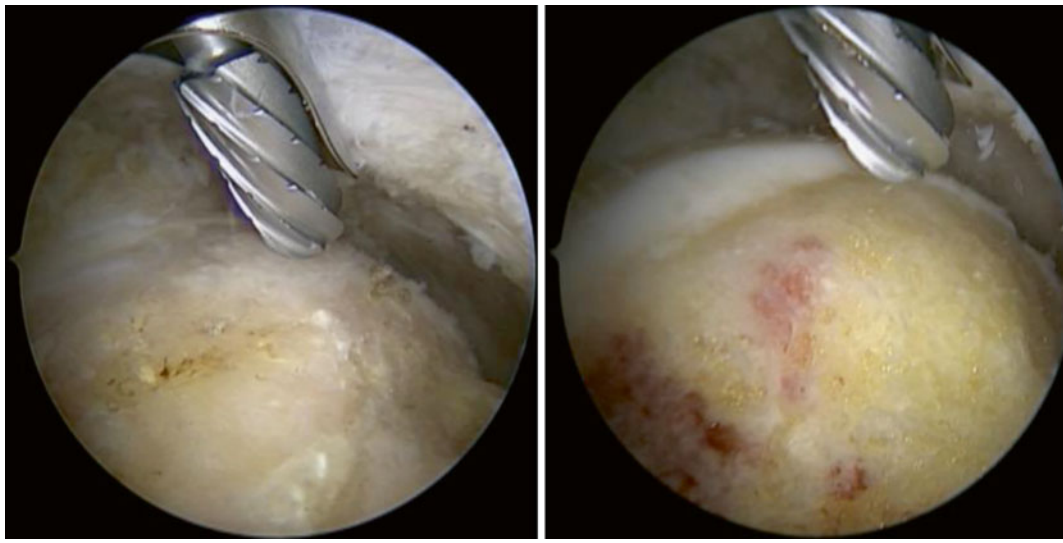


Fig. 66.7 Arthroscopic view of the peripheral compartment before (*left*) and after (*right*) bony resection on the anteromedial part of femoral head. The lens is in the PAL[PC] and directed proximally; the abrader is in the AP[PC] and lies proximal to the lens (Courtesy of Michael Dienst)

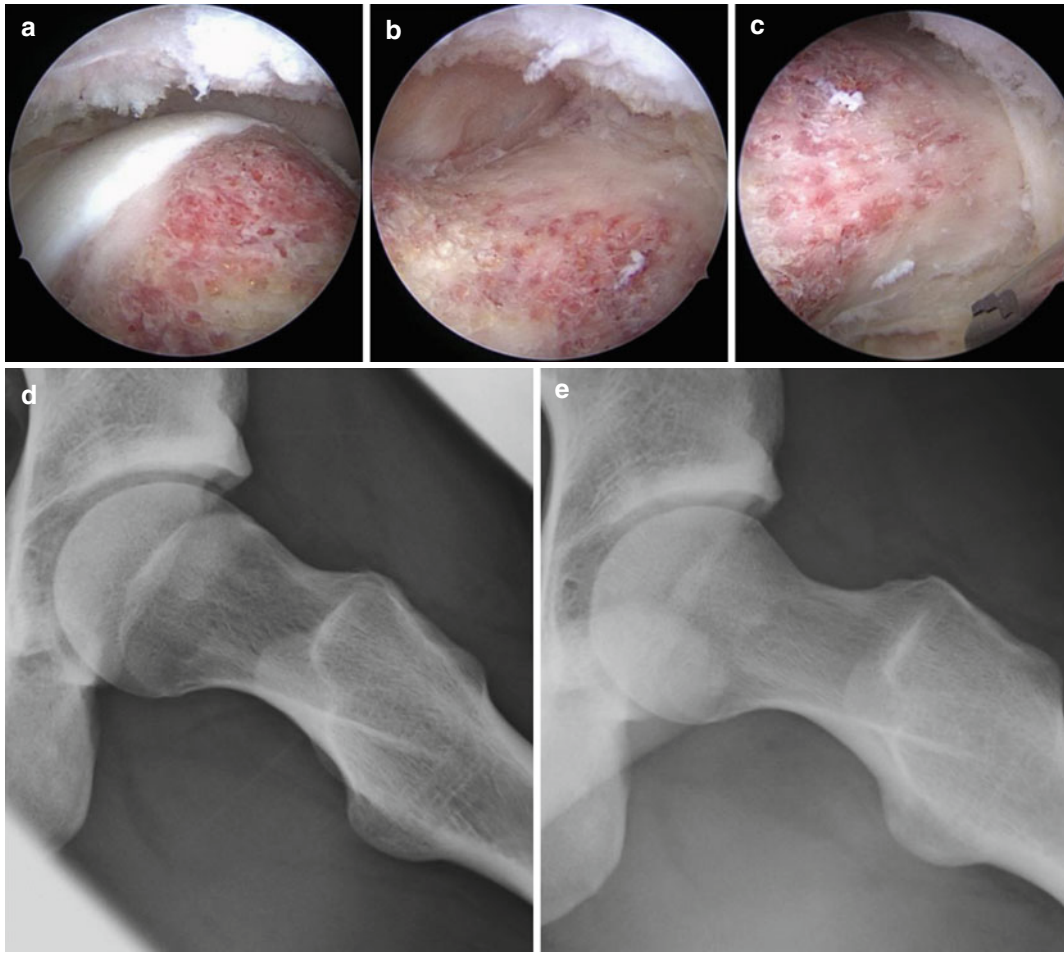


Fig. 66.8 (**a**–**c**) Arthroscopic view of the peripheral compartment, right hip, showing end result of anterolateral cam resection. (**a** the lens is in the PAL^{PC} and directed proximally showing anterolateral head, **b** the lens is in the PAL^{PC} and directed distally and lies in a more horizontal plane showing the anterior neck, **c** the lens is in the PAL^{PC} and directed distally and lies in a more vertical plane showing the lateral neck). (**d**, **e**) Pre- and postoperative frog leg radiographs of a left hip showing creation of a neo-waist while keeping the roundness of the femoral head to avoid breakage of labral seal (Courtesy of Michael Dienst)

sometimes be visualized in the periosteum medial to the fold.

66.2.4.5 Posterior/Posterolateral Cam Resection (CC)

When pistol grip deformity is prominent, cam resection needs to be advanced posteriorly. Frequently, this cannot be handled via the PC and must be addressed while the arthroscope is introduced from the CC.

With distraction of the head from the socket and arthroscopic control from the PC, the AP^{CC} and ALP^{CC} are placed to the CC. The PALP^{PC} is maintained with a nitinol wire or a small outflow cannula. The arthroscope is moved to the AP^{CC}, and the burr is moved to the ALP^{PC} and not to the ALP^{CC}. The direction of the ALP^{PC} toward the posterolateral cam is better; in addition the capsule has already been incised to allow better motion of the burr toward the posterolateral cam (Fig. 66.10). Applying various degrees of internal rotation, the posterolateral and posterior cam can be easily addressed and even more difficult posterolateral cam treated (Fig. 66.11). The more posterior the

burr is working on the head-neck junction, the more the burr needs to stay at the head in order to avoid injury to the end branches of the MCFA.

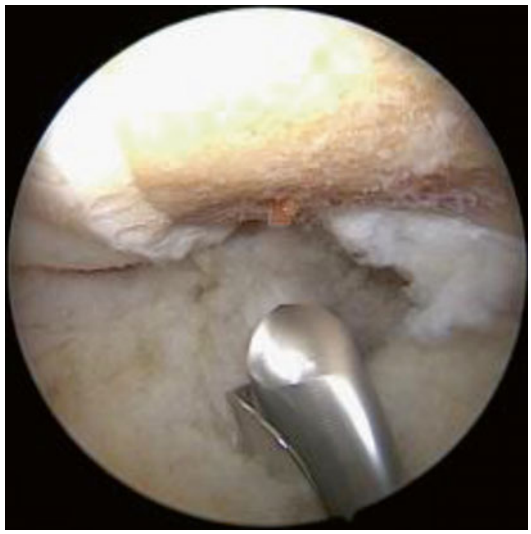


Fig. 66.9 Arthroscopic view of the peripheral compartment of the right hip. The lens is in the PALP^{PC}, rotated proximally and laterally and held almost vertical. The abrader is inserted through the ALP^{PC} after a limited release of iliofemoral ligament was performed. Internal rotation and extension of the hip plus distraction are needed in order to complete the cam resection in its lateral and posterolateral parts (Courtesy of Michael Dienst)

66.2.4.6 Arthroscopic and Fluoroscopic Control of Adequate Cam Resection

Before evacuating the joint, an adequate cam resection needs to be confirmed. After addressing a potential pincer component, chondrolabral pathology, and other lesions within the CC, fluoroscopy is moved in. In AP direction, with the hip in neutral and various amounts of internal rotation, the contour of lateral and posterolateral head-neck junction is analyzed. If resection is not yet sufficient, cam resection can be easily completed without time-consuming replacement of portals. After confirmation and documentation of an adequate cam resection, portals to the CC are removed and traction is completely released. The arthroscope is again introduced to the PC via the maintained PALP^{PC} and a shaver introduced via the AP^{PC}. After flushing the PC, the labrum and rim are evaluated from the peripheral side without traction. The hip is finally flexed and rotated in order to confirm motion of the hip joint without evidence of FAI. The arthroscope and instrument are removed and replaced by nitinol wires. In about 70° of flexion and various degrees of abduction (30–50°), the anterolateral head-neck junction is checked by AP fluoroscopy. Adequate

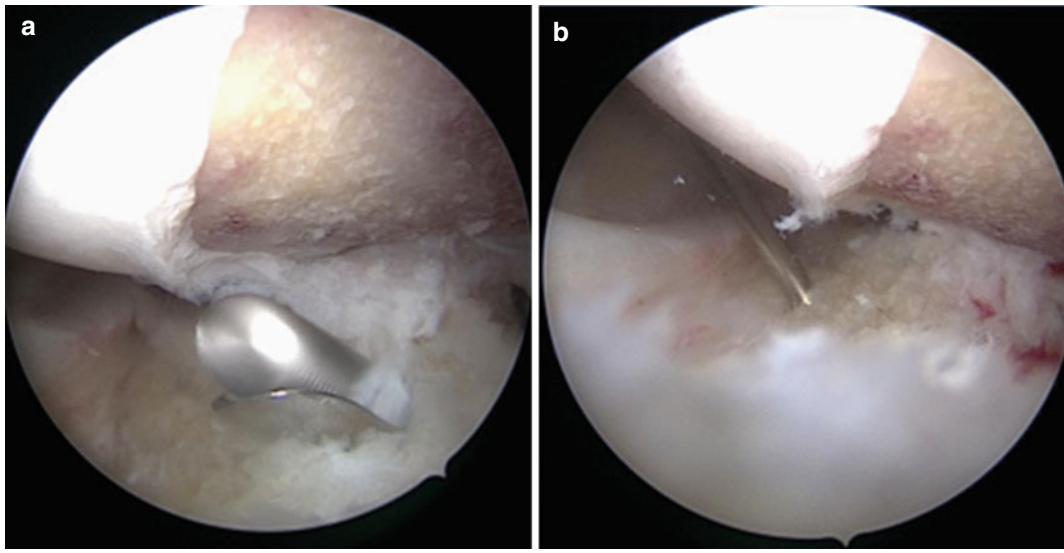


Fig. 66.10 Resection of the posterolateral extension of the cam. With the lens in the central compartment and rotated posteriorly and distally toward the head, the abrader is introduced through the ALP^{PC}. (**a** before, **b** after resection) (Courtesy of Michael Dienst)

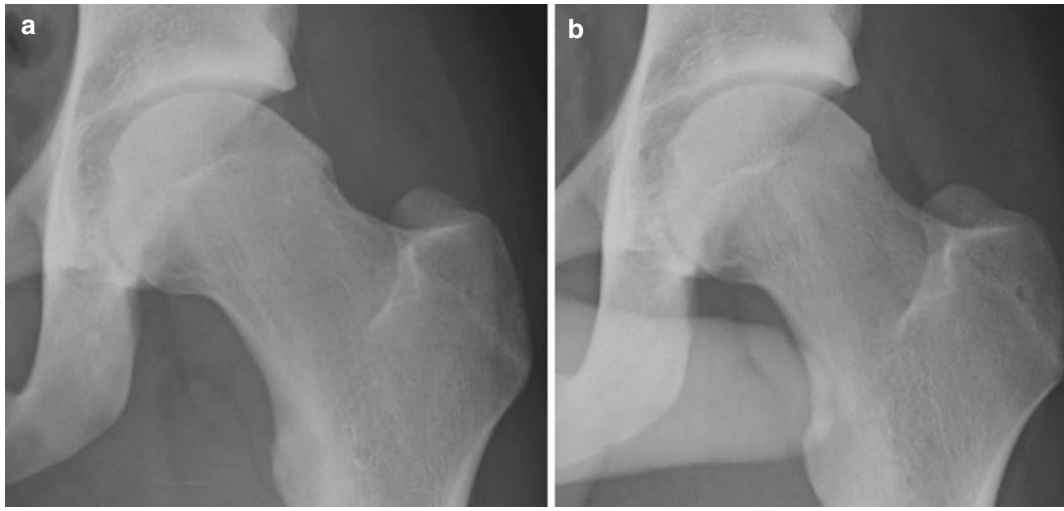


Fig. 66.11 (**a**, **b**) Pre- and postoperative AP radiographs of right hip showing a successful arthroscopic resection of the posterolateral extension of cam lesion (Courtesy of Michael Dienst)

anterolateral cam resection is documented or any residual deformity corrected.

66.3 Postoperative Care

Wound care: Postoperative, a thick dressing is applied to absorb leakage of fluid from the portals. Sutures are removed after 12–14 days.

Medication: All patients receive nonsteroidal anti-inflammatory drugs for at least 10 days after the operation in order to reduce postoperative edema, joint effusion, and the risk of developing heterotopic ossification. Prophylaxis of thromboembolism with daily subcutaneous injection of a low molecular weight heparin until full weight bearing is achieved.

Weight bearing: In cases of pure cam resection without labral repair or cartilage procedures, the patient is advised to proceed to full weight bearing over a period of about 10 days. Impacting activities are however prohibited for 6 weeks in order to avoid stress fracture of the femoral neck. In case of osteoporosis, the impression of weaker head-neck-bone during arthroscopy and particularly female patients over 40 years of age, partial weight bearing to half body weight is recommended for 4 weeks because of the higher risk of fatigue fracture. After labral repair, partial weight bearing of 20–30 kg is recommended for 4 weeks and, after abrasion, microfracture of other advanced cartilage procedures for 6 weeks.

Range of movement and continuous passive motion (CPM): Range of movement is not restricted and allowed as tolerated. Painful passive flexion or rotation should be avoided. Continuous passive motion is initiated from the first postoperative day and continued for 4–6 weeks at least three times a day with 30 min each to avoid intra-articular adhesions, reduce swelling, and support cartilage regeneration and labral remodeling. Stationary bike exercises can be added in the third week.

Physiotherapy: Physiotherapy can start at the first postoperative day with gait training and isometric strengthening exercises. Proprioceptive and coordinative training can be started in partial weight bearing and progressed to full weight bearing depending on pain, treatment of chondrolabral damage, and bone quality. Physiotherapy has to include active and, in the beginning, gentle passive mobilization of the hip. Later, usually not before week 8, rubber band and flexible board training can be started for innervation training of external rotators and abductors. At this stage, static and dynamic exercises for stability in the two-leg and later one-leg stand should be started. After regaining stability,

strength and endurance must be trained. The athlete usually starts with controlled sports-specific training between weeks 9–14.

Return to sport: The return to sport at competition level depends on various factors such as the condition of the joint, the operative procedures, and, last but not least, the type of sport. From our experience, most high level athletes need 4–5 months before they come back to competition.

66.4 Pitfalls and Complications

Several studies indicated a small rate of complications for hip arthroscopy [12–14]. However, the risk significantly increases in case of beginners and less experienced hip surgeons. Particularly in FAI, the level of arthroscopic experience needs to be high in order to achieve an adequate femoral and acetabular correction and handle collateral chondrolabral damage.

Complications of arthroscopic hip surgery and pincer FAI arthroscopies are being described in another chapter. Below, the focus is on pitfalls and complications related to arthroscopic treatment of cam FAI:

- *Persistent cam FAI* (*cam under-resection*): Under-resection of the cam and a persistent cam FAI are probably the most common cause for revision hip arthroscopy [15]. It leads to residual impingement with persistent symptoms and ongoing joint deterioration. Cam under-resection is not uncommon in the beginning of the learning curve. Limited arthroscopic overview, underestimation of the extents of the cam deformity, and problems how to access the deformity are the main causes for failure. Frequently, the resection is:
  - Limited to the anterolateral cam but not sufficient at the lateral or posterolateral extension of the cam
  - Only at the head and not tapering into the thickened neck
- *Loss of labral seal/joint vacuum* (*cam over-resection*): Over-resection of the cam is less frequent. Usually, the resection is either too deep and/or too proximal. Both conditions lead to loss of contact of the acetabular labrum and acetabular cartilage with the cartilage of the femoral head resulting in loss of the labral seal and contact force between the hyaline cartilage surfaces during flexion and rotation of the hip. Results from finite element studies suggest higher and shifted forces during loading and motion leading to earlier secondary osteoarthritis. In addition, over-resection results in a higher risk for acute or fatigue fracture [16, 17]. Revision is much more difficult in comparison to an "easy" arthroscopic re-resection. To our knowledge, only one case report has been published where an excessive defect of the head-neck junction was filled with an iliac-crest bone graft via a surgical dislocation [18].
- *Hip instability* (*resection/big incisions of capsule*): Several authors have been promoting more aggressive work on the capsule in order to ease access to the head-neck junction including bigger T-shape iliofemoral ligament incisions and partial capsular resections [19, 20]. Historically not reported, recent case series indicated frank dislocations and subtle instability as a result from those approaches. Meanwhile, there is accordance that the capsule must not be resected and that bigger incisions need to be repaired.
- *Stress fracture of the femoral neck*: Stress fracture of the femoral neck after cam resections has been reported. Möckel and Labs reported in a retrospective multicenter study of 13.154 patients over a 5-year interval of 12 (0.1 %) stress fractures of the femoral neck [21]. Potential risk factors are more extensive cam resection, early impacting sports, and a worse bone quality in older and osteoporotic patients or patients under immune suppression. Thus, with such risk factors, the transition to full weight bearing needs to be postponed to weeks 4–6. Typically, patients developing stress fractures present with increasing pain about 4–5 weeks postoperatively. At that time, radiographs are usually equivocal. The diagnosis is made with MR imaging.
- *Avascular necrosis of the femoral head* (*AVN*): The authors have not seen such a complication

personally. Review of the literature shows that this complication is very rare to be caused by arthroscopy. In the big multicenter study of Möckel and Labs, 7 of 13.154 arthroscopies were rated as arthroscopic cam resection-related AVNs. In the literature another two cases were reported: one patient developed AVN after labral and osteophyte debridement [22] and the other after pincer trimming [23]. It has to be considered that AVN can develop independently to arthroscopy. However, the potential risk by injury of the end vessels of the MCFA during cam resection needs to be considered.

- *Intra-articular adhesions*: The exposed bony surface of the head-neck junction and the bleeding opposite layer of incised or repaired capsule have the tendency to stick and heal together and form adhesions. Willimon et al. reported a rate of 4.5 % after hip arthroscopy and identified younger age, more bony resection, and missing circumduction therapy during the postoperative rehabilitation as risk factors for development of this complication [24]. There is accordance that continuous motion therapy and early rotational and abduction exercises are crucial to avoid the formation of adhesions.

66.5 Literature Overview

Table 66.2 shows an overview of selected case series of arthroscopically managed FAI.

66.6 Future Directions

With respect to the short history of FAI and its treatment, the past decade has been very encouraging. Both the understanding and technique of treatment have been massively improving. However, further intensive work is needed. We need to further study the etiology and pathogenesis of FAI in order to detect if a development of FAI during adolescence can be avoided and reduced. Further techniques and better instrumentation have to be developed to ease arthroscopic treatment of the cam deformity. In particular, the role of the capsule and strategies to avoid iatrogenic instability need to be studied. Last but not least, we need to evaluate if operative treatment not only leads to symptomatic improvement but also slows down the development of secondary joint degeneration. High-quality long-term comparative controlled trials comparing the results of surgery and conservative treatment are needed.

Table 66.2 Results of arthroscopic treatment of cam FAI

Authors	N	M/F	Cam/pincer/mixed	F/U mean (range) months	Outcomes	Complications
Larson and Giveans [25]	100	54/42	17/28/55	9.9	Improvement in HHS by 22 points, SF- 12 by 18 points. VAS for pain from 7 to 2, and positive impingement test from 100 % to 14 %	6 HO 1 24-h partial sciatic neurapraxia 3 THA
Byrd and Jones [10]	207	138/62	163/0/44	16 (12–24)	20 points improvement in HHS	1.5 %, 0.5 % THA
Horisberger M et al. [10]	105	60/28	NR/NR/48	27.6 (15.6–49.2)	NAHS improved by 28 points	11 %. Nine pudendal/ LCFN-neurapraxia, two sciatic neurapraxia, one superficial labia minora tear. THA in (8.6 %)

(continued)

Table 66.2 (continued)

Authors	N	M/F	Cam/pincer/mixed	F/U mean (range) months	Outcomes	Complications
Haviv and O'Donnell [26]	164	67/15	164/NR/NR	26 (12–80)	mHHS and NAHS significantly improved in all cases	8 re-arthroscopy (persistent cam)
Byrd and Jones [27].	100	67/33	63/18/19	24	mHHS median improvement was 21.5 points	6 re-arthroscopy one transient pudendal neurapraxia, one transient LCFN-neurapraxia and 1 mild HO
Javed and O'Donnell [28]	40	26/14	40/0/0	30 (12–54)	Improvement in mean mHHS, 19.2 points; mean NAHS, 15.0 points	7 THA
Philippon et al. [29]	65	17/34	10/15/75 %	42 (24–60)	Mean mHHS improved by 34 points	8 re-arthroscopy for capsulolabral adhesions
Palmer et al. [30]	201	99/102	152/0/49	46	Improvement in NAHS: 22 points. VAS for pain: from 6.8 to 2.7. Pincer resections had significantly poorer results versus the remainder of the cohort	13 THA. One of each of superficial phlebitis, superficial infection, transient foot paresthesia, and HO
Malviya et al. [31]	612	355/257	537/14/61	38.4 (12–84)	QoL scores at 1 year improved in 76.6 %, unchanged in 14.4 % and deteriorated in 9.0 %	NR
					Significant predictors: preoperative QoL score and gender. The lower the preoperative score, the higher the gain in QoL postoperatively	

HHS Harris hip score, *HOS* hip outcome score, *NAHS* non-arthritic hip score, *NR* not reported, *QoL* quality of life, *SF-12* Short Form-12, *LCFN* lateral cutaneous femoral nerve, *THA* total hip arthroplasty, *VAS* visual analog scale

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Pincer Lesions

67

Kotaro R. Shibata and Marc R. Safran

67.1 Indications

Pincer type of femoroacetabular impingement (FAI) is described when there is an overcoverage of the femoral head by an acetabular abnormality, either focal (acetabular retroversion) or global (acetabular protrusio), which causes abnormal linear contact between the acetabular rim and the femoral head-neck junction during hip joint motion. Repeated abutment between the acetabular rim and the proximal femur produces an impaction injury leading to labral damage and subsequent acetabular cartilage damage. Labral pathology may range from bruising to degeneration, tears, ganglion formation, and ossification. Chondral lesions in pincer impingement often are limited to a limited depth from the rim (though are more global around the circumference of the acetabulum) and therefore are considered more benign than what is often seen with cam impingement. The persistent abutment, which is often anterior, causes chronic levering of the anterior femoral head region against the acetabulum, resulting in abnormal shear forces on posterior inferior acetabulum, labeled the "contre-coup" lesion [1, 2].

Pincer impingement is more common in middle-aged women with morphologic abnormalities of the acetabulum. This is in contrast to cam impingement, which is more common in young males with morphologic abnormalities involving the femoral head [2]. The onset of symptomatic pincer lesions is multifactorial as a predisposition of anatomic acetabular overcoverage of the femoral head in combination with dynamic activities may result in abutment of the femoral head-neck junction with the acetabulum causing damage and symptoms. Overcoverage of the femoral head can be congenital as seen in acetabular retroversion and protrusio acetabuli and/or an acquired phenomenon, as seen in ossification of the labrum or osteophyte formation at the acetabular rim [1, 3]. It can also be a result of iatrogenic causes [4]. Dynamic factors such as changes in lifestyle or physical activities that require deep flexion of the hip or spinal morbidity, which can lead to decreased movement of the lower back and pelvis causing excessive compensatory movement of the hip, can also trigger symptoms.

K.R. Shibata, MD, PhD
Department of Orthopaedic Surgery,
Kyoto University, Kyoto 606-8507, Japan

Department of Orthopaedic Surgery,
Stanford School of Medicine, 450 Broadway Street,
M/C 6343, Redwood City, Stanford, CA 94063, USA
e-mail: kota11cn@stanford.edu

M.R. Safran, MD (✉)
Sports Medicine and Arthroscopy,
Department of Orthopaedic Surgery,
Stanford School of Medicine, Stanford,
CA 94063, USA
e-mail: msafran@stanford.edu

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Patients presenting with intra-articular hip pain, regardless of the etiology, may have similar complaints. Although the typical activity that reproduces pincer FAI symptoms involve cutting and pivoting sporting activities and torsional activities of daily living, pain can also be noted with getting in and out of a chair and in some cases running, especially uphill. Patients may complain of pain getting in and out of a car, difficulty with prolonged sitting, sitting in a low chair, difficulty putting on socks and shoes, and the inability to sit with their legs crossed. Even though cam impingement is recognized as having a greater degree of motion limitations, combined FAI and isolated pincer-type pathology can lead to significant motion limitation.

Surgery is best suited for patients with intermittent activity-related pain primarily involving torsional activities and minimal to no degenerative hip disease seen on plain radiographs. Patients with hip pain with bony anatomy consistent with pincer-type impingement that has failed conservative management consisting of activity modification, particularly avoiding extremes of motion and flexion and internal rotation of the hip and nonsteroidal anti-inflammatory medications, are considered for surgery. To confirm whether the pain is originating from inside the hip, an intra-articular anesthetic guided by fluoroscopy or ultrasound is given into the joint to see if pain relief is obtained. Patients are encouraged to try to reproduce their pain immediately after the injection and confirm the relief of this pain. It can also be given with contrast when performing magnetic resonance arthrography as a useful diagnostic test to confirm that the joint is the source of pain.

When Professor Ganz first published the concept of FAI in the literature, he specifically described it as a patho-mechanism of the degenerative process of "idiopathic" osteoarthritis [1]. There has been continued debate, however, over whether FAI is the cause of osteoarthritis and whether its treatment can prevent the progression of osteoarthritis. There still is no conclusive evidence to prove this theory. The nationwide prospective cohort study of the Netherlands, the Cohort Hip and Cohort Knee (CHECK) Study radiographically followed people with a mean age of 55.9 years old for an average of 5.06 years. Those investigators defined pincer deformity as a lateral center-edge angle and/or an anterior center-edge angle of over 40°. At the 5 years follow-up, subjects did not have a significant increase in osteoarthritic change [5]. While this is short follow-up, one cannot support prophylactic treatment of FAI an indication for surgery at this time.

The pathology that needs to be addressed at the time of surgery for symptomatic pincer FAI includes labral and chondral pathology in addition to the underlying bony cause. It has been shown that those undergoing hip arthroscopy for labral tears in which the FAI was not addressed had poorer results than those without FAI and that labral tears rarely occur in the absence of bony abnormalities [6]. Thus, addressing intra-articular pathology without addressing the underlying cause will be less likely to result in a good outcome.

Indications for surgery include the following:

- Hip pain with bony anatomy that is consistent with pincer-type impingement
- Pain relief with intra-articular anesthetic injection
- Concomitant labral surgery

67.1.1 Imaging

Plain radiographs are extremely valuable for assessment of patients with hip pain that is the result of hip impingement. The standard imaging series for patients with hip pain include an anteroposterior pelvic view with the coccyx centered 1–3 cm above the center of the pubic symphysis, a true cross-table lateral, and a false-profile view radiograph. The cross-table lateral view, Dunn view, and a modified Dunn view are true lateral views of the hip that can provide information about the acetabulum. Loss of the sphericity or offset of the femoral head-neck region may be consistent with cam impingement. Pincer

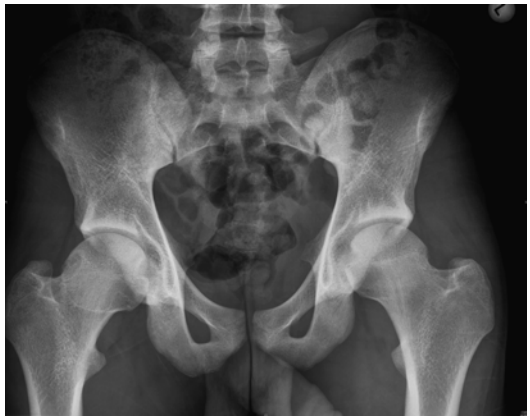

Fig. 67.1 AP pelvis radiograph of a college basketball player with combined FAI. Note the bilateral acetabular crossing signs, indicative of cranial acetabular retroversion, the ischial spine prominence within the pelvis, also indicative of acetabular retroversion, and the posterior wall sign, where the posterior acetabular rim is medial to the center of the femoral head, also indicative of acetabular retroversion

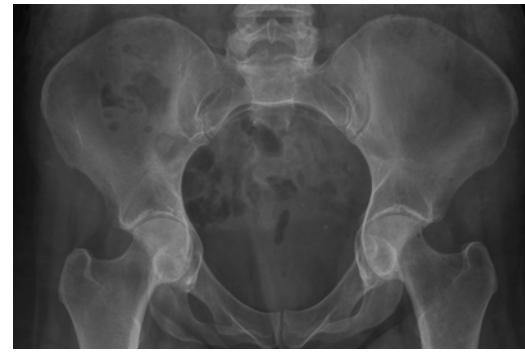

Fig. 67.2 Excessive acetabular overcoverage. This is a 37-year-old woman with bilateral acetabular protrusio, where her femoral head reaches or is medial to the ilioischial line. Her center-edge angle was greater than 60° in both hips

impingement can also be seen on plain radiographs in association with protrusio, relative retroversion, true retroversion, cranial retroversion, and osteophyte formation of the acetabulum [7]. In the past coxa profunda (where the medial wall of the acetabulum reached or crossed the ilioischial line on AP pelvis radiographs) had also been defined as a sign of general overcoverage, but recent studies have shown that Coxa profunda should not be used to define a pincer deformity [8, 9]. Abnormal version of the acetabulum can be determined by the presence of a crossover sign (Fig. 67.1), posterior wall sign, and the ischial spine sign. Excessive lateral center-edge angle (Fig. 67.2), anterior center-edge angle, low acetabular inclination angle, and notching on the anterior femoral head-neck junction are also signs suggesting pincer impingement morphology. Os acetabuli, fragmentations of the acetabular rim, and ossification of the labrum are also signs of pincer impingement (Fig. 67.3a, b) [10]. It is also important to recognize dysplasia and borderline dysplasia, as these patients can also have concomitant pincer or cam lesions. Not recognizing the dysplasia (or borderline dysplasia) when addressing the bony anatomy for FAI may result in new, persistent, or aggravation of prior symptoms, as instability may coexist or be the predominant symptoms in these patients, but may not have been adequately addressed.

Newer technology that allows for motion analysis and collision software to identify areas of impingement from CT and MRI data are being utilized, though their benefit has yet to be demonstrated.

67.1.2 Advanced Imaging

Three-dimensional computerized tomography (3D CT) can be particularly valuable for assessing the bony anatomy associated with pincer lesions (Fig. 67.3b) [11, 12]. It allows the surgeon to appropriately identify impingement lesions on the acetabular and femoral side in three dimensions (Fig. 67.4) [11]. Rim hyperostosis, rim fractures, and os acetabuli locations and size are well visualized, and axial images allow for evaluation of acetabular version and anterior and posterior coverage can also be assessed. Magnetic resonance imaging, particularly magnetic resonance arthrography, is beneficial for evaluation of soft tissues and to a lesser degree, bony pathology. The sensitivity for identifying chondral pathology is still suboptimal although newer techniques may prove more accurate in the future [13, 14].

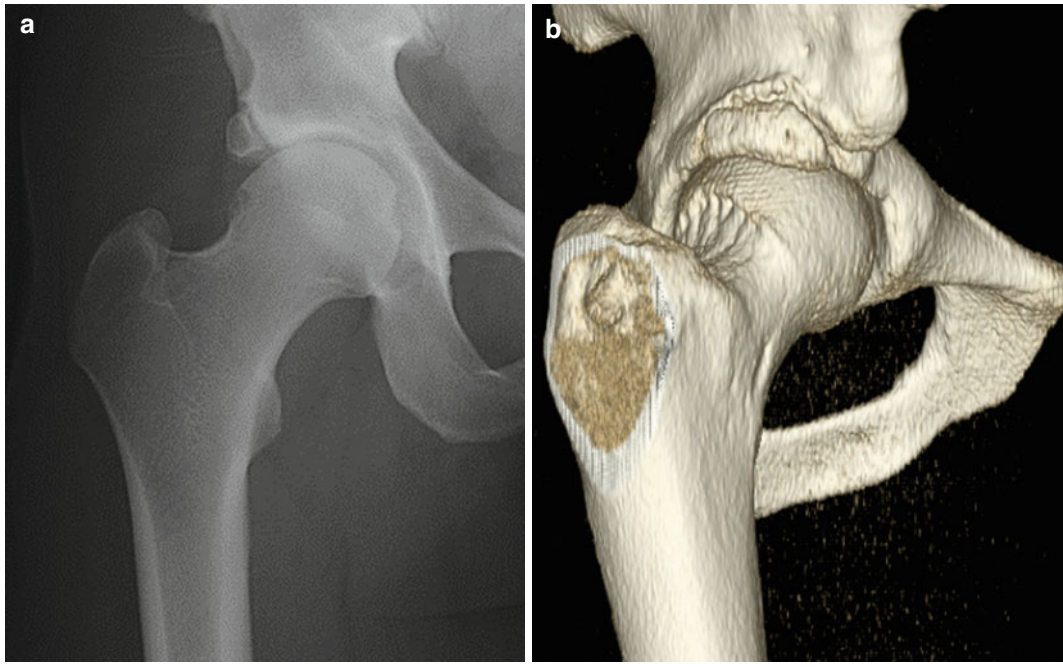

Fig. 67.3 Os acetabuli. Figure (**a**) is a radiograph of a 27-year-old football player with a peri-acetabular ossification separate from the acetabulum. As this line is perpendicular to the sourcil/acetabular roof, this is an acetabular rim fracture (nonunion). (**b**) Is a 3D CT reconstruction of the rim fracture

67.2 Techniques

The goals of pincer lesion surgery are to relieve the abutment between the femoral head-neck junction and the acetabular rim and to treat the associated pathology (labral tears and chondral lesions). Although this may be done with the patients in the lateral or supine position, our preference is the supine position.

Surgery starts with the evaluation and treatment of pathology in the central compartment. All central compartment pathology is addressed first even in cases that cheilectomy or femoral osteoplasty in the peripheral compartment is needed. The only exception would be a severely globally overcovered femoral head where access to the central compartment is limited by the bony acetabular coverage. A three portal technique is used without conducting a capsulotomy that joins the anterior and anterolateral portals, which would involve sectioning the iliofemoral ligament. Thus for this technique, portal positioning is particularly critical to the success of the procedure. With the patient lateralized relative to the perineal post and traction applied, the three standard central compartment portals – anterior, anterolateral, and posterolateral – are made. The anterolateral and posterolateral portals are the well-described portals that are made at the anterior and posterior margins just proximal to the tip of the greater trochanter. The modified anterior portal that we use is 4–7 cm distal and anteromedial to the anterolateral portal at a 45-degree angle. This portal is used for the following reasons: (1) it reduces the risk of injury to the lateral femoral cutaneous nerve, (2) it is a better line of approach to the central compartment of the joint if there is significant anterior acetabular overcoverage, (3) it reduces the risk of postoperative rectus femoris tendonitis, and (4) it allows for a better approach to drill into the acetabular rim if labral repair becomes necessary. Once proper portal placement is accomplished and sufficient visualization of the central compartment with 70-degree lens is obtained, the synovium and labrum are debrided of inflammatory and frayed

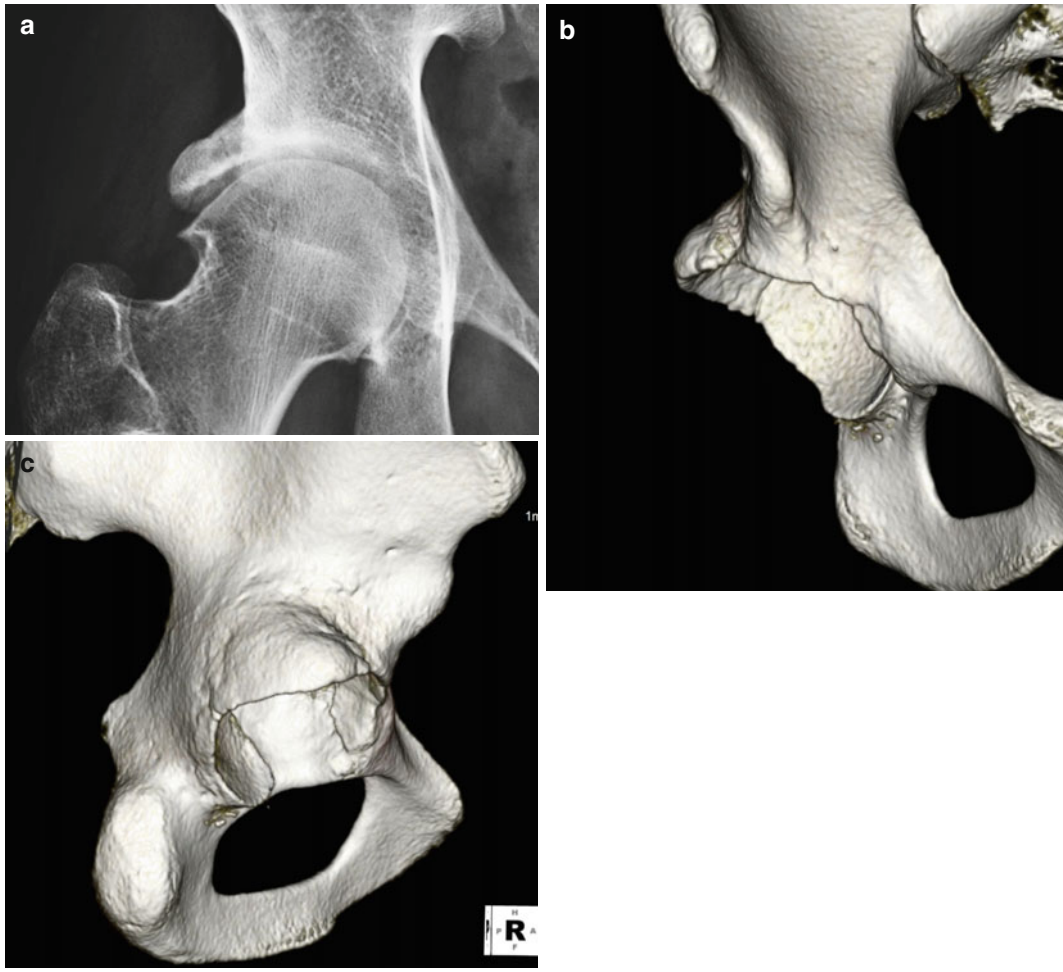

Fig. 67.4 19-year-old male with isolated lateral acetabular rim overcoverage seen on plain AP radiograph (**a**), and with 3D CT reconstruction on AP (**b**) and lateral (**c**) views

tissue. This can be performed with a variety of instruments including radio-frequency ablation, motorized shavers, and biters.

Next the preserved tissue is thoroughly probed to assess the location and extent of pathology in the joint. Intraoperative pathology, both type and location, can give the surgeon important information as to the pathophysiology of damage and, thus, what is causing the damage. As a pincer lesion is an abutment of the edge of the acetabulum with the femoral head-neck junction, extensive labral damage at the impingement site, with or without peripheral rim chondral damage, is seen. Chondral lesions usually do not extend deep into the acetabulum from the rim. The lesions are often seen at the anterior-superior location (3–11 o'clock position with 3 o'clock being anterior and 12 o'clock being lateral). A contre-coup lesion can be seen as chondral or labral damage in the posterior inferior acetabular region. Identification of these lesions can help confirm the diagnosis of a pincer impingement.

Once pincer impingement is verified, chondral flaps are removed and chondral defects and lesions are debrided to a stable edge. If the lesion is large and global degeneration is not evident, a microfracture is performed (uncommon in isolated pincer impingement). The same treatment is done for chondral lesions of the femoral head; however, it is generally recognized that femoral

head chondral lesions do not have as good a prognosis relative to acetabular lesions. Regardless, when chondral lesions of the acetabular articular surface are present, the results of hip arthroscopy in general, including FAI surgery, are also less predictable as compared with patients in whom the articular cartilage is intact.

Labral and pincer lesions are addressed next. If there is significant degeneration and intrasubstance tearing of the labrum, partial labrectomy is carried out, as there is limited blood supply within the labrum and, as a result, limited capacity to heal. Partial labrectomy may be performed with the use of meniscal-type biters, shavers, or radio-frequency devices.

If labral damage is minimal and preservation is possible, an accessory anterior portal is made 1 cm lateral to the junction of a line drawn distally from the anterosuperior iliac spine and a line drawn medially from the greater trochanter. A cannula is introduced directly over the pincer lesion for maximum workability around the labrum and pincer lesion. To increase or initiate the detachment of the labrum from the acetabular rim, an arthroscopic knife is brought through this accessory portal, as the line of approach is more perpendicular to the labral attachment to the acetabular rim, allowing for a more clean detachment of the labrum. Once the labrum is partly detached, an elevator is used to bluntly complete the take down of the labrum over the area of the overcoverage. A traction stitch may be placed around the detached labrum to retract it for better visibility and workability through this accessory cannula. Once again chondral damage is assessed and chondroplasty of the remaining damaged area is completed, the rim of the acetabulum is thoroughly exposed. The amount of exposed bone from the rim of the acetabulum is measured using a calibrated laser-etched probe, and the amount of bone that needs to be resected is assessed. The CE angle roughly decreases by just under 2° for every millimeter of bone resected from the lateral acetabular rim, and this rough estimate is used to determine the limit of bone that can be resected. The burr is a useful intraoperative tool for determining the amount of bone that is being removed. We also use the laser-etched probe to determine how much bone that has been removed. It is important to realize that the acetabular rim removed affects more than just the lateral center-edge angle, when determining the amount of bone to remove. The pincer lesion is carefully resected with a burr making sure not to resect too much bone. The rim resection should begin and end gradually with the deepest resection at the pincer lesion. In patients with labral injuries, it is important to not only treat the labrum but also address the underlying osseous abnormalities. Failure to address these deformities is the main cause of failure and revision surgery [15–18]. That being said, the aim is to remove the site of impingement but not to take too much bone from the acetabulum so as to make the patient unstable. We do not resect bone to "normalize" the CE angle and rarely is over 5 mm of bone resected, unless there is protrusio or labral ossification. If the labral tear extends beyond the zone of the pincer lesion, we will also trim the portion of the bone in that region as well to provide a good surface for labral refixation.

Once the acetabuloplasty is finished, refixation of the labrum is accomplished using suture anchors. Caution must be placed on determining the angle and location of anchor insertion as intra-articular placement and intrapelvic migration of the anchor are severe complications. Sutures are passed with the assistance of a suture penetrator or shuttle suture. If the substance of the labral tissue allows it, refixation of the labrum is best achieved using a noneverting vertical mattress stitch, which prevents labral deformity and preserves the suction seal function of the labrum. This has been called labral base fixation technique. Preservation of the labrum has been advocated in recent literature. In general long-term results appear to be better in patients who had labral refixation than labral debridement [19–22].

In the event that the labral tear cannot be repaired primarily and the patient has concomitant instability and/or dysplasia of the hip joint, labral reconstruction can be an option to help restore hip joint stability. Other indications include revision arthroscopy surgeries in which restoration of hip joint stability is warranted. Several techniques involving autograft and allografts have been described including the use of the gracilis tendon [23], ligamentum teres capitis [24], iliotibial band

[25], and hamstring allograft [26]. Philippon et al. reported on autograft iliotibial band reconstruction using an open harvest, and at 18-month follow-up, patients had improved modified Harris hip scores and patient satisfaction scores [25]. Detailed description of labral reconstruction technique is beyond the scope to this chapter.

Protrusio acetabuli is considered an extreme form of pincer FAI in which acetabular overcoverage is global. Because of its global overcoverage and complexity, some authors have considered protrusio acetabuli a contraindication to arthroscopic intervention. Though technically demanding, the senior author has shown a case series of patients with protrusio acetabuli (medial femoral head touching or extending medial to the ilioischial line) with minimal or no arthritis and a center-edge angle (of Wiberg [27]) of 50° or greater and who were treated with arthroscopic acetabuloplasty that expressed reduced symptoms and improved function at a minimum of 2.5 years' follow-up [28]. Briefly, technically it is more difficult to enter the central compartment of the hip as a result of the overcoverage, but access is possible, taking the curvature of the acetabulum into account when making the portals, by starting more distally than normal for the portal skin incisions. Alternatively, arthroscopy may start in the peripheral compartment, and an acetabuloplasty may be performed from the peripheral compartment before entering the central compartment. Even though there is global overcoverage, the symptoms of the patients usually reside in the anterior hip; thus the goal of the surgery is not to perform a global acetabuloplasty or resection of the entire acetabular rim but just to resect the anterior and lateral acetabulum. Removing a few millimeters of bone from the anterior and lateral acetabular rim improves the patient's clearance with hip flexion and rotation maneuvers, eliminating the pain and improving range of motion.

Ossicles located at the acetabular rim are generally referred to as unfused secondary ossification centers and are named "os acetabuli." In true "os acetabuli," the orientation of the cartilaginous growth plate is more parallel to the joint surface, but cases where the separation line is at a more perpendicular angle to the joint line are recognized to be fatigue fractures of the acetabular rim due to abutment of the femoral head-neck junction on the acetabular rim (Fig. 67.3) [10]. Resection of small fragments is indicated, but in some cases where a large fragment is present, resection of the whole fragment may lead to dysplasia and instability of the hip. In these cases refixation of the fragment using a standard fracture fixation technique is advocated. The senior author has two approaches to this problem. If the articular cartilage is entirely intact, then percutaneous drilling across the nonunion site is performed with a 0.62 k-wire. Multiple passes are completed to stimulate bone growth across the nonunion site. Then two percutaneous 4.0 mm partially threaded cannulated screws are inserted to compress the nonunion site. Alternatively, if the articular cartilage has been damaged due to motion of the rim fragment, then the senior author prefers to remove the fibrous tissue at the nonunion site, prior to percutaneous screw fixation to compress and fix the fragment. Once the fragment is fixed, the pincer lesion is reassessed from the central compartment and is appropriately treated, and refixation of the labrum is done, as necessary.

67.3 Tips and Pearls

- Resecting too much bone from the acetabular rim can cause postoperative instability, including subluxation and dislocation.
- Resecting too much bone from the acetabular rim may cause overload of the remaining rim, resulting in accelerated wear of the joint.
- Caution must be placed on determining the angle and location of anchor insertion, as intra-articular placement and/or intrapelvic migration of anchors may have significant consequences including joint degeneration and injury to pelvic structures.
- Patients with instability and/or dysplasia and borderline dysplasia must be identified preoperatively and treated accordingly with limited acetabular bony resection.
- Determine the anterior and lateral center-edge angles preoperatively. Assume 2° loss of angle for every millimeter of bone removed to reduce the risk of making a patient dysplastic postoperatively, resulting in pain from edge loading or instability.

67.4 Complications

In general, complications in hip arthroscopy are related to traction: too much or too little, patient positioning, and fluid management. Two recent systematic reviews led by Harris and Gupta have shown that the complication rates were 7.5% and 4.2% for minor complications and 0.58% and 0.41% for major complications, respectively [29, 30]. Reported complications include the inability to perform the arthroscopy as a result of access issues in addition to neuropraxias of the sciatic, femoral, perineal, pudendal, peroneal, and lateral femoral cutaneous nerves that often resolve spontaneously. Also reported are infections, hematomas, portal bleeding, intra-articular instrument breakage, trochanteric bursitis, vaginal tears, and scrotal necrosis related to excessive lateral traction force. Heterotopic ossification has also been noted [29–33]. There have been reported cases of intra-abdominal fluid extravasation, in addition to reports of avascular necrosis [34]. Labral repairs may not heal, and in some cases, labral repairs have been associated with capsular adhesions postoperatively, which may limit motion and cause pain [15]. Probably the most common complications are iatrogenic articular cartilage damage and labral injury which are rarely reported. Deep venous thrombosis and pulmonary embolism related to hip arthroscopy are a concern but the rate is likely low. In a large series of 6,395 hip arthroscopies from the national data of the English National Health Service, it has been reported that the risk for short-term complications, in particular the risk of DVT and PE, was low at 0.08% at 90 days post operation [33].

Postoperative stability of the hip particularly after extensive capsulotomy has been of controversy, and there is much debate as to how to address the capsule at the end of the surgery. Matsuda et al. reported the first case of hip joint dislocation after arthroscopic FAI treatment, though, in this case all the major static stabilizers of the hip were surgically compromised and a multifactorial causation was proposed. Surgically compromising the stability of the hip could cause residual hip symptoms and in worst case scenario postoperative hip dislocation [35, 36]. Over-resection of the acetabular rim can also be a cause of residual instability or functionally overloading the remaining acetabular rim. Bhatia et al. investigated the change in contact area, contact pressures, and peak forces within the hip joint with sequential acetabular rim trimming. They showed that resecting more than 4–6 mm of the acetabular rim during hip arthroscopic surgery to address a pincer deformity may dramatically increase contact pressures by threefold at the acetabular base [37]. Frank et al. compare the clinical outcomes of patients undergoing hip arthroscopic surgery for FAI with T-capsulotomy with partial capsular repair versus complete capsular repair and found that the group that had complete capsular repair had a significantly better HOS-sports-specific score at 6 months and 2 years [38]. These reports underscore the importance of preserving the stability of the hip and the need to address it meticulously for better postoperative hip function and results. Preoperative evaluation of the center-edge angle on radiographs to exclude hip dysplasia, sufficient intraoperative visualization to avoid over-resection of the acetabulum, and utilization of techniques to preserve hip soft tissue stability and capsular closure at termination of surgery should be considered.

Also a hip stability-related complication is to misdiagnose the unstable hip or the hip with instability with or without acetabular dysplasia. Failure to not address the instability may lead to residual pain and in some cases worsening of hip symptoms postoperatively. The intraoperative signs of laxity when applying traction to the hip and hip joint pathology can help in identifying these cases. We have reported that patients with the diagnosis of instability alone, without any other bony pathology, had a significant trend to have a straight-anterior (4–2 o'clock region) inside out labral chondral damage pattern. This is a distinctly different characteristic pathology compared to the damage pattern seen in pincer and cam lesions. Intraoperative recognition of distinct patterns of pathology can help in diagnosing the origin of the pathology and properly addressing the problem. In patients with concomitant instability, capsular plication is strongly advocated (Table 67.1).

Table 67.1 Studies investigating arthroscopic treatment of FAI

Study	Year	Patient number	Age	FAI type	Follow-up	Main outcome	Complications	Others
Schilders et al. [40]	2011	96	37	Type of FAI not specified but all labral repair patients had acetabuloplasty	2.4 years	HHS in the labral repair group improved significantly more than in the labral resection group	No patient went on to THA	No significant effect of cartilage lesions on HHS
Larson et al. [41]	2012	94	30	Pincer and combined FAI	42 months	HHS, SF-12, and VAS all improved more in labral refixation group versus labral debridement group	2 patients revision surgery for HO, 2 revision arthroscopy, 1 THA	No difference in reduction of alpha angle between groups
Espinosa et al. [42]	2006	52	30	All patients treated as combined FAI	2 years	Open treatment. Merle d'Aubigne score significantly better at 1 and 2 years for labral reattachment group versus labral resection group		Radiographic arthritis more prevalent in labral resection group at 1 and 2 years
Skendzel et al. [43]	2014	466	39.6	Type of FAI not specified	73 months (60–97)	Compared patients with preserved (>2 mm) or limited (<2 mm) hip joint space. At follow-up 16% of preserved and 86% of limited patients converted to THA. HOS for daily living and sports were 82 vs. 62 ($p=0.012$) and 77 vs. 47 ($p=0.003$)		
Palmer et al.[44]	2012	201	40.2	Only cam	46 months (36–70)	Significant improvement in NAHS and VAS scores	12 conversion to THA, significant number of patients had preoperative OA	
Byrd et al.[39]	2011	100	34	Cam 63, pincer 18 and combined 19	24 months	Median HHS improvement was 21.5, 79 patients had good to excellent results	2 transient neuropraxia, and 1 HO	
Philippon et al. [45]	2009	122	40.6	Cam 23, pincer 3, combined 86	2.3 years	The was a significant improvement of median HHS improved by 26	10 conversion to THA	Better outcome were the preoperative modified HHS ($p=0.018$), joint space narrowing ≥2 mm ($p=0.005$), and repair of labral pathology instead of debridement ($p=0.032$)

67.5 Summary

A well-selected and well-preformed arthroscopic surgery for FAI can yield good to excellent results in terms of symptomatic improvement and high patient's satisfaction.

Byrd et al. [39] reported a series of his first 100 consecutive patients who had undergone arthroscopic FAI surgery, with a 2-year follow-up. In this series, the labral tears were all debrided. There was a significant improvement in the median modified Harris hip scores of 21.5 points. Schilders et al. [40] conducted a retrospective study of 96 patients divided in to a labral repair and labral resection group, who had undergone arthroscopic FAI treatment. At a mean follow-up of 2.44 years, both groups showed improvements in the modified HHS, a mean increase in the modified HHS of 33.4 points for the repair group and 26.1 for the resection group, with significantly more improvement in the labral repair group. Larson et al. [41] conducted a retrospective study on two groups of 42 patients who underwent focal labral debridement or excision, and 48 patients who underwent labral refixation, following arthroscopic FAI treatment. At a mean follow-up of 3.5 years, there was significant improvement in the modified HHS, Short Form 12 (SF-12), and visual analogue score (VAS) for pain in both groups. However, the labral refixation groups performed better than the excision/debridement group in terms of better outcomes scores at latest follow-up. Similar good to excellent short-term results have been reported, but as FAI and the arthroscopic treatment of it is still a new and evolving field, more long-term studies are needed to answer questions such as the influence of postoperative micro-instability and where this procedure can delay or even prevent the progression of hip osteoarthritis.

67.6 Future Directions

Hip arthroscopy is still a relatively new and evolving field. Techniques and technology have allowed for more reliable and reproducible results for the diagnosis and treatment of FAI.

The ideal amount of bone resection needed in pincer lesions is still a controversy. There is still not a good objective modality to pre- and postoperatively measure the ideal amount of bone to remove preoperatively, nor is there a way to determine the ideal bony resection in depth or circumference. In the future we should be able to assess pre-, post-, and intraoperatively the optimum amount of bone resection for a stable and pain-free joint.

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Conflict of Interest Statement None declared.

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Hip Arthroscopy for the Treatment of Osteochondral Defects and Loose Bodies

68

Nicole A. Friel, Michaela Kopka, Volker Musahl, and Craig S. Mauro

68.1 Introduction and Indications

Chondral and osteochondral injuries on the acetabulum or femoral head are increasingly recognized as important contributors to intra-articular hip pain and degeneration. Common etiologies include trauma, femoroacetabular impingement (FAI), labral tears, loose bodies, osteochondritis dissecans, osteonecrosis, slipped capital femoral epiphysis, and hip dysplasia. Often, the cartilage damage coexists with other pathology. Loose bodies are often the sequelae of cartilage damage but can also occur independently such as in the setting of osteoarthritis and synovial chondromatosis. Once formed, loose bodies can propagate the process cartilage destruction through third body wear.

Patients with cartilage injury or loose bodies often complain of pain with motion localized to the groin, with radiation to the buttocks or thigh. Some may note limited motion or mechanical symptoms. Physical examination should focus on range of motion and strength but must include provocative maneuvers to help localize the zone of injury. A thorough assessment to rule out extra-articular pathologies is also important. Imaging begins with plain radiographs, including an AP of the pelvis, and a lateral (prefer modified Dunn or frog leg) of the hip, followed by specialized views such as a false profile and weight-bearing series. MRI or MRI arthrography, which may increase sensitivity of detecting concomitant injuries, should be obtained to evaluate all of the soft tissues. CT scan can be useful in the traumatic setting or to rule out rotational deformities and dysplasia. However, judicious use is recommended due to the radiation dose involved.

The decision-making process in the treatment of cartilage injuries or loose bodies of the hip is multifactorial and involves careful consideration of the patient's history, physical exam, and imaging. A trial of nonoperative management may often be appropriate. If surgical treatment is pursued, a variety of arthroscopic and open techniques are available. Partial-thickness cartilage lesions are often best treated with debridement. Cartilage delamination at the chondrolabral junction can be addressed with debridement or cartilage sparing techniques such as microfracture with fibrin glue or suture repair (since the overlying cartilage is often viable). Small areas of focal, full-thickness cartilage loss may be treated with microfracture. Various cartilage restoration procedures exist to address larger, full-thickness

N.A. Friel • M. Kopka • C.S. Mauro
Department of Orthopaedic Surgery,
University of Pittsburgh, Pittsburgh, PA, USA

V. Musahl, MD (✉)
Department of Orthopaedic Surgery,
University of Pittsburgh, Pittsburgh, PA, USA

Department of Bioengineering,
University of Pittsburgh, Pittsburgh, PA, USA

UPMC Center for Sports Medicine,
University of Pittsburgh, 3200 South Water Street,
Pittsburgh, PA 15203, USA
e-mail: musahlv@upmc.edu

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defects. Examples include osteochondral grafting, autologous chondrocyte implantation (ACI), matrix-associated chondrocyte implantation (MACI), and autologous chondrocyte transplantation (ACT). Overall, cartilage restoration of the hip is a relatively new and evolving area of research. To date, only a few studies have reported on outcomes, and the majority are small case series or cohort studies. Comprehensive evidence-based guidelines for the treatment of chondral lesions of the hip remain to be defined.

68.2 Nonoperative

In many cases, conservative management of cartilage injuries is the appropriate first step. Offloading and activity modification that avoids positions which increase load at the site of cartilage damage can be beneficial. Physical therapy, focused on hip and core strengthening, should be trialed for a minimum of 6 weeks and continued at home on a regular basis. Intra-articular injections may also be considered. Intra-articular corticosteroid injections can be of both diagnostic and therapeutic value. Viscosupplementation has been trialed; however, evidence to support its efficacy is still lacking. There is also increasing interest in the role of biologic injections, including PRP and bone marrow aspirate concentrates, but the literature remains limited.

68.3 Surgical Techniques

As with any arthroscopic procedure, operating room setup, patient positioning, and portal placement are vital components of a successful surgery. The patient can be positioned either supine or lateral on a radiolucent table designed to provide traction. An important consideration is the protection of soft tissues from undue pressure caused by traction and countertraction maneuvers. Correct portal placement is critical for adequate visualization of the hip. The most commonly used portals include the anterolateral portal, the posterolateral portal, the anterior or mid-anterior portal, and the distal anterolateral portal. The anterolateral portal is established first using x-ray guidance. The remaining portals are then established under direct vision using an inside-out Seldinger technique. A 70° arthroscope is most useful within the central compartment as it affords a wider field of view. A 30° arthroscope may be helpful in the peripheral compartment to gain more anatomic perspective.

68.4 Chondroplasty and Repair

Based upon the location of the cartilage lesion, as well as the degree of damage, debridement of the lesion may be the most appropriate management. Debridement of a chondral flap, for example, provides resolution of mechanical symptoms and may prevent the formation of a loose body. The use of a shaver or radiofrequency ablator at the site of cartilage injury is the preferred method of debridement (Fig. 68.1).

Partial-thickness cartilage lesions with delamination at the chondrolabral junction may be treated with chondroplasty alone or suture-based repair. When combined with a labral repair, the stitch can be incorporated into the cartilage to maintain reduction to the underlying subchondral bone and promote healing (Fig. 68.2). This technique is most effective when the chondral flap and the labrum have detached from the acetabulum as a confluent sleeve. A vertical mattress suture configuration has been shown to be the most effective construct to restore the anatomic position of both the labrum and the delaminated cartilage.

68.5 Microfracture

Focal, full-thickness cartilage defects are often treated with microfracture. The goal of this marrow stimulation technique is to promote the migration of stem cells from the subchondral bone and induce the formation of fibrocartilage at the site of the defect. While microfracture does not produce native, type II hyaline cartilage, fibrocartilage serves as a reasonable alternative, and the technique is far less technically demanding than other cartilage restoration procedures.

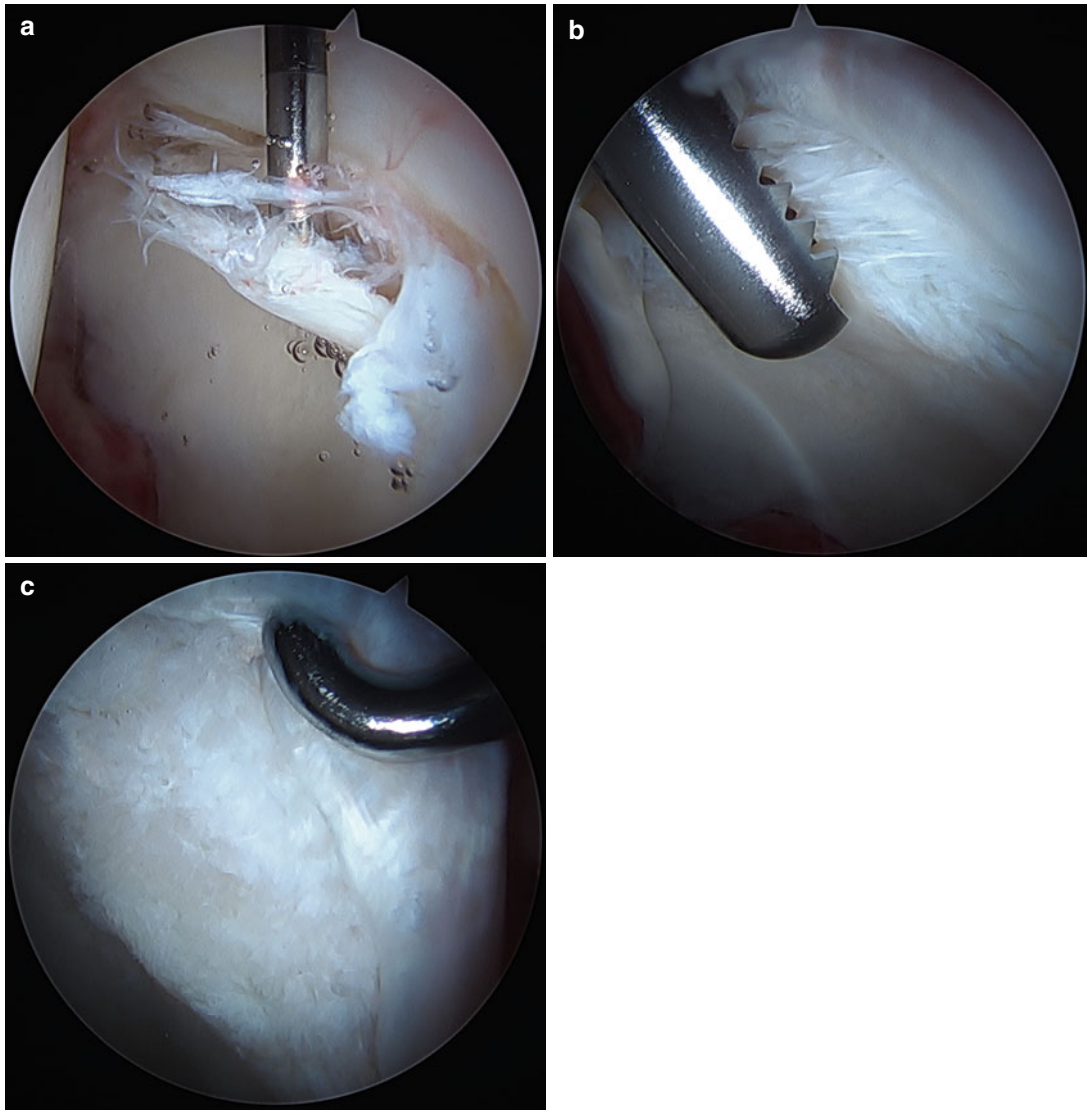

Fig. 68.1 (**a**) Cartilage damage at the chondrolabral junction. (**b**) Following repair of the labral tear, the cartilage is debrided with a shaver. (**c**) Stable partial-thickness cartilage lesion at the chondrolabral junction following debridement and labral repair

In the majority of cases, the standard anterolateral and anterior (or mid-anterior) portals are the only portals necessary for successful microfracture. However, access through the distal anterolateral portal may provide a better angle for drilling certain areas of the acetabulum. The first step is debridement of any loose cartilage flaps or edges with a shaver. A curette is then used to create a stable peripheral margin with vertical walls. Any calcified cartilage is also removed with a shaver or curette, taking care not to violate the underlying subchondral bone. Microfracture of the acetabulum may be performed with standard awls, specialized angled hip awls, or curved/flexible drilling systems. Specialized instruments may be necessary to allow appropriate access and angulation perpendicular to the subchondral surface. The goal is to create holes in the subchondral bone spaced approximately 3–4 mm apart. There has been a recent movement to

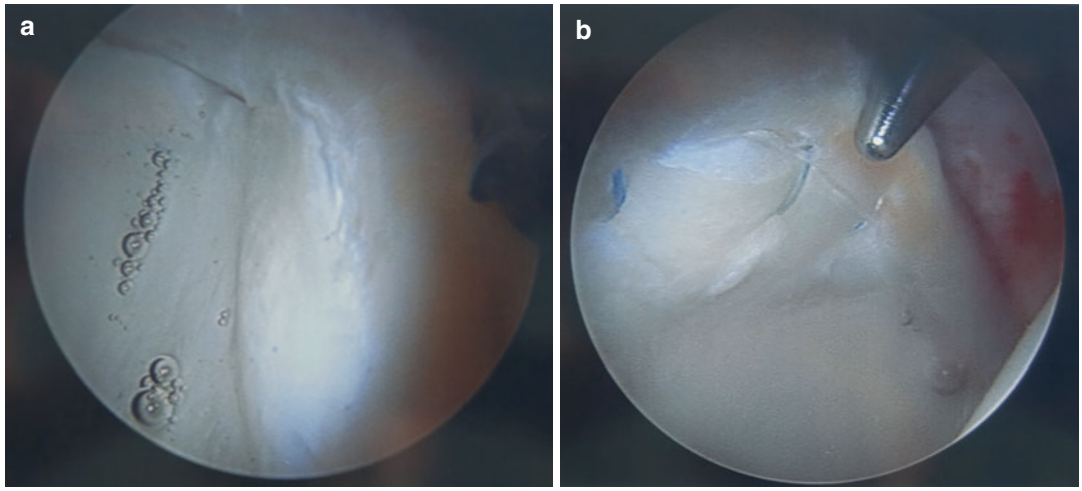

Fig. 68.2 (**a**) Appearance of cartilage damage at the chondrolabral junction. (**b**) A suture was placed under the labrum and through the damaged cartilage to stabilize both structures

create smaller microfracture holes in the defect. This technique still allows egress of the marrow elements but does not create the significant fracture callus response that may be seen with larger microfracture holes.

The procedure is deemed successful when the escape of blood and fat droplets from the subchondral bone is visualized. Protected weight-bearing postoperatively is important to help protect the marrow blood clot.

While the steps and goals of microfracture in the hip are similar to those of the knee, the procedure is arguably more technically challenging in the hip due to issues with access and appropriate angulation. Specialized instruments can often be very helpful with this issue (Fig. 68.3). Hip-specific curettes are shaped to facilitate the creation of vertical walls. Specialized hip awls and drill guides are angled to allow perpendicular access to the subchondral bone. All instruments have increased working lengths to accommodate the hip joint anatomy.

68.6 Enhanced Microfracture

There are several newer augmentation techniques that may be used to stabilize the microfracture defect site with a resorbable scaffold that covers the defect after penetration of the subchondral space. These techniques may enhance cartilage healing, but outcomes studies are limited, and their use has been studied most extensively in knee cartilage defects. These techniques include Autologous Matrix-Induced Chondrogenesis (AMIC), which involves the insertion of fibrin gel followed by a collagen matrix over a microfractured defect. Biocartilage (Arthrex) is dehydrated allograft cartilage which is micronized to increase surface area (Fig. 68.4). It is mixed with autologous blood or platelet-rich plasma, injected into the defect site, and sealed into place with fibrin glue. DeNovo (Zimmer) is a particulated juvenile cartilage implant that is implanted in a similar fashion and also sealed with fibrin glue.

68.7 Microfracture with Fibrin Glue

Femoroacetabular impingement (FAI) produces a very characteristic cartilage delamination at the chondrolabral junction. Arthroscopically, this injury can be identified by the wave sign – in which the cartilage can be indirectly lifted off the subchondral bone by applying pressure to the labrum. While these lesions represent damage between the cartilage and underlying subchondral

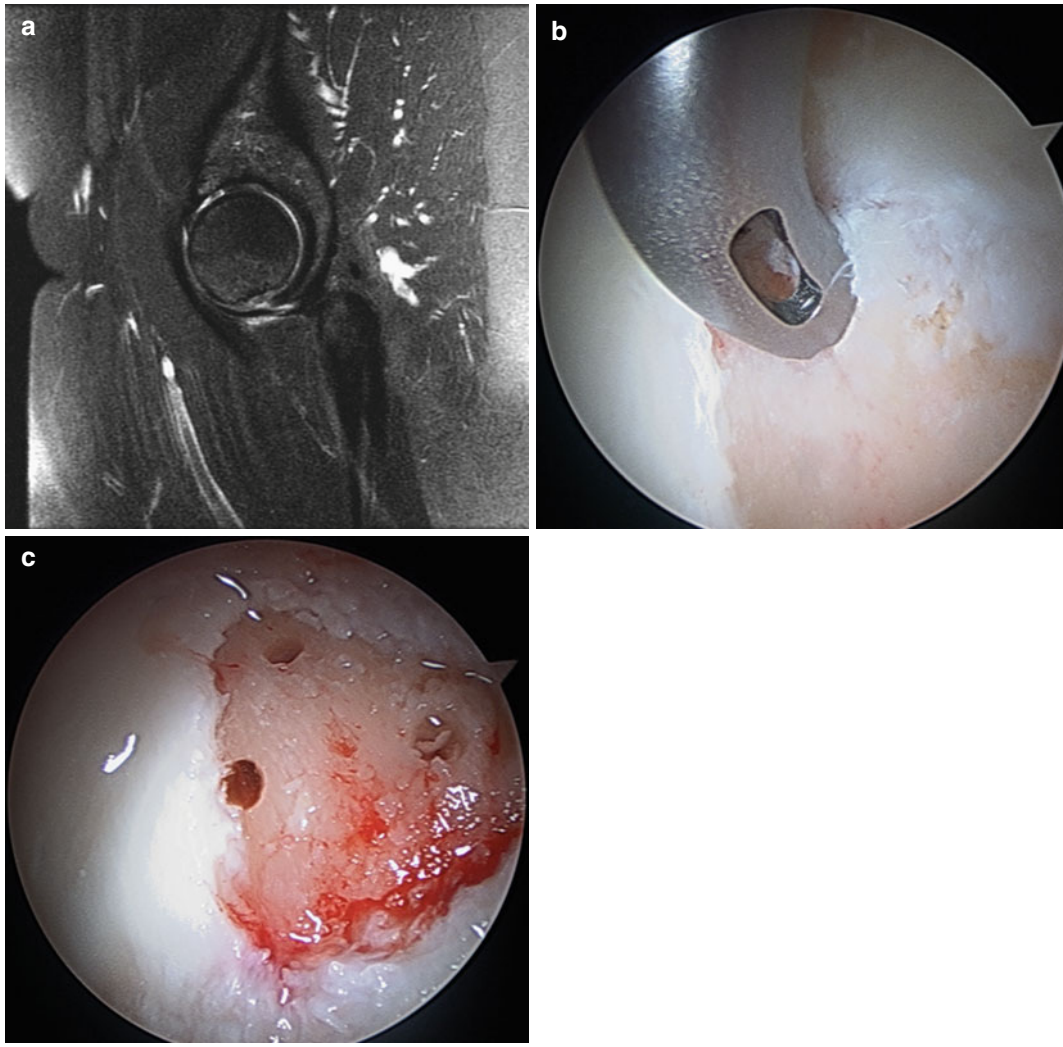

Fig. 68.3 (**a**) Full-thickness acetabular cartilage defect. (**b**) Microfracture using specialized microfracture awls to access the hip joint. (**c**) Chondral defect following microfracture

bone, the chondrocytes within the cartilage remain viable. In an effort to preserve the cartilage, techniques to stimulate its reattachment to the underlying subchondral bone have been developed.

The first step involves evaluation of the adjacent labrum and creation of a perilabral sulcus in the capsule to gain access to the labral base on the acetabular rim. An arthroscopic knife is then used to lift the labrum to gain access to the area of delaminated cartilage. Care must be taken not to transect the labrum during this maneuver. A microfracture awl is introduced under the labrum and under the area of delaminated cartilage, and the subchondral bone is perforated while maintaining integrity of the cartilage. Fluid flow on the arthroscope is turned off and all remaining fluid is aspirated from the joint. A needle is used to inject fibrin glue into the pocket of delaminated cartilage. Pressure must be applied to the cartilage in order to compress it against the subchondral bone while the fibrin glue dries. This technique is technically challenging but has shown promising midterm results.

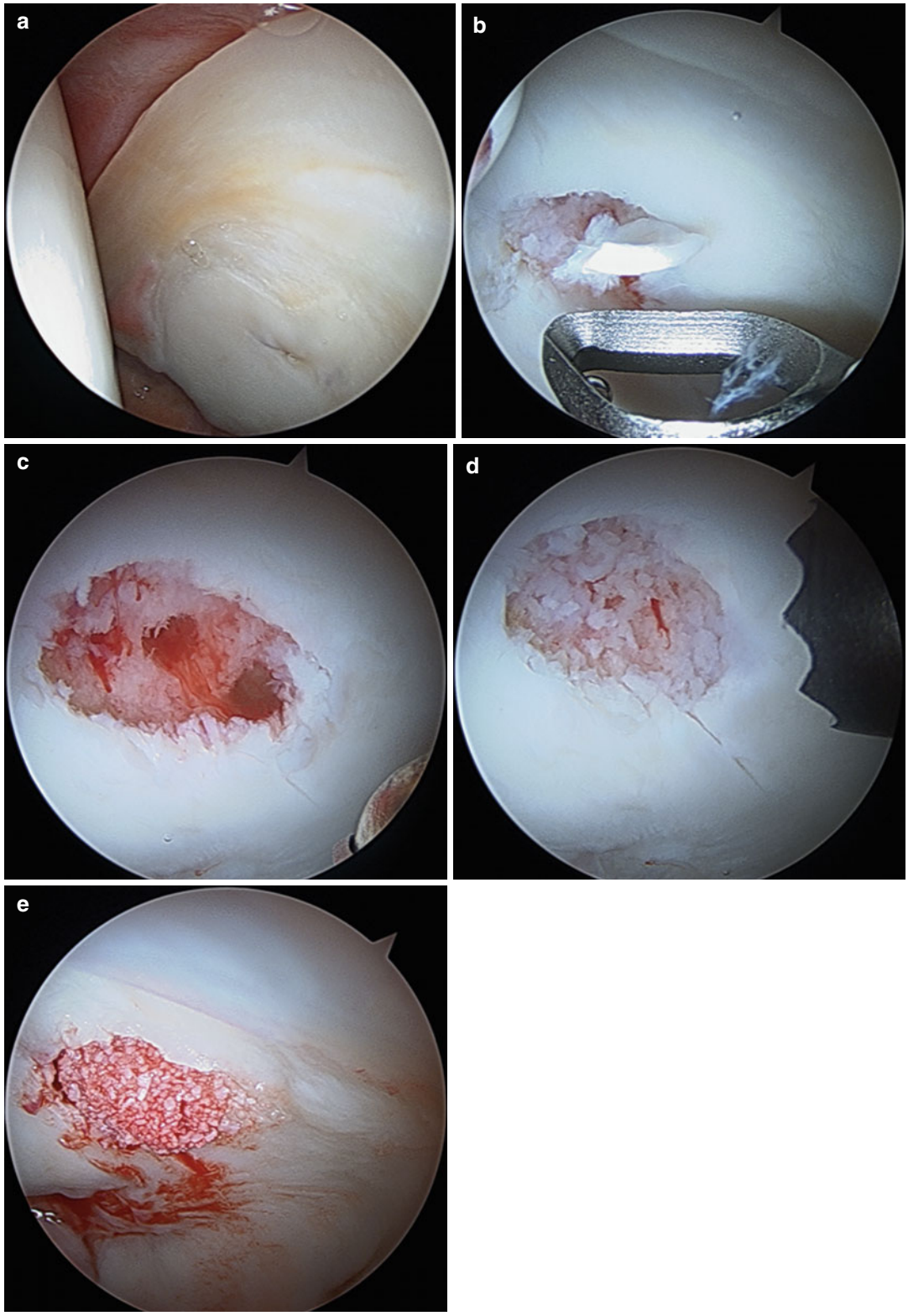

Fig. 68.4 (**a**) Grade 4 cartilage lesion of the acetabulum. (**b**) Debridement of the cartilage to vertical walls. (**c**) Microfracture of the lesion, with evidence of bleeding from the subchondral bone. (**d**) Application of biocartilage (Arthrex). (**e**) Final product

68.8 Chondrocyte Expansion: Autologous Chondrocyte Implantation (ACI), Matrix-Associated Chondrocyte Implantation (MACI), and Autologous Chondrocyte Transplantation (ACT)

Several techniques of cartilage expansion, frequently utilized in the knee, are being introduced in the hip. Autologous chondrocyte implantation (ACI), matrix-associated chondrocyte implantation (MACI), and autologous chondrocyte transplantation (ACT) are all variations of the two-stage procedure. The first stage involves the harvest of chondrocytes from the patient's hip (or other joint). The cells are then sent to a specialized facility which follows a specific protocol to stimulate chondrocyte expansion. The second stage requires implantation of the chondrocytes into the cartilage defect. Various techniques for cell delivery have been described, including the use of a biodegradable scaffold (MACI or ACT) or a patch to act as a seal (ACI).

The main advantage of these procedures is that unlike microfracture, they have the ability to regenerate hyaline cartilage. The major limitations include cost, technical difficulty, need for two procedures, and (in the case of ACI) the requirement of an open approach to secure the patch.

68.9 Osteochondral Autograft and Allograft

These techniques generally require an open arthrotomy and are thus not discussed further in this chapter. However, they are an important component of the treatment algorithm and should be considered for large cartilage defects or those with a large area of associated bone loss.

68.10 Loose Body Removal

Intra-articular loose bodies may originate from a variety of sources, including trauma, gunshot wounds with retained bullets or shrapnel, iatrogenic broken hardware, FAI, degenerative joint disease, and synovial chondromatosis.

Arthroscopy is an effective tool for loose body removal. Typically, standard portals (anterolateral and anterior or mid-anterior) are utilized, but modifications based upon the location and the size of the loose body may be necessary. For example, to optimize the trajectory for direct access into the joint, the standard anterior portal can be moved proximally by 2–3 cm (Fig. 68.5) [15]. A posterolateral portal may also be created to access loose bodies in the posteroinferior aspect of the joint.

Depending on the size of loose bodies, it may be necessary to use instruments that are not part of the normal hip arthroscopy set. If the fragment(s) are large, a larger grasper may be advantageous to maneuver the piece(s). Larger cannulas may be helpful for extraction. If the loose bodies are too large, they may need to be broken into smaller pieces before extraction. The surgeon should also be familiar with an open approach to hip (Smith-Peterson anterior approach being the most common) in the event that arthroscopy proves unsuccessful.

68.11 Tips and Pearls

- The sagittal MRI images tend to be the most useful for characterizing anterior chondral lesions.
- Patients with acetabular subchondral edema may have more advanced disease and often require a longer period of off-loading to allow the joint to heal postoperatively.
- Smaller microfracture holes cause less damage to the subchondral bone and do not result in the same degree of osteophyte formation.
- Specialized hip instruments, including microfracture drills, picks, and awls, are invaluable for accessing the difficult angles of the hip joint surfaces.
- Caution is advised when treating patients with acetabular dysplasia, as these patients can have quick progression of chondral damage following surgery due to altered hip biomechanics and the possibility of increased edge loading (Fig. 68.6).

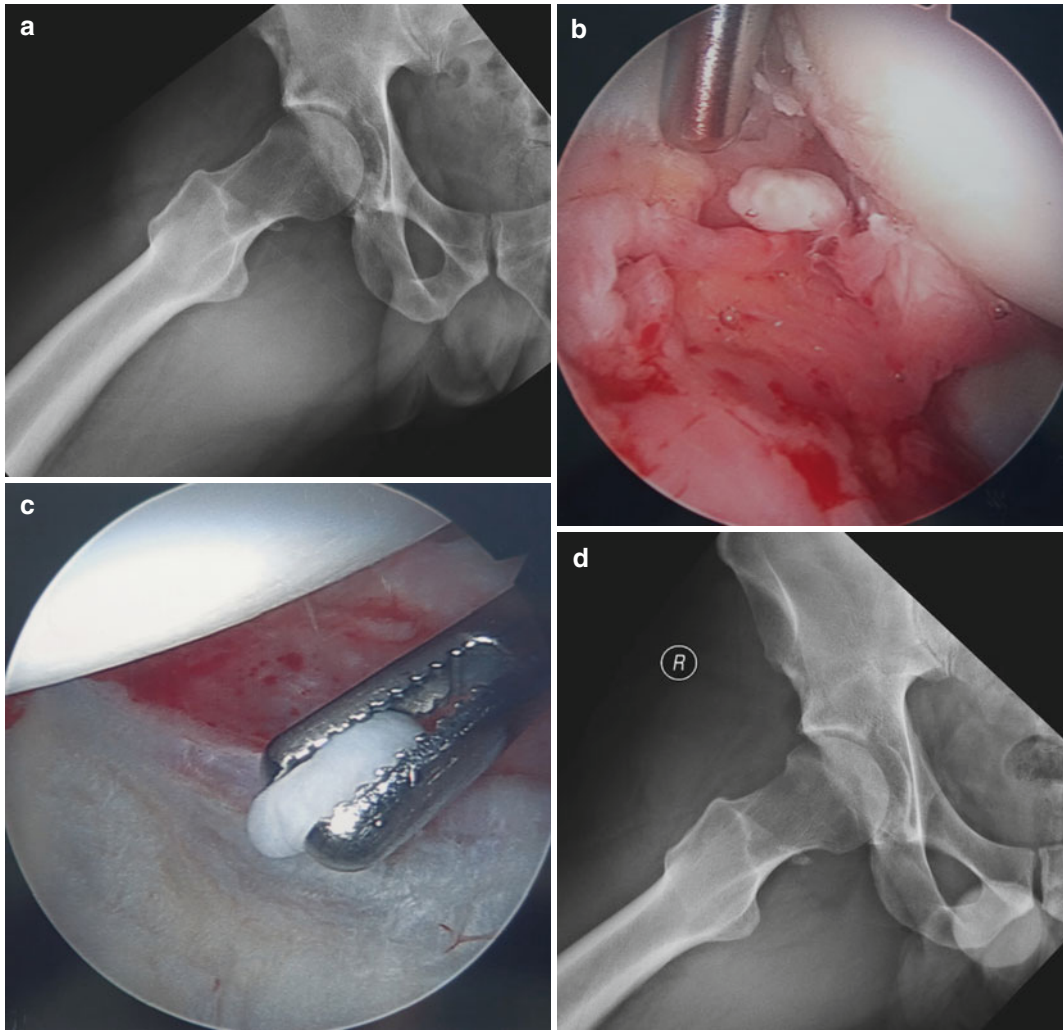

Fig. 68.5 (**a**) Radiograph showing loose bodies. (**b**, **c**) Arthroscopic views showing extraction of the central loose bodies. (**d**) Postoperative radiograph showing that the fragments have been removed

68.12 Complications

The complication rate of hip arthroscopy has been reported as 8.1 % [5]. Major complications are most often related to traction neuropraxia, fluid extravasation, and iatrogenic chondral injury. Other major but less common complications include deep venous thrombosis, septic arthritis, and hip destabilization leading to dislocation/subluxation. Specific complications related to cartilage restoration of the hip are often related to the technique employed. For example, debridement and microfracture risk further chondral injury due to the passage of sharp instruments, as well as stress fracture from over-aggressive subchondral bone perforation. Techniques such as ACI carry the risk of two surgical procedures, as well as infection due to the introduction of foreign material into the joint.

68.13 Literature Review

Cartilage restoration of the hip is a relatively new area of interest, and much information remains to be gained from ongoing research. Many of the

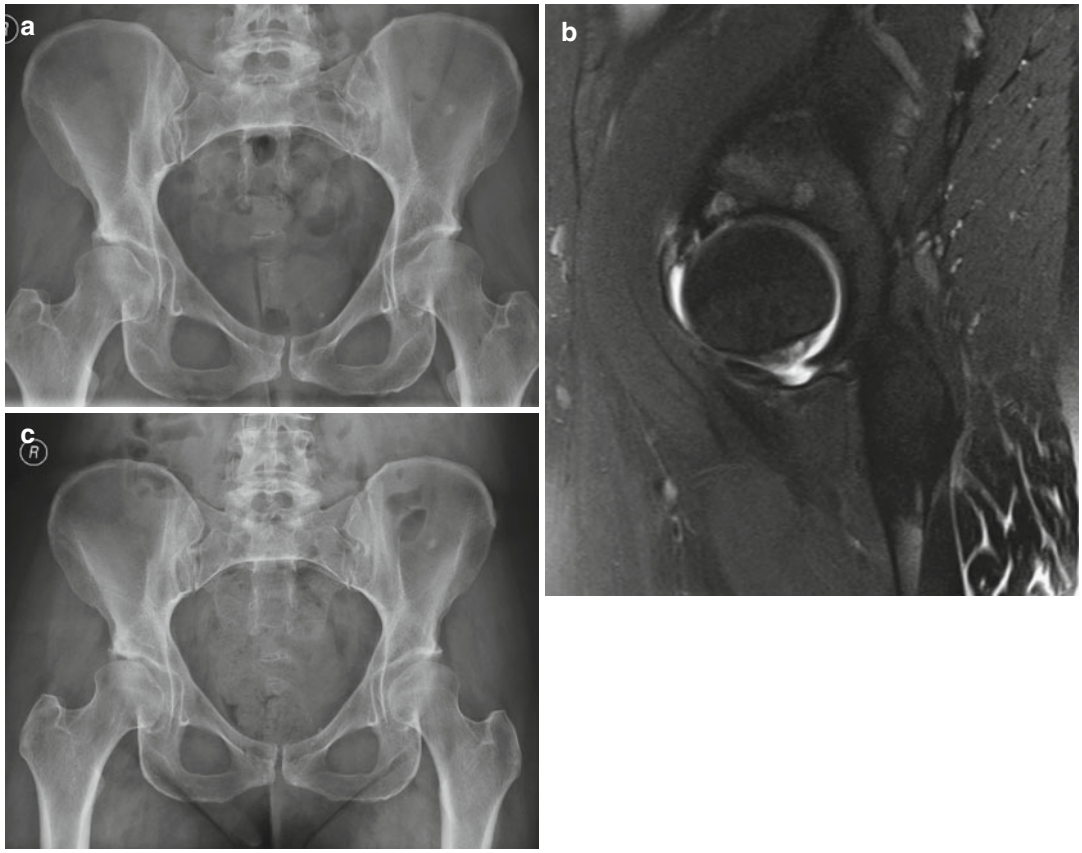

Fig. 68.6 (**a**) Pre-op pelvis radiograph showing acetabular dysplasia. (**b**) Pre-op sagittal MRA of the right hip showing an anterosuperior labral tear as well as subchondral cysts. (**c**) Post-op pelvis radiograph showing progression of osteoarthritis

treatment strategies being investigated have been successfully employed in the knee for many years. However, the hip joint is unique in anatomy and biomechanics, pathogenesis of disease, as well as access to the femoral and acetabular cartilage. Furthermore, cartilage damage is often related to bony deformity or labral lesions which must be addressed concurrently in order to prevent further cartilage destruction.

The body of literature evaluating cartilage procedures about the hip is rapidly expanding. Byrd et al. [2] were the first to report on the outcomes of microfracture for acetabular cartilage lesions. They investigated nine patients with isolated Outerbridge grade 4 acetabular cartilage lesions undergoing hip arthroscopy. Three patients underwent microfracture, while the remaining six underwent chondroplasty alone. At 2-year follow-up, only the three patients that underwent microfracture were able to return to an active lifestyle. Later, the same group showed significant improvement in the modified Harris Hip Score (65 preoperatively to 86 postoperatively) in a cohort of patients undergoing hip arthroscopy and microfracture for grade 4 chondral defects [1]. In a larger cohort, Haviv et al. [6] also showed that patients with full-thickness cartilage lesions that underwent microfracture had better hip outcome scores compared to those that underwent chondroplasty alone. Philippon et al. [11] and Karthikeyan et al. [7] used second-look arthroscopy to determine that >90 % (91 % and 96 %, respectively) of the defect becomes filled with fibrocartilage following microfracture. McDonald et al. [9, 10] have reported promising results in elite athletes undergoing microfracture.

In a study of elite male athletes, those who underwent arthroscopic microfracture in combination with treatment of labral pathology were able to return to play. In a separate study, 17 professional hockey players underwent microfracture of the femoral head for Outerbridge grade 4 lesions. Fourteen of the 17 athletes were able to return to play with no significant difference in games played and points earned.

In cases of cartilage delamination, debridement alone is not recommended, and every attempt should be made to preserve the cartilage and promote reattachment to the underlying subchondral bone. Sekiya et al. [12] reported a good subjective outcome in a case report of a teenage athlete following treatment of cartilage flaps with microfracture and suture repair. Tzaveas et al. [14] and Stafford et al. [13] managed delaminated cartilage lesions with microfracture followed by application of a fibrin adhesive and also reported improvement in subjective outcome scores from pre-op to post-op. In a slight variation of the procedure, Fontana et al. [4] compared AMIC (microfracture with a bilayer collagen matrix) to microfracture alone. They found improvements in modified Harris Hip Scores in both groups; however, only the patients that underwent AMIC were able to maintain good results. The authors also noted that patient with larger (greater than 4 cm^2) cartilage defects had better results.

The same group [3] also compared ACT to debridement in patients with cartilage damage. They showed that ACT was effective in relieving pain. In contrast, Korsmerier et al. [8] reported significant improvement in subjective functional outcome scores in patients undergoing ACT. While these studies provide some encouraging results for the future of chondrocyte expansion and reimplantation in the hip, high-level studies with larger sample size and longer follow-up are necessary before any conclusions can be drawn regarding the efficacy and long-term outcomes of these novel treatment strategies.

Conclusions

With the advent of hip arthroscopy, cartilage defects of the hip are becoming more commonly recognized, and various techniques for management are being developed. Partial-thickness cartilage lesions are best treated with debridement. For delamination lesions at the chondrolabral junction, microfracture with fibrin glue or suture repair is an appropriate strategy that aims to preserve the viable cartilage. Small, focal, full-thickness cartilage defects can be addressed with microfracture. For larger, full-thickness lesions, a variety of cartilage restoration techniques can be considered. Options for arthroscopic management include autologous chondrocyte implantation (ACI), matrix-associated chondrocyte implantation (MACI), and autologous chondrocyte transplantation (ACT). Open techniques, such as osteochondral allograft transplantation, are also important components of the algorithm. Although the body of literature is constantly expanding, comprehensive evidence-based guidelines for the treatment of chondral lesions of the hip remain to be defined.

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Labral Lesions of the Hip

69

Sanjeev Bhatia, Karen Briggs,
and Marc J. Philippon

69.1 Introduction

The acetabular labrum is a fibrocartilaginous ring, but triangular in cross section, that is normally confluent with the acetabular rim. At the inferior, or 6 o'clock position on the acetabulum, it is contiguous with the transverse acetabular fossa. Like the meniscus in the knee, the vascularity of the acetabular labrum is primarily within the peripheral one third of the labrum, while the central, or articular side, is avascular [1]. It is this limited vascularity that is principally believed to be the chief cause of the labrum's poor healing capacity. The acetabular labrum does possess nociceptive nerve fibers which may explain the pain that is often felt with larger tears [2]. These nerve fibers may allow detection of pressure, deep sensation, and proprioception in addition to pain at the time of injury [2].

One of the principal functions of the acetabular labrum is to effectively maintain the acetabular seal [3, 4]. Unlike the meniscus, the labrum is not responsible for dissipating loads by converting them to hoop stresses [5]. Rather, the acetabular labrum primarily functions to maintain the hydraulic seal effect within the femoroacetabular joint that reduces intra-articular joint pressures and maintains stability. As demonstrated by Ferguson and colleagues, the labral seal maintains a fluid film within the femoroacetabular joint that results in an even distribution of contact forces across the acetabular articular surface [6, 7]. In a cadaveric investigation by Philippon and Nepple, the authors found that partial labral resection significantly reduced the intra-articular fluid pressurization but labral repair or reconstruction restored the pressurization to a level similar to the intact state [4]. Similarly, the authors noted that the acetabular labrum was the primary stabilizer to distraction forces on the hip, and partial labral resection significantly decreased the distractive strength of the hip fluid seal; labral reconstruction significantly improved this distractive strength [3]. Espinosa et al. found that in clinical situations when a subtotal labrectomy was performed, a faster progression of arthritis occurred [8]. Because of the significant effect of labral integrity on stability and joint pressures, labral preservation has become a guiding principle in hip preservation surgery [9].

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S. Bhatia, MD • K. Briggs, MPH
M.J. Philippon, MD (✉)
Steadman Philippon Research Institute,
Attn. Center for Outcomes-based Orthopaedic Research,
181 W Meadow Drive, Suite 1000,
Vail, CO 81657, USA
e-mail: drphilippon@sprivail.org

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Labral pathology typically occurs because of a process known as femoroacetabular impingement (FAI). As proposed by Reinhold Ganz, FAI is resultant from abnormal contact between the proximal femur and the acetabular rim that occurs during terminal motions of the hip [10–14]. In the process, these pathomechanics often lead to labral tears, labral ossification, or damage to the acetabular articular cartilage [10, 12]. In a study by Dolan et al., ninety percent of patients with labral tears had underlying bony pathology [14]. As such, any procedure for addressing labral pathology must also simultaneously address bony causes for impingement [14, 15].

69.2 Indications

General indications for arthroscopic management of labral lesions of the hip include symptomatic hip pain in the presence of a labral lesion with history and physical exam consistent with the diagnosis, failure of conservative management, presence of bony femoroacetabular impingement, and presence of greater than 2 mm of femoroacetabular joint space on standing AP radiographs [9, 13, 16, 17]. In some instances, if joint space is well preserved and ossified labral pathology is appreciated on radiographs and advanced imaging, the patient may be a candidate for a labral reconstruction procedure [18, 19].

69.3 Techniques

69.3.1 Setup and Anesthesia

The patient is positioned onto the traction operating table in a modified supine position. Anesthesia is induced using general endotracheal means—a combined spinal epidural block is frequently utilized in conjunction to provide pain relief. After induction of anesthesia, both hips are examined to assess range of motion. A large padded perineal post is positioned and care is taken to avoid injury to the perineal structures. It is recommended to use an extra wide perineal post in order to minimize pressure on the pudendal nerve while also forcing the head more laterally during traction. Traction is gently applied to the leg with 15° internal rotation, 10° of lateral tilt, 10° of flexion, and neutral abduction. Adequate traction is verified with fluoroscopy.

69.3.2 Diagnostic Arthroscopy

Access to the hip joint is first established using the anterolateral portal. Fluoroscopy can be utilized to direct a spinal needle through the trajectory of the anterolateral portal and a guidewire is then used to maintain access into the joint while the spinal needle is removed. A 4.5 mm cannula is then introduced into the joint via the guidewire and the arthroscope is then inserted into the joint. Using triangulation and while viewing the anterior femoral capsular triangle arthroscopically, a second spinal needle is inserted at the location of the midanterior portal. Care should be taken not to make this portal medial to a line drawn distally from the anterosuperior iliac spine as this could place the lateral femoral cutaneous nerve more at risk. Once the spinal needle is in the appropriate location, a guidewire is once again introduced over it and a 5.0 mm cannula is then inserted into the joint and the arthroscope is placed into this cannula. A beaver blade is then introduced into the joint via the anterolateral portal and an interportal capsulotomy is performed allowing more visualization.

Diagnostic arthroscopy is done with a probe and is aimed at visually inspecting vital structures in the hip joint. Structures within the central compartment that should be carefully assessed include the labrum, capsule, chondral surface of the anterosuperior acetabulum, cotyloid fossa, ligamentum teres, synovium, capsule, and femoral head cartilage. The presence of chondromalacia, labral tear pathology, and loose bodies should be thoroughly assessed and documented.

69.3.3 Addressing Pincer Morphology

After completing a diagnostic arthroscopy, attention may be turned to the acetabular side. Often,

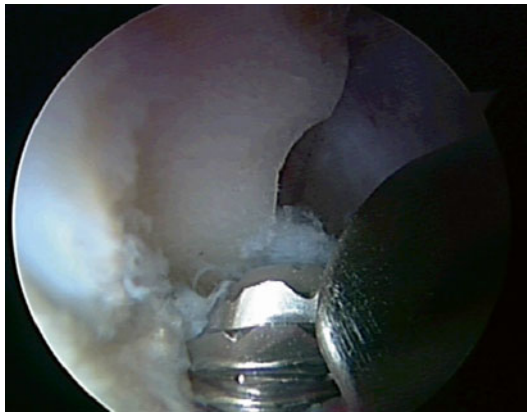

Fig. 69.1 A 4.5–5.5 mm burr is used to remove excess bone on the acetabulum in hips with pincer impingement

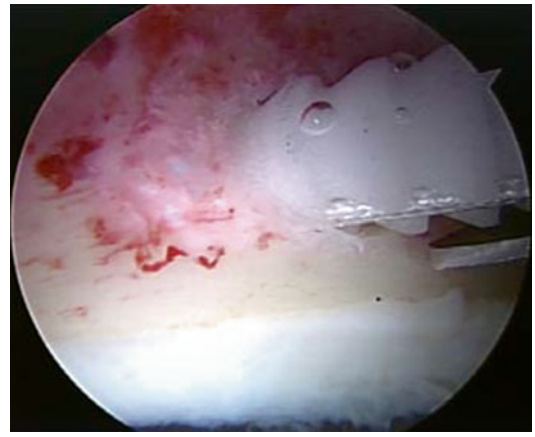

Fig. 69.2 Suture anchors are placed as close to the acetabular chondral surface as possible without perforating into the actual joint. The angle of the anchor is based on the location of the anchor

particularly in cases of pincer dominant or mixed femoroacetabular impingement, there is excessive bone on the acetabular side that often is implicated [10, 20]. To address pincer sided impingement, the native labrum is gently peeled forward exposing the labral-osseous junction. In some instances, the labrum may disconnect from the acetabular rim at which point it should be refixed to its anatomic position after rim trimming. Arthroscopic rim trimming is typically performed with a 4.5–5.5 mm burr (Fig. 69.1) on either forward or reverse spin using the preoperative radiographs as a guide on pincer location and morphology. A curved burr is often helpful for improved access to the anterosuperior rim and subspine region. Typically, with the exception of ossified labral pathology, it is recommended to remove no more than 4–6 mm of bone from the lunate surface as removing a greater amount may dramatically increase the joint contact pressures within the femoroacetabular joint [21].

69.3.4 Labral Repair Techniques

The chief goal of labral repair is to reaffix the labrum to its normal anatomic position on the edge of the acetabular articular surface in a manner that restores the femoroacetabular labral seal [4, 12]. For this reason, it is recommended to place suture anchors as close to the acetabular chondral surface as possible without perforating into the actual joint (Fig. 69.2). The most difficult anchor to place is usually the medial-most anchor, one that is close to 3 o'clock based on the classically described acetabular clockface [22]. To accomplish this effectively, either a curved anchor system can be employed or the anchor can be placed from a more distal, accessory, anterolateral portal.

Typically, three anchors are placed sequentially on the anterosuperior surface. Anchors are placed in either a looped or pierced fashion through the labrum in order to better provide good fixation and anatomic reapproximation without iatrogenic injury to the labral tissue (Fig. 69.3). Although biomechanical studies have demonstrated improved hip stability in labral repairs performed in a pierced fashion as opposed to a loop [3], clinical studies have not found a significant difference between the two repair strategies [23, 33].

69.3.5 Femoral Osteoplasty

Femoral osteoplasty is performed to address the CAM bony impingement morphology of the proximal femur. With the hip in 45° of flexion and neutral rotation, a 5.5 mm burr is used to help restore the normal head/neck offset of the

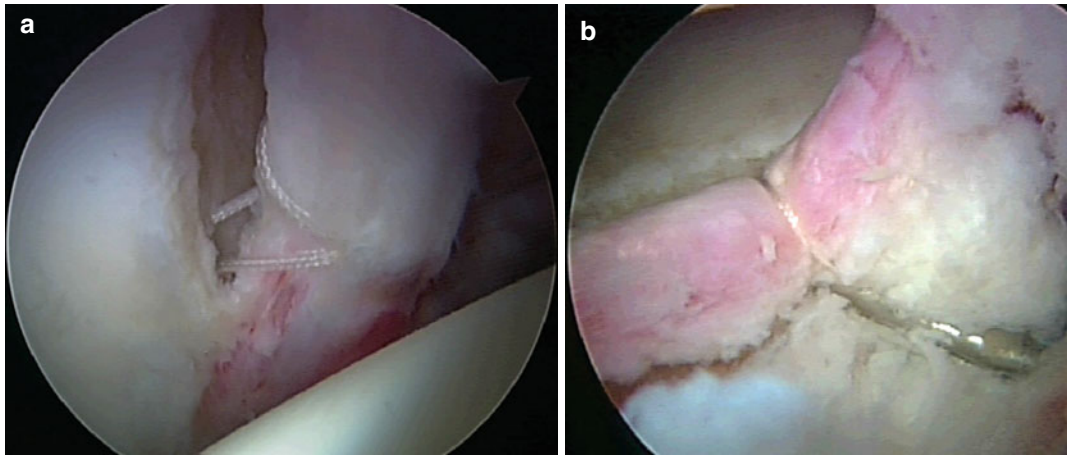

Fig. 69.3 The labrum can be sutured using a pierced technique, where the suture goes through the body of the labrum (**a**), or a looped technique, where the suture goes around the entire labrum (**b**). Using both techniques provides good fixation and anatomic reapproximation

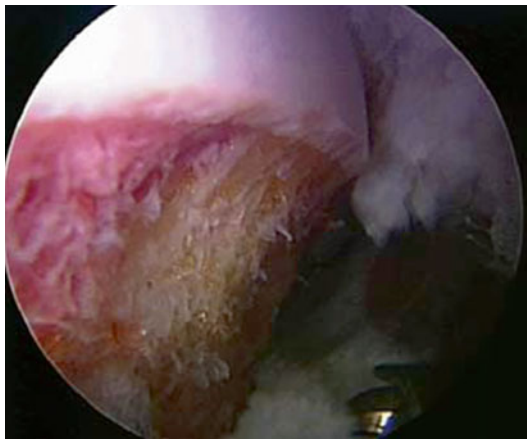

Fig. 69.4 A 5.5 mm burr is used to remove excess bone and restore the normal head/neck offset of the proximal femur

proximal femur (Fig. 69.4). When performing the femoral osteoplasty, the hip will need to be internally and externally rotated in order to appropriately access all areas of impingement as determined by preoperative radiographs. Intraoperative fluoroscopy is helpful in locating residual areas of impingement that should be removed.

Common pitfalls during the femoral osteoplasty include over resection of bone, either in location or in depth. Excessive proximal resection of bone not only results in loss of the chondral surface from the femoral head, but, more importantly, may be a significant cause of iatrogenic microinstability due to loss of the suction seal—the femoral head will no longer be tightly constrained within the acetabulum. Similarly, excessive notching of the femoral head and neck junction may iatrogenically predispose patients toward a femoral neck fracture [24, 25].

69.3.6 Capsular Preservation Strategies

Although the contributions of the iliofemoral ligament and hip capsule on femoroacetabular stability are increasingly being better understood, it has recently become quite apparent that maintaining capsular integrity after hip arthroscopy is paramount to avoid iatrogenic microinstability [26–29]. For this reason, an unrepaired capsulotomy, or any type of capsulectomy, is not recommended in any fashion. To facilitate closure and capsular preservation, an interportal capsulotomy, as opposed to a T-capsulotomy, may offer advantages. Additionally, a traction stitch can be placed over the proximal leaflet to prevent inadvertent damage to the proximal capsular leaflet during acetabular rim trimming and labral repair.

Capsular closure is typically accomplished with two to three double racking half-hitch knots

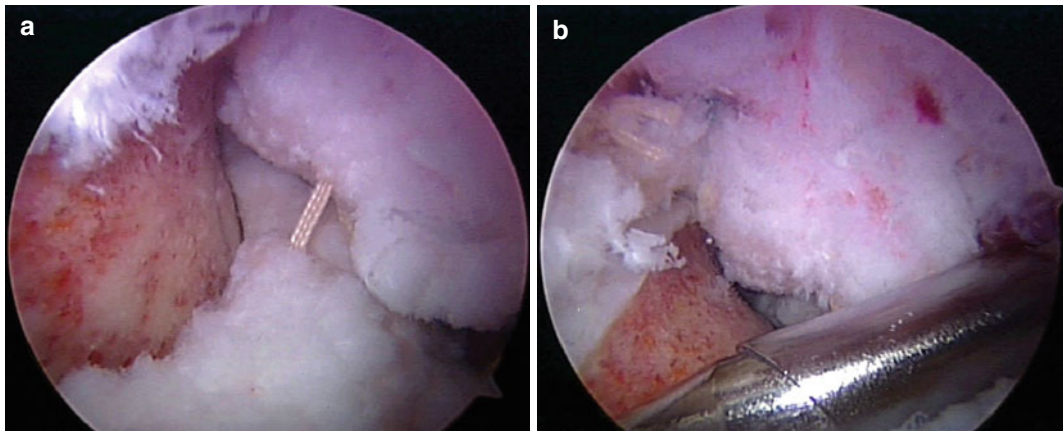

Fig. 69.5 For capsular closure, sutures are passed through both sides of the capsulotomy (**a**) and the opening is closed (**b**)

with absorbable suture. Sutures are passed with either a lasso or a self-passing device (Fig. 69.5). Regardless of the strategy employed, capsular preservation is a technique that all hip arthroscopists should become facile with.

69.4 Tips and Pearls

Hip arthroscopy can sometimes be very difficult due to the constrained nature of the femoroacetabular joint, the limited space, and the need to preserve various intra-articular structures. As such, pearls for improving efficiency are usually helpful for improving outcomes as well.

Like any medical procedure, it is paramount to avoid iatrogenic injury when performing hip arthroscopy. To avoid iatrogenic chondral injury from the arthroscope and arthroscopic tools, care should be taken to avoid coming near the femoral head surface when establishing access. Fluoroscopy is often helpful to avoid damaging the femoral when entering the central compartment.

As mentioned previously, labral and capsular preservation is imperative, particularly in young individuals, to prevent iatrogenic microinstability of the hip postoperatively. For this reason, the labrum should not be damaged during the initial interportal capsulotomy. Moreover, the capsule should be preserved as much as possible throughout the procedure and any capsulectomy should be avoided. A traction stitch, either proximally or distally, is often helpful for suspending the capsule for retraction.

Understanding arthroscopic landmarks of the acetabulum also is a very helpful tip that facilitates identifying the precise anatomic location within the joint efficiently and without the use of fluoroscopy. The most identifiable landmark is the psoas U, or anterior labral sulcus, a concave impression of the anterior rim of the acetabulum corresponding to the location of the iliopsoas tendon anteriorly [22]. The superior point of this sulcus is reliably in the 3 o'clock position on the clockface [22]. Other intra-articular landmarks include the stellate crease as well as the rectus femoris muscle [22].

69.5 Complications

Complications associated with arthroscopic management of the hip are fortunately very low. In a systematic review of 92 studies comprising more than 6,000 patients, Harris et al. found an overall major and minor complication rate to be 0.58 % and 7.5 %, respectively [30]. The most common complication was iatrogenic chondral and labral injury followed by temporary nerve palsy. Other described complications that have been described include heterotopic ossification, infection, pulmonary embolus or deep venous thrombosis,

femoral neck fracture, hip dislocation, and vascular injury [30]. Additionally, as previously mentioned, excessive bone resection of the proximal femur or acetabulum may have significant effects on instability or iatrogenically increasing hip joint contact pressures [21, 31, 32].

69.6 Summary of Outcomes

A significant degree of research has been performed to assess the impact of arthroscopic hip preservation on quality-of-life improvements. In a prospective study of 612 patients with mean follow-up of 3.2 years, Malviya and Villar described a statistically significant improvement in quality of life using responses to the modified Harris hip score [33]. Similarly, in a prospective study of 112 patients, Philippon and coauthors noted that the mean modified Harris hip score improved from 58 to 84 at mean 2.3 years of follow-up [17].

Among patients over the age of 50 at time of hip arthroscopy, good outcomes were seen by Philippon et al. provided there was greater than 2 mm of joint space [34]. In this cohort, survivorship of arthroscopic hip preservation efforts was 90 % when greater than 2 mm of joint space was present at the time of arthroscopy but only 57 % when joint space was 2 mm or less [34]. Other authors have noted similar findings [35].

Hip arthroscopy has also had demonstrated efficacy in high-level athletes. In a study of 28 professional hockey players undergoing hip arthroscopy, Philippon and colleagues found that the modified Harris hip score improved from 70 to 95, on average, at a mean 2 years of follow-up [12]. Average time until return to skating was 3.4 months [12].

69.7 Future Directions

Future directions in arthroscopic management of the hip will likely focus on improving surgical techniques for preserving stability, both of the labrum and capsule. As more insight is gained into the functional importance of these structures, techniques for repair, augmentation, and reconstruction will also likely improve. Additionally, the field of orthopedics is just beginning to become more adept at chondral transplantation and restoration; thus it is likely that these technologies will soon be applied to the hip given the predictable cascade of pathomechanical events that femoroacetabular impingement produces. Lastly, it is likely that arthroscopic solutions for addressing painful hip arthroplasty dilemmas will also arise, particularly as instrumentation and understanding of pain generation in the hip improve.

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Avascular Necrosis, Osteoarthritis and Synovitis

70

Nicolas Bonin, Christophe Tissot, and Antoine Dangin

70.1 Avascular Necrosis

70.1.1 Indications

Avascular osteonecrosis mostly concerns young adults in full activity. Besides traumas, most of the aetiologies are corticosteroid therapy, drepanocytose and alcoholism. After avascular necrosis, the cancellous bone rebuilt itself rather promptly unlike the subchondral bone. The subchondral bone disappears faster than it is reformed. It becomes a sensitive junction between the subchondral bone and the cancellous bone, with less resistance and a weak point that can promote subchondral fractures. If MRI allows establishing a complete statement of the necrosis, CT scan can be more precise in detecting subchondral fracture and minimal femoral head deformities [26].

N. Bonin, MD (✉)
Hip and Sports Medicine Department,
Lyon-Ortho-Clinic, 29 Avenue des sources (Bat B),
Lyon 69009, France
e-mail: dr.bonin@gmail.com,
dr.bonin@lyon-ortho-clinic.com

C. Tissot, MD
Orthopaedic Hospital,
Av. Pierre-Decker 4, CH-1011 Lausanne, Switzerland
e-mail: Christophe.Tissot@chuv.ch

A. Dangin
CHU Saint-Etienne, Service de Chirurgie
Orthopédique et de Traumatologie, France
e-mail: antoine.dangin@gmail.com

The presence of a subchondral fracture is a turning point in avascular osteonecrosis and at this stage, no conservative treatment can be undertaken. Thus, conservative surgery should be performed before the apparition of a subchondral fracture, to prevent evolution towards collapse of the femoral head and to hip osteoarthritis in young adults [10].

70.1.2 Surgical Techniques

Epiphyseal drilling decompression is the conservative therapeutic gold standard of avascular osteonecrosis of the femoral head. The usual technique presents the inconvenience of only having indirect control of the surgery by the X-ray. Moreover it imposes to drill the entire femoral neck. Hip arthroscopy allows a direct and precise approach of the lesion.

With axial traction on an orthopaedic surgical table, the femoral head is palpated under arthroscopic vision and X-ray control to determine the necrotic zone [28]. A 3.2 mm Steinmann pin is used through the mid-anterior approach. It is positioned at the junction between the femoral head and the femoral neck, focused towards the necrotic epiphyseal nucleus and introduced slowly with the engine. Under X-ray and arthroscopic control, small 3.2 mm drilling holes are realized with divergent orientation passing through the sclerotic lesion [15].

In the case of a sclerotic or cystic lesion of the epiphyseal nucleus, it is necessary to obtain a com-

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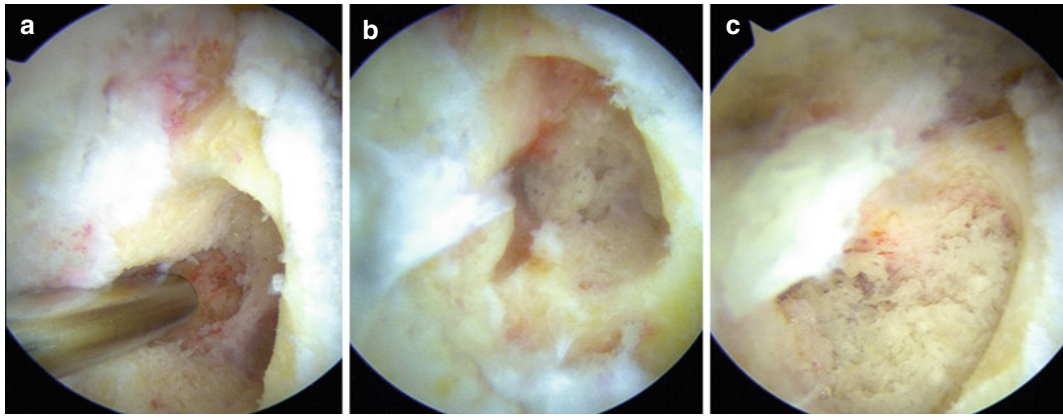

Fig. 70.1 Resection and grafting of necrotic bone of the head by drilling at the head-neck junction (neck on the left – femoral head cartilage on the right). (**a**) Shaver finishing to extract necrotic tissue. (**b**) Grafting the hole by fragmented autograft. (**c**) End of the procedure: the entire hole is grafted

plete resection of the necrotic tissues associated secondary to a bone autograft. To achieve it, a Kirschner wire is positioned in the lesion area from the junction of the femoral head and the femoral neck as explained previously. Using the Kirschner wire as a guide, an 8 mm hole is drilled through a 9 mm cannula. The pathologic area is then carefully drilled under X-ray control. The necrotic bone is resected with an adapted curette. Then, the bone autograft removed from the ipsilateral iliac bone is introduced by the cannula positioned at the entry of the cavity and carefully impacted [44] (Fig. 70.1).

The delay without support on the treated lower limb depends on the localization and the importance of the treated zone. Since most of avascular osteonecrosis are located at the anterosuperior area of the femoral head, which is undergoing the majority mechanical bearing stress, 45 days to 3 months of partial weight bearing is recommended.

70.1.3 Tips and Pearls

To obtain a good direction for the drilling, the installation of the patient is mostly important. It can be necessary to adjust hip flexion and hip rotation during surgery.

Before grafting the lesion, the arthroscope can be introduced in the drilled tunnel to check the absence of residual sclerotic tissues. The 70° scope is then very useful to obtain complete vision.

Cancellous bone autograft should be introduced in the cannula after fixing the cannula at the entry of the drilled tunnel in order not to spread bone around the hip.

70.1.4 Complications

Iatrogenic chondral lesion by overdrilling the femoral head is one of the specific complications. Special care should be done during this procedure and X-ray control is mandatory. Arthroscopic control must be used to monitor for chondral vibrations indicating that the drill in just under the subchondral bone. In this case, drilling must be stopped preventing chondral lesions.

Another specific complication is wire breakage that should be avoided by keeping the same direction between the wire and the drill.

70.1.5 Literature Overview

Rosenwasser et al. found 87 % of very good results by extra-articular conventional technique at 10 years follow-up [36].

From 1990 to 2000, Hernigou treated 534 illness hips presenting an early stage of femoral head osteonecrosis. He used a surgical technique associating extra-articular drilling and stem cell autograft [18]. At a mean follow-up of 13 years,

94 total hip replacements (THR) were realized. Among the remaining patients, Harris score increased from 70 in preoperative to 88 at the revision. On the MRI control, the osteonecrosis was healed in 69 hips. Among the remaining hips, the osteonecrosis area had decreased by half.

With the arthroscopic technique, Wang reports 60–85 % of very good results at 2 years follow-up according to the degree of the pathology [44].

70.1.6 Future Direction

An adjuvant treatment by stem cell autograft from bone marrow was proposed to increase the cure rate [18]. The transplant stem cells are taken from the iliac crest by aspiration through a trocar. Multiple punctures are necessary to obtain enough cells. Stem cells are then concentrated by filtration and centrifugation prior to injection.

An alternative of the stem cells is the treatment by platelet-rich plasma (PRP), whose interest in this indication remains theoretical to this day [15]. A prospective and randomized study recognized a better bone integration after the adjunction of PRP to bone allograft in opening wedge tibial osteotomy [3].

Regardless of the chosen adjuvant treatment, it is used by injection through the drilled holes in case of decompression of the epiphyseal nucleus. When there is a cancellous bone graft, part of the adjuvant treatment is injected and part is mixed with the graft a few minutes before grafting. Water irrigation should be stopped during the procedure.

70.2 Osteoarthritis

70.2.1 Indications

Since 1936, Smith-Peterson highlighted hip impingement as a cause of secondary osteoarthritis and treated his patients by acetabuloplasty [40]. Ganz et al. [11] and then Tanzer et al. [41] established the link between femoroacetabular impingement and arthritis. They established a causal link between the "pistol grip" head deformity, labral tears, pain and ostéoarthritis. In their study group of 125 hips with THA, the "pistol grip" deformation was systematically found [11, 41].

The Copenhagen study about osteoarthritis revealed the presence of a cam impingement in 17 % of the male population and in 4 % of the female population in a cohort of 4,151 patients [14]. This data has been recently confirmed concerning young asymptomatic adults [16, 35].

Even if the arthroscopic treatment of femoroacetabular impingement reveals excellent results, the presence of osteoarthritis at time of surgery remains a bad prognosis factor. Thus, a confirmed osteoarthritis is a contraindication to an arthroscopic treatment. However, some cases of starting osteoarthritis are likely to respond to this surgery.

The recommended indications are degenerative damage limited to less than or equal to grade 2 from Tönnis classification, induced by a femoroacetabular impingement, in young patients, with satisfactory acetabular cover. The radiological thickness of the joint space is important to take into consideration. The failure rate is 86 % at 40 months of follow-up for a joint space of less than 2 mm against 16 % with a thickness of more than 2 mm [39].

70.2.2 Surgical Techniques

Hip arthroscopy on pre-osteoarthritis is usually realized by the same surgical technique as the treatment of femoroacetabular impingement. Arthroscopic approaches remain the same, and treatment will aim to remove any cam or pincer effect and treat chondral and labral damage.

The specificities of hip arthroscopy in pre-osteoarthritis are linked to the presence of a fragile and degenerative labrum, sometimes calcified, and to the presence of advanced cartilage lesions. Femoral osteoplasty and acetabuloplasty are complicated by the presence of osteophytes, associated to osteoarthritis (Fig. 70.2). These osteophytes and capsular thickness can limit hip distraction making central compartment access difficult. In these cases, capsulotomy should be

enlarged in order to allow a complete resection of osteophytes and to obtain enough distraction for intra-articular procedures.

Regarding the labrum, despite a degenerative aspect, it is important to preserve it by anchor refixation. If repair is not possible, reconstruction should be discussed. Indeed, it has been shown that labral preservation or labral reconstruction is a better prognostic factor [7, 20, 21, 37]. The preservation or reconstruction of the labrum is especially important in cases of chondral lesions since it can stabilize a cartilage repair and reduce the mechanical stresses on this pathological cartilage.

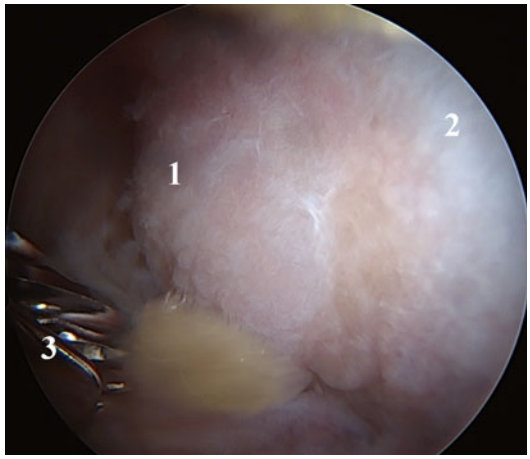

Fig. 70.2 Resection of osteophytes at the head-neck junction. Shaver finishing to extract necrotic tissue. *1* Osteophyte. *2* Head-neck junction. *3* Burr

Regarding chondral damages, they are usually described as focal lesions located on the anterior-superior edge of the acetabulum [31]. They must be debrided, being as conservative as possible. The goal is to fill the cartilage defect by the best filler available, in order to produce the best cartilage or fibrocartilage. This filling tissue allows the decrease of the pressure on the adjacent and healthy cartilage by 200 %, thus protecting it. The lesion either femoral or acetabular, the filling tissue to use will depend on the depth and the extent of the lesion, either it is femoral or acetabular:

- *Non-transfixing lesions*, with partial damage of the cartilage thickness (Outerbridge grade I–III), or isolated deep cracks (Fig. 70.3a) are usually treated by **cartilage debridement** (**chondroplasty**). Debridement is carefully made with a shaver or a basket punch (Fig. 70.3b). It may be made with a radio-frequency device, but if the result is more appealing, there is a risk of damage of the healthy peri-lesional chondrocytes by diffusion [25]. The debridement of unstable or small cartilage flaps must be undertaken in an economical way.
- In the presence of *stable transfixing lesions such as cartilage flap* (Fig 70.4), some surgical

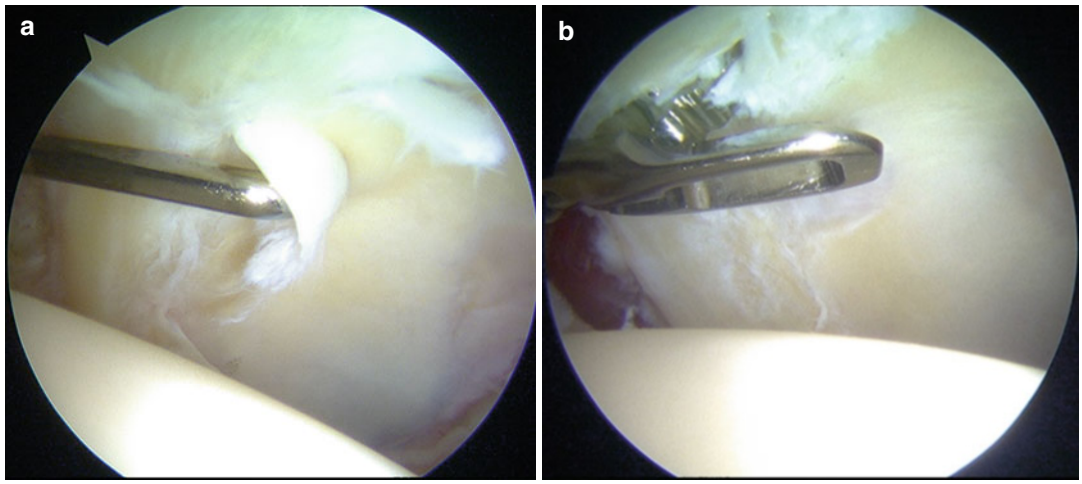

Fig. 70.3 (**a**) Isolated deep cracks at the anterosuperior border of the acetabulum. (**b**) Careful debridement of chondral cracks with a basket punch

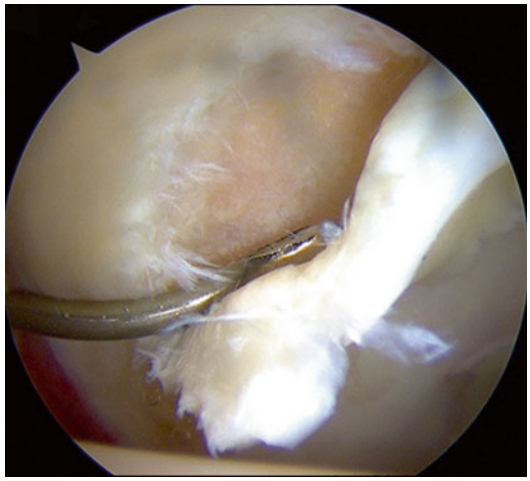

Fig. 70.4 Stable chondral flap at the superior border of the acetabulum

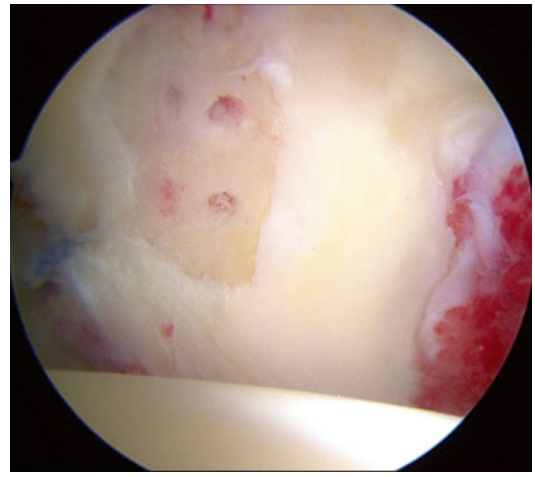

Fig. 70.5 Micro-fractures in the subchondral bone of a chondral defect at the anterosuperior margin of the acetabulum

teams suggest their conservation by repositioning after subchondral bone preparation [38, 43]. The preparation of the subchondral bone is performed according to the same principles as micro-fractures, while keeping the cartilage flap. After preparation, irrigation is stopped and the fluid removed from the hip. In a dry environment, fibrin glue is placed under the cartilage flap and pressure is applied for 2 min. This pressure is carried out by the balloon of a urinary catheter or by stopping the distraction on the orthopaedic table. The cartilage preservation is limited to treat large cartilage flaps with the entire cartilage thickness and with a healthy underlying bone [46]. If the flap is considered unstable or nonviable, excision is then the rule. We find ourselves in the situation of a cartilage defect.

- *Complete cartilage defects* (Outerbridge grade IV) should be treated depending on their extent after debridement: currently **micro-fracture** is the most used technique [34]. This technique is suitable for localized and circumscribed lesions *smaller than 2 cm* [2], with an intact subchondral bone. The indication can be extended to larger lesions, *up to 4 cm* [2], according to the patient's age (*higher*), weight (*lighter*), level of activities (*lower*) and the location of the lesion (*not a support area*) [32, 34, 46]. After debridement of the lesions until the subchondral bone, with regularization of its margins to be in healthy cartilage, it is essential to remove the calcified subchondral bone layer with a curette or a shaver. Holes ("micro-fractures") are then made in the subchondral bone, perpendicular to the bone surface and with a depth of 2–4 mm (Fig. 70.5). Since surgical approach during hip arthroscopy is not in the axis of the lesion, it is necessary to use specific square points, with different angulations (45–90°). The distance between each hole should be approximately 5 mm. Once the micro-fractures are performed, the irrigation pressure is lowered to check the appearance of bleeding from the holes.
- *Grade IV lesions of more than 2 cm²* in young patients are preferentially treated by **Autologous Matrix Induced Chondrogenesis** (**AMIC®**) [8, 23]. This technique begins with the realization of micro-fractures. The matrix, cut to the size of the defect, can then be introduced through an arthroscopic cannula. Its pore side is applied in contact with the prepared subchondral bone. Releasing the traction is sufficient to fix the matrix. Its attachment can however be improved by the application of biological glue.

If more than 4 cm² of grade IV chondral lesion, **Matrix Techniques with Autologous**

Chondrocyte Implantation (**MACI**) are often preferred to AMIC®. The technique is the same but needs a two-step surgery: first arthroscopic surgery to visualize the lesions and to harvest cartilage for planting. The second arthroscopic step is the application of the membrane supporting the chondrocytes harvested. The cost is significantly higher and to this day, their advantage is not proven.

All these filling techniques of cartilage defects lead to a fibrocartilage formation. However, some studies have shown that after a period of 2 years, fibrocartilage becomes real cartilage when using the AMIC® technique [30].

70.2.3 Tips and Pearls

The "central first" approach can be challenging to realize due to osteophytes and joint stiffness that can limit the joint distraction. Thus, it is sometimes necessary to start from the peripheral compartment, hip in flexion, to enter the joint. This "peripheral first" approach can also be difficult to realize by the presence of osteophytes. In these cases, we recommend the "extra-articular approach" technique described by F. Laude [42]: The affected limb is in a slight flexion without traction. The anterolateral portal is first placed at the level of the trochanter. The arthroscopic trocar is introduced under the fascia lata up to a contact with the femoral neck's capsule. While keeping the contact with the capsule, the 70° scope is introduced in the trocar. The anterior portal is then placed anterior to the facia lata and more distal. A fat-pad area (muscle-free zone) is present and removed with the shaver by the anterior portal. The capsule is exposed and with an electrocoagulation device it is incised as a "T" -shape from outside to inside. The labrum and cartilage surfaces are identified before exercising traction on the hip.

It is usually necessary to remove osteophytes first and realize a capsulotomy to be able to distract the hip and to free the instruments. Intraoperative X-ray will facilitate removing all the osteophytes.

At the end of the procedure, a dynamic testing is required to ensure the absence of residual impingement in abduction for superior cam and in deep flexion for anterior came.

70.2.4 Complications

Heterotopic ossification is the first complication in the cases of these stiff hips requiring high bone reaming, sometimes of inflammatory origin. It will be best avoided by a careful per operative joint washing, an early hip mobilization and the use of the NSAI drugs during the postoperative period.

Complications caused by the distraction device (perinea skin lesions, sensitive pelvic disorders…) are also more frequent in the case of joint stiffness due to the use of a stronger and longer distraction, linked to the difficulty and many intra-articular procedures (labrum and cartilage).

Finally, it is important to mention the risk of secondary displacement of the interposition matrix (*AMIC®/MACI*) used in cartilage reconstruction techniques [8]. This complication can be reduced by the use of biological glue.

70.2.5 Literature Overview

According to a recent systematic review of Domb et al. in 2015 [6], the risk of failure or the risk of osteoarthritis evolution is directly related to the importance of degenerative disorders with conversion to THA, ranging from 16 % to 52 % concerning Tönnis grade 2 or higher. Haviv and O'Donnell [17] described a rate of 16 % of THA conversion after 3 years, concerning 564 hip arthroscopies between 2002 and 2009 with cartilage disorders from 1 to 3 according to Tönnis rates. Larson [22] described a rate of 52 % THA conversion after 227 cases on higher grades than 2 after the same delay, between 2004 and 2008.

Excluding Tönnis grades 2 and higher, Palmer [33] showed 8 % conversion in 201 arthroscopies followed after 2–4 years. In a prospective study, at a minimum of 4 years follow-up, Gicquel [12] reported that the main prognostic factor was the preoperative osteoarthritis Tönnis grade: compared to Tönnis grade 0 hips, Tönnis grade 1 hips had lower WOMAC scores (77 vs. 88), lower satisfaction rates

(50 % versus 77 %), a higher rate of osteoarthritis progression (57 % versus 24 %) and a higher rate of arthroplasty (33.3 % versus 2.9 %).

In a study about the joint space narrowing on preoperative X-ray in 466 patients, Skendzel and Philippon [39] described that the conversion rate to THA is 86 % at 40 months when preoperative joint space is lower than 2 mm, against 16 % for a joint space of more than 2 mm.

70.2.6 Future Direction

Grade IV cartilage disorders treated by interposition of synthetic matrix (AMIC®) seem to provide at short and medium term encouraging results. The recent Italian study from Fontana and Girolamo [9] compares the treatment of hip chondral lesions by AMIC® (70 patients) to isolated micro-fractures (77 patients). They note an improvement up to 5 years from the surgery in the AMIC® group, while the micro-fracture group deteriorates after 1 year. No THA was required in the AMIC® group against 7.8 % in the micro-fracture group.

In the knee, McCarthy [30] realized a study comparing AMIC® versus autologous chondrocytes implantation (ACI) for the treatment of chondral defect. In systematic biopsies, realized at 18 months postoperatively, he found a significantly better quality of repaired tissue, with higher ICRS II score and higher hyaline cartilage formed, after AMIC® than ACI.

Labral reconstruction, often necessary in these degenerative hips, gives encouraging results compared to the labral resection. At 2 years follow-up, Domb [5] described greater results concerning labral reconstruction compared to segmental resection. Matsuda [29], comparing labral repair versus labral reconstruction with the gracilis tendon, confirms the interest of labral reconstruction.

70.3 Synovitis

70.3.1 Indication

Synovitis diagnosis should be considered when there is a mechanical, unilateral and progressive joint pain. It must also be discussed when patients complain of blockages or pseudo-blockages. X-rays can show subchondral cyst of the acetabular or the femoral head associated with a preserved joint space. It can also highlight intra-articular foreign calcified bodies.

MRI with gadolinium vascular injection is the best radiological imaging exam. It allows a diagnostic approach, a staging of the synovium and a screening of infra-radiological bone lesions.

Synovial chondromatosis is the most frequent synovial pathology. Multiple intra-articular foreign bodies characterize it but sometimes chondroid foreign bodies can be missed with MRI, because of radiological signal near the one with joint effusion. In this case, it is interesting to have a complete injected radiological assessment (arthro-CT or arthro-MRI) (Fig. 70.6). It will guide the arthroscopy surgery by the count of foreign bodies and by highlighting and localizing the pathological synovial membrane, which appears thickened and irregular.

In case of villonodular synovitis, the presence of hemosiderin deposition has a pathognomonic MRI aspect due to its particular ferromagnetic properties (Fig. 70.7).

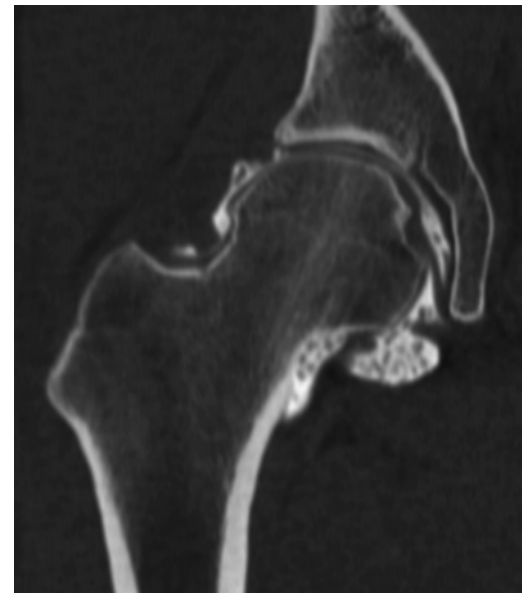

Fig. 70.6 Arthro-CT coronal view of chondromatosis in a right hip

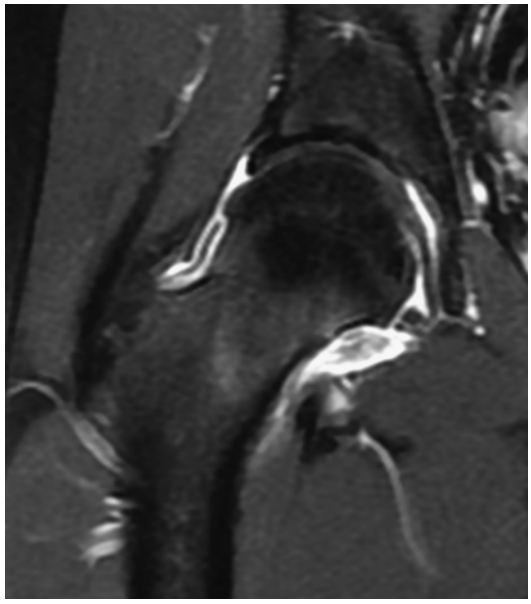

Fig. 70.7 MRI coronal view (T1-FS-gadolinium) of the right hip: pathognomonic hemosiderin deposition signal of a villonodular synovitis

Synovial pathologies were the first indications for hip arthroscopy. Arthroscopy will allow a macroscopic evaluation of the synovium and a diagnostic confirmation by histological biopsies. It will also allow the realization of the surgical treatment consisting in partial or subtotal synovectomy depending on the importance of the lesion and the removal of foreign bodies if needed. In the case of inflammatory rheumatism, the use of new biotherapies makes synovectomy under arthroscopy exceptional. Nevertheless, the endoscopic appearance of inflammatory arthritis should be well known. It is useful to practice a synovial biopsy whenever there is a suspicious appearance of the synovium.

70.3.2 Techniques

The articular exploration must be systematic to obtain a precise and complete diagnosis of the synovium.

The peripheral compartment is divided in four areas that must be described:

- The anterior zone
- The medial zone (inferior)
- The lateral zone (superior)
- The posterior zone

The anterior, medial and lateral zones are separated from proximal to distal by the orbicular ligament. The posterior compartment is very difficult to explore because it is a narrow space between the acetabular wall, covering the integrity of the posterior femoral head in hip extension, and a posterior capsular attachment that is more proximal on the femur than in the anterior space [4]. Furthermore, the flow of vessels crossing the supero-posterior edge of the neck makes the arthroscopic approaches of this area at risk of vascular injury.

The central compartment is composed by [4]:

- The articular surface of the acetabulum
- The acetabular fossa
- The ligamentum teres
- The articular surface of the femoral head

Areas covered by synovium are the integrity of the peripheral compartment and, for the central compartment, the acetabular fossa with the ligamentum teres.

Capsulotomy is realized as necessary. It will allow a better mobilization of surgical instruments to reach difficult areas and the removal of large foreign bodies if necessary. It is realized anteriorly in between portals, parallel to the acetabular edge. It can be extended to the lower anterior edge to reach the medial zone and to the upper and posterior edge to reach lateral zone. If needed, a vertical capsulotomy can be realized in the axis of the femoral neck, along the iliofemoral ligament. This capsulotomy will cut the orbicular ligament allowing a spectacular view and access to the anterior, medial and lateral areas (Fig. 70.8). To prevent the risk of bleeding in the context of inflammatory synovium, the capsulotomy is ideally performed with the thermocoagulation electrode.

After biopsies, the pathological synovium can be resected with a 4.5 mm or 5.5 mm shaver (Fig. 70.9) or with the thermocoagulation electrode, depending on the bleeding risk level. Curved shavers and adjustable angle electrodes help the surgical procedure. These two instruments are complementary to access most of the capsular recess.

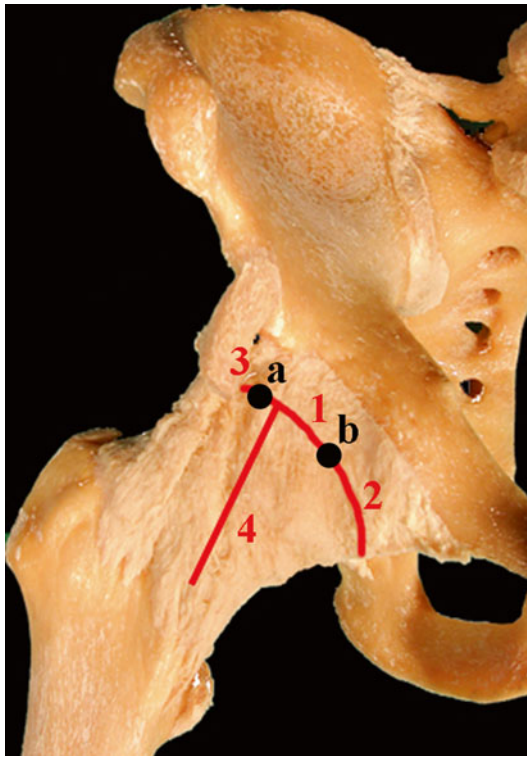

Fig. 70.8 Anterior view of a right hip and capsule: possibilities of capsulotomy extensions. (**a**) Capsular entry point of the anterolateral portal. (**b**) Capsular entry point of the mid-anterior portal. *1* In-between-portals capsulotomy, parallel to the acetabular edge. *2* Lower anterior edge capsulotomy to reach the medial zone. *3* Upper and posterior edge capsulotomy to reach lateral and posterolateral zone. *4* Vertical capsulotomy in the axis of the femoral neck, along the iliofemoral ligament, cutting the orbicular ligament

The central compartment is explored in extension, under traction of the lower limb. Internal rotation of the hip helps access to the anterior compartment, and external rotation helps access to the posterior compartment. Also, external rotation induces a tensioning of the ligamentum teres allowing visualizing all the synovium of the acetabular fossa. If synovectomy of this area is necessary, the curved instruments and different surgical approaches are essential.

70.3.3 Tips and Pearls

It is useful to use a 70° oblique optic as a periscope: according to its rotation, it will allow visualization of the femoral neck, the capsule, the orbicular ligament and capsular recesses.

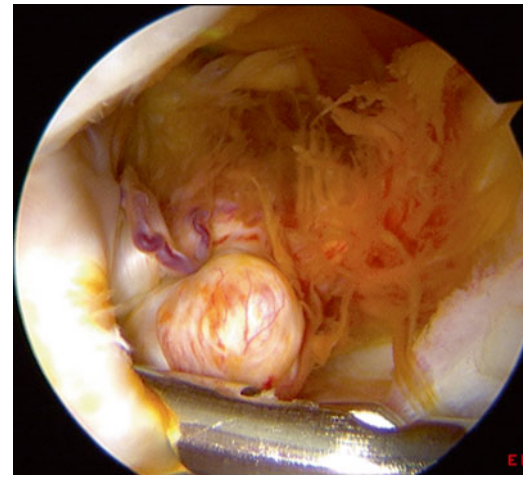

Fig. 70.9 Mechanical synovectomy with a 4.5 angulated shaver of the inferior recessus of the hip in the case of a villonodular synovitis

Capsulotomy is an important part of the procedure. It has to be adapted to the location and extension of the synovitis resection. If subtotal synovectomy is necessary, section of the orbicular ligament is recommended.

It is essential to master the different surgical arthroscopic approaches. They will be used depending on the area of the pathological synovial to reach. Some access requires switching optical and instrumental tracks.

Access to the entire central compartment will be facilitated by setting internal or external rotation of the limb.

70.3.4 Complication

The risk of bleeding in the context of inflammatory synovium exists. It is rarely a major complication but it can obscure the procedure. In this case, the pressure of the irrigation fluid should be higher in order to diminish bleeding and to help thermocoagulation of the vessels.

Extra-articular fluid extravasation is an unfrequent complication. Possible risk factors can be a prolonged operative time, a high pressure of the irrigation fluid, and an extended capsulotomy [19]. Those risk factors are mostly present in hip arthroscopy for synovectomy.

70.3.5 Literature Overview

The results of arthroscopic removal of chondroma or osteochondromas were analysed [2, 24, 27]. They are good and excellent in 48–57 % of cases according to the literature with a conversion to total hip replacement (THR) in 17 % at a mean follow-up of 6 years [2, 27]. Arthroscopy can be considered as the reference for the treatment of hip chondromatosis. However, the recurrence rate is high (16.2 % re-arthroscopy). Open surgery for synovectomy may have a lower recurrence rate but a greater morbidity with a higher conversion rate to THR.

Localized forms of villonodular synovitis (VNS) heal after removal of the nodule [1]. It should be realized under arthroscopy, with almost no risk of recurrence if resection is performed in healthy area with a large resection of the pedicle.

Concerning diffuse forms of VNS treated by arthroscopic synovectomy, each articular area must be methodically explored and cleaned to be as complete as possible. The main difficulty of a complete synovectomy under arthroscopy is to access the posterior compartment. This difficulty is increased by the presence of blood vessels tangential to the posterior capsule, with therefore a bleeding risk. We must therefore remember that arthroscopic synovectomy cannot be total. It is only justified by its lower aggressiveness in a disease where recidivism after surgery is frequent (up to 50 %), leading to osteoarthritis [1, 13]. To reduce the high risk of recurrence, synovectomy may be preceded and/or completed by a synoviorthesis (a few weeks before and/or 1–6 months after the surgery) [45].

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Part VI

Wrist

Paolo Arrigoni

General Aspects on Wrist Arthroscopy

71

Loris Pegoli, Alessandro Pozzi, and Paolo Arrigoni

71.1 Diagnosis: Clinical and Radiological

The first description of wrist arthroscopy was given in 1979; since then this technique saw a huge development, both in terms of technological progress and skill improvement. Nowadays wrist arthroscopy is, as a matter of facts, an extremely useful and sometimes necessary tool in the hands of the modern hand surgeon [1].

The implication of wrist arthroscopy ranges between the diagnosis of complex wrist pathologies such as ligament injuries and chondral lesions to the treatment of major wrist conditions. Many authors in fact contributed to the development of this technique once considered a mere diagnostic tool and today considered in some cases the gold standard for the treatment of particular wrist lesions.

L. Pegoli (✉)
Responsabile Servizio Chirurgia della Mano,
Casa di Cura San Pio X, Milano, Italy
e-mail: info@drpegoli.com

A. Pozzi
Servizio Chirurgia della Mano,
Casa di Cura San Pio X, Milano, Italy

P. Arrigoni
Divisione di Ortopedia II – Policlinico San Donato,
Member of the Elbow Committee – European Society of Sport Traumatology, Knee Surgery Arthroscopy (ESSKA), Milano, Italy

The aim of this chapter is to give to the reader an overview of what is a modern wrist arthroscopy and a glance of what is the technological state of the art almost 40 years after its first introduction in the medical world.

Before describing what is needed to perform such procedure, it is mandatory to step back and have a brief look how to evaluate a wrist before inserting an arthroscope. The two main diagnostic pillars are the clinical and the instrumental evaluation. It won't be stressed here the importance of each wrist test and all the radiological signs that can be acquired with modern technologies.

The clinical examination in the author's opinion is still fundamental to guide the surgeon in a correct diagnosis pathway. The examination of a wrist starts with the inspection of it, looking for signs of swelling, irritation, and asymmetry. In many cases it is very useful to compare a painful wrist to the other, looking for discrepancy. Another important item that does not have to be underestimated is the evaluation of the clinical history, the mechanism of the injury, and the evolution of the pain over the time [2].

It is mandatory to check for ligament instability, such as signs of scapho-lunate or distal radio-ulnar joint instability, presence of ulnar pain and trigger points (anatomical snuffbox pain, pain at the level of the ulnar or the radial styloid, etc.).

With a proper wrist evaluation, the clinician is then ready to step forward in his diagnostic algorithm and is then ready to require some

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instrumental evaluation of the wrist. The first line of evaluation passes from the radiological evaluation and in some cases from the ultrasound evaluation too.

The standard radiographic projections are of course very important but there are conditions that can be spotted by special views. A radiograph taken under ulnar or radial deviation can give information on the biomechanics of the wrist together with the pencil view or the projection under stress that can spot an increased angle between carpal bones or an abnormal distance between two or more of them, indicating the presence of a soft-tissue lesion. Ultrasounds are very effective in detecting tendon sheet swelling; they give us information on tendon gliding and integrity and can also be useful in the diagnosis of wrist ganglions.

The second line of evaluation includes CT scans, MRI scans, and arthrography. It is well established that CT scans give surgeons an enormous amount of information on the bony anatomy that is far better than any other technique. In case of complex fractures or under suspicion of a bony lesion of one of the carpal bones that is not clear on radiographs, a CT scan should be acquired to assess the gravity of the fracture or to confirm the presence of such a lesion or not.

The MRI scan can theoretically give to surgeons all the information that CT scans lack to provide on soft tissue. It is very useful for the diagnosis of triangular fibrocartilage complex (TFCC) tears, ligament strains or ruptures, cartilaginous defects, or intra-articular synovitis. It has been clarified though that the specificity and the sensitivity of MRI scans are lower than the one of a diagnostic arthroscopy [3].

The arthrography could still be useful to confirm the presence and to assess the severity of a lesion spotted during an MRI scan. A communication between the distal radioulnar joint and the radio-carpal joint should be significative of a major TFFC tear as well as a communication between the latter and the midcarpal joint should suggest a major lesion of the intracarpal ligaments of the first row [4].

The diagnostic arthroscopy should therefore be reserved a third and last line of the diagnosis pathway, due to the higher invasiveness of the procedure. The arthroscopy has for sure the best sensitivity and sensibility for diagnosis of chondral wrist lesions and ligament injuries, as well as for TFCC tears. It can also be associated with therapeutic gestures such as joint debridement, refreshment of the lesion site, and synovectomy.

71.2 Instrumentation: Basic and Advanced

Traditionally the arthroscopy is performed under traction. Although it has been described the possibility of doing an arthroscopy without traction, there is nowadays general agreement that traction gives more working space, relaxes the different structures, and offers a better view of the joint. Several methods have been described and are available to obtain wrist traction. The authors prefer a traction tower that allows modulating the strength applied to the wrist and permits full access to all the aspects of the wrist (Fig. 71.1).

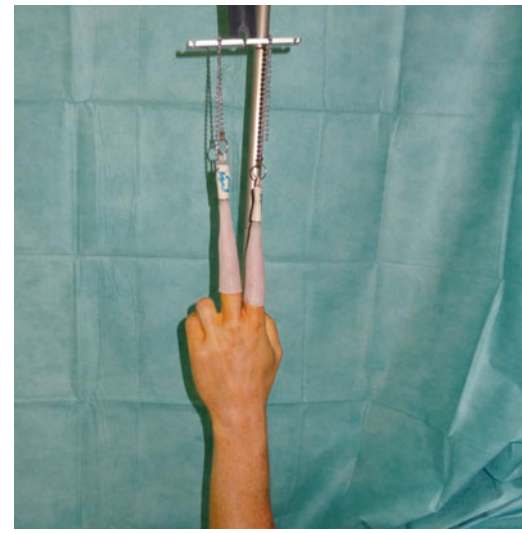

Fig. 71.1 Traction tower to perform a wrist arthroscopy. With this system it is possible to adjust the tension applied to the wrist according to the patient anatomy and the needs of the surgeon

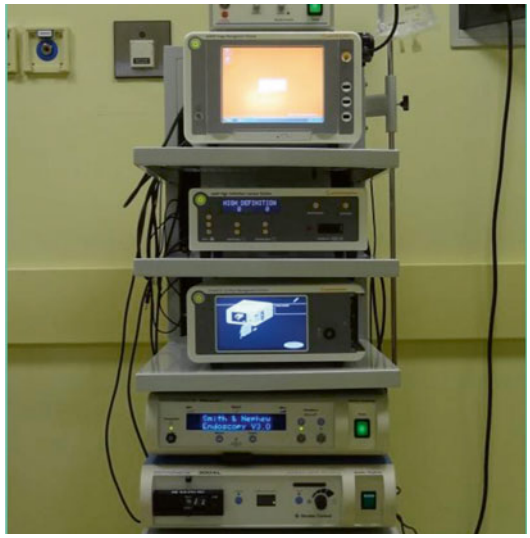

Fig. 71.2 Arthroscopy column. It includes screen, light source, video recording device, shaver water pump, and electrothermal system

The preferred method for fixing the hand to the traction tower is by fingertraps that are safe, do not occupy space, and distribute forces along a wide surface.

An arthroscopic column is needed, and it should have the possibility to allocate a shaving device and a video recorder; while the first is almost mandatory to perform any procedure, we think that the latter is also extremely useful and highly recommended although not strictly necessary to perform a wrist arthroscopy (Fig. 71.2).

A special consideration should be done for water. If it is true that in other joints the presence of a water pumped inside the joint is necessary to complete the procedure for the wrist, the presence of water, either pumped directly into the joint or just falling into it by gravity, is not necessary. There are actually two different approaches to wrist arthroscopy: the so-called dry arthroscopy does not require presence of water unless small volumes for washing the joint from debris, while the wet arthroscopy implies water from the very beginning of the procedure [5]. Each of the two approaches has pros and cons. The authors think that for diagnostic procedures and relatively short interventions, the dry approach is preferable, while the wet approach should be reserved for more complex procedures.

The basic instrumentation that is needed for a wrist arthroscopy is showed in the picture (Fig. 71.3) and is mainly composed by a skin marker, a needle to identify the portals, a blade to incise the skin over the portals, scissors, forceps, a mosquito to blunt dissect the subcutaneous tissue and the joint capsule, a trocar to insert the optic, and a probe to test the stability of ligaments, to assess the dimension of a TFCC tear, or to test its stability. A grasper can be also used during TFCC repair procedures to recover suture from the joint.

As for the optic, there are different calibers that can be used for wrist arthroscopy. Usually there are three different diameters that can be considered: 2.9 mm, 2.4 mm, and 1.9 mm. The smaller the diameter, the more it gets fragile and easy to brake, but also the smaller it gets, the easier will be for the surgeon that has enough practice to move the optic inside the small joint space, being also less invasive. The authors suggest using a 1.9 mm optic.

The last instrument that can be included in the basic instrumentation is the shaver. It can be used during wrist arthroscopy to perform synovectomy, to regularize the margins of a TFCC lesion, or to perform a joint debridement. Several shavers are actually available on the market.

More advanced instrumentation includes burrs, necessary to complete more complex procedures such as wafer resection of the ulnar head, radial styloidectomy, or core decompression of the lunate for Kienbock's disease. Electrothermal devices can be used during wrist arthroscopy for the treatment of cartilaginous lesion in early stages or for the regularization of synovial proliferation. It has to be reminded that the utilization of those system necessary implies the presence of water and therefore cannot be used during a dry arthroscopy.

For complex procedures such as the treatment of distal radius articular fractures, partial carpectomy, or partial carpal fusion performed under arthroscopy, there is also a various range of drills, trocars, probes, and graspers.

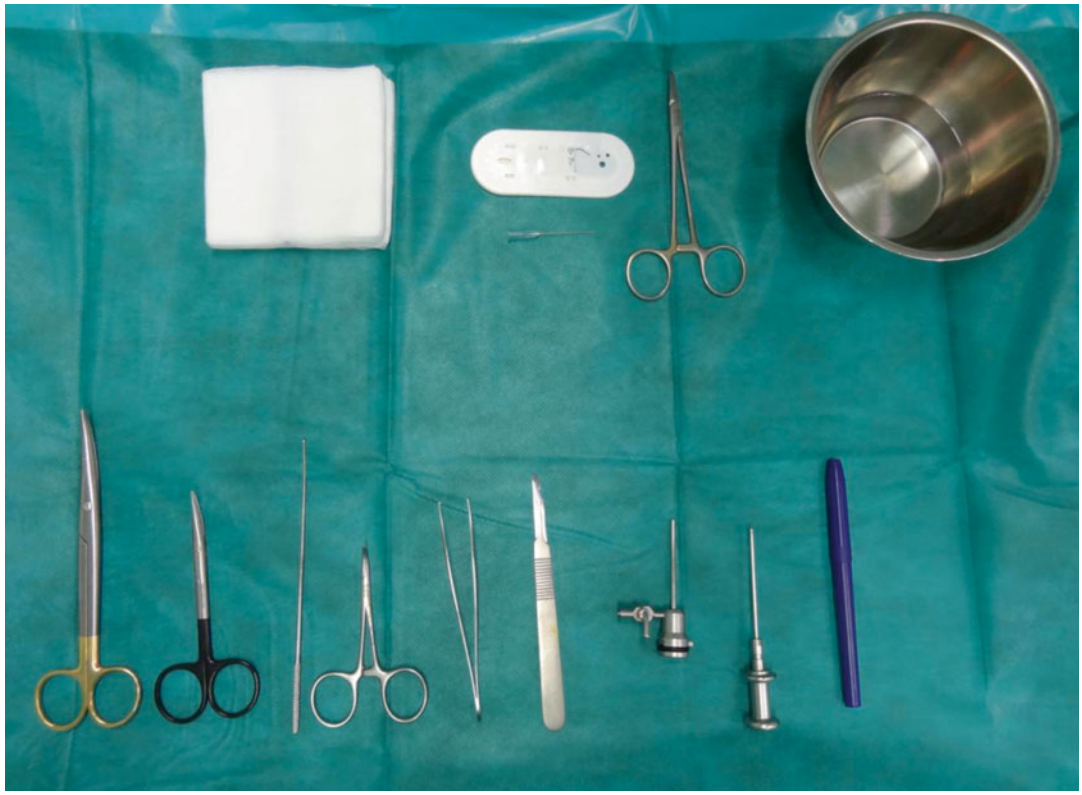

Fig. 71.3 The basic instrumentation for a wrist arthroscopy

71.3 Classification of Injuries

As mentioned above, diagnostic arthroscopy is an extremely useful tool to make a correct diagnosis and also to classify already diagnosed conditions according to their severity.

It is in fact very hard to classify a soft-tissue lesion just on the base of an MRI scan. There are at least three different and relatively common diseases that can be properly classified just during an arthroscopy. These include TFCC lesions, scapholunate ligament lesions, and chondral lesions.

The TFCC tears' most common classification is the Palmer classification [6]. This system divides TFCC tears in two main groups: in group 1 are included acute injuries, while in group 2 are included chronic and degenerative injuries. The complete classification will be discussed further in the dedicated session.

Another important arthroscopically classification is the Geissler Classification for scapho-lunate lesion. It divides the lesions in four different stages according to their severity [7]. Also in this case, the complete classification will be found later in this book.

The last important condition that requires a diagnostic arthroscopy to complete the diagnosis pathway is chondral lesions. The MRI scans can detect cartilaginous defect in a wrist, but the thickness of the cartilaginous layer in this not load-bearing joint is relatively small compared to other joints such as knees or ankles. Therefore the MRI cannot be accurate in assessing the severity of a chondral defect [3]. The diagnostic arthroscopy is mandatory in our opinion before giving to patients any indication for partial carpal fusion or partial carpal resection.

In our experience it happened to find better or worse condition during the arthroscopy compared to the diagnostic founding acquired up to that point, modifying according to the new findings our indication.

Here are the complete classifications:

Group 1:	A. Central lesion
	B. Ulnar tear
	C. Ulnocarpal ligament rupture
	D. Radial tear
Group 2:	A. TFCC wear
	B. TFCC wear with lunate and/or ulnar chondromalacia
	C. TFCC perforation with lunate and/or ulnar chondromalacia
	D. TFCC perforation with lunate and/or ulnar chondromalacia and lunotriquetral ligament perforation
	E. TFCC perforation with lunate and/or ulnar chondromalacia, lunotriquetral ligament perforation, and ulnocarpal arthritis

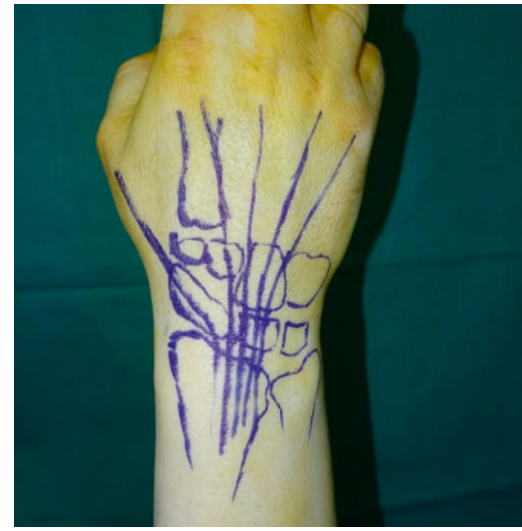

Fig. 71.4 After traction is applied landmarks can be marked on the patient's hand

71.5 Portals

Patient is supine, with the shoulder abducted at 90°; the elbow flexed at 90° and the wrist is in neutral position. The traction is then applied as mentioned above, and only after the traction is positioned, it is possible to draw skin landmarks with a skin marker (Fig. 71.4). The extensor tendons should be drawn, the Lister tubercle and finally the other bony structures can be identified.

Standard portals are mainly located dorsally because of the lack of neurovascular structures compared to the volar aspect of the wrist and the structural importance of the volar ligaments compared to the dorsal ones.

Dorsal portals usually took their name on the base of the extensor compartments that they lay between.

The standard portals are the following: the 1–2, the 3–4, the 5–6, and the 6U portal [8].

The first portal, the 1–2 (Fig. 71.5), is located between the ABPL and EPB tendon on the radial side and the radial wrist extensors on the other. It gives a good view of the dorsal capsule and of the ulnar aspect of the joint.

The 3–4 portal is one of the most useful portal; it lies between the EPL just above the Lister tubercle and the common extensor

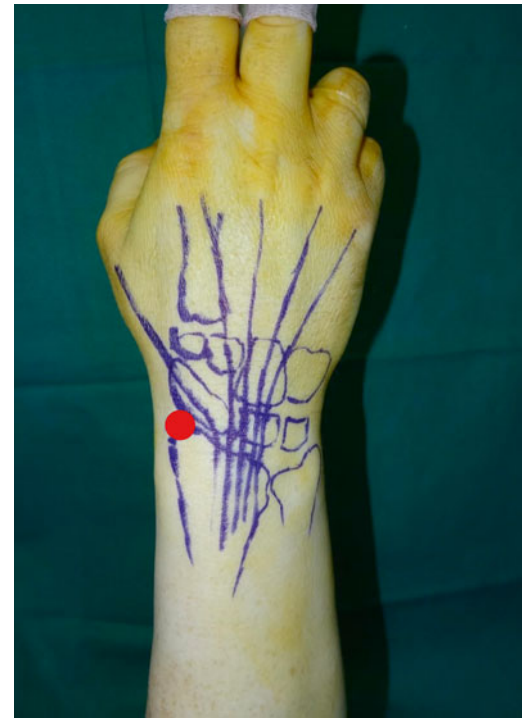

Fig. 71.5 The *dot* on the picture shows the position of the 1–2 portal, located between the first extensor compartment and the radial wrist extensors

(Fig. 71.6). It has a comprehensive view of all joints and is extremely useful during diagnostic procedures.

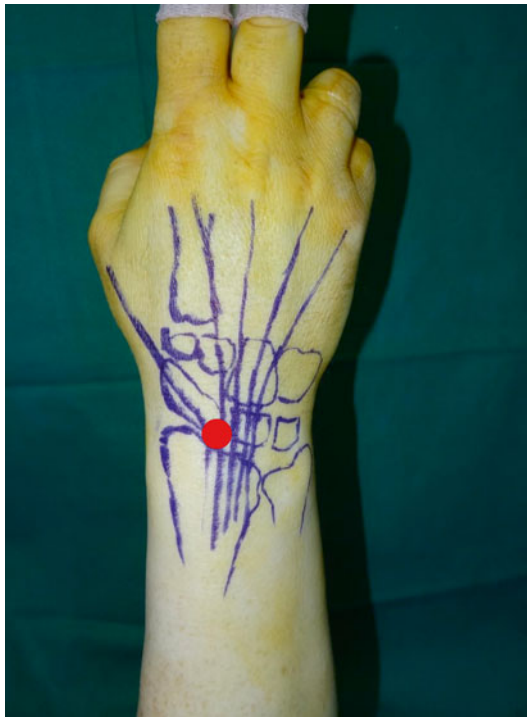

Fig. 71.6 The *dot* on the picture shows the position of the 3–4 portal, located between the EPL tendon and the EDC. Note that this is one of the most useful portals in wrist arthroscopy and is located just distally to the Lister tubercle

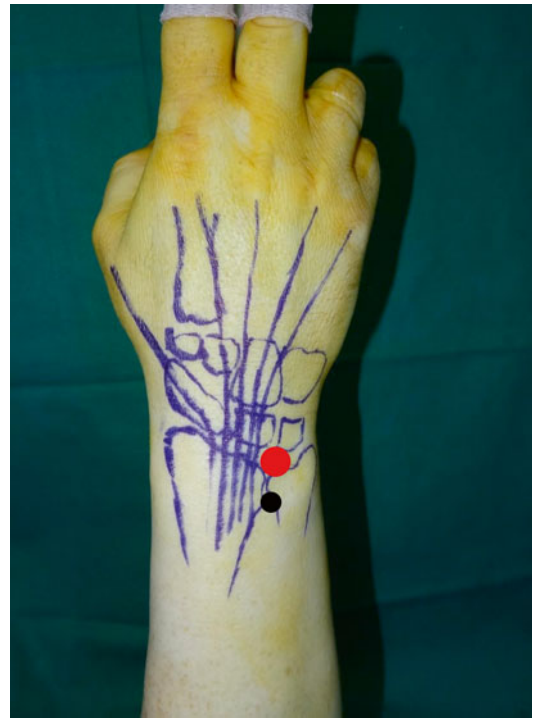

Fig. 71.7 The *bigger dot* on the picture shows the position of the 5–6 or also called 6R portal, located between the EDM tendon and the ECU. As well as for the 3–4 portal, this is one of the most important portals to access the radio-carpal joint. Just proximally to this portal, there is the DRUJ portal, which is represented by the *smaller and darker dot*

The 5–6 portal, also called 6 R, lays radially to the ECU (Fig. 71.7) between the latter and the extensor digiti minimi; together with the 3–4 portal, it allows the surgeon to achieve a complete view of the joint and swapping between the two portals with the optic, and the instrumentation allows to complete the majority of the procedures.

The last standard portal is the 6U that in this case is placed on the ulnar side of the extensor carpi ulnaris tendon. It gives a perfect view of the dorsal capsule and a complete view of the radial aspect of the joint; from here it is also easy to debride TFCC tears with a shaver. Attention to the dorsal branch of the ulnar nerve should be paid when creating this portal as the distance between the nerve and the portal is reduced.

Another dorsal portal is the S-T portal, located distally to the 1–2 portal, that allows to have a clear view of the scapho-trapezial joint and the DRUJ portal located proximally and radially to the 6R portal, just beneath the TFCC; it gives a clear view of the distal radioulnar joint and the proximal aspect of the TFCC and is very useful when a good view of the ulnar head is needed (Fig. 71.7).

The last two dorsal portals are the midcarpal portals; one is located ulnar to the head of the capitate and is therefore called MCU, and the other one is located on the radial aspect of the capitate and is called MCR. Both these portals can be used for the camera or for an instrument and switched easily according to necessity (Fig. 71.8) [9].

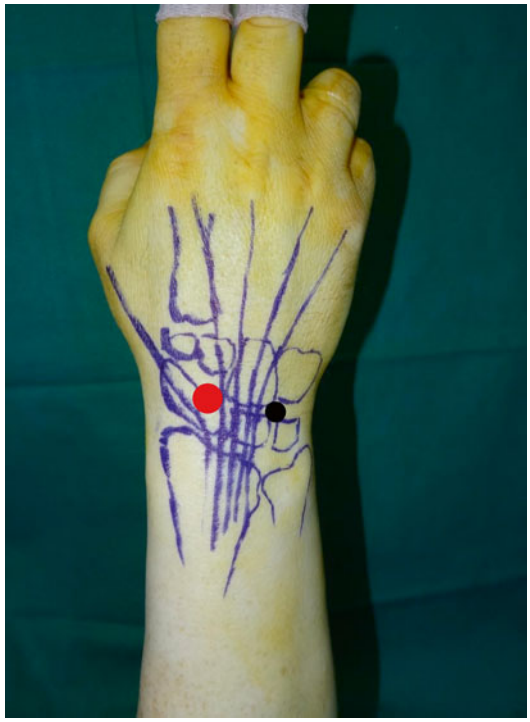

Fig. 71.8 The *bigger dot* on the picture shows the position of the MCR portal, located just radial to the capitate; the smaller dot represents the position of the MCU portal. Through these two portals it is possible to access the midcarpal joint

Volar portals have been described as well; one is the radial volar portal (VRP) that is located just beneath the FCR tendon sheath on the radial side. Attention should be made in this case in order to avoid lesions of the palmar cutaneous branch of the median nerve that lies ulnar to the tendon. The second volar portal is the ulnar one (VUP). The latter is located just proximally to the ulnar styloid and ulnar to the ulnar artery and nerve. It is located on the ulnar side of the FCU tendon between the volar ulnar ligaments and the volar insertion of the TFCC.

In Table 71.1 presents the most common indications for wrist arthroscopy and the portals that could be needed to perform the operation correctly are presented (Table 71.1).

Table 71.1 The following table shows the commonest indications for wrist arthroscopy (column 1); the surgical procedures are defined (column 2); useful portals for specific procedures (column 3)

Diagnosis	Action	Portals
Dorsal ganglion cyst	Removal	3–4
		1–2
		6R
Volar ganglion cyst	Removal	3–4
		1–2
		6R
		Volar
TFCC	Diagnosis	3–4
	Repair	4–5
	Debridement	6R
		DRUJ
Ulna plus	Ulna head resection	3–4
		4–5
		6R
Radio scaphoid impingement	Radial styloid resection	3–4
		1–2
		6R
Scaphoid nonunion	Bone grafting	3–4
		4–5
		6R
		MCU
		MCR
Scaphoid fractures	Assisted fixation	3–4
		4–5
		6R
		MCU
		MCR
Lunate cyst	Bone grafting	3–4
		4–5
		6R
		MCU
		MCR
Kienbock	Bone grafting	3–4
		4–5
		6R
		MCU
		MCR
Scapho-lunate ligament	Diagnosis	3–4
	Shrinkage	4–5
		6R
		MCU
		MCR

(continued)

Table 71.1 (continued)

Diagnosis	Action	Portals
Lunotriquetral ligament	Diagnosis	3–4
	Shrinkage	4–5
		6R
		MCU
		MCR
Synovitis	Synovectomy	3–4
		4–5
		6R
		MCU
		MCR
Loose body	Removal	3–4
		4–5
		6R
		MCU
		MCR
Cartilage	Proper evaluation	3–4
		4–5
		MCU
		MCR
Adhesions	Arthrolysis	3–4
		4–5
Distal radius fractures	Assisted fixation	3–4
		4–5
		6R
		Volar

71.6 Complications and How to Avoid Them

Although wrist arthroscopy is a relatively safe technique in expert hands, it is not completely complication-free. The learning curve is quite steep at the beginning, especially for surgeons that have no experience at all with arthroscopy in general, but can be easier for surgeons that are already skilled in knee or shoulder arthroscopy, for example. The basic technique for arthroscopy is the same for the wrist as for other districts; the main difference is that the wrist is relatively a small joint compared to shoulders and knees; therefore it's easier to cause iatrogenic damage to the surrounding structures [10].

Edema and joint swelling are quite common after a wrist arthroscopy, and they should resolve spontaneously within 2 weeks. The edema is quite common in the case of wet arthroscopy. For this reason it is highly recommended to put a bandage after each procedure and even in the case of diagnostic procedure is advisable to send patients to a therapist after 1 or 2 weeks to quickly recover a full range of motion and treat the edema.

The beginner should start with diagnostic procedures, performed under surveillance of a senior colleague, learning how to recognize the different structures and how to avoid damaging them.

The most common complication due to a wrist arthroscopy is the iatrogenic chondral lesion. It is very easy in fact to cause a damage of the radial or the lunate cartilage when entering the joint if the trocar is not inserted with 10–15° of dorsal inclination. It is also easy to bump with the optic on the surface of the carpal bones moving from the radial to the ulnar side and vice versa.

Another common complication is to produce a tendon lesion when attempting to make a portal. It is true that the dorsum of the wrist is not particularly rich of neurovascular structures, but nevertheless is rich of tendons. A common mistake is to damage a tendon with the scalpel during the skin incision if the surgeon is not sufficiently accurate or to grasp one of them with a mosquito during the blunt dissection that is necessary to reach the capsular plain. Finally a tendon can be hooked by a suture that has been made to repair a TFCC lesion. A good tip for the beginner would be always to check for the integrity of the EDM when repairing a dorsal TFCC tear.

There is a risk of nervous lesion, mostly regarding the dorsal branch of the ulnar nerve that lies not so far from the ulnar portals. Lesions of this structure vary from neurapraxia to neurotmesis. Other nervous trunks that can be damaged are the superficial sensory branches of the radial nerve that can be damaged while making the radial portals or a lesion of a major nervous trunk such as the median nerve or the ulnar nerve while creating the volar portals or while attempting to repair a lesion of the volar capsule.

The last complications that can be seen during wrist arthroscopy are vascular lesions. The spectrum of these lesions ranges between the complete rupture of a major vascular trunk to the obliteration of it or to the formation of aneurisms of those vessels. An interesting case of arterial lesion has

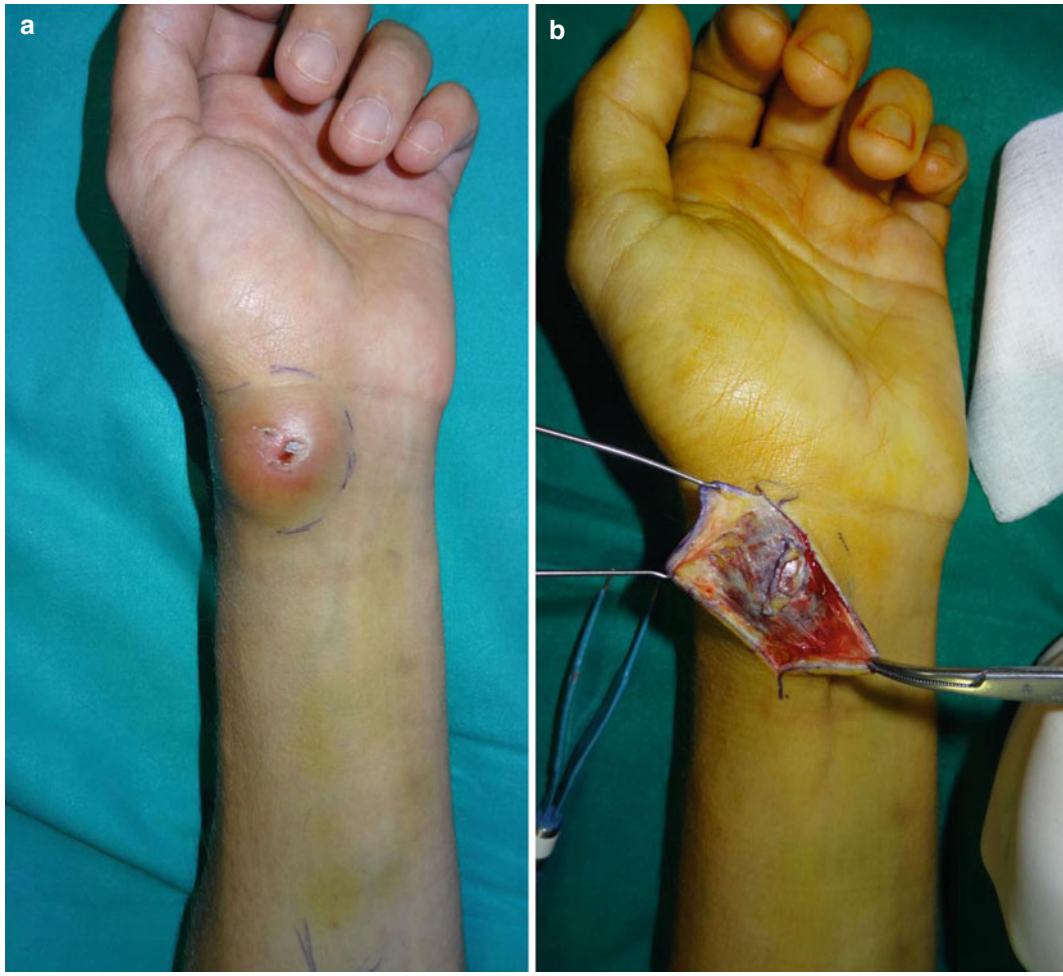

Fig. 71.9 An example of a complication occurred during a wrist arthroscopy. The patient developed an aneurism of the radial artery after an arthroscopic removal of a volar ganglion (**a**). The patient underwent a second surgery to remove the aneurism that was probably due to an iatrogenic injury of the radial artery occurred during the first surgery (**b**)

been recorded in our center as showed in Fig. 71.9; other authors reported similar cases [11].

In conclusion is advisable to perform such procedure after a proper training that includes courses and lectures. Wrist arthroscopy is an interesting technique that is extremely useful if carried out after a proper learning curved.

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Arthroscopic Resection of Wrist Ganglia

72

C. Mathoulin, J. Garret, M. Gras, and V. Mesquida

72.1 Introduction and Indications

A dorsal wrist ganglion is a benign tumor that can disappear spontaneously. Surgery used to be reserved for the rare painful ganglia or more often for cosmetic concern. Recent cadaver studies allowed us to precise the scapholunate (SL) region which is a complex composed of three distinct elements:

- The dorsal segment of the SL ligament
- The dorsal intercarpal ligament (DIC)
- The dorsal capsulo-scapholunate septum (DCSS) [20], which unites the SL ligament to the DIC and contributes to the stabilization of the SL bony interval

The hypothesis of the origin is a mucoid dysplasia associated with ganglia intracapsular and extrasynovial and occurs at the level of this dorsal SL complex. Medially, the dysplasia herniates into the wrist joints, usually into the midcarpal joint. Laterally, the dysplasia extends by a pedicle between the DIC and the radiolunotriquetral (RLT) ligament, either distally beneath the DIC or laterally toward the radial border of the radiocarpal compartment.

Conservative treatment is probably the best primary treatment for dorsal wrist ganglia owing to the benign character and the frequency of its spontaneous disappearance by 6 months. Arthroscopic resection is a simple technique, minimally invasive. The patient must be informed of the recurrence rate of 11 % [9], similar to that following open surgery. Arthroscopic resection avoids the complications of open excision, especially unsightly scarring and joint stiffness.

A scapholunate instability can be associated with a dorsal wrist ganglion and should not be missed. Arthroscopic treatment allows to test and repair the SL ligament if necessary.

Volar wrist ganglia are less common. They occur mainly in the radiocarpal joint, and rarely in the midcarpal joint, evidence of scapho-trapezio-trapezoid (STT) osteoarthritis. They are due to capsule destruction across from the volar insertion of the scapholunate ligament in midcarpal joint. Like dorsal ganglia, these are benign tumors. The risks are related to the proximity of the cyst with the radial artery and nerve, especially in open procedure. Arthroscopic resection is a simple and reliable procedure as long as the surgical technique is performed correctly, given that the intracapsular origin of the

C. Mathoulin (✉) • M. Gras
Institut de la Main, 23 rue Bizet,
Paris 75116, France
e-mail: cmathoulin@orange.fr

J. Garret
Clinique du Parc, 155 Ter Boulevard de Stalingrad,
Lyon 69006, France

V. Mesquida
Médipole de Savoie, service chirurgie du
membre supérieur, 300 avenue des Massettes,
73190 Challes les Eaux, Milano, Italy

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ganglion is far away from tendons, ligaments, and muscles.

Surgical treatment is indicated only in cases where the ganglion causes pain or is unsightly. Its recurrence rate is similar to open resection, but without the risk of injuring tendons, ligaments, nerves, and muscles. Arthroscopic resection involves less scarring, minimal time away from work, and faster functional recovery.

72.2 Techniques and Tips and Pearls

72.2.1 Surgical Technique for Arthroscopic Removal of Dorsal Wrist Ganglia

72.2.1.1 Patient Preparation

This is done as a day-case surgery under regional anesthesia. The tourniquet is placed on the arm near the elbow to minimize the lever arm during upward traction. Countertraction is applied on the tourniquet. After exsanguinating and placing an upper limb sterile drape, traction is administered using a traction tower – it is possible to use the same one as used for shoulder arthroscopy. The required traction of 5–7 kg is applied using Chinese finger traps. The patient lies supine, the shoulder at 90° abduction. If a traction tower is used, it is placed on the arm table. The surgeon is at the head of the patient with the assistant beside or facing the surgeon. The arthroscopy column may be on the other side of the patient facing the surgeon or sometimes facing the arm table (Fig. 72.1).

72.2.1.2 Assessment of the Size and Position of the Ganglion

The first step is to locate the proximal and distal extent of the ganglion using a needle. The scope is inserted through the ulnar midcarpal portal and the exact limits of the capsule are identified (Fig. 72.2a, b).

72.2.1.3 Exploration of the Midcarpal Joint

The MCU portal is the simplest arthroscopic wrist approach. The blunt trocar is introduced, followed by the scope.

Midcarpal exploration usually reveals a dorsal synovial bulge at the scapholunate interval corresponding to the intra-articular portion of the ganglion. Associated SL instability must be excluded.

72.2.1.4 Resection of the Dorsal Mucoid Dysplasia at the Midcarpal Interval Through a Transcystic Approach

A needle is introduced through the ganglion into the midcarpal joint via the radial midcarpal portal (MCR). A direct transcystic MCR approach is established, and an aggressive cutter, the shaver, is introduced through the ganglion into the joint (Fig. 72.3a–c). The dorsal pathological capsule representing the mucoid dysplasia herniating into the midcarpal joint is resected under vision thanks to the scope angulation and triangulation effect. This resection is relatively easy compared to resection of a healthy capsule. Sometimes it is easier to use a basket grasper to resect some parts of the capsule. The DCSS and the continuity of the DIC must be preserved. Electrocoagulation should be avoided for risk of cartilage and extensor tendon lesions.

72.2.1.5 Resection of the Ganglion Wall

It is now possible to bring out the scope from inside outward through the joint capsule at MCR. Vision is now obscured by the cyst wall.

The shaver is always in MCR position but extra-articular. This part of the procedure is more of an endoscopy than an arthroscopy (Fig. 72.4a, b). Caution is required at this stage to avoid extensor tendon injury. It is easy to move the scope and the shaver from top to bottom to resect all the walls of the cyst and immediately obtain a cosmetically perfect final result. The resection is done bit by bit with the shaver until the extensor tendons are visible at the end (Fig. 72.5).

72.2.1.6 Closing and Postoperative Care

Classically, the arthroscopy portal incisions do not need to be sutured closed, only covered with a dressing, but sometimes Steri-Strips (3M, St. Paul, MN) are used to close the skin. Immediate

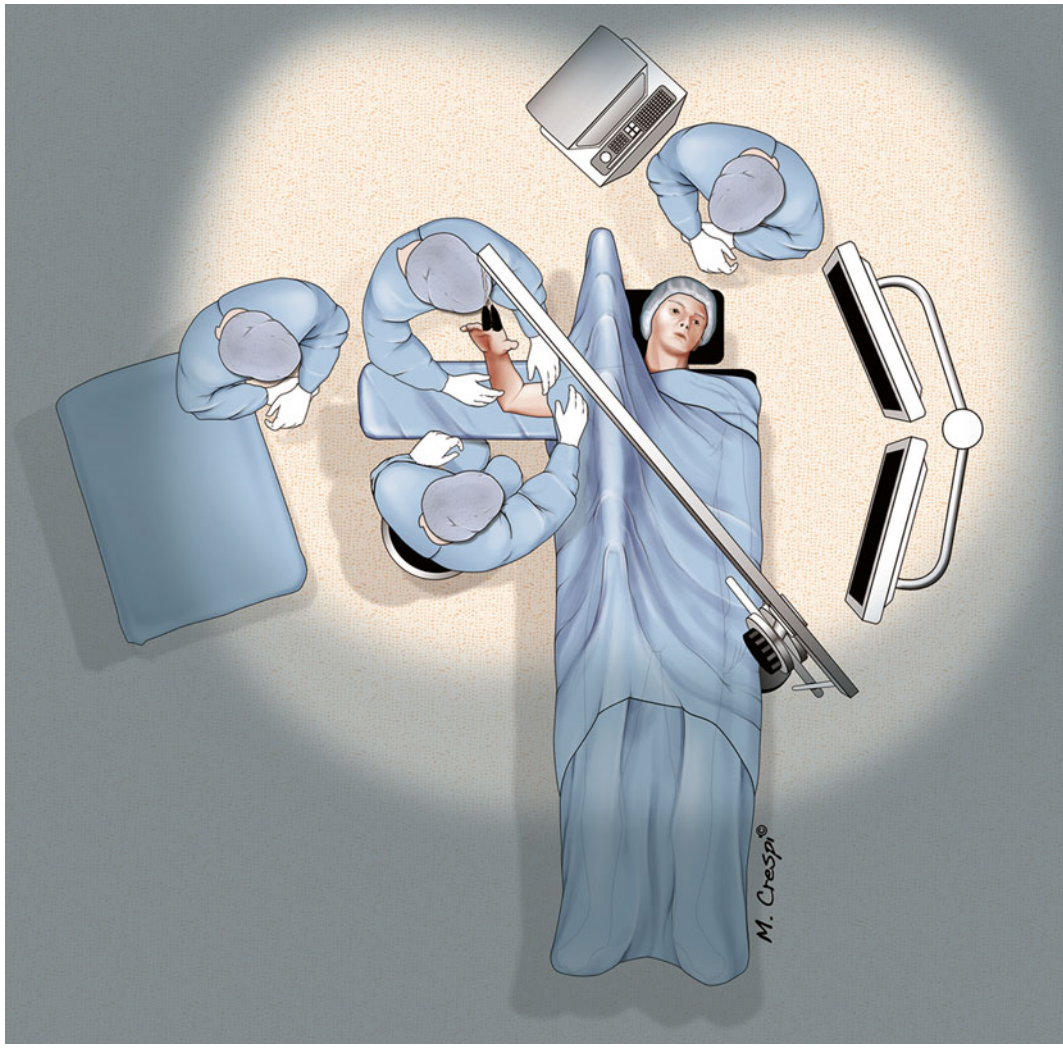


Fig. 72.1 Diagram showing the position of the patient and the operators. The surgeon is at the head of the patient

movement of the joint is encouraged, but without any forcing for 3 weeks.

72.2.2 Surgical Technique for Arthroscopic Removal of Volar Wrist Ganglia

72.2.2.1 Patient Preparation and Positioning

Surgery is performed on an outpatient basis under regional anesthesia. The patient is placed supine with the arm resting on an arm board and a tourniquet placed at the base of the upper arm. A traction tower is used to make the procedure easier; 5–7 kg (11–15.5 lbs.) of traction is sufficient. The ganglion in the volar wrist crease below the thumb is outlined with a skin marker (Fig. 72.6). This documents the volume of the ganglion before starting the procedure; this information is used at the end of the procedure to make sure all the cyst fluid has been removed.

72.2.2.2 First Surgical Phase: Intra-articular Assessment

The scope is typically placed in the 3–4 portal. After inspecting the various wrist compartments and making sure there are no other injuries, the position of the volar ganglion is determined from inside the joint. The scope is placed in front of

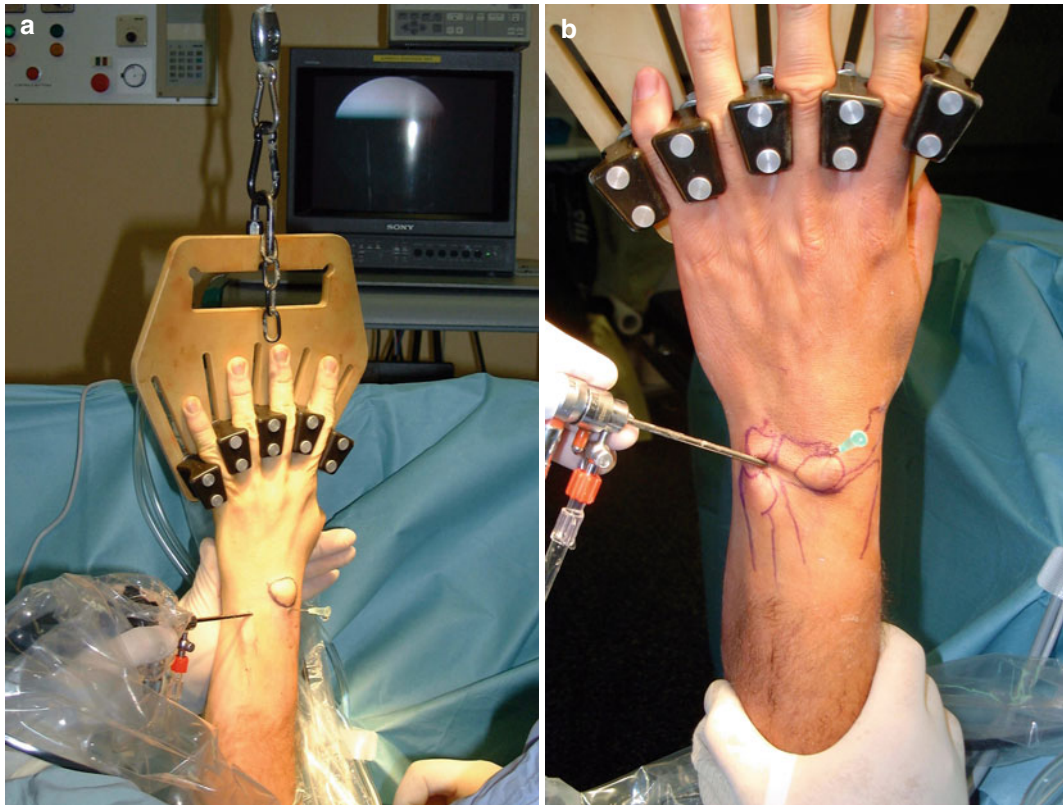


Fig. 72.2 (**a**, **b**) Operative view showing needle localization of the ganglion origin. (**a**) Proximal identification and (**b**) distal identification

the hiatus between the radioscaphocapitate (RSC) and long radiolunate (LRL) ligaments (Fig. 72.7a, b). By gently pressing on the swollen volar structure with a finger, the volar ganglion's poorly defined, frayed hypertrophic synovial membrane will bulge out between these two ligaments. The volar ganglion will be resected through this opening.

72.2.2.3 Second Surgical Phase: Identification and Resection of the Ganglion

The scope is placed in the 3–4 portal and a shaver is inserted through the 1–2 portal. The assistant holds the camera and scope. The surgeon holds the shaver in one hand and uses the other hand to push the ganglion toward the radiocarpal joint. The stalk of the ganglion can be resected by placing the shaver between the RSC and LRL ligaments (Fig. 72.8). Once the capsule is breached, visibility will be reduced because of the inflow of mucus into the joint, which is proof of a broken ganglion wall. The resection can then be made, starting from inside the joint and carefully continuing deeper toward the volar side. The shaver's gradual progression must be continuously monitored through the resection window until all the abnormal synovial tissue is removed. Direct pressure can be placed on the skin over the ganglion to help with the resection (Fig. 72.9). It is not necessary to remove the entire cyst wall. The shaver should not be moved outside the joint because of the risk of damaging the radial artery and median nerve. During the last part of this procedure, the presence of fat fragments (visible as small yellowing flakes) indicates that the cyst has been opened. The resection opening will be clearly visible, as will the flexor tendons in some cases (Fig. 72.10). It is important to make sure the ganglion has completely disappeared from

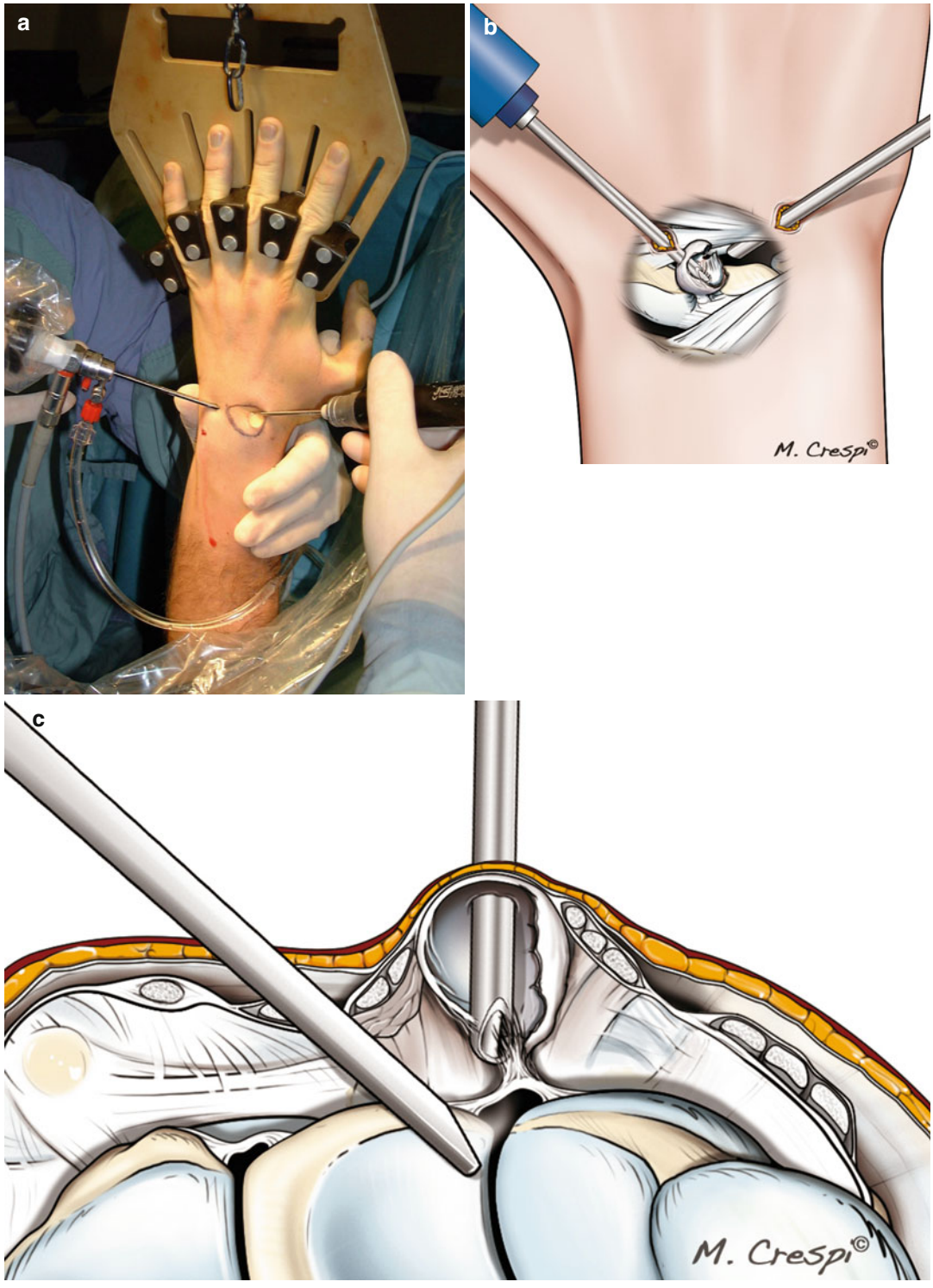
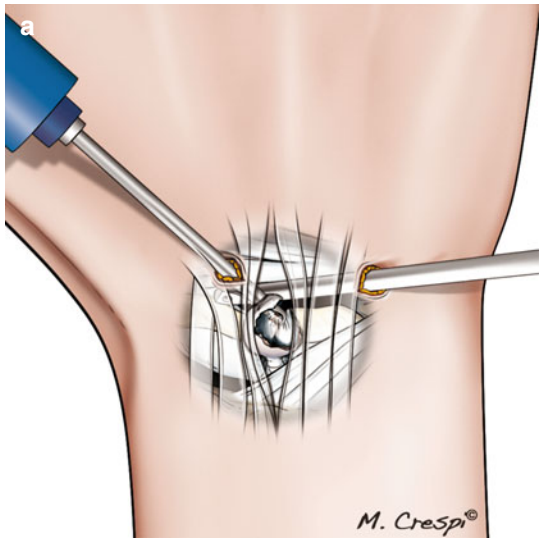


Fig. 72.3 (**a**) Operative view showing the scope in MCU and the shaver in a transcystic position. (**b**) Diagram showing scope and shaver positions. (**c**) Diagram showing the transcystic position of the shaver



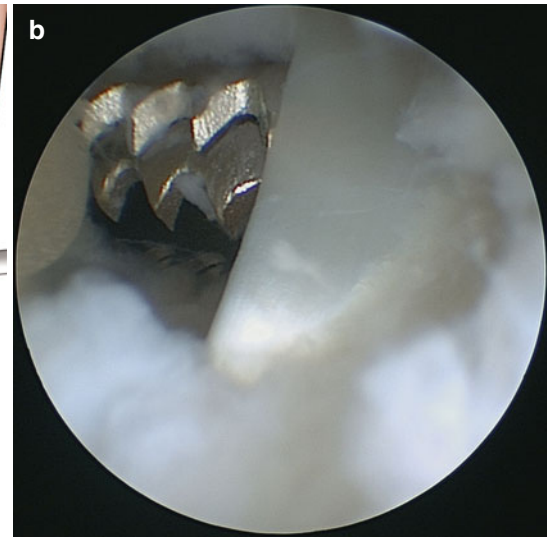


Fig. 72.4 (**a**) Diagram showing the scope position entering the MCU portal and exiting through the MCR to control the resection of the ganglion walls extra-articularly. (**b**) Arthroscopic view through MCR portal with the scope in MCU, showing the shaver resecting the cyst walls from inside out while the extensor tendons are protected

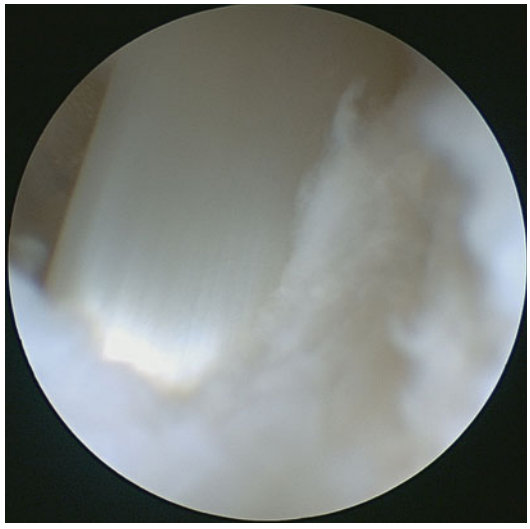


Fig. 72.5 Arthroscopic view through MCR portal from inside out with the scope in MCU, showing the extensor tendons after the resection of the cyst wall

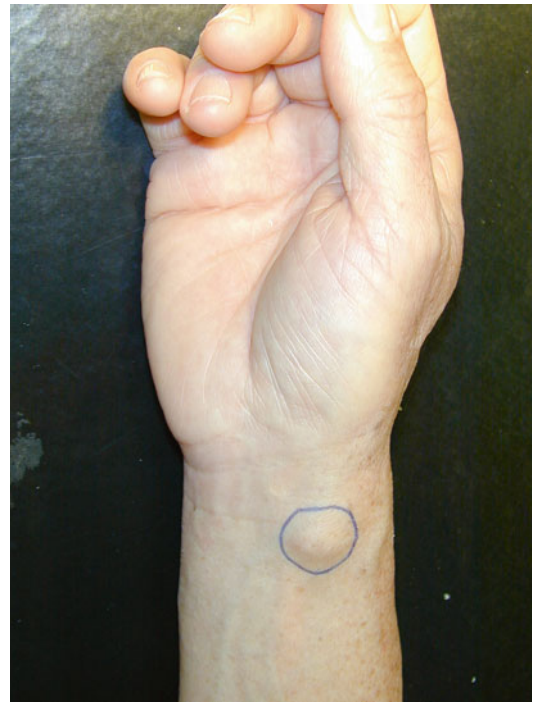


Fig. 72.6 Intraoperative view of a volar wrist ganglion being outlined before resection is carried out

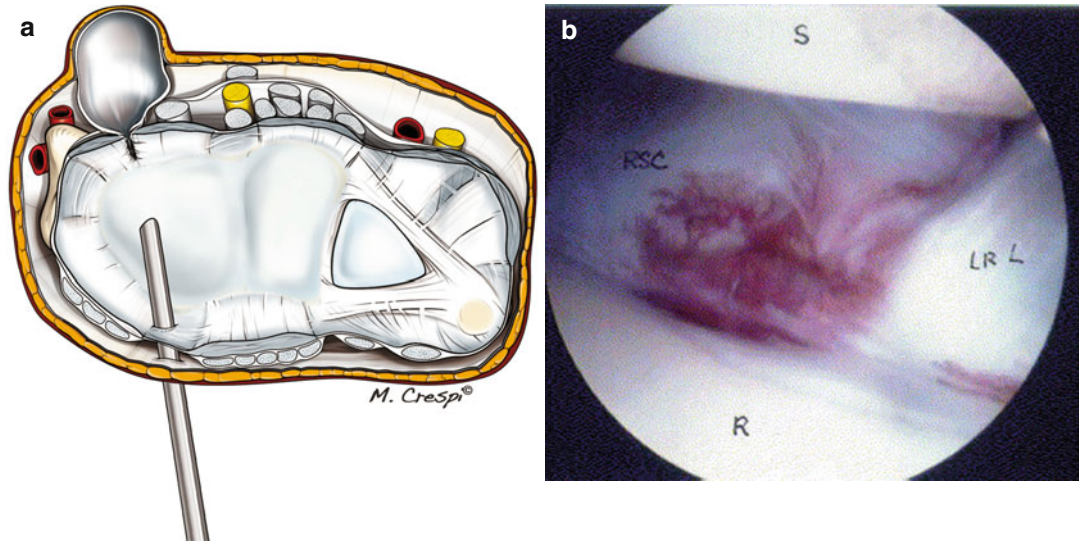
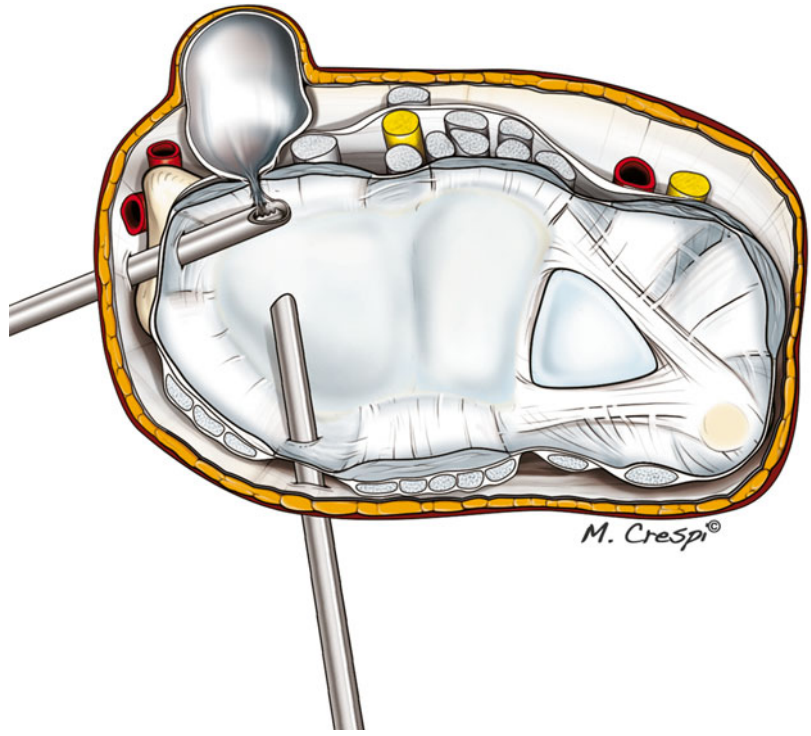


Fig. 72.7 Diagram (**a**) of the scope inserted in the 3–4 portal to locate the stalk of the ganglion between the RSC and LRL ligaments; intra-articular view (**b**) of the ganglion's stalk between the RSC and LRL ligaments

Fig. 72.8 Drawing of the scope in the 3–4 portal and the shaver in the 1–2 portal being used to start resecting the foot of the ganglion cyst



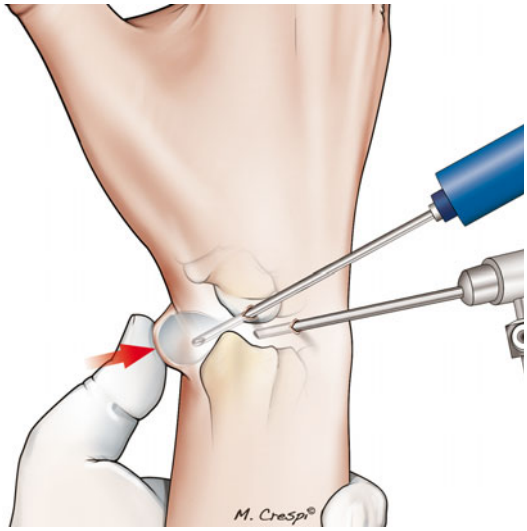


Fig. 72.9 Drawing of the hand and wrist viewed laterally with the scope in 3–4 and shaver in 1–2. The surgeon's index finger presses on the volar ganglion to make it easier to resect with the shaver

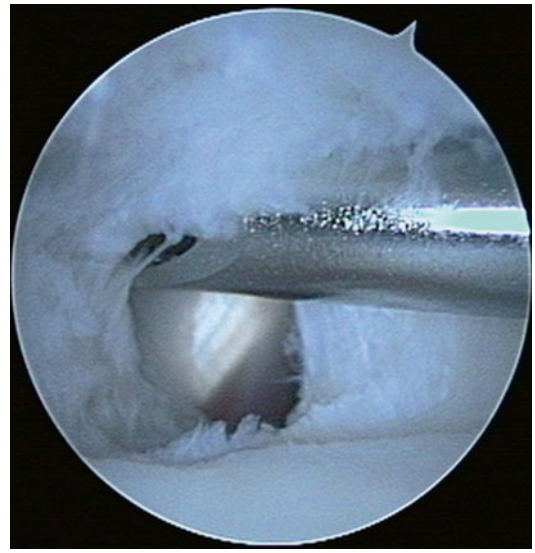


Fig. 72.10 Intra-articular view of the flexor pollicis longus tendon after the cyst has been resected; the RSC and LRL ligaments remain intact

the volar wrist crease below the thumb. This step can be performed by placing the scope in the 6R or 4–5 portal; the shaver is placed in the 3–4 portal so that it is directly over the dihedral space that separates the RSC and LRL ligaments (Fig. 72.11).

72.2.2.4 Closure and Postoperative Care

The arthroscopy portal incisions do not need to be sutured closed, only covered with a dressing. Wrist motion is allowed immediately.

72.3 Complications

The various complications described after arthroscopic surgery as a wrist cyst lesions are sensory branches of the median nerve or the radial nerve (neurapraxia), lesions of the radial artery or its branches, tendon injuries (stents), and hematomas [5, 13–15, 17].

The complication rate varies from 0 % to 17.5 % (Table 72.1). For Fernandes et al. [18], the average rate of complications for the palmar cysts is 6.8 %.

No postoperative infection has been described in the literature. Similarly, no complications related to the scar were identified (sensitivity, aesthetics).

72.4 Summary/Results and Literature Overview

72.4.1 The Merits of Arthroscopic Surgery for Removal of Wrist Ganglia

Various conservative treatments for wrist ganglia exist such that the aspiration associated or not an anti-inflammatory injection [1–3], hyaluronidase injection [4], or yet simple immobilization [3]. Therapeutic abstinence may also be proposed because the spontaneous resolution of ganglion is 40–58 % [1, 5].

Nevertheless, several authors [3, 4] have demonstrated superiority of surgery compared to medical therapy on the risk of recurrence, major complication. In 2007, Dias et al. [1] highlight a recurrence rate of 39 % after ganglion surgery against 58 % with a suction processing. Similarly, in 2011, Khan [2] compares the

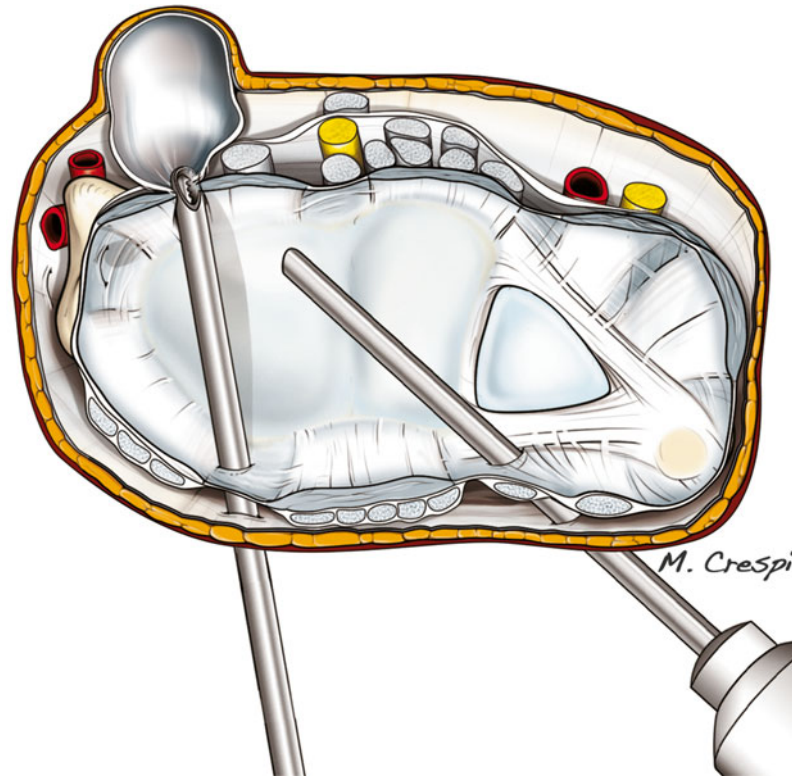


Fig. 72.11 Drawing of the scope in the 6R portal and the shaver in the 3–4 portal, which is another possible configuration during resection

Table 72.1

Authors	Ganglion location	Rate of complications	Details
Osterman and Raphael [7]	Dorsal	0 %	
Luchetti et al. [10]	Dorsal	0 %	
Ho et al. [11]	Dorsal	0 %	
	Palmar	0 %	
Mathoulin et al. [13]	Dorsal	0 %	
	Palmar	3,1 %	1 hematoma
Rocchi et al. [14]	Dorsal and palmar	8,5 %	1 radial artery lesion, 1 hematoma, and 2 axonotmesis
Kang et al. [6]	Dorsal	2,1 %	1 neurapraxia
Rocchi et al. [5]	Palmar	8 %	1 neurapraxia and 1 radial artery lesion
Edwards and Johansen [15]	Dorsal	5,5 %	3 tenosynovitis of extensors
Mathoulin et al. 2010	Dorsal	17,5 %	1 neurapraxia of radial nerve, 1 synovitis EPL, 1 tendinitis ECD, and 2 hematoma

vacuum randomized by treatment with steroid injection and asset against a surgical excision of the ganglion in 36 patients. The recurrence rate is statistically lower with surgery (less than 6 %) compared to medical therapy (39 %).

Surgical treatment allows a lower risk of recurrence but complications occur more frequently. Dias et al. [1] show a complication rate of 20 % with surgery against 5 % with suction. The rate of secondary complication to an open

surgery is 0–28 % [4–6]. In 1995, Osterman and Raphael [7] perform arthroscopic resection of dorsal ganglion in 18 patients without any complications.

The goal of arthroscopic surgery for ganglion is to have a low risk of recurrence, fewer surgical complications than open, and satisfactory cosmetic appearance of scars. Indeed, the aesthetic side is important as it represents the majority of the excision of the ganglion removal indications [8, 9]. Arthroscopy also has the advantage of performing an assessment of potential damage associated with the wrist [7] and treating "hidden" ganglion, not visible and not palpable on physical examination but symptomatic [5].

72.4.2 Results of Arthroscopic Removal of Wrist Ganglia

72.4.2.1 Recurrences

The recurrence rate of arthroscopic removal of wrist ganglia varies from 0 % to 26 % [5–7, 9–17] (Table 72.2). In 2014, Fernandes [18] shows an average recurrence rate of 6 % for palmar ganglia treated by arthroscopy in his review of the literature.

72.4.2.2 Objective and Subjective Clinical Results

- Pain
  Many authors highlight an improvement in pain after arthroscopic resection of the ganglion [1, 7, 16]. In 2010, Mathoulin et al. [9] describe a complete disappearance of pain in 44 % of patients. Kang et al. [17] in 2013 show a decrease of EVA 2.4 preoperatively to 0.6 after surgery at 2 years.
- Postoperative Range of Motion and Strength
  Mobility and wrist strength seem preserved or even improved postoperatively in most cases [7, 9, 15–17] (Table 72.3).

  In his review of literature on the palmar ganglia operated arthroscopically, Fernandes [18] does not describe any loss of postoperative mobility.
- Functional Scores and Patient Satisfaction
  Edwards et al. [15] demonstrate an improvement in the DASH score from 14 to 1.7 stable at 2 years postoperative follow-up. Similarly, Kang et al. [17] show an improvement of Mayo wrist score from 74 to 91.

  For Mathoulin et al. [9], over 96 % of patients are satisfied with arthroscopic surgery.

Table 72.2

Authors	Ganglion location	Follow-up (months)	Number of ganglia	Rate of recurrences
Osterman and Raphael [7]	Dorsal	–	18	0 %
Luchetti et al. [10]	Dorsal	16	34	5,9 %
Ho et al. [11]	Dorsal	25	19	26 %
	Palmar	16	5	0 %
Rizzo et al. [12]	Dorsal	47	41	4,9 %
Mathoulin et al. [13]	Dorsal	34	96	4,2 %
	Palmar	26	32	0 %
Rocchi et al. [14]	Dorsal and palmar	15	47	4,3 %
Kang et al. [6]	Dorsal	12	28	7,1 %
Rocchi et al. [5]	Palmar	24	25	12 %
Edwards and Johansen [15]	Dorsal	Minimum 24	55	0 %
Mathoulin et al. 2010	Dorsal	42	114	12,3 %
Aslani et al. [16]	Dorsal	39	52	17,3 %
Kang et al. [17]	Dorsal	39	41	7,3 %

Table 72.3

Authors	Range of motion	Strength
Osterman et al. 1995	↗ in 94 % of patients	↗ until 90 % of comparative side in 27 % patients
Rizzo et al. [12]	↘ in 21 % of patients	–
Edwards et al. 2009	↘ of 13° flexion at 6 weeks	↗ of 5,9 kg
	↘ 5° max after 2 years	
Mathoulin et al. 2010	↗ 15° of flexion	↗ from 22 to 31 kgf (jamar)
	↗11° of extension	
Aslani et al. [16]	↗ flexion and extension	↗
Kang et al. [17]	= idem preoperative	↗ from 28 to 36 kgf after 2 years

- Return to Work and Daily Activity
  Postoperative time-off work is on average 10–14 days [5, 9, 16]. Mathoulin et al. [9] describe an immediate return to work in 37 % of patients. Similarly, Aslani et al. [16] described that 36 % of patients return to work immediately.

72.4.3 Comparison Between Open Surgery and Arthroscopic Removal of Wrist Ganglia

72.4.3.1 Indications

All ganglia of the wrist are not easily treated arthroscopically. Indeed, several authors describe a technical difficulty in midcarpal wrist ganglia [5, 14, 18]. In his comparative study in 2008, Rocchi et al. [5] show better results with arthroscopic treatment for radiocarpal palmar ganglia and better outcomes with open surgery for midcarpal palmar ganglia. He therefore recommends an open surgery for these midcarpal palmar ganglia. For Ho et al. [11], the ganglion of STT joint is not a good indication of arthroscopic surgery.

72.4.3.2 Recurrence and Complications

The recurrence rate of a ganglion after arthroscopic surgery looks identical to that of open surgery [5, 6, 9].

In 2008, Kang et al. [6] carried out a prospective randomized study comparing the recurrence rate between open surgery and arthroscopy in 72 patients with a dorsal ganglion. No significant difference was found on the recurrence rate at 1 year of decline.

Similarly, Rocchi et al. [5] performed a randomized study comparing open surgery and arthroscopy for the treatment of palmar ganglia. He did not find any significant difference in recurrence rates.

However, he shows that arthroscopy provides better results in the treatment of radiocarpal ganglia without major complications. Similarly, functional recovery seems faster and shorter time-off work with arthroscopic surgery.

72.4.3.3 Aesthetics

The majority of requests for removal of a wrist ganglion is for aesthetic discomfort; the appearance of postoperative scar is therefore essential. The assessment of the scar however can be found in the literature.

After open cyst surgery, Dias et al. [1] put in evidence four sensitive scars and keloid scar. Similarly, Lidder et al. [19] described scar sensitivity in 32 % of patients, of which it is severe in 13 %. It also describes an unsightly scar in 3.4 % of cases. Rocchi et al. [5] found four cases of sensitive scars, painful and/or hypertrophic on 25 patients operated in the open.

No complications related to the scar have been described in the literature during cyst surgery arthroscopically [5, 7, 9, 14, 18]. This is another significant advantage of arthroscopy over open surgery in the treatment of wrist ganglia.

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Scapholunate Ligament Injuries 73

Jane C. Messina

73.1 Indications

Scapholunate dissociation is the most common form of carpal instability [1] (Fig. 73.1). Despite the attention given to this condition, with a large amount of publication, it has remained a therapeutic challenge especially in chronic cases. In fact many different techniques have been proposed, but they do not always give satisfactory results in all cases with a residual amount of stiffness, pain, decrease of grip strength, recurrence of SL widening and development of osteoarthritis especially in long-term follow-up [2–10].

The staging of the disease and indications to surgery in the different stages has been well described by Garcia Elias in 2006, and his paper has greatly clarified the treatment of this condition [6].

In the recent years, surgeons have identified partial ligament lesions as responsible for wrist pain especially in the young active patients. This symptom can be associated with reduction of grip strength, and radiological examination and MRI can be normal [11].

It is also well known that if the scapholunate (SL) dissociation is left untreated, it may lead to degenerative osteoarthritis and scapholunate advanced collapse (SLAC wrist) [1]. This condition is frequently identified late when arthritis has already developed and presumably previous SL injuries have remained for many years completely asymptomatic or underestimated by patient and physician.

This arthritic evolution nevertheless does not happen in all patients at all ages and can remain asymptomatic for years; this also depends of the type of work (manual or not), sports or leisure activities and the overall use of the hand by the patient [12].

Arthroscopic examination of the wrist has led to the identification of partial tears (pre-dynamic instability) in the absence of radiological abnormalities with a dynamic testing of SL interval to be performed from the midcarpal joint. This test is easy to perform and is diagnostic for laxity of the ligament [11, 13, 14]. Geissler examined under arthroscopy wrists affected by distal radius fractures and described an arthroscopic classification for acute injuries, which has been widely used [4]. He also gave guidelines for the treatment of acute injuries, while the treatment of chronic injuries is still under definition. Incidence of scapholunate ligamentous lesions in young patients with intra-articular distal radius fracture was found to be as high as 54 % [15].

Recently some authors have identified different SL lesions as anterior SL lesions and proposed anterior arthroscopic or anterior open approaches thus considering the posterior stabilisation insufficient or inadequate to treat all injuries [16–18].

J.C. Messina
Hand Surgery Unit, Gaetano Pini Orthopaedic Institute, Milan, Italy
e-mail: jcxmessina@gmail.com

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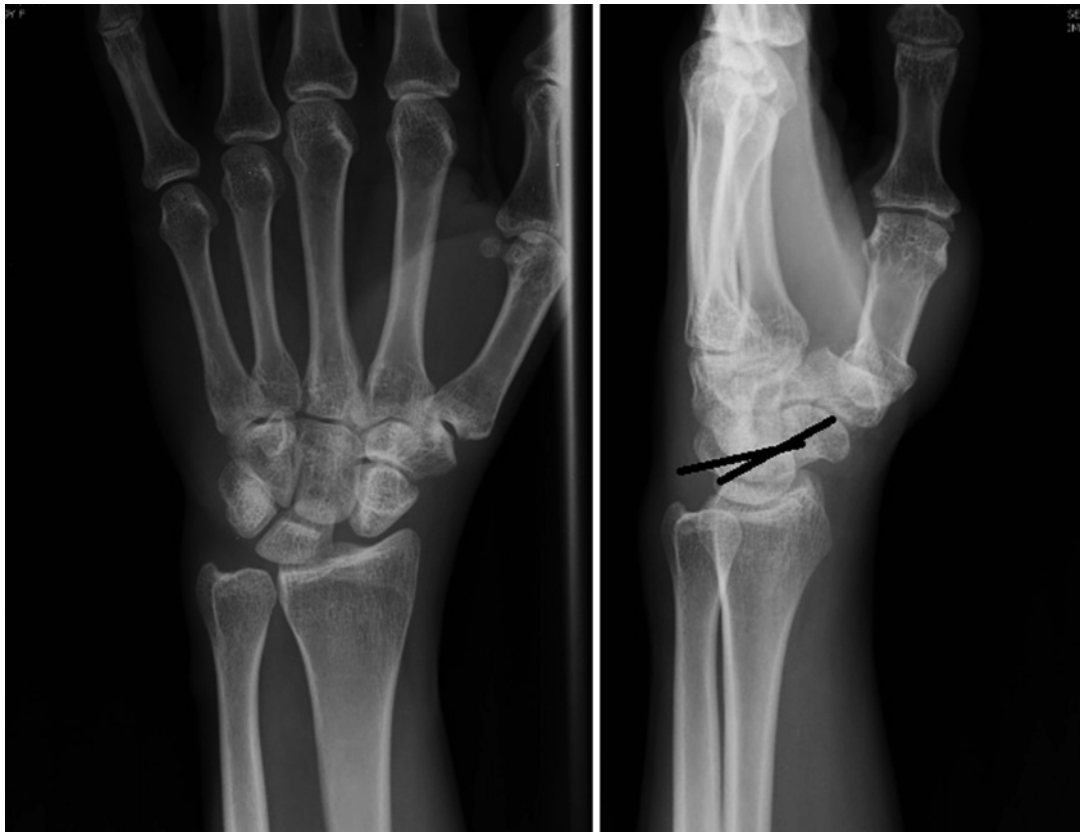

Fig. 73.1 Chronic scapholunate injury with dissociation of scaphoid and lunate bones visible on PA view. In LL view, scapholunate angle is reduced (<30°)

The classification has then evolved and Lindau later proposed a refinement of Geissler classification based on the millimetres of diastasis and step-off measured with the probe during arthroscopy [15]. To address all arthroscopic findings in acute and chronic injuries, another evolution of the classification has been developed by the Ewas group in order to identify the anatomo-pathological damage that occurred during trauma (Table 73.1) [19–21]. This classification allows to identify the site of injury in the anterior part, posterior part or complete as well as injuries of SL interosseous ligament associated with extrinsic ligament involvement (Table 73.1).

Main indication to surgery in this type of injuries is wrist pain under load or even at rest, reduction of wrist strength and inability to do heavy activities, manual work or sports.

73.2 Techniques

Examination under arthroscopy allows the identification of injuries and the correct staging of it (Table 73.1). The sensibility and specificity of this examination is superior to all imaging techniques as it allows the direct visualisation of the intercarpal ligaments at radiocarpal and midcarpal joint [22]. It allows particularly the identification of partial tears which are underestimated by other examinations, while in later stages, when static instability occurs, most injures can be identified by X-ray and MRI (Fig. 73.1).

Radiocarpal access is performed: 3–4 and 6R portals are used. The scope (usually 2.7 mm/30°) is initially inserted from 3–4 portal and then switched to 6R portal in order to insert the probe in the 3–4 portal in order to test SL ligament. From radiocarpal portals, the scapholunate

Table 73.1 Arthroscopic classification of scapholunate injuries according to Ewas [19–21]

Stage		
		RC radiocarpal
A, acute/C, chronic		MC midcarpal
I	A only	RC, MC: attenuation SL ligament, haemorrhage
		No passage of the probe through SL joint
II	A/C	RC: attenuation of SL ligament
Lesion of central part		MC: tip of probe or the whole probe can go through SL space (central part). *Dynamic test neg* (*no widening of SL space*)
IIIA	A/C	RC: thickening of Testut ligament
Lesion of anterior part		MC: partial anterior SL widening at dynamic instability test (*anterior laxity*)
IIIB	A/C	RC: protrusion of SL ligament
Lesion of dorsal part		MC: partial posterior SL widening at dynamic instability test (*posterior laxity*)
IIIC	A/C	RC: protrusion of SL ligament, step-off, dynamic gap
Complete SL lesion+ DIC lesion		MC: complete SL widening at dynamic instability test (*complete laxity*)
IV	A/C	RC, MC: *passage of the arthroscope* through SL joint, SL dissociation
Complete SL lesion+ DIC+LRL, RSC lesion		
V	C	As stage IV. SL gap, *passage of arthroscope* through SL space+ *radiological signs* of instability, rotatory subluxation of scaphoid
Complete SL lesion + multiple extrinsic ligament lesions		

DIC dorsal intercarpal ligament, *LRL* long radio-lunate ligament, *RSC* radio-scapho-capitate ligament

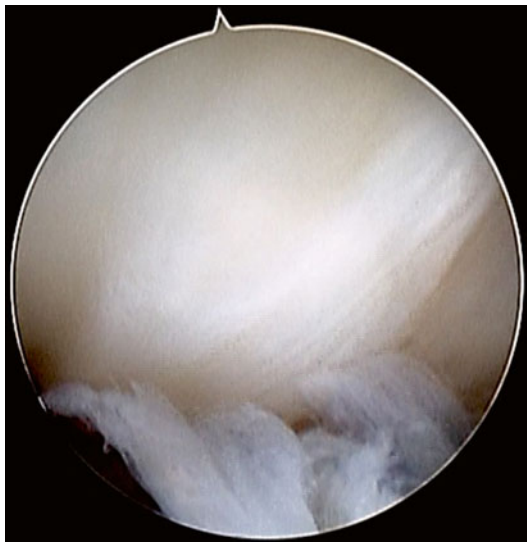

Fig. 73.2 Arthroscopic view from radiocarpal joint. The SL ligament is protruding in the joint because of a partial tear. It can be palpated with a probe inserted from 3–4 portal, while the scope is positioned in 6R portal

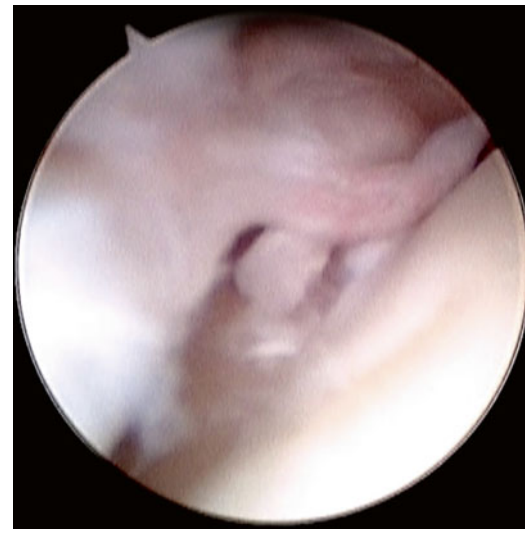

Fig 73.3 Scapholunate injury stage IV. Because of the dissociation of the two bones, the scope can go through the SL joint

ligament can be visualised as well as the whole radiocarpal and ulnocarpal joint. The normal ligament is usually almost invisible at examination as it is in continuity with scaphoid and lunate articular surface. If there is a significant rupture, the ligament is protruding in the joint (Fig. 73.2), and if the lesion is complete, there can be the passage of arthroscope through the SL joint from radiocarpal to midcarpal joint (Fig. 73.3).

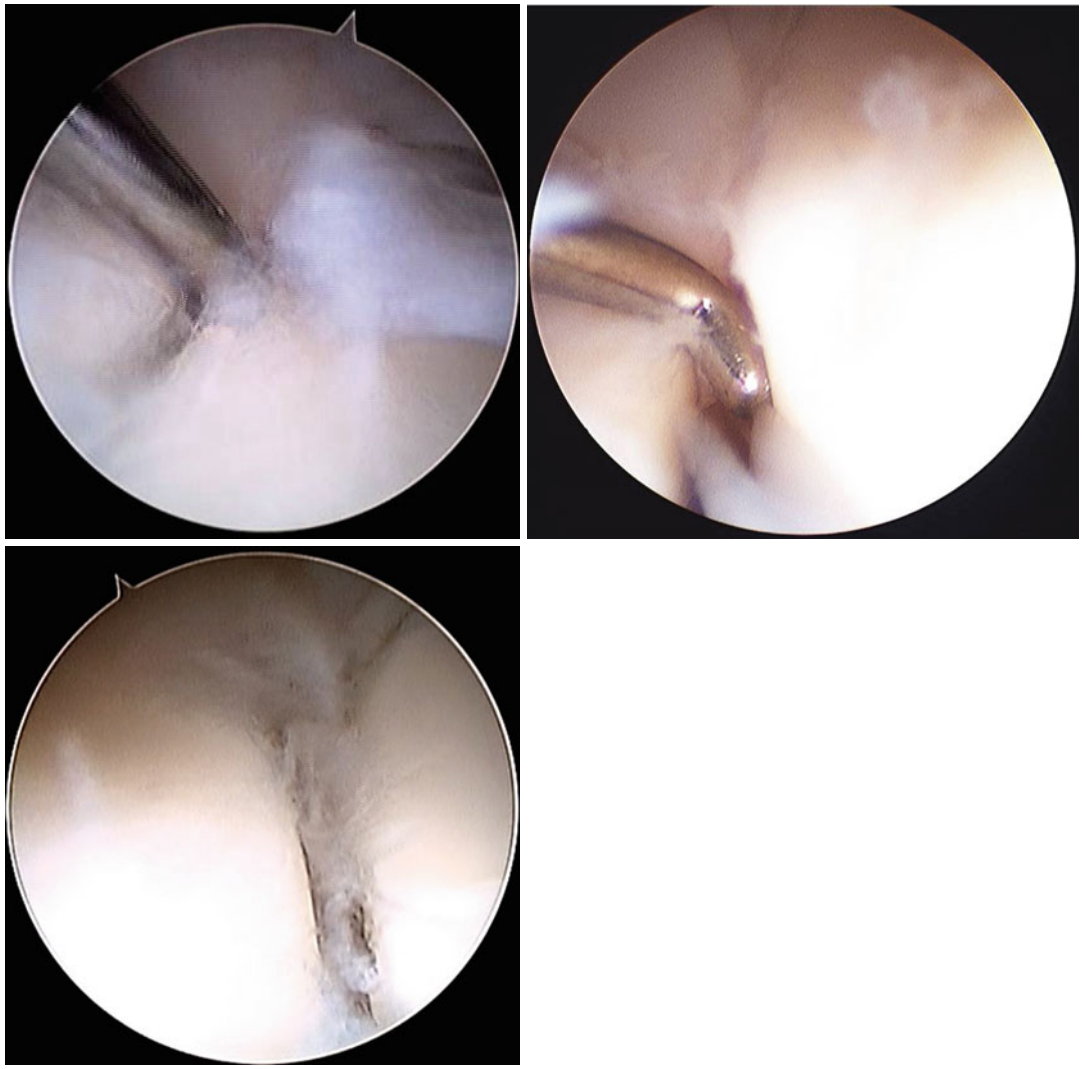

Fig 73.4 Dynamic instability test performed with a probe inserted from MCR portal in the midcarpal joint. It can be twisted in the anterior part of SL joint, in the posterior part or in the central part. The scope is inserted in MCU portal. This allows the staging of the lesion

Midcarpal portals MCR and MCU are also performed. From the midcarpal joint, the SL interval can be tested with a probe. Usually the scope is positioned in MCU portal, while the probe is positioned in MCR portal. A dynamic instability test can be performed with a probe that can be twisted in the SL space from the midcarpal joint (Fig. 73.4). This allows the classification of injuries (Table 73.1). While stages I and II are stable injuries, in the case of anterior widening of the space, the injury is classified as IIIA (Fig. 73.4a); if the widening is posterior, it is classified as IIIB (Fig. 73.4b), and if it is complete, it is classified as IIIC (Fig. 73.4c). In stage IV, there is the passage of the arthroscope though SL joint without radiological abnormalities (Fig. 73.3), while in stage V radiological abnormalities are present.

After the identification of injury, it is possible to repair it by arthroscopic technique or by open approach [3–10, 17, 23, 24–27]. In acute injuries, simple arthroscopic reduction and pinning can be

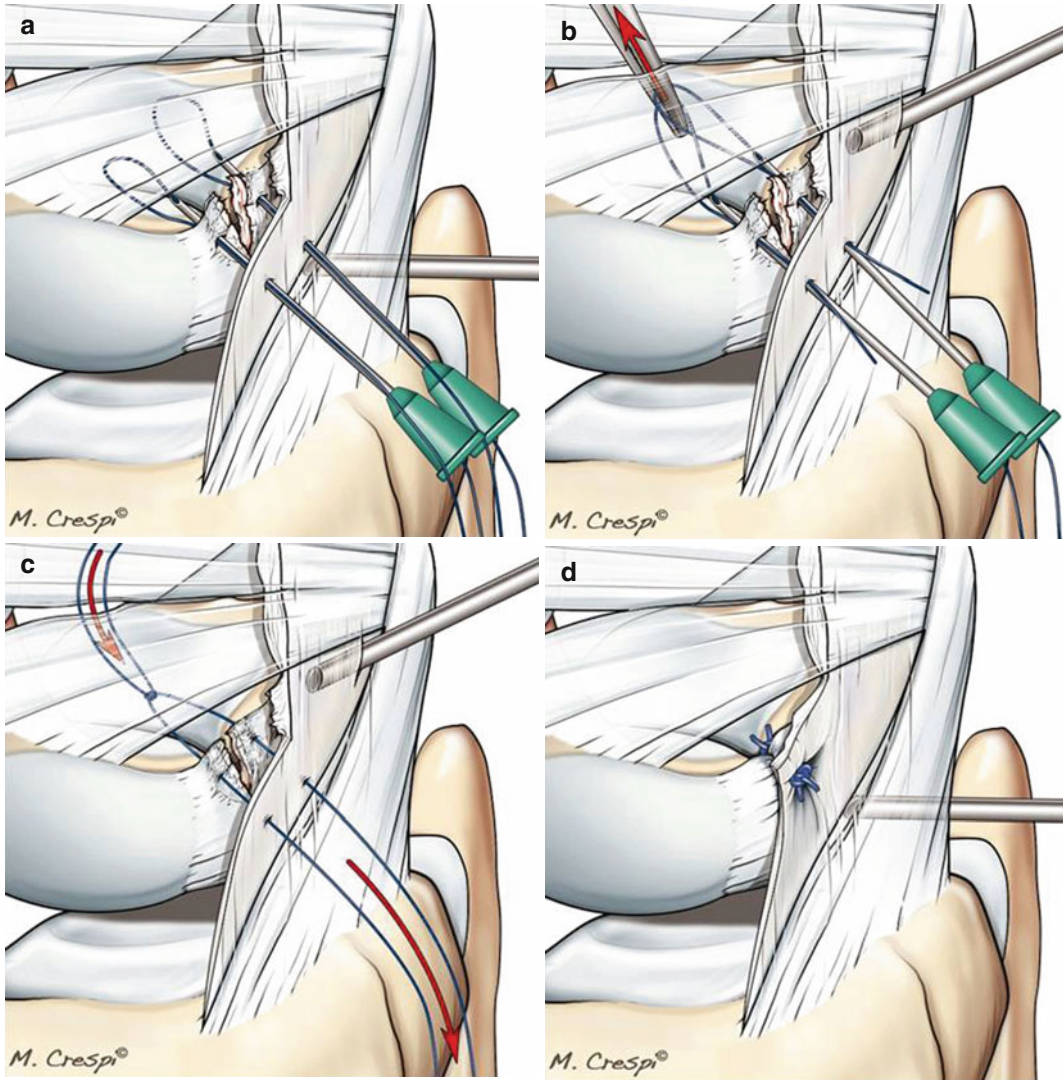

Fig 73.5 Technique of arthroscopic capsuloligamentodesis [24]. From the radiocarpal joint, two needles with a thread are inserted from the radiocarpal to the midcarpal joint at scapholunate space (**a**). One is positioned at the radial side of SL joint and one at the ulnar side. Then the threads are retrieved from the midcarpal joint (**b**) and extracted from the MCR portal. A knot is performed (**c**) and then the proximal part of two threads is then pulled from the 3–4 portal. Another knot is positioned at this level. Courtesy of C. Mathoulin (**d**)

used, and reduction is performed with slight release of traction, extension and ulnar deviation of the wrist [4, 23].

In chronic injuries, different arthroscopic techniques have been described in the recent years. The arthroscopic capsuloligamentodesis, proposed by Mathoulin, is a technique which has the function of reconstruction of the dorsal part of the scapholunate ligament, retensioning of dorsal intercarpal ligament and reattachment of the dorsal scapholunate septum [24]. From the radiocarpal joint, two needles with a thread are inserted from the radiocarpal to the midcarpal joint at scapholunate space (Fig. 73.5a). One is positioned at the radial side of SL joint and one at the ulnar side. Then the threads are catched from the midcarpal joint (Fig. 73.5b) and extracted from the MCR portal. A knot is performed

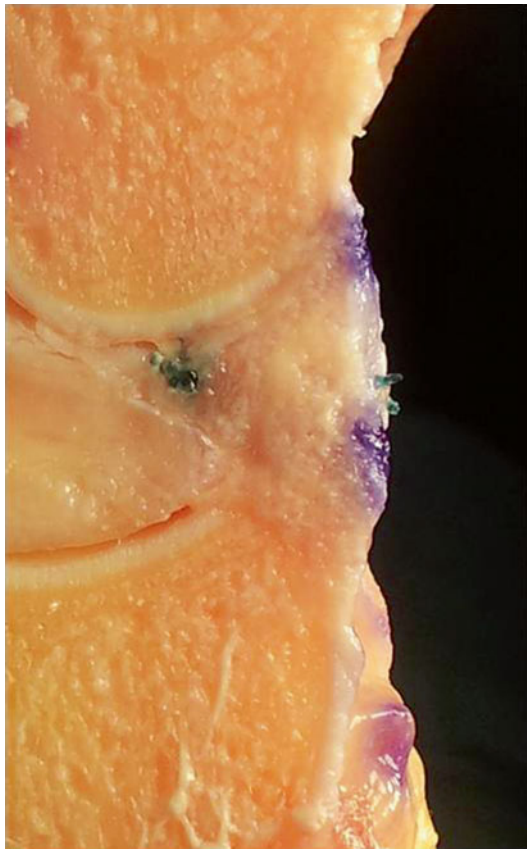

Fig 73.6 Anatomical sagittal section of the wrist at scapholunate space in a cadaver specimen. We can observe the suture performed after arthroscopic capsulo-ligamentodesis [24]

(Fig. 73.5c) and then the proximal part of two threads are then pulled from the 3–4 portal. Another knot is positioned at this level (Figs. 73.5d and 73.6). At arthroscopy, after the repair, it is possible to check that the SL space has closed and that the probe cannot be twisted anymore [24].

Another arthroscopic technique, which aims to repair the volar part of the scapholunate joint, has been proposed by Del Pinal. This technique needs a volar portal, and an arthroscopic retensioning of volar ligaments is performed in order to close the volar SL space [18].

Other techniques of arthroscopic reconstruction have been recently proposed which necessitate the creation of two bone tunnels, one in the scaphoid and another in the lunate bone with the passage of a tendon which has the function to approximate the two bones and reconstruct the SL ligament. According to Ho, the two tunnels are performed in the sagittal plane in the proximal pole of scaphoid and in the lunate which allows the passage of a tendon graft, which is tightened with a knot [25]. Corella proposed to use a part of FRC to be passed in scaphoid tunnel from anterior to posterior and then in a lunate tunnel from posterior to anterior [26]. In the technique by Della Rosa, the tunnels are performed in the frontal plane and the tendon graft is a bone-tendon-bone graft which is fixed with interference screws [27]. These techniques are technically demanding and should be performed by experienced hand surgeons. The major complications are scaphoid proximal pole necrosis or fracture of scaphoid and lunate bone, so they are not still widely used. The preliminary results of these techniques are interesting, but a longer follow-up is needed to demonstrate the real validity of the techniques.

73.3 Tips and Pearls

The identification of acute and chronic injures is difficult. Presence of haemorrhage indicates an acute injury. The lesions can develop in several steps, and in the absence of a clear haemorrhage, many injures are discovered when they are already chronic.

73.4 Complications

Complications of wrist arthroscopy are rare. Nevertheless, they can be related to traction (paraesthesia, skin injuries at traction site) or due to arthroscopy itself (cartilage damage, rupture of instruments in the joint, swelling, compartment syndrome for fluid extravasation). Infection is extremely rare.

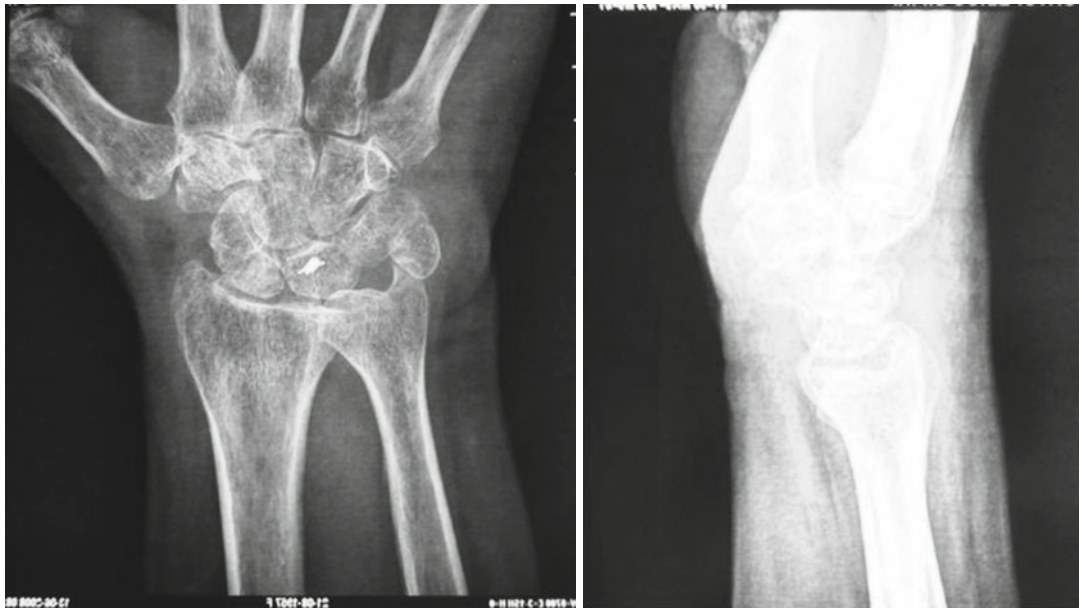

Fig 73.7 Persistent dorsal wrist pain after a healed distal radius fracture in a lady aged 50 years old. At arthroscopic examination, a SL tear stage IIIC has been identified. A dorsal capsulodesis has been performed according to Moran-Berger

73.5 Summary/Results/Literature Overview

Surgeons have recently identified partial ligament lesions as responsible for pain and reduction of grip strength in young active patients. These injuries are identified under arthroscopy and can be treated by open or arthroscopic technique. Open capsulodesis has given excellent and good results in partial chronic injuries [10] (Figs. 73.7 and 73.8). Arthroscopic techniques of repair are developing and have the advantage to perform diagnosis and treatment at the same operating time.

It is also well known that if the scapholunate (SL) dissociation is left untreated, it may lead to degenerative osteoarthritis and to scapholunate advanced collapse (SLAC wrist). This condition is frequently identified late when arthritis has already developed, thus the importance of early diagnosis with arthroscopic examination to treat them before arthritis.

Scapholunate dissociation is the most common form of carpal instability with scaphoid non-union advanced collapse [1]. The treatment of these conditions is still a challenge even for the most experienced surgeon, especially in chronic cases. In fact the different treatments proposed in the past years do not always give satisfactory results with restoration of a complete functional wrist. Frequently in the end, when arthritis has developed, a salvage procedure is performed (partial wrist fusion as "four-corner" fusion, proximal row carpectomy or total wrist fusion). Wrist arthroscopy is important as it allows the identification and possibly the treatment of these injuries at an early stage in order to avoid further development of arthritis.

73.6 Future Directions

Wrist arthroscopy is a developing technique which gives more and more information about intercarpal ligament injuries. Arthroscopic techniques of scapholunate repair are developing and have the advantage of being minimally invasive,

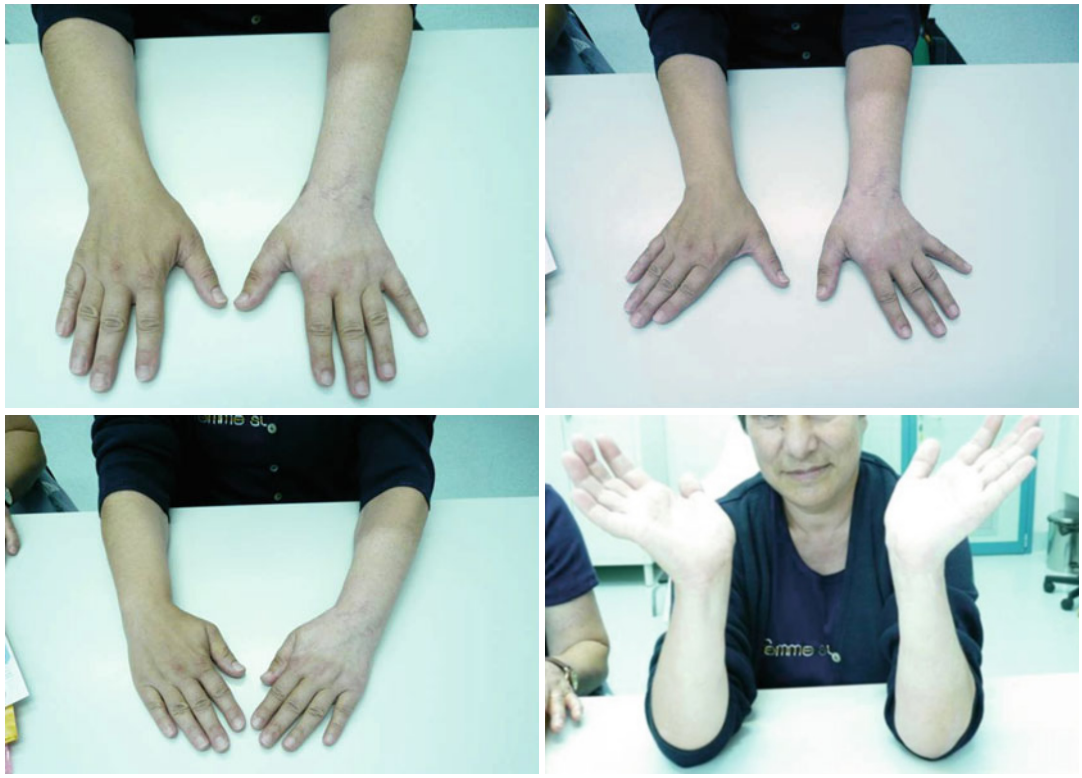

Fig 73.8 The same patient as Fig. 73.7. Excellent result with complete wrist function at follow-up at 3 months

especially the arthroscopic capsulodesis techniques. Long-term results are needed to evaluate the effectiveness of the most recent techniques with the use of bone tunnels and tendon grafts.

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Wrist Arthroscopy in Degenerative Conditions of the Wrist

74

Michael Chu-Kay Mak and Pak-Cheong Ho

74.1 SLAC and SNAC Wrist: Arthroscopy for Decision-Making

74.1.1 Indications

Scapholunate dissociation and scaphoid nonunion with time result in degenerative changes in the wrist joint. This occurs in a progressive and generally predictable manner. The development of scapholunate advanced collapse (SLAC) occurs in three stages as described by Watson [1] (Fig. 74.1), with a fourth stage also described by subsequent authors [2]. It begins at the articulation of the distal scaphoid and radial styloid in stage I, advances to involve the whole scaphoid fossa in stage II, and progresses to the capitolunate articulation in stage III. Pancarpal arthritis involving the midcarpal and the whole radiocarpal joint may occur in the very late stage. In a small portion of patients, there may be arthrosis of the scaphotrapeziotrapezoid (STT) joint. Scaphoid nonunion advanced collapse (SNAC) develops similarly from the distal radioscaphoid articulation, progressing to the scaphocapitate joint, and then to the capitolunate joint [3]. In treating these conditions, the choice of surgery depends on the location of the arthritic and the remaining healthy articulations.

The indication of wrist arthroscopy in these post-traumatic conditions is a painful arthritic wrist. The pain may be localized to the radial styloid especially in radial deviation in the early stage and becomes a more generalized radial wrist pain and swelling in later stage.

Wrist arthroscopy allows one to identify the diseased segments and the relatively unaffected articulating surfaces, thereby allowing an accurate staging of the arthritis and facilitates clinical decision-making. Arthroscopic staging allows an unimpeded view to most of the articular surfaces in the wrist and the important soft tissue elements. Under direct visualization with a magnified view, one can readily identify cartilage lesions such as tear, softening, and fibrillation, which could be otherwise undetected on MRI. Cartilage thickness of the wrist is much less than that of the large joints such as the knee (0.6 mm for distal radius [4] versus 5–6 mm for the patella [5]). As a result, although MRI is firmly established in the diagnosis of chondral lesions in the knee, it is much less reliable for detecting cartilage lesions in the wrist. Using MR arthrogram with a 1.5-T coil, one study reported a sensitivity of 9–62 % for the wrist [6]. Another

M.C.-K. Mak, MBChB, FRCS, FHKCOS, FHKAM(ORTHO) (✉)
P.-C. Ho, MBBS, FRCS, FHKCOS, FHKAM(ORTHO)
Department of Orthopaedics & Traumatology, Prince of Wales Hospital, Chinese University of Hong Kong, 30-32 Ngan Shing Street, Shatin, New Territories, Hong Kong SAR, China
e-mail: mmak@ort.cuhk.edu.hk; pcho@ort.cuhk.edu.hk

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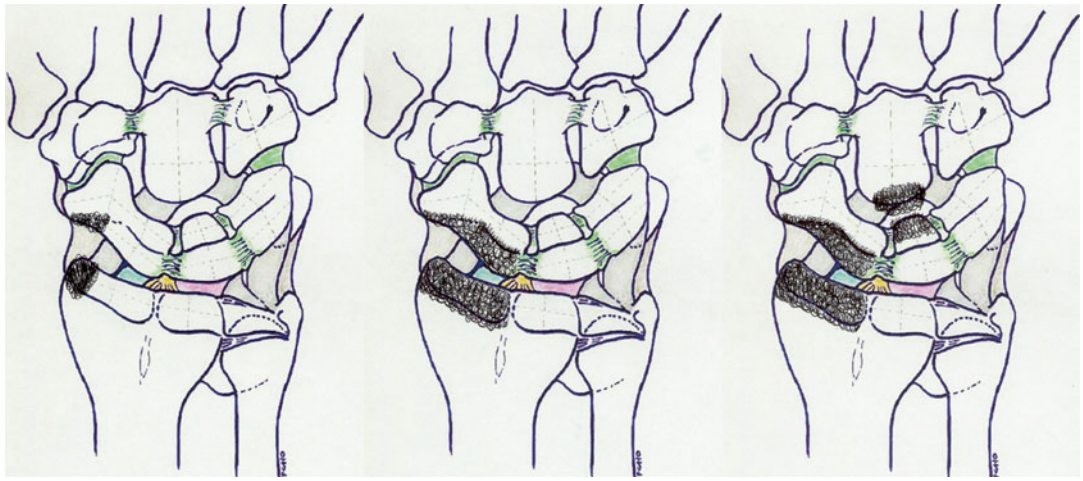

Fig. 74.1 Stages 1–3 of SLAC wrist

study using 3.0-T MRI reported a sensitivity of 48–52 % for the wrist and in particular only 14–24 % for the distal carpal row [7].

74.1.2 Technique

A diagnostic arthroscopy for staging is typically performed under portal-site local anesthesia [8]. The patient is awake throughout the procedure without sedation. In this way, the patient is able to look at the arthroscopic view via the main or supplementary monitor and gain a better understanding of his or her condition (Fig. 74.2). The patient is put in the supine position, while the operated arm is supported on a hand table. An arm tourniquet is not usually necessary, but if placed as a standby, it should not be applied too tightly, or venous engorgement can result in more bleeding. A vertical traction of 4–6 kgf is applied through plastic finger traps to the middle three fingers for joint distraction via a wrist traction tower. We employ continuous saline irrigation and distension of the joint by using a 3-l bag of normal saline solution suspended at 1–1.5 m above the operating table and instilled with the aid of gravity to maintain a clear arthroscopic view. An infusion pump is not used as it can potentially cause harm from fluid extravasation. It is mainly the distraction device that keeps the joint opened.

Inspection of the radiocarpal joint is done through the 3/4 portal and the midcarpal joint through the MCR portal using a 2.7- or 1.9-mm video arthroscope. Additional portals for instrumentation are established at the 4/5 and MCU portals, respectively. Two percent lignocaine with adrenaline in 1:200,000 dilution is injected to each of the portal sites for anesthesia and hemostasis. After all portals are marked, normal saline is injected intra-articularly to distend the joint. A small transverse incision is made with a blade just through the skin and not any deeper. A curved hemostat is then used to puncture and create an opening in the capsule just large enough for the trocar-cannula. After the joint is entered with the videoscope, the creation of an additional portal is facilitated by first inserting an 18-G needle for localization of the exact site and the direction of entry. This is particularly helpful in entering contracted joint spaces. An outflow portal is established at the 6-U portal just volar to the extensor carpi ulnaris (ECU) tendon using an 18-G needle.

Attention is paid to the status of the cartilage, degree of synovitis, and integrity of the interosseous ligaments. The quality of the cartilage in all articular surfaces is assessed to establish a precise arthroscopic staging of the disease and to determine whether the proposed intercarpal fusion is suitable. For this purpose, the cartilage in the segments in which motion is

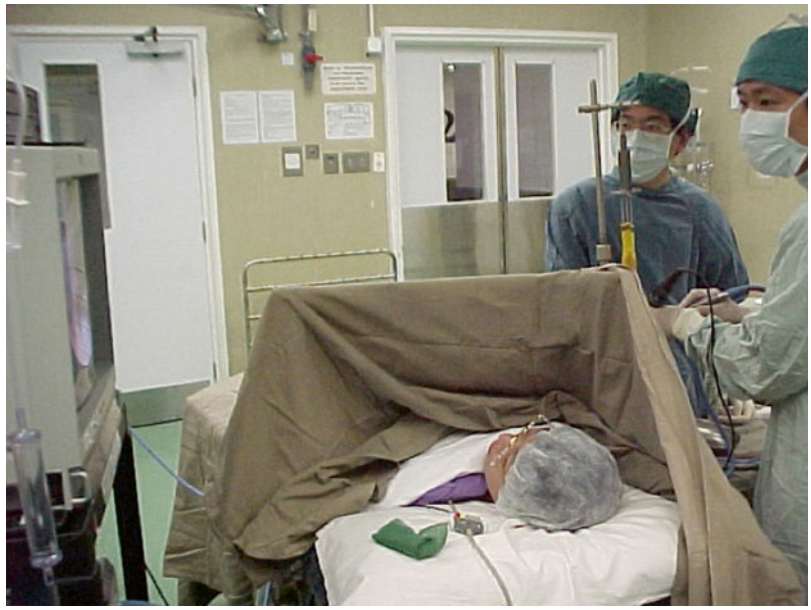

Fig. 74.2 The monitor is positioned such that the patient is able to watch when instructed

to be preserved is assessed. Chondral lesions are graded according to its continuity and depth of involvement. In grade 1, there is softening of the cartilage that is in continuity, which can be demonstrated by a probe. In grade 2, there is superficial fissuring. In grade 3, there is deep fissuring reaching down to subchondral bone. In grade 4, subchondral bone is exposed (Fig. 74.3) (French Society of Arthroscopy (SFA) classification [9]).

Starting in the radiocarpal joint, surveillance is performed from radial to ulnar. The radial styloid is first inspected for any early SLAC changes, in which the dorsal rim is affected first. It is assessed by rotating the 30° forward slanting lens downward to reach the area. Synovial proliferation obscuring the view of the cartilage is removed by a 2.0-mm or 2.9-mm shaver or radiofrequency probe. The portals for instrumentation and videoscope may be switched for a better angle of attack. After the radiocarpal and the ulnocarpal joints are inspected, the triangular fibrocartilage complex (TFCC) is inspected for any central or peripheral tears. Central unstable flap tears of the TFCC are debrided to eliminate a potential source of pain especially if partial wrist fusion is to be performed.

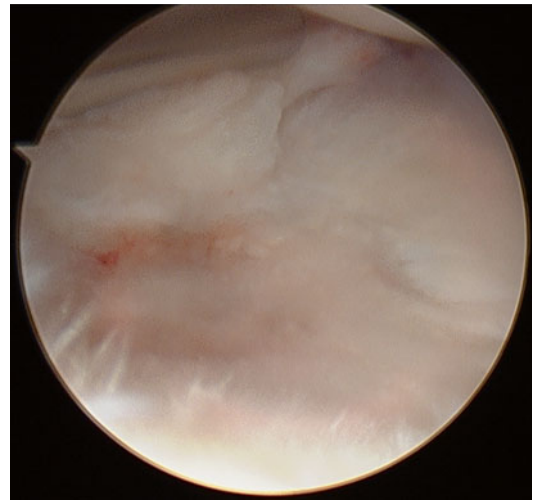

Fig. 74.3 Grade 4 chondral lesion in the scaphoid fossa in stage 2 SLAC wrist

The midcarpal joint is inspected through the MCR portal. The scaphotrapeziotrapezoid, scaphocapitate, capitolunate, and triquetrohamate joints are inspected for chondral lesions and synovitis. The scapholunate and lunotriquetral ligaments are assessed with a 2-mm probe inserted from the MCU portal, and any instability graded by the Geissler classification [10].

For scaphoid nonunion or stage 1 SNAC wrist, in addition to staging, fibrosis at the nonunion site is taken down from the MCR portal with angled curette, punch, and shaver. Vascularity of the scaphoid is then assessed by observing for any punctate bleeding from cancellous bone, especially for the proximal pole.

74.1.3 Definitive Procedures in SLAC and SNAC Wrist

Depending on the arthroscopic findings, different surgical treatments are available. These are discussed with the patient at length after the staging procedure.

For early SLAC or SNAC wrist, with localized osteoarthritis at the articulation of the distal scaphoid and radial styloid but otherwise preserved cartilage, our preferred treatment is correction of the primary pathology and arthroscopic radial styloidectomy. This aims to halt the progression of further degenerative change and relieve pain. Our preferred technique is arthroscopic assisted dorsal-volar SL ligament reconstruction with free tendon graft for SL dissociation and arthroscopic bone grafting for scaphoid nonunion. In a review of 17 cases of SL dissociation with arthroscopic SL reconstruction in our center, six had SLAC 1 changes [11]. In an average 4-year follow-up, there were no progression of arthritis in these patients, and all were satisfied with the outcome. Wong and Ho reported 69 cases of scaphoid nonunion treated with arthroscopic bone grafting, in which cases with SNAC 1 changes also received radial styloidectomy [12].

For stage 2 and 3 SLAC and SNAC wrists, our preferred treatment is scaphoidectomy and capitolunate (CL) fusion or four-corner fusion in certain cases. An intact radiolunate joint has to be ascertained in the staging arthroscopy; we have encountered cases of radiolunate arthrosis in the presence of an intact midcarpal joint. Arthroscopic proximal row carpectomy is also an option in elderly or low-demand patients. Weiss reported good outcomes with this technique in 17 patients [13]. Mean operation time was 70 min, and a flexion-extension arc of 80 % of the unaffected side could be achieved.

In pancarpal arthritis involving both radiocarpal and midcarpal joints, options are total wrist fusion and total wrist replacement. Recently, Bellemère in 2012 reported the use of a newer technique of pyrocarbon interpositional arthroplasty in 16 patients, with good short-term results [14].

74.2 Radial Styloidectomy

Osteoarthrosis of the articulation between the radial styloid and the distal scaphoid can occur in post-traumatic conditions such as the early stages of SLAC, SNAC wrist, and distal radius fracture; in Kienbock disease with lunate collapse; in rheumatoid arthritis where collapse of the radial column leads to radial deviation of the carpus [15] and potential impingement between the radial styloid and carpus; and after STT fusion, proximal row carpectomy, and four-corner fusion.

Studies have shown increased loading on the radial side of the radiocarpal contact area in post-traumatic conditions. Viegas found that the scaphoid contact area and pressure was redistributed after a simulated scaphoid fracture in cadaveric wrists, resulting in increased contact area and pressure under the distal fragment and no change or a slight decrease in the contact area under the proximal fragment of the scaphoid [16]. Blevens showed increased radioscaphoid loading in sequential sectioning of periscaphoid ligaments [17].

Radial styloidectomy can be performed as an adjunct procedure together with reconstruction in post-traumatic conditions or alone in patients who have low demand or do not wish to undergo formal reconstruction. Compared with an open procedure, arthroscopic radial styloidectomy has the advantage of a better visualization and thus preservation of the radioscaphocapitate ligament to prevent ulnar translocation and secondary carpal instability (Fig. 74.4). It also allows a resection limited to the extent of the arthritic surface.

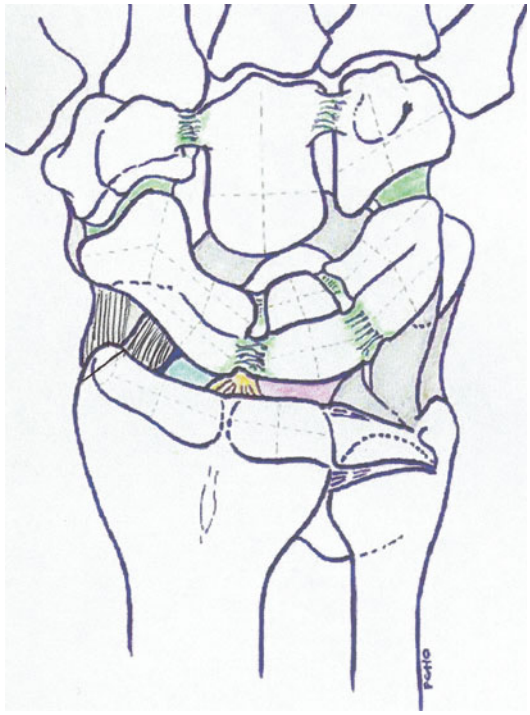

Fig. 74.4 The radial-most ligament is the radial collateral ligament and ulnar-volar to it is the radioscaphocapitate (RSC) ligament (both shaded). A 3–4-mm bone resection as marked would preserve the RSC ligament

74.2.1 Technique

The positioning, basic arthroscopy set-up, and anesthesia are the same as for a staging arthroscopy as described above. The 4/5 portal is first created and the arthroscope directed toward the dorsal aspect of the radial styloid. A 1/2 portal is created in the interval between the APL and EPB tendons and the ECRL and ECRB tendons, just radial to the ECRL tendon and just distal to the radial styloid, to avoid injury to the radial artery. A 2.9-mm burr can be introduced from the 1/2 portal to burr on the arthritic articular surface of the styloid region, taking care to preserve the rest of the cartilage. The origin of the radioscaphocapitate ligament, the most radial volar ligament, marks the ulnar border of the resection. A resection of an even depth of 3–4 mm is made, using the thickness of the burr as a reference. The volar aspect of the radial styloid can be spared as it is the important origin of the radioscaphocapitate ligament and impingement symptom seldom arises from this area. On-table fluoroscopy can be used to confirm adequacy of the radial styloidectomy and to ensure no impingement of the scaphoid with the distal radius with radial deviation (Fig. 74.5). Nakamura recommended a styloidectomy of no more than 3–4 mm as significant radial, ulnar, and palmar carpal displacement on loading had been demonstrated after 6-mm and 10-mm radial styloidectomy [18].

74.3 Partial Wrist Arthrodesis

74.3.1 Indications

Partial wrist arthrodesis is indicated for patients with a painful arthritic wrist limited to part of the carpal articulation linkage, who would like to have pain relief while preserving a functional arc of motion. These conditions may include SLAC, SNAC, Kienbock disease, post-distal radius fracture radiocarpal joint arthrosis, STT arthritis, and inflammatory arthritis such as rheumatoid arthritis and crystal deposition disease. Chronic painful carpal instabilities such as lunotriquetral instability, capitolunate instability, palmar midcarpal instability, and radiocarpal translocation are also good indications. Since arthritis and instability can occur in a variety of locations within the radiocarpal, midcarpal, and intercarpal areas, there are a variety of bones that can be fused.

Partial wrist fusions are not without complications, which are mainly the risks of nonunion and incomplete pain relief. Nagy reviewed a cohort of 15 cases of radioscapholunate fusion and reported a nonunion rate of 27 % [19]. Four patients had continuing symptoms despite solid fusion. Revision total wrist fusion was required in 33 % of cases ultimately. Krakauer reported 51 cases of partial wrist fusions that included 23 cases of four-corner fusion, eight cases of capitolunate fusion, five cases of radioscapholunate fusion, and three cases of radioscaphoid fusion [20]. There was a 9 % nonunion rate in four-corner

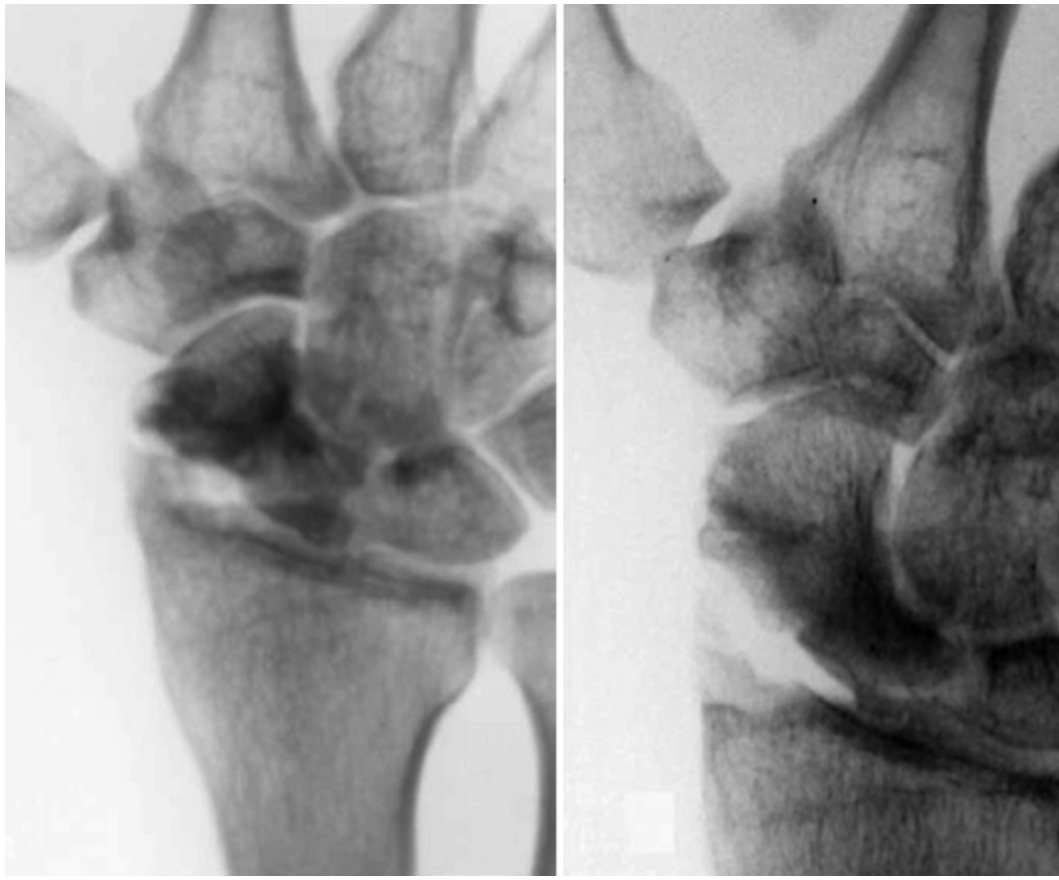

Fig. 74.5 Before (*left*) and after (*right*) radial styloidectomy. The volar part of the radial styloid, where the RSC and long RL ligaments attach, is preserved

fusion and 50 % in capitolunate fusion. The rate of painful nonunion requiring revision fusion with bone grafting was 14 % in all cases, and 12 % eventually required total wrist fusion. Therefore, in patients who wish for a more guaranteed pain relief, are not bothered by a loss of wrist motion, and do not want to risk having a second operation, total wrist fusion may be a better option. Other options to consider include wrist denervation for pain control and wrist arthroplasty for older patients who do not require a strenuous use of the wrist.

74.3.2 Technique

All forms of arthroscopic partial wrist fusion include the following steps:

1. Set-up and instrumentation
2. Arthroscopic surveillance for final staging of the disease
3. Cartilage denudation
4. Correction of carpal malalignment
5. Provisional fixation of the fusion interval
6. Augmentation of the fusion segment(s) with bone graft or bone substitute in selected indications
7. Definitive fixation

Instruments required include:

1. 1.9-mm or 2.7-mm videoscope
2. Motorized full-radius shaver (2.0/2.9 mm) and burr (2.9/3.5 mm)
3. Small angled curette and ring curette
4. 2.5-mm suction punch

5. Radio-frequency thermal ablation system
6. K-wires and small cannulated screw system

We typically perform this operation under general anesthesia, although regional anesthesia could be used if bone grafting (usually taken from the iliac crest) is not required. We tend not to use bone graft or bone substitute if the fusion surfaces are congruent and rigid cannulated screws can be used.

The patient is placed supine with the operated arm on a hand table. Either side of the iliac crest can be used for bone grafting. An arm tourniquet is applied and inflated only when needed. Arthroscopic surveillance is performed as described above, again assessing the cartilage status of the articulating areas that will be preserved.

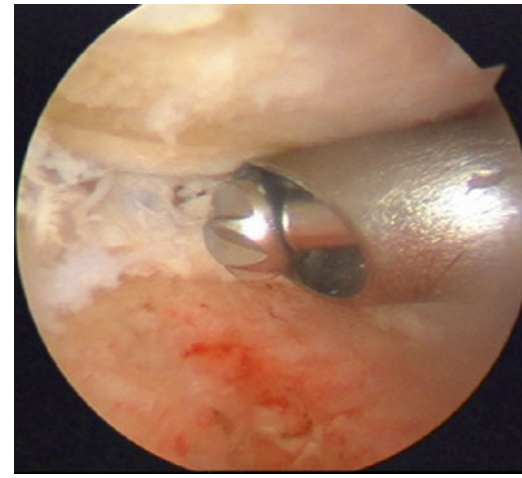

Fig. 74.6 The articular surfaces of the radiolunate articulation are debrided until punctate bleeding from subchondral bone is observed

74.3.3 Cartilage Denudation

The articular surfaces of the fusion site are then prepared. We aim to preserve as much subchondral bone as possible so as to maintain carpal height. Using a 2.9-mm burr, the cartilage is denuded in a precisely controlled manner to obtain a smooth surface, maintaining the original contour. To achieve a good control of the instrument, it is recommended to adopt a finger pivoting control technique, i.e., holding the instrument at the far end with the thumb and index finger, while the middle finger steadies the instrument against the skin of the wrist dorsum. The depth is reached just as when there is healthy punctate bleeding in the subchondral cancellous bone, which can be observed easily without an inflated tourniquet (Fig. 74.6). In debriding the carpal interval of the same carpal row, such as lunotriquetral or capitohamate interval, a smaller burr such as a 2 mm sized should be used to cater for the narrower joint space. The speed of the burr is set at 2,000–3,000 rpm, and a unidirectional mode is more effective than an oscillating mode. If there is profuse bleeding that obscures the view, one may elevate the bag of irrigation normal saline to increase the hydrostatic pressure or use radio frequency for coagulation. During the burring process, suction is switched on and off intermittently to remove any accumulated bone debris. Continuous suction may draw in excessive air bubbles that obscure the view.

74.3.4 Correction of Carpal Malalignment

DISI deformity, if present, is corrected to maximize the range of motion, reduce persistent pain from capitate impingement, and improve radiolunate load transmission. The radiolunate angle is reduced to zero degree by wrist flexion and slight ulnar deviation, and a 1.6 mm-K-wire is used to transfix the radiolunate joint (Fig. 74.7). The K-wire is introduced percutaneously through a small stab wound over the distal radius slightly proximal to the sigmoid notch level, aiming at the level between the 3/4 and 4/5 portals. Blunt dissection with a fine hemostat or stitch scissors is first performed to avoid iatrogenic injury or tethering of the extensor tendons before introduction of the K-wire. The alignment is checked by fluoroscopy, ensuring the tip of the K-wire is within the lunate and not protruding into and blocking the capitolunate fusion site. The other carpal bones are manually realigned in relation to the fixed lunate.

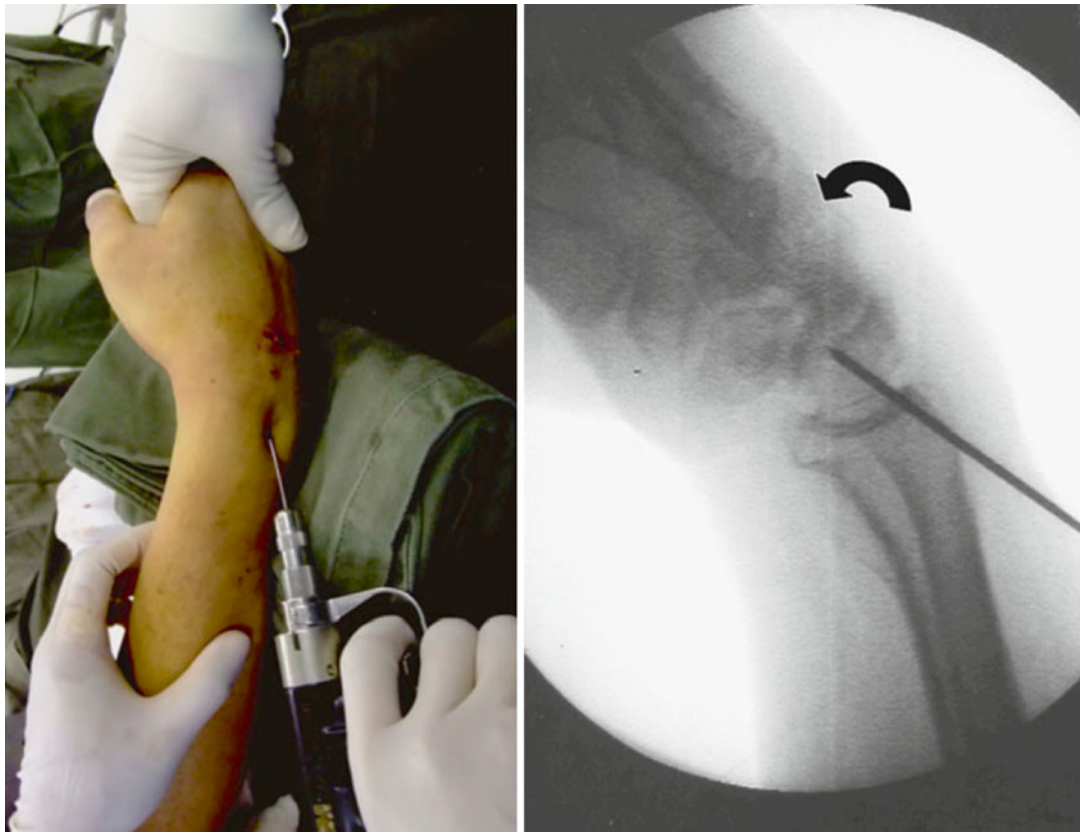

Fig. 74.7 The lunate is reduced by wrist flexion and slight ulnar deviation and fixed by K-wire

74.3.5 Provisional Fixation of the Fusion Interval

Under fluoroscopy guidance, the carpal interval to be fused is temporarily fixed with 1.1-mm K-wires in an alignment as anatomical as possible. In elderly patients with osteoporotic bone, K-wires can be used as the definitive fixation device. In patients with better bone quality, the K-wires are used as guide pins for cannulated screws. In this case, the K-wires are then backed out until they are just short of the fusion surface, to prepare for bone grafting or insertion of bone substitute when needed.

74.3.6 Augmentation of the Fusion Segment(s) with Bone Graft or Bone Substitute

Autogenous cancellous bone graft, usually taken from the iliac crest, and bone substitute are used where there are voids between the articular surfaces to be fused. This situation is more common in RSL, RL, STT, and four-corner fusions. As the vascularity and the bone quality of the fusing bones are usually adequate, cancellous graft from iliac crest may not be necessary, and bone substitute can achieve a similar outcome without donor morbidity. Both the injectable and small granule forms can be used.

The wrist is placed on the traction tower. To avoid spillage of graft or substitute into adjacent uninvolved joint spaces, a special Foley catheter balloon-blocking technique has been developed (Fig. 74.8). A French size 6 Foley catheter is used, and its tip cut short so that the balloon is at the far end. Together with the stylet, it is introduced through a portal adjacent to the fusion site. A grasper, introduced from a third portal, can be used to advance the catheter and position the balloon portion at the appropriate space. The balloon can then be inflated with saline solution

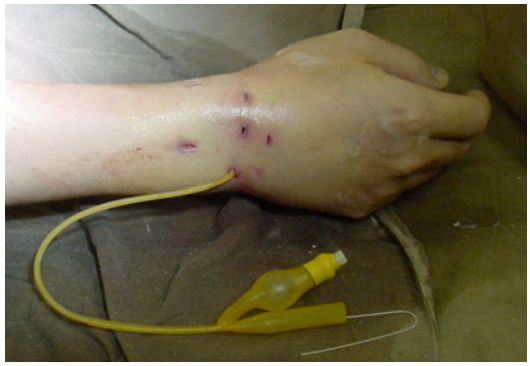

Fig. 74.8 A Foley catheter is inserted at an adjacent portal and the balloon inflated adjacent to the fusion site

until the joint compartment away from the fusion interval is largely obliterated by the balloon.

If bone grafts are used, they are cut into small chips and inserted into an arthroscopic cannula introduced into a portal directly over the fusion site. A flat-ended trocar, such as a bone biopsy trocar, is used to push the graft through the cannula into the fusion site. A slightly undersized trocar is used as the delivery is easier. The graft is impacted in the site with the trocar, and a seemingly large amount of graft can fit into the void until it is filled completely. This process is made easier with a reduced flow of irrigation fluid and can also be made quicker with the use of a larger 4.5-mm cannula. If injectable substitute is used, joint irrigation is stopped and joint fluid evacuated by suction. The substitute is then injected through a wide bore needle that is passed through the portal. Fluoroscopy can be used to confirm complete filling of the void.

74.3.7 Definitive Fixation

The wrist is taken off the traction tower. Under fluoroscopy, the K-wires are driven through the fusion site in correct carpal alignment. If K-wires are to be used for fixation, they are cut short and buried and removed under local anesthesia after bone healing. If cannulated screws are to be used for fixation with the K-wires as guide pins, the screw length is measured and the pin tract drilled with a cannulated drill. Stable internal fixation can then be achieved with headless compression screws to avoid screw head impingement. The wrist is then immobilized with a plaster slab, which is later changed to a thermoplastic splint while allowing supervised out-of-splint mobilization exercises.

74.3.8 Specific Fusion: Capitolunate (CL) Fusion

Capitolunate (CL) fusion was advocated by Watson as one of the SLAC wrist reconstruction procedures [1], although the four-corner fusion was the more favored technique at the time as bony union seemed to be more guaranteed. However, with the routine use of cannulated compression screws that offers more stable fixation, and the advent of the minimally invasive arthroscopic technique that is less disruptive to the soft tissue and vascular supply than traditional open techniques, CL fusion has become our preferred technique for treating stage II or III SLAC and SNAC wrists. In contrast with four-corner fusion, the lunotriquetral and triquetrohamate articulations remain mobile in CL fusion, thus potentially preserving more motion. A cadaveric biomechanical study has shown that the triquetrum rotates 11° more than the lunate in the flexion-extension arc [21]; obliterating this motion can potentially further limit flexion-extension at the remaining radiolunate articulation. The arthroscopic approach also has the advantage of facilitating a more conservative bone resection and thus decreasing the chance of triquetral-hamate impingement.

In addition to SNAC or SLAC wrist conditions, additional indications for CL fusion include midcarpal instability, isolated midcarpal arthritis, or lunotriquetral dissociation with fixed volar intercalated segmental instability (VISI) deformity.

Arthroscopic surveillance is first performed to confirm an intact radiolunate articulation and intact triquetral-hamate articulation. Scaphoidectomy is then performed from the midcarpal portals; the tourniquet is usually not inflated at this stage. The arthroscope is introduced from the MCU portal; an arthroscopic burr of 2.9 mm is inserted into the MCR portal and directed toward the proximal and mid-scaphoid region. The scaphoid is resected by

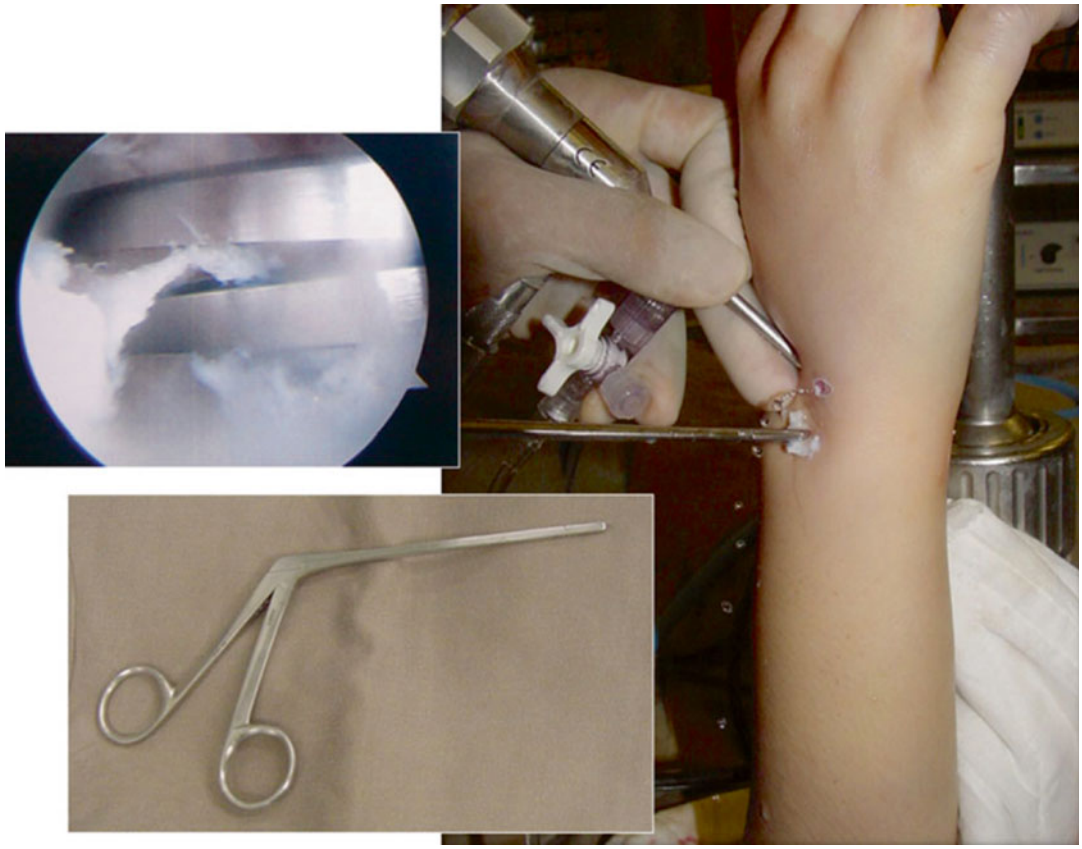

Fig. 74.9 The cartilage shell is removed with a small pituitary rongeur

the burr at high speed from the articular surface down to the core cancellous bone. Bone debris is removed by intermittently applied suction. As more space is created, a 3.5-mm burr can then be used. To avoid accidental damage of the adjacent articular surfaces, a shell of cartilage can be left intact, and the cancellous bone removed from the inside, separating the burr from the adjacent carpal bone, until most of the cancellous bone is removed. This shell can then be removed piecemeal by using a small pituitary rongeur or an arthroscopic punch (Fig. 74.9). The most distal few millimeters of the scaphoid can be left in situ to preserve the scaphotrapezial ligament. The distal scaphoid tubercle does not articulate with the radial styloid and will not cause impingement.

The arthroscope is introduced through the MCR portal and the instruments for removing cartilage through the MCU portal. The CL articulation is denuded of cartilage with a 2.9-mm burr. For a type I lunate, the whole distal articulating surface of the lunate should be debrided. For a type II lunate, the small ulnar facet that articulates with the hamate need not be debrided as it will not be involved in the fusion process. If the ulnar facet is sizeable, one may choose to flatten the ridge between the two facets. If aggressive flattening is required, one may consider performing a formal four-corner fusion to decrease the chance of triquetral-hamate impingement.

In the presence of DISI deformity, the lunate is reduced and pinned as described above. The wrist is then taken off the tower. A small stab wound is made over the distal dorsal surface of the capitate at the junction with the radial aspect

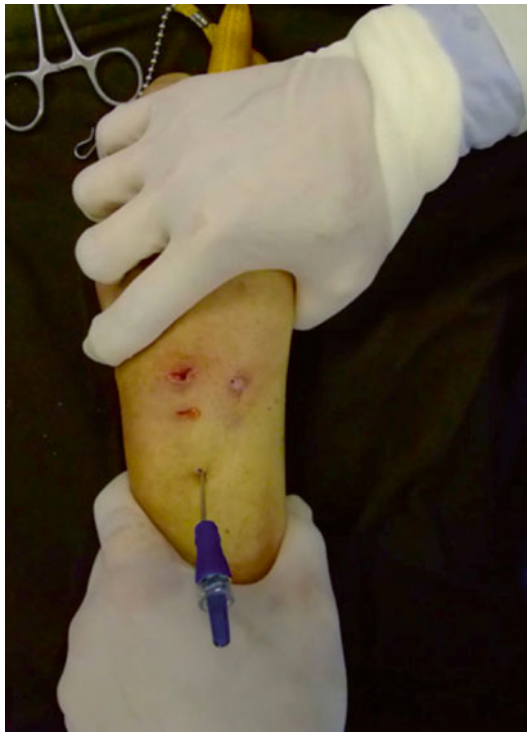

Fig. 74.10 Bone contact between capitate and lunate can be increased by ulnar translation of the distal carpal row

of the base of third metacarpal. The mini-stab wound should be bluntly dissected to avoid iatrogenic injury to the extensor tendon. A guide wire of a small cannulated screw system is inserted and driven across the capitate toward lunate and parallel to the radial border of capitate, aiming at the central part of the lunate for better bone purchase. A small metal awl is helpful to establish the entry point over the capitate prior to the insertion of the guide pin. Before the guide wire is driven across the CL joint, a second one should be placed to the ulnar side of the capitate-metacarpal joint. The guide wire is driven across the capitate, with an aim to catch the dorsal third of the lunate at the CL junction. The slightly different angle of attack of the two guide pins can avoid overcrowding of the screws. With the two pins on the capitate, the hand is ulnar translated so that the contact between the capitate and lunate is maximized (Fig. 74.10). The pins are then driven into the lunate (Fig. 74.11). As there is good articular congruence, bone graft or bone substitute is usually not required. After alignment is confirmed with

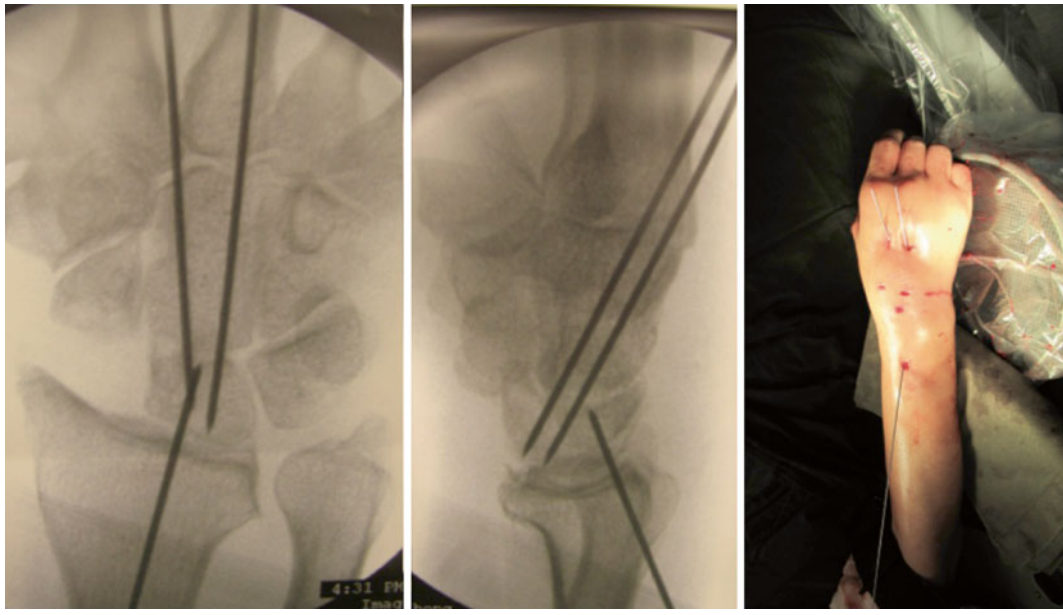

Fig. 74.11 CL fusion with temporary fixation with K-wires

fluoroscopy, screw fixation is proceeded as described. Passive finger motion is checked to ensure no impingement of the extensor tendons by the screws.

74.3.9 Specific Fusion: Radioscapholunate (RSL) Fusion

Radioscapholunate fusion is indicated for painful post-traumatic arthritis involving the whole radiocarpal joint with a relatively preserved midcarpal joint [22]. For inflammatory arthritis of the radiocarpal joint, the disease should not be at its height and should be adequately controlled with medication [23]. It has been shown that an accompanying distal scaphoidectomy procedure can help to improve midcarpal motion especially on ulnar radial deviation [24].

After arthroscopic surveillance to confirm midcarpal joint integrity, arthroscopic distal scaphoidectomy is performed. With the arthroscope placed through the MCU portal, a 2.9-mm burr is inserted into the MCR portal and directed toward the trapezoid articulating surface of the distal scaphoid. Alternatively the STT ulnar portal can also be used for the burr introduction. Burring of the scaphoid is started at this point toward the distal pole from dorso-ulnar to volar-radial direction. Care is taken to avoid damage to the cartilage of the trapezoid, trapezium, and capitate. The junction between the capitate, scaphoid, and trapezoid marks the proximal extent of resection (Fig. 74.12). Again, a shell of cartilage can be left intact until the majority of the cancellous bone of the distal scaphoid pole is removed, as described for subtotal scaphoidectomy in CL fusion. This is removed at the end piecemeal by a small pituitary rongeur or suction punch.

The radiocarpal joint is then prepared for fusion, using the 3/4 portal for viewing and the 4/5 portal for instrumentation for the radiolunate area, and switching to the 4/5 portal for viewing and 3/4 portal for instrumentation for the radioscaphoid area. Cartilage is removed using a 2.9-mm burr until subchondral bone with punctate bleeding is seen, without an inflated tourniquet. For wire insertion, a small incision is made about 2 cm proximal to the midpoint between the 3/4 and 4/5 portals. This corresponds to the radiolunate articulation. The extensor tendons are bluntly dissected off from the potential wire insertion point using a fine pointed stitch scissors. With the wrist placed in neutral position both in flexion-extension plane and radioulnar deviation plane, two guide pins are inserted with a sheath to fix the lunate. One or two guide pins are used according to the size of the carpal bone. The two wires should aim at the anterior radial and ulnar borders of the lunate. Another incision is made over the radial styloid at the bare area between the first and second extensor compartment. After careful blunt dissection of the superficial branches of radial nerve, the two K-wires or guide wires are inserted through the radius to the scaphoid. After verification of the wire position, they are backed out from the carpal bones while remaining in the distal radius.

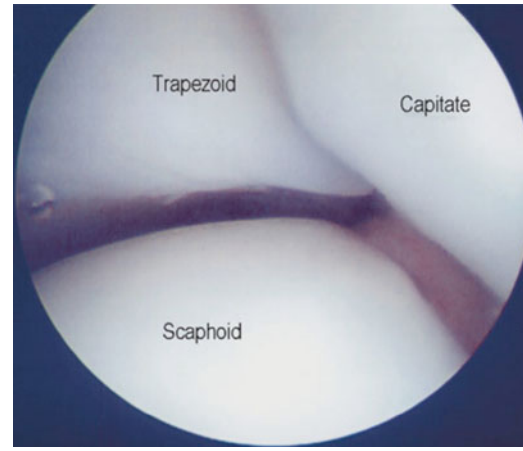

Fig. 74.12 The junction of the trapezoid, scaphoid, and capitate marks the proximal extent of distal scaphoidectomy

The wrist is put on the traction tower for insertion of bone substitute. As there is good vascularity, bone graft is not usually necessary. A Foley catheter is inserted through the 6R portal and the balloon inflated to occupy the ulnocarpal joint. A cannula for bone substitute insertion is introduced through the 3/4 portal to fill up the

radioscaphoid joint. It is then switched to the 4/5 portal for filling up the radiolunate joint. After complete filling confirmed by fluoroscopy, the guide pins are reintroduced into the carpal bones and converted to 3.0-mm headless cannulated screws (Fig. 74.13).

74.3.10 Outcome and Complications

From November 1997 to October 2011, we have performed arthroscopic partial wrist fusions in 23 patients, including 19 males and 4 females, with

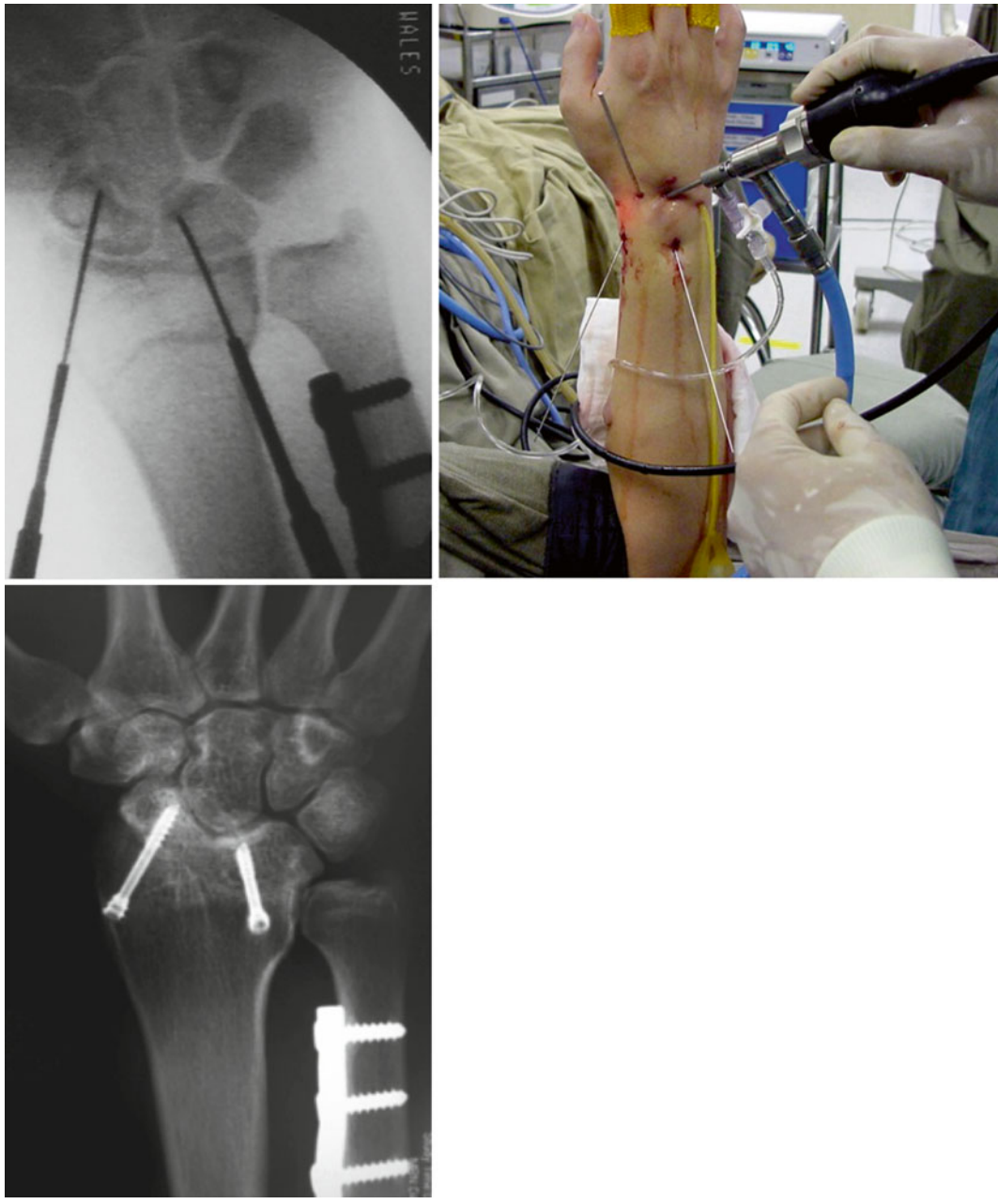

Fig. 74.13 Guide pins are inserted in an antegrade fashion from the distal radius to the carpal bones in RSL fusion. This was converted to cannulated screws and solid fusion was achieved

an average age of 42 (18–68). The indications were SLAC wrist in six, SNAC wrist in five, chronic LT instability in two, Kienbock disease in three, post-traumatic arthrosis in five, and inflammatory arthritis in two. The average duration of symptom was 34.2 months (range 9–82 months). These procedures included STT fusion in three, scaphoidectomy plus four-corner fusion in five, scaphoidectomy plus capitolunate fusion in four, lunatectomy plus scaphocapitate fusion in three, radioscapholunate fusion in four, radiolunate fusion in two, and lunotriquetral fusion in two.

The average follow-up period was 59.9 months (11–112 months). The median time of radiological union in the united cases was 10 weeks (5–50 weeks). A list of the surgical types and their union rates is shown in Table 74.1. One case of nonunion occurred, which was in a case of post-traumatic arthritis with RL fusion performed. It was converted to an open RL fusion with iliac crest bone graft. Both cases of LT fusion resulted in asymptomatic fibrous union which did not require further intervention. Early complications included two cases of pin tract infection which responded to dressing, antibiotic, and early pin removal. There was one case of superficial second-degree skin burn due to the use of a high-speed burr without a good protective sheath. Late complications included one case of delayed union of the radioscapholunate fusion which required 50 weeks to achieve radiological union. One old and osteoporotic patient required removal of the screws at 8 months postoperation due to protrusion of screw threads at the proximal lunate articular surface.

Table 74.1 Cases of partial wrist fusion performed in our center from 1997 to 2011

	No.	Bony union	Fibrous union	Nonunion
STT	3	2	1	
LT	2	1	1	
S + 4CF	6	6		
S + CL	4	4		
SC	3	3		
RSL	4	4		
RL	2	1		1
Total	24	21	2	1

74.4 Ulnar Impaction Syndrome

Ulnar impaction syndrome is the chronic impaction of the ulnar head against the TFCC and ulnar carpus. This results in degeneration of those structures and in perforation of the central part of the TFCC, which progressively involves chondromalacia of the proximal lunate and triquetrum and ulna head, tear of the lunotriquetral ligament, and finally ulnocarpal arthritis. In wrists with neutral variance, 82% of the load transmission occurs across the radiocarpal joint and 18% across the ulnocarpal joint [25]. The load across the ulnocarpal joint decreases to 4% with a 2.5 mm decrease in ulnar variance but increases to 42% with a 2.5 mm increase in ulnar variance. Repetitive loading with an elevated pressure level induces degeneration of the cartilage. It has also been shown that the more the ulnar variance, the thinner the TFCC becomes [26] and the less effective it is in load transfer and force attenuation.

The normal ulnar variance varies across different studies. In a study of 864 normal subjects, the mean ulnar variance was reported to be +0.38 mm [27]. In a study of 120 normal subjects, the mean ulnar variance was reported to be +0.74 mm. This study also showed that with the forearm in pronation together with a forceful grip, the ulnar variance increases to +1.95 mm. There was a mean maximum change in variance of 1.34 mm from supination to pronation [28]. Therefore, the primary causes of ulnar impaction syndrome are positive ulnar variance and dynamic positive ulnar variance in patients with neutral or negative ulnar variance. An X-ray with the wrist in full pronation with forceful gripping is needed for diagnosis [29].

Secondary causes of ulnar impaction include malunion after distal radius fracture, Essex-Lopresti injury, post-radial head excision, physeal arrest most notably in gymnasts [30], and congenital Madelung deformity.

For significant wrist pain related to ulnar impaction syndrome that failed to respond to conservative measures, arthroscopic debridement is an effective treatment, particularly in cases with neutral or negative variance. Osterman reported a study of 52 patients who

had undergone arthroscopic debridement, with limited arthroscopic resection of the ulnar head in cases with severe chondromalacia or positive ulnar variance [31]. There was a satisfaction rate of 88 %, with complete pain relief in 73 % and pain improvement in another 12 %. Similarly Hulsizer reported an 86 % satisfaction rate in 97 patients and a good result with ulnar shortening osteotomy in those who did not respond to arthroscopic debridement [32]. Minami cautioned that there may be less satisfactory result in patients with positive ulnar variance, associated lunotriquetral ligament tears, and degenerative TFCC lesions [33]. These reports were in agreement that shortening of the ulna aiming at neutral or minus ulnar variance was effective in cases that failed initial arthroscopic debridement. For ulnar-positive patients, therefore, an additional ulnar recession procedure such as the wafer procedure, which can be done arthroscopically, or ulna shortening osteotomy may be required as a definitive treatment.

Wnorowski performed a biomechanical study of the arthroscopic wafer procedure on ulnar-positive cadaver specimens [35]. It was found that excision of the horizontal portion of the TFCC and the radial two-third width of the ulnar head to a depth just below the articular cartilage level significantly decreased the loading over the ulnocarpal joint. Further recession was needed for unloading the ulnocarpal joint in more advanced TFCC pathology. Bernstein and Nagle compared the results of combined arthroscopic TFCC debridement and arthroscopic wafer procedure versus arthroscopic TFCC debridement and ulnar shortening osteotomy [36]. This was a retrospective review, with matched cohort, and included 11 arthroscopic wafer procedures with 16 ulnar shortening osteotomies. The procedures aimed at producing –1 mm ulnar variance. Good to excellent result was obtained in 9 out of 11 and in 11 out of 16 patients, respectively. Secondary procedures and post-op tendonitis were far more common in ulnar shortening osteotomy ($p < 0.5$). They concluded that the combined arthroscopic TFCC debridement and arthroscopic wafer procedure provides similar pain relief and restoration of function compared to ulnar shortening but with fewer complications. Relative contraindications include concomitant lunotriquetral instability and distal radioulnar joint instability. The wafer procedure cannot be performed in ulnar variance of more than +4 mm [37], as the bony resection is limited by the amount of distal ulna that can be removed before compromising the distal radioulnar joint. As the wafer procedure is a fairly destructive procedure in removing the distal end of the ulnar head, the author reserves this to advanced stage of ulnar impaction syndrome with significant preexisting chondral damage of the ulnar head and in patients with less favorable potential for ulnar shortening, such as in old patients and in chronic smokers. Potential disadvantages of the wafer procedure include a prolonged recovery time of 3–6 months [37] and an increase in pressure at the sigmoid notch that is proportional to the amount of resection [38], which can be a potential source of pain and lead to arthrosis.

74.4.1 Arthroscopic Debridement

Wrist arthroscopy is conducted in the usual manner under wrist traction tower and portal-site local anesthesia. The arthroscope is inserted at the 3/4 portal. A working portal should not be established over the 4/5 or 6R site at the beginning of the procedure until the entire ulnocarpal joint area has been inspected through the 3/4 portal. This precaution helps to eliminate the dilemma of determining whether a dorsal capsular defect or synovial folding over the dorso-ulnar corner commonly found at arthroscopy is a pathological lesion or as result of capsular intrusion by the trocar set. Occasionally it may be difficult for the arthroscope entered at the 3/4 portal to negotiate through the most narrow portion of the radiocarpal joint at the convex proximal pole of the lunate to reach the ulnocarpal area. A useful trick is to direct the scope dorsally where the capsular space is roomier until the tip passes the lunate. The scope can then glide into the ulnocarpal joint, swinging volarly under the lunate. Alternatively a small arthroscope such as a size 1.9 mm can be used. The patient should also be advised to relax

the fingers, which apart from those in finger traps should have a slightly flexed posture, and very often the joint space becomes ample for the arthroscope to manipulate. After visual assessment, a 4/5 portal is created for a probe to assess the true integrity of the extrinsic and interosseous ligaments and the TFCC. On occasion the 6R portal may also be used at the later part of the procedure. In a typical case of central TFCC tear, probing should be performed through the 4/5 portal to assess the stability and extent of the flap tear as well as the integrity of the dorsal and volar marginal ligaments. Partial excision of the TFCC tear is indicated only when the peripheral parts are shown to be intact and stable. In many cases of peripheral tear of the TFCC, the actual tear may be obscured by the overlying reactive synovial overgrowth. In these instances, the synovial overgrowth should be debrided first by shaver before probing of the lesion is performed. In addition, the loss of trampoline rebound feeling of the TFCC on probing is also an important sign of destabilizing TFCC lesion at the peripheral portion. Once a central perforation is confirmed, the tear is approached through the 4/5 portals. An arthroscopic banana or hook knife can be introduced to excise the major fragment of the flap tear (Fig. 74.14). The TFCC fragment can then be retrieved from the joint using small grasper. Any remnant of the tear can be smoothened with a suction punch or fine shaver. The remaining portion of the TFCC, particularly the dorsal and volar marginal ligaments over the peripheral 2–3 mm, should be rendered stable after the partial excision procedure. Because of the limited joint space, most of the commercially available arthroscopic knives cannot be placed into the joint through a protective sheath. Extreme caution has to be taken during the introduction of the knife into the joint to avoid iatrogenic injury to the overlying extensor tendons or dorsal nerve. Occasionally, a mosquito grasper can be inserted into the joint from the 4/5 or 6R portal to grasp onto the flap tear so as to facilitate the excision.

Fig. 74.14 Resection of the TFCC with an arthroscopic knife

Alternatively, central TFCC tears can also be debrided using small radio-frequency probes, such as the VAPR™ or VULCAN™ probes. With appropriate energy setting, the radio-frequency probe of 2.0–2.3 mm diameter can vaporize the flailed portion of the torn substance with high degree of precision and ease yet without the danger of causing iatrogenic damage to adjacent normal cartilage and ligament structures. The probe also can also be used for hemostasis in the coagulation mode. The major drawback is the inevitable production of large amount of air bubbles during the debridement process that can cause significant blockage of the visual field within the typical limited space of the wrist joint. This is alleviated by introducing the probe through a small arthroscopic cannula to allow gas bubbles to escape. Continuous saline irrigation and outflow is mandatory to prevent overheating.

Associated intra-articular pathologies should be treated simultaneously. Degenerative tear of the lunotriquetral ligament without joint instability can be debrided using shaver until the protruded part rounds off. Chondral defects should be treated by chondroplasty. Prognosis depends on the size of the lesion as well as underlying cause for the lesions. Whipple reported that chondral defects smaller than 5 mm respond well to arthroscopic treatment [34]. Lesions with secondary underlying cause such as instability or fracture have lower symptomatic relief rate. Conventional treatment consists of abrasion or drill chondroplasty. The aim is to excise unstable cartilage flaps and debris, to render the rim of the chondral defect stable, and to encourage fibrocartilage formation to cover the exposed subchondral bone. A motorized shaver or burr is employed.

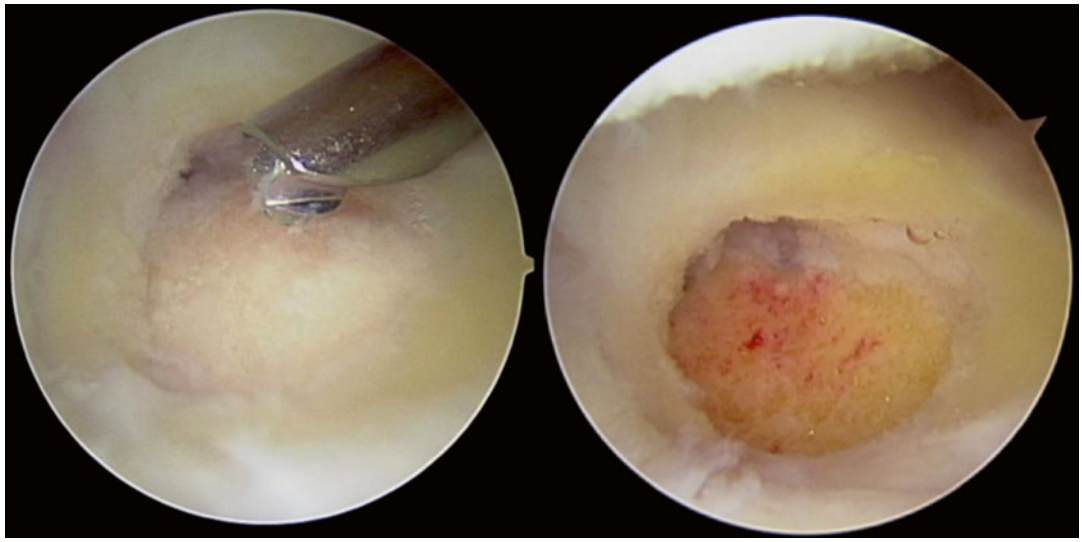

Fig. 74.15 Burring of the ulnar head through the TFCC perforation

A fine K-wire of 0.9 or 1.1 mm diameter is used to drill multiple times through the subchondral bone over the base of the defect to encourage the emigration of mesenchymal cell for the formation of fibrocartilage. Iatrogenic injury to extracapsular structures can be minimized by threading the K-wire through the metallic sheath of a 14G angio-catheter. After the operation, temporary splintage is optional, and active mobilization is resumed after a few days of rest.

74.4.2 Arthroscopic Wafer Procedure

With the arthroscope inserted from the 3/4 portal, a shaver is introduced from the 4/5 portal for debridement of the TFCC to the peripheral stable rim and associated synovitis at the ulnocarpal joint as well as the distal radioulnar joint. For the latter, debridement of the synovium is facilitated by asking a surgical assistant to manually squeeze the distal radioulnar joint dorso-volarly at different angles of forearm rotation, so that synovial growth in the distal radioulnar joint can be herniated into the space at the ulnocarpal joint. Burring of the ulnar head can be performed with the 2.9-mm arthroscopic burr introduced from the 4/5 portal (Fig. 74.15). This should be done in an even manner at the horizontal plane, taking care of 270° of the circumference. This can be achieved by gradually rotating the forearm from pronation to supination while burring the ulnar head at the same time, with the aim to create ulnar minus 1–2 mm. Intraoperative fluoroscopy may be necessary as it can be quite difficult to accurately assess the amount of ulnar head excised by the arthroscopic view alone. Additional portals in the distal radioulnar joint can be employed to facilitate the resection process. Usually the distal DRUJ portal located just proximal to the dorsal TFCC and distal to the ulnar head is the best portal for the inserting the burr to complete the ulnar resection particularly at the periphery of the ulnar head. After completion of the procedure, the wrist is splinted for 3–4 days before mobilization exercise is initiated.

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Wrist Arthroscopy

75

John R. Fowler

75.1 Introduction

The arthroscopic-assisted treatment of fractures aims to improve reduction and identify associated injuries. Distal radius articular step-off of 2 mm increases maximum joint stress by 50 % [1] and results in posttraumatic arthritis at 6–7 years after injury [2]. Lutsky et al. demonstrated that intraoperative fluoroscopy underestimates articular step-off [3]. Wrist arthroscopy allows the surgeon to accurately assess alignment and step-off directly and provides an opportunity to evaluate and treat the soft tissue pathology associated with injuries to the wrist. Auge et al. noted that arthroscopic findings resulted in repeat reductions due to persistent articular incongruity in the majority of patients in their series [4]. Certain distal radius fracture patterns may be amenable to arthroscopic-assisted reduction and percutaneous fixation, thereby avoiding the morbidity of open reduction and internal fixation [5]. Wong et al. found that 34 % of patients with an acute scaphoid fracture had an associated carpal ligament injury [6], and Ruch et al. noted that more than half of the patients in their series had associated TFCC tears [5]. These studies highlight the importance of arthroscopy in the treatment of these associated injuries. Additionally, arthroscopic-assisted treatment of scaphoid fractures allows evaluation of adequate fracture reduction, prevention of screw prominence, and improved visualization of the appropriate starting point when using percutaneous techniques [7].

Perilunate dislocations and fracture dislocations represent a spectrum of severe wrist injury. Open treatment of these injuries has been the standard of care. However, stiffness and arthrofibrosis are nearly universal complications with the open approach. Recently, there has been interest in the arthroscopic-assisted treatment of these injuries to decrease the morbidity of the surgical approach [13, 14].

75.2 Indications

Arthroscopic-assisted reduction of distal radius fractures is indicated if there is greater than 2 mm of articular step-off or 2 mm of fracture gap [7]. It should be noted that plain radiographs may underestimate the amount of articular step-off, and consideration may be give to obtaining computed tomography in cases of intra-articular fractures to more accurately determine the amount of articular step-off [3]. Clinical suspicion (based on physical examination, mechanism of injury, and/or preoperative imaging) for concomitant soft tissue injury (scapholunate ligament tear, triangular fibrocartilage complex (TFCC) tear, or other radiocarpal ligament injuries) is another indication for arthroscopic-assisted treatment of distal radius

J.R. Fowler, MD
University of Pittsburgh, Pittsburgh, PA, USA
e-mail: fowlerjr@upmc.edu

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fractures [7]. A major contraindication is the presence of a large capsular tear that would allow fluid extravasation, potentially resulting in acute carpal tunnel syndrome and/or forearm compartment syndrome [7, 8]. Arthroscopic-assisted reduction of intra-articular malunion is indicated after intra-articular osteotomy [9].

Arthroscopic-assisted treatment of scaphoid fractures is indicated for any displaced fracture of the scaphoid, non-displaced proximal pole fractures, and non-displaced scaphoid nonunions without evidence of avascular necrosis [7]. Contraindications include avascular necrosis, nonunion with humpback deformity or dorsal intercalated instability, and presence of significant degenerative changes [7].

The indications for arthroscopic-assisted treatment of perilunate dislocations are more controversial. Arthroscopic-assisted treatment may be indicated in cases where a closed reduction can be performed and stability can be maintained using percutaneous techniques.

75.3 Techniques

There are several techniques for arthroscopic-assisted treatment of distal radius fractures depending on the specific fracture pattern. Geissler recommends arthroscopic reduction and fixation of radial styloid fractures as a good fracture pattern for surgeons with minimal arthroscopic-assisted experience [10]. The patient is placed in a wrist traction tower, and standard wrist arthroscopy techniques are performed. The radial styloid is best visualized from the 6R portal. A K-wire is placed into the radial styloid and used as a joystick to reduce the fracture. The reduction is confirmed arthroscopically and fluoroscopically; the K-wire is then advanced.

Intra-articular distal radius fractures with metaphyseal involvement present more of a challenge. The fracture should be reduced under fluoroscopic guidance and an external fixator or locked volar plate placed to hold the overall alignment. Wrist arthroscopy is then performed using the 3, 4 and 6R portals. The 3, 4 portal allows visualization of the lunate fossa, scaphoid fossa, TFCC, and volar extrinsic ligaments [11]. The camera is then switched to the 6R portal to visualize reduction of the articular fragments in the sagittal plane, lunotriquetral ligament, and scapholunate ligament [11]. Articular depression is elevated using a probe and/or dental pick. Fracture gap can be reduced through the use of tenaculum clamps. Once the reduction has been obtained, rafting K-wires can be used to support the articular surface. Reduction is then once again confirmed using fluoroscopy [5].

For scaphoid waist fractures and proximal pole fractures, Geissler described a dorsal approach [12]. The patient is placed in a traction tower and arthroscopy performed through standard portals. The 3, 4 portal is used to evaluate for the presence of associated injuries. The 6R portal is used to visualize the starting point for the guidewire. The midcarpal portal is used to evaluate reduction of the scaphoid fracture. The wrist is flexed approximately 30° and a 14-gauge needle inserted through the 3, 4 portal. The starting point is just radial to the SL ligament and centrally in the anteroposterior plane. The guidewire is advanced along the central axis until it touches the subchondral bone of the distal pole and its location confirmed fluoroscopically. A second guidewire is placed percutaneously until it touches the proximal pole. The difference between the first and second guidewires is the scaphoid length, and 4 mm is subtracted to avoid screw prominence. The guidewire is then advanced through the distal pole cortex and out the volar skin. This allows the wrist to be extended for arthroscopic confirmation of reduction. The camera is placed in the midcarpal portal to evaluate the reduction of a scaphoid waist fracture. If the scaphoid fracture is malreduced, additional K-wires may be inserted percutaneously and used as joysticks to obtain reduction. The screw is placed and location confirmed fluoroscopically. Arthroscopy is used to confirm that the screw is below the subchondral surface of the proximal pole.

Herzberg and colleagues recommended a treatment protocol for perilunate injuries that

includes dry arthroscopy and a mini-dorsal approach [13]. The perilunate injury (dislocation and/or fracture-dislocation) is reduced by closed means. Standard wrist arthroscopy is performed through a 3, 4 and 6R portal. The 3, 4 portal is enlarged to a 3 cm horizontal incision. The interval between the third and fourth compartments is developed and a v-shaped incision in the capsule is made, sparing the dorsal intercarpal ligament. The scapholunate interval is evaluated and reduced using K-wire joysticks. The interval is pinned under fluoroscopic guidance. The scapholunate ligament is directly repaired with suture anchors. Kim and colleagues advocate an all-arthroscopic technique without repair of the intercarpal ligaments [14].

75.4 Tips and Pearls

- Keep the pressure low to minimize fluid extravasation [8].
- Perform surgery 3–10 days after injury. This allows soft tissue swelling to decrease but allows treatment before callus formation makes the reduction more difficult [11].
- Avoid mobilizing intra-articular fragments too aggressively. If this is done, the fragments can become loose bodies and be hard to reduce [11].
- Use the midcarpal portal to visualize scaphoid waist fractures and the 3, 4 portal to visualize proximal pole scaphoid fractures [12].

75.5 Complications

The standard complications associated with wrist arthroscopy also apply for arthroscopic-assisted techniques. Tendon injury and superficial sensory nerve laceration are potential complications from portal creation. Acute carpal tunnel syndrome and/or forearm compartment syndrome may occur secondary to fluid extravasation [7, 8]. Osteochondral lesions may occur from insertion of arthroscopic equipment. Complex regional pain syndrome may occur secondary to overdistraction during wrist arthroscopy.

75.6 Summary Results/Literature Overview

Several studies have demonstrated improved objective outcomes using arthroscopic-assisted distal radius fixation compared to standard open treatment. Ruch and colleagues treated 30 patients with either standard external fixation and pining or arthroscopic-assisted external fixation and pinning. The arthroscopic-assisted group had improved supination, wrist flexion, and wrist extension compared to the standard group [5]. Doi et al. prospectively compared 34 patients treated with arthroscopic-assisted techniques to 48 patients treated with standard open techniques. Range of motion and grip strength were superior in the arthroscopic-assisted group. Additionally, the arthroscopic-assisted group had superior radiographic parameters at final follow-up [15]. Chen et al. reviewed 20 distal radius fractures that underwent arthroscopic-assisted fixation with a mean follow-up of 24 months. The authors noted articular collapse in two patients who did not have bone grafting and loss of height in one patient who did not have external fixation. The authors recommended routine bone grafting and use of external fixation [16].

Arthroscopic-assisted percutaneous scaphoid fracture fixation has resulted in high union rates. Slade and colleagues reported a 100 % union rate at 12 weeks in 27 scaphoid fractures treated with arthroscopic-assisted percutaneous scaphoid fixation [17]. Martinache et al. retrospectively reviewed 37 scaphoid fractures treated with arthroscopic-assisted technique and reported a 100 % union rate at an average of 9 weeks [18].

Kim et al. reviewed 20 patients with perilunate injuries treated with arthroscopic-assisted techniques [14]. At mean follow-up of 31 months, the average flexion and extension were 51 and 53°, respectively. The mean grip strength was 78 % of the contralateral wrist and mean DASH score 18. Herzberg and colleagues reviewed 18 patients and reported mean wrist flexion of 39° and mean wrist extension of 41° at final follow-up [13]. Mean grip strength was 69 % of the contralateral side and mean QuickDASH score was 31. Complex regional pain syndrome developed in 4 of 18 patients.

75.7 Future Directions

Small series with short-term follow-up have demonstrated improved radiographic and clinical outcomes for arthroscopic-assisted treatment of distal radius and scaphoid fractures. Larger, prospective, randomized trials will be needed to determine if this difference truly exists or is dependent on surgeon experience and selection bias. Additionally, long-term follow-up is needed to determine if the promising short-term results with these techniques is sustained.

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Arthroscopic Arthrolysis

76

Riccardo Luchetti, Gregory Bain, Levi Morse, and Duncan McGuire

76.1 Introduction

Joint contracture (stiffness) is a common problem, with many possible causes (see Table 76.1). We *classify joint contracture* according to these different causes, namely, intra-articular, capsular, or extra-articular.

Why have the capsule as a separate group? The capsule is a different anatomical structure with a different function, pathology, treatment, and prognosis. The function of the capsule and its ligaments is to constrain the extremes of motion while allowing the articular surface to move smoothly. This concept of having the capsule have its own category was initially developed for the wrist [2, 3, 7, 26] and has been extended into the elbow [28] and shoulder [5].

Each anatomical structure can have a *primary insult*, such as trauma, disease, or degeneration. This includes infection and surgery. Following this insult, the *normal healing process* occurs.

Any necrotic tissue is removed and replaced with fibrous scar tissue, which contracts as it matures. This produces a soft tissue contracture and also predisposes to other pathological processes such as nonunion and AVN.

The capsule is a unique structure that is often injured with the primary insult and prone to contracture since it is the interface between the inside and outside of the joint. Capsular contracture can occur when the joint is immobilized, even following a minor injury, and universally occurs with joint degeneration.

Due to the complex intercalated anatomy of the wrist, there can be pain or stiffness due to intra-articular or capsular disorders of the radiocarpal (RC), midcarpal (MC), and/or distal radioulnar joints (DRUJ).

The *treatment* of the contracture needs to be directed at the anatomical structures involved and take into account the pathological processes. Intra-articular pathology will usually be managed with debridement, reconstruction, or arthroplasty. Arthroscopy is the best way to perform the

R. Luchetti, MD (✉)
Rimini Hand and Upper Limb Surgery and Rehabilitation Center (Private Activity), Via Pietro da Rimini 4, Rimini 47924, Italy

Hand Surgery Unit, Clinic of Plastic and Reconstruction Surgery, University of Milan
e-mail: riccardoluchetti53@gmail.com

G. Bain, MBBS, FRACS, FA (Orth) A, PhD
L. Morse, BPhty, BMBS (Hons)
Department of Orthopaedic Surgery, Flinders University, Flinders Drive, Bedford Park, Adelaide 5042, South Australia, Australia
e-mail: greg@gregbain.com.au; levimorse@yahoo.com

D. McGuire, MBCHB, FC(Orth) (SA), MMed
Department of Orthopaedic Surgery, Groote Schuur Hospital, Cape Town 7705, South Africa
e-mail: duncan.mcguire@gmail.com

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Table 76.1 Patho-anatomical classification of wrist stiffness

Anatomy	Intra-articular	Capsular	Extra-articular
Function	Friction-free motion	Joint constraint	Motors
1. Pathology	Synovium – RA, crystals	Capsular tear	Nerve – injury, compression
	Cartilage – defect	Immobilization	Muscle – spasticity
	Ligament – tear (e.g., SLIL)		Tendon – laceration, impinge
	Bone – fracture, Kienbock's		Skin – laceration, burn
2. Pathology	OA, nonunion, AVN	Capsular contracture	HO, soft tissue contracture
Treatment	Debridement, resection, reconstruction, or replacement	Capsular release, resection	Excision, release, or lengthen offending structure

Modified from Bain et al. [3]
The extra-articular causes are outside of the joint. Note systemic conditions can cause joint contracture in many ways, e.g., diabetes causes tendency to nerve compression, thickening of the capsule, and extra-articular soft tissues

debridement [18], and there are now an increasing number of arthroscopic reconstructive procedures [4]. Capsular contractures can also be managed with an open or arthroscopic capsular release [5, 26]. Extra-articular conditions are just starting to be managed with endoscopic procedures [6].

The *prognosis* of the surgery will depend upon many factors. If the articular surface is intact, a joint debridement +/− capsular release is likely to do well. If the articular surface is severely compromised, the prognosis will be poor with a joint debridement, in which case a reconstructive or salvage procedure should be considered.

The most common scenario at arthroscopy is posttraumatic arthrofibrosis between an intra-articular distal radius malunion and the proximal carpal row. There is usually a capsular contracture, and often disruption of the scapholunate interval. Intra-articular and extra-articular malunions need to be corrected with osteotomies to restore normal anatomy and alignment of the articular surface of the distal radius [9]. Following distal radius fractures, three main conditions can contribute to painful limitation of motion: (1) (most commonly) capsular contracture with intra-articular adhesions (arthrofibrosis), (2) radiocarpal impingement caused by either malunion of fractures involving the dorsal rim of the distal radius (Figs. 76.1 and 76.2) or an increase in volar tilt of the distal radius articular surface, and (3) articular surface irregularity [11] and step-off. The three conditions can sometimes coexist and must be treated at the same time. It is important to note the rehabilitation protocol for the various surgical procedures that may need to be performed. Any procedure that would involve postoperative immobilization such as ligament reconstructions must be avoided or performed as a stage procedure. Immediate mobilization following surgery is mandatory.

Pain and stiffness may be due to extra-articular pathologies, such as median nerve compression, stenosing tenovaginitis of the flexor tendons, or even an injury to the terminal branch of the posterior interosseous nerve. These pathologies may be treated concurrently with the arthroscopic arthrolysis since the postoperative rehabilitation protocol is similar.

76.2 Indications

Indications for arthroscopic wrist arthrolysis include cases in which wrist stiffness persists despite a prolonged course of conservative therapy following trauma or prolonged immobilization. It is well known that intra-articular and capsular injuries as well as prolonged immobilization may stimulate arthrofibrosis. Pain is almost always present with articular rigidity, and it is the main reason for medical consultation.

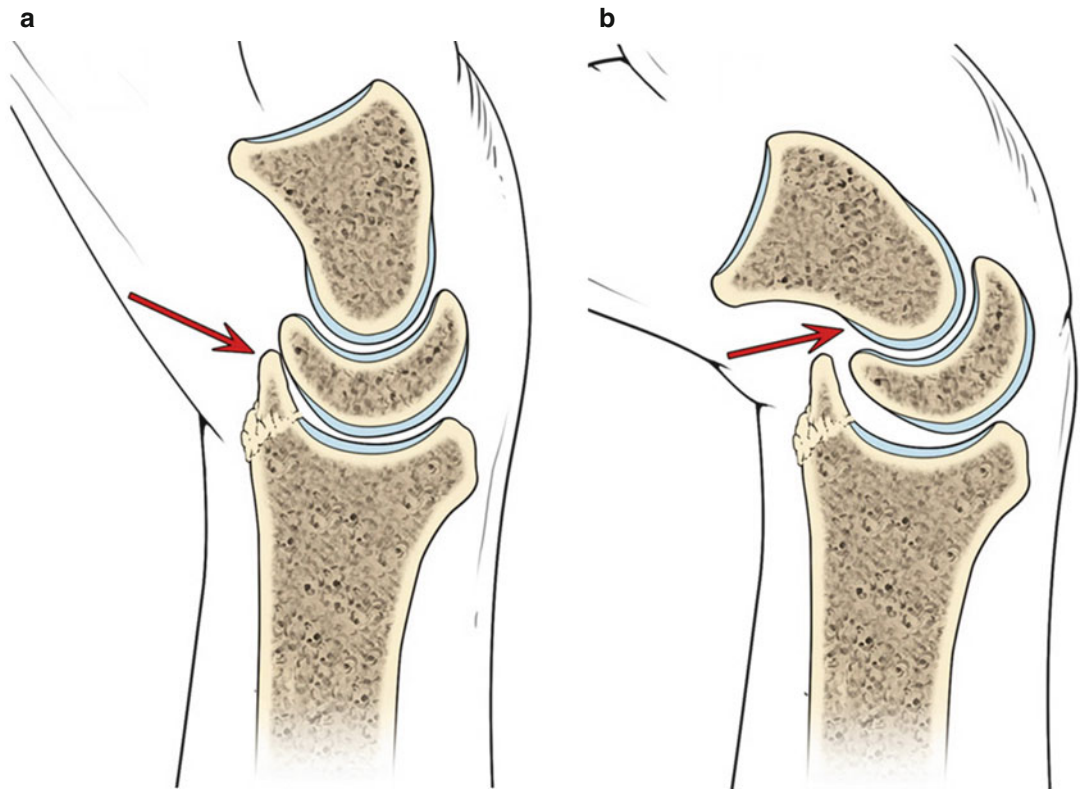

Fig. 76.1 Malunion of the dorsal rim of the distal radius following fracture (**a**) Note the impingement between the dorsal rim and the carpus (**b**) (Reproduced and modified with permission from Springer Verlag)

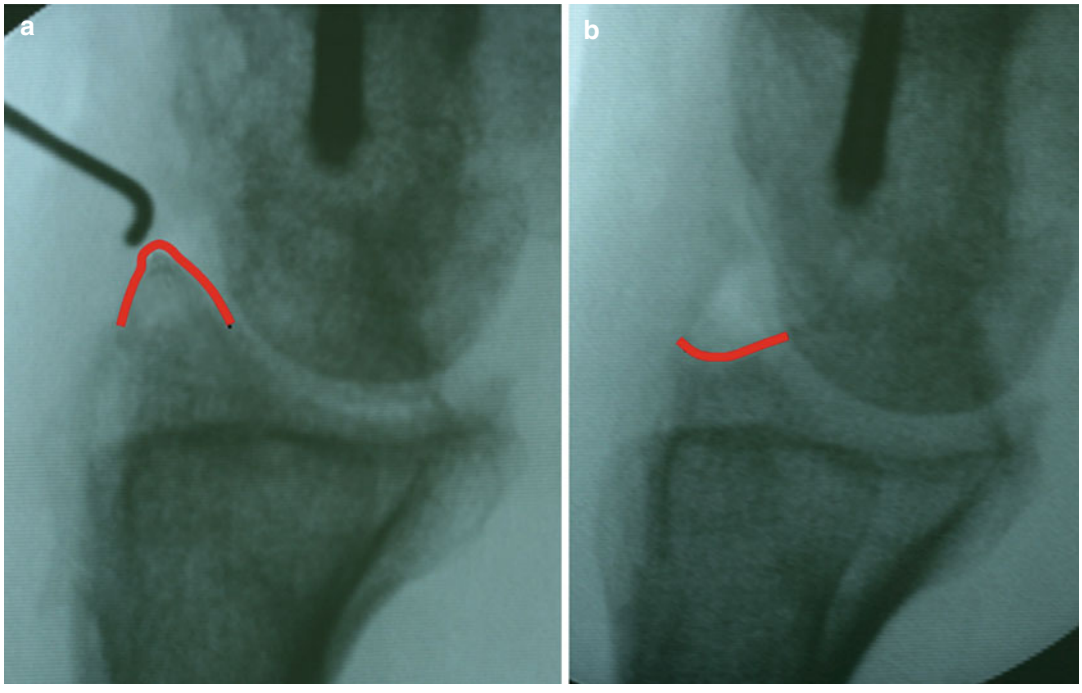

Fig. 76.2 Lateral radiograph of a wrist showing dorsal impingement (*arrow*) of the distal radius following malunion of a fracture. (**a**) Before and (**b**) after arthroscopic debridement of dorsal rim (Courtesy of Francisco del Piñal)

Conservative treatment with physiotherapy and splinting is the treatment of choice. Surgery is reserved for those cases refractory to conservative treatment.

76.3 Technique (Tip and Pearls Included)

Traditional RC portals are used for arthroscopic arthrolysis of the wrist. Two volar portals (radial and ulnar) may also be used for the RC and ulnocarpal (UC) joint [2, 15–18, 21]. The distal radioulnar joint (DRUJ) may also be involved in the pathological process and may also be debrided arthroscopically. The midcarpal (MC) joint is rarely involved; however, if it is affected, traditional or new MC portals are used.

Arthrolysis may be performed using a variety of instruments (Table 76.2). Dry arthroscopy is utilized more frequently for this condition as it has the benefit of avoiding fluid extravasation into the soft tissues [1, 10].

Articular distraction is obtained using the traditional vertical position with countertraction at the elbow of about 3 kg. Occasionally the articular distraction is not sufficient enough to permit the use of a 2.7 mm scope even when more traction weight is applied. In these cases, a 1.9 mm scope is recommended.

Although arthroscopy starts at the level of the RC joint, the MC joint should always be assessed. When there is a loss of pronation and supination, arthrolysis of the DRUJ should also be performed.

In the most difficult cases, it is impossible to recognize the normal arthroscopic anatomy of the wrist due to the presence of fibrosis that completely encloses the joint space. Difficulties could be encountered in performing triangulation with the instruments. Synovitis, fibrosis, and adhesions that obstruct the visual field must be resected with caution, ensuring that no damage occurs to the surrounding structures.

Table 76.2 Instruments for arthroscopic arthrolysis

Motor powered
Full radius blade
Cutter blade/incisor
Razor cut blade
Barrel abrader
Suction punch
Mini-scalpel (banana blade)
Laser
Radiofrequency
Dissector and scalpel

76.3.1 Radiocarpal Joint

All standard portals (1–2, 3–4, 4–5, 6R and 6U) may be used, along with volar ones, if needed. These can be interchanged as required (Fig. 76.3). Inflow is permitted through the scope. Outflow is by the 6U portal, or none. When dry arthroscopy is used, the trocar inflow portal is left open, permitting the entrance of air as the shaver is used with constant aspiration. This allows removal of synovial fluid, blood, and debris. Furthermore, a 5 cc syringe can be used to inject fluid in order to wash the joint debris and blood, which is then

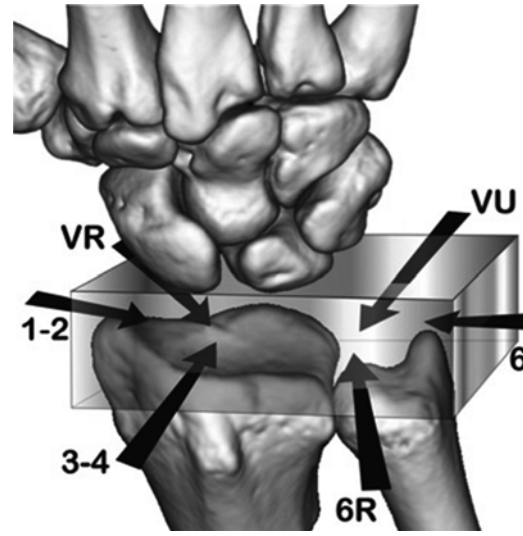

Fig. 76.3 Box concept. The wrist can be thought of as a box, which can be visualized from every perspective. Through a combination of arthroscopic portals, it is possible to have viewing and working portals that encircle the wrist. This enables the arthroscopist surgeon to modify the position of his scope to obtain an optimal view and then to ensure the working instruments can adequately perform their duties. The portals can be changed and adjusted to be able to best perform the job at hand (Reproduced with permission pending, *J Arthroscopy* [3])

removed by the suction of the chondrotome. Only when the radiofrequency instrumentation is used does fluid become necessary. Once the radiofrequency is no longer required, it is possible to return to dry arthroscopy by using the chondrotome to aspirate fluid and debris in the joint. In the dry arthroscopy, the trocar connection with the fluid introduction must be remained open (the tube should be removed), permitting the aspiration of the shaver to work effectively.

The procedure is divided into two steps to permit a better understanding of the technique.

76.3.1.1 Step One: Fibrosis and Fibrotic Band Resection

Arthroscopic arthrolysis always starts from the radial side of the RC joint (Fig. 76.4). The starting portal is usually the 3–4 and the 1–2 is used as a working portal; however, portals are switched frequently.

Adhesions are initially removed from the radial side of the joint using the chondrotome (full radius, 2.9 mm; aggressive or incisor, 3.2 mm) and radiofrequency instruments. However, not infrequently, difficulties are encountered in triangulation due to intense intra-articular fibrosis. In these circumstances, it is better to switch the scope from the 3–4 portal to the 1–2 portal and use the 3–4 portal as the working portal. The 1–2 portal is established with an outside-in technique using a needle. A longitudinal skin incision is made and blunt dissection with a mosquito forceps is performed to gain access to the joint. Shaving should only be started after ensuring that the full radius is turned toward the scope and not to the articular surface. As the intra-articular vision improves, the resection of fibrosis becomes easier.

Once fibrosis is completely removed from the radial side of the RC joint, the arthroscopic procedure is shifted to the ulnar side (Fig. 76.5). The scope is introduced through the 3–4 portal and the chondrotome through the 6R. Visualization of the shaver is frequently limited by the presence of the fibrotic band. Traditionally the fibrotic band [21] is localized between the scapholunate (SL) ligament and the ridge between the scaphoid and lunate facet of the distal radius (Figs. 76.6

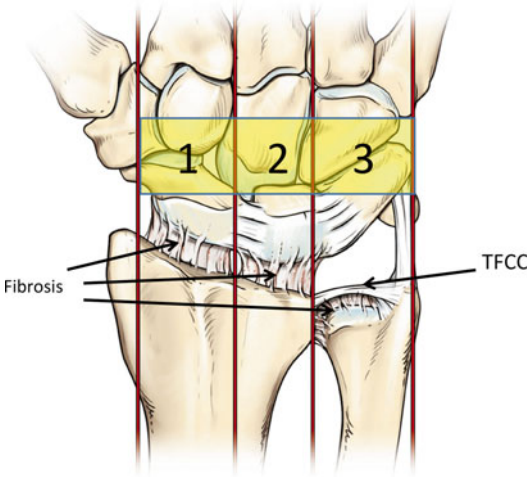

Fig. 76.4 Drawing showing the division of the radiocarpal joint into three parts. The proper radiocarpal joint is divided into two parts by a *longitudinal line* passing through the scapholunate joint. The ulnocarpal joint is separated from the radiocarpal joint by a *longitudinal line* through the medial border of the radius at the sigmoid notch. The ulnocarpal joint is rarely involved. In this drawing fibrosis is located in the radiocarpal joint, the DRUJ, and under the TFCC ligament (Reproduced and modified with permission from Springer Verlag)

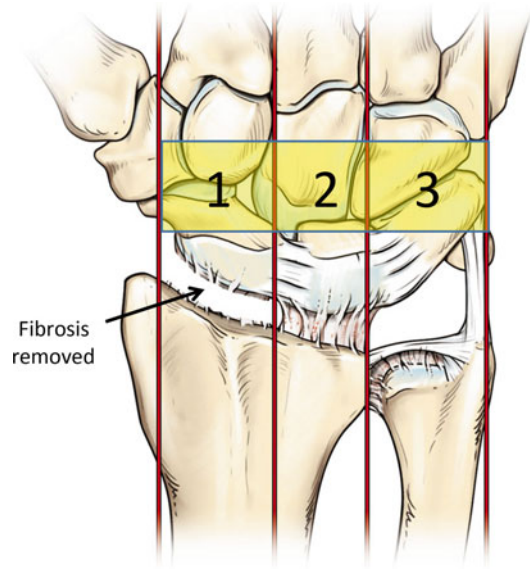

Fig. 76.5 Drawing showing division of the radiocarpal joint into three parts, where fibrosis in the radial side has been removed (step 1) (Reproduced and modified with permission from Springer Verlag)

and 76.7a). It may be partial or complete. When it is complete, it divides the radiocarpal joint into two separate spaces. The fibrotic band may be incised using a small dissector introduced via the 6R portal in the direction of the scope. The band is carefully detached from the articular surface using the dissector. The fibrotic band may then be resected using a basket forceps or a shaver from the 6R portal (Fig. 76.7b). To obtain a complete resection of the band, instruments must be switched from the 6R to 3–4 portal and scope from 3–4 to 6R. Radiofrequency instruments may also be used to resect the fibrotic bands. Multiple fibrotic bands may be encountered in a joint with osteochondral damage to the articular surface of the distal radius (Fig. 76.8), with all of them originating from the defect.

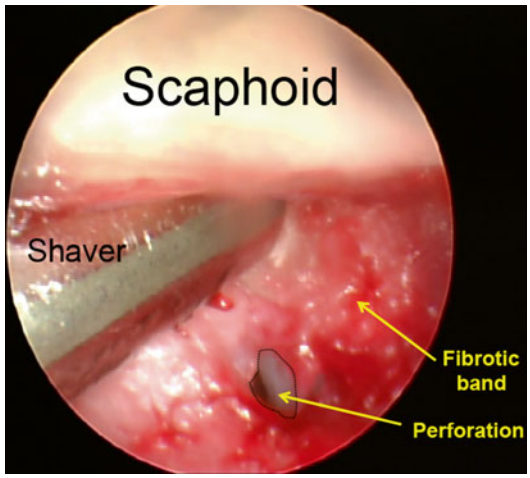

Fig. 76.6 Arthroscopic view of the fibrotic band that has resulted in a virtual complete separation of the radiocarpal joint in two compartments. A shaver is being used to excise the fibrotic band (Reproduced and modified with permission from Springer Verlag)

Resection of this intra-articular fibrosis is often sufficient to improve passive wrist ROM. However, on occasion, this fibrosis may be much more complex making arthrolysis more difficult. Rarely these bands may ossify and form an osteofibrotic band and, with progression, may result in an ankylosis of the RC joint (Fig. 76.9). In this situation it is very difficult to remove the band and may sometimes be impossible. Resection of these osteofibrotic bands may not be indicated if it will cause an osteochondral defect that would then result in persistence of pain and recurrent formation of the bands.

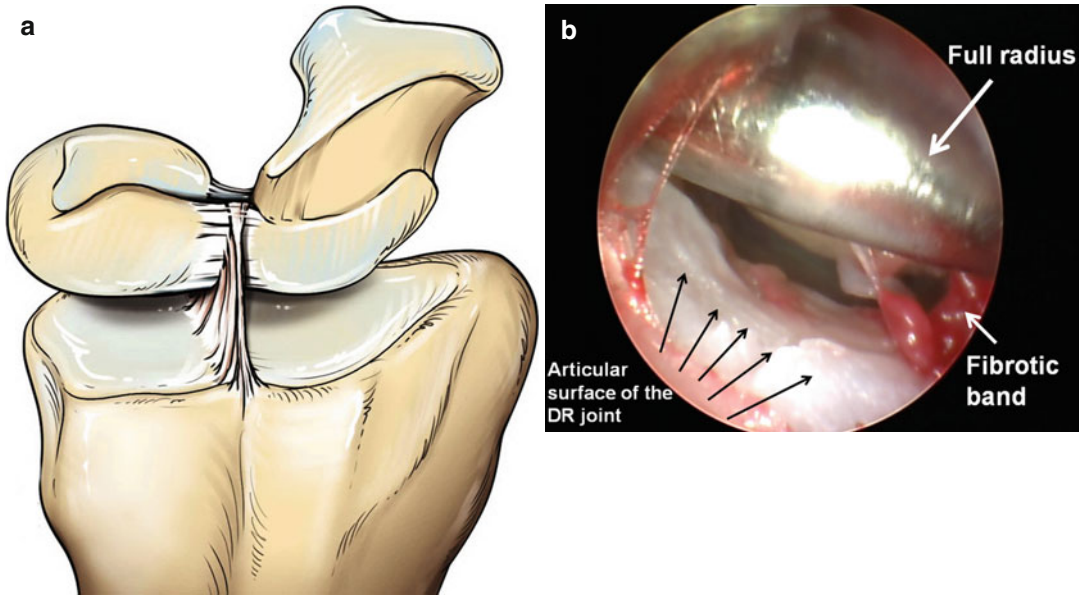

Fig. 76.7 (**a**) Drawing showing the location of the fibrotic band (Reproduced with permission from Springer Verlag). (**b**) Arthroscopic view of the wrist joint after fibrotic band resection. Note the irregularity of the articular surface of the distal radius due to a previous fracture (Reproduced with permission from Springer Verlag)

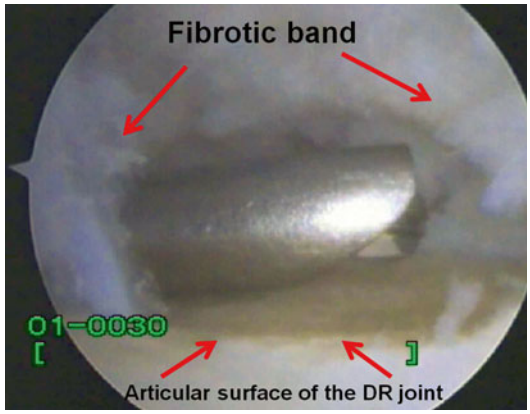

Fig. 76.8 Cartilage damage to the articular surface of the distal radius becomes evident after resection of the fibrosis (Reproduced with permission from Springer Verlag)

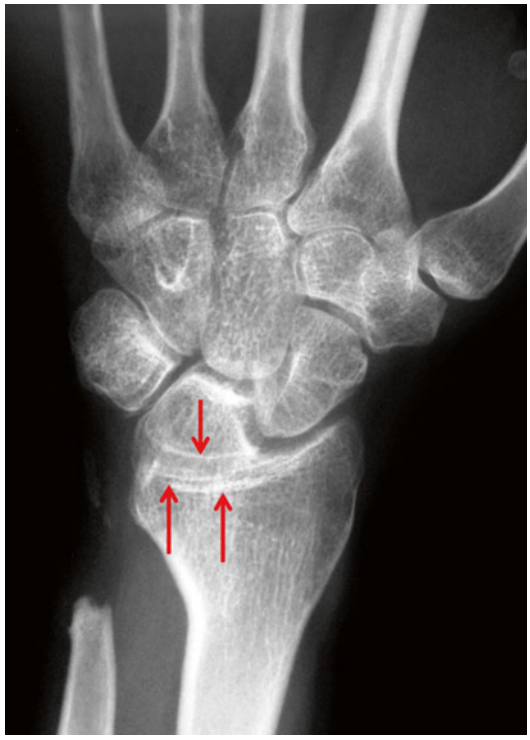

Fig. 76.9 X-ray of a wrist showing an ankylosis (*red arrows*) of the radio-lunate joint due to progression of an osteofibrotic band (Reproduced with permission from Springer Verlag)

When fibrosis in the ulnar side of the RC joint has been completely excised, the procedure continues into the ulnocarpal joint (Fig. 76.10). This part of the wrist joint is rarely affected by

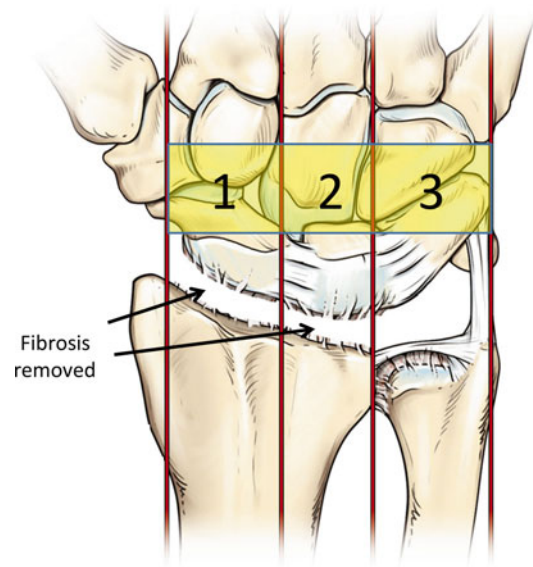

Fig. 76.10 Drawing showing complete resection of fibrosis in the radiocarpal joint (Reproduced and modified with permission from Springer Verlag)

fibrosis, and arthroscopy is often diagnostic only. Occasionally, peripheral TFCC tears may be found; however, in treatment, these should be limited to a debridement in order to avoid the need for postoperative immobilization.

Before moving to the second step of the procedure, it is mandatory to evaluate the wrist ROM (Fig. 76.11). This should be performed out of traction.

76.3.1.2 Step Two: Volar and Dorsal Capsule Resection

Depending on the ROM obtained after step one, the volar and/or dorsal capsule and RC ligaments may need to be released. A mini-scalpel, such as a banana blade for peripheral nerve surgery, or micro-scalpel for ocular surgery is used. Radiofrequency instruments may also be used. Volar capsulotomy is easier than dorsal because the structures are immediately in the field of vision when viewing from the dorsal arthroscopy portals. Initially, the chondrotome is used to debride the intra-articular portion of the volar ligaments in order to visualize the entrance point of the mini-scalpel. Once inside the joint, the surgeon addresses each affected ligament

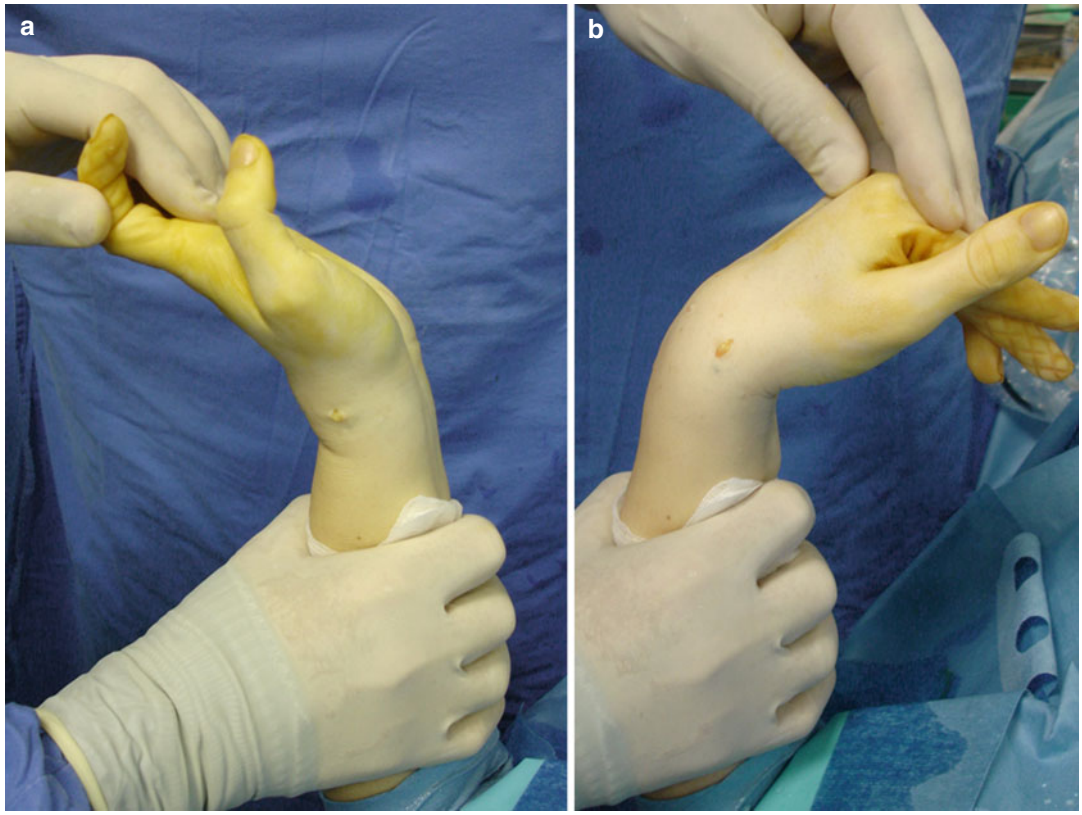

Fig. 76.11 Wrist ROM evaluation after step one of the arthroscopic arthrolysis procedure: (**a**) wrist extension; (**b**) wrist flexion (Reproduced with permission from Springer Verlag)

(Fig. 76.12). Often this is made difficult by articular incongruity, making it impossible to reach all areas of the capsule. This may be made easier by smoothing off the articular steps using a burr that helps in reaching the volar capsule. It is much easier to cut the radial side of the capsule from the 1 to 2 portal with the scope in the 3–4 portal. Radioscaphocapitate and radiolunate ligaments are resected at their base and the procedure continues through to the ulnar side (Fig. 76.13). The ulnar side of the volar capsule is released through the 6R portal (scope in 3–4). Identification of the volar ulnar limit of the distal radius permits the surgeon to stop the ligament dissection at this point to prevent resection of the volar UC ligament. At this point traction is removed, and a gentle manipulation is performed.

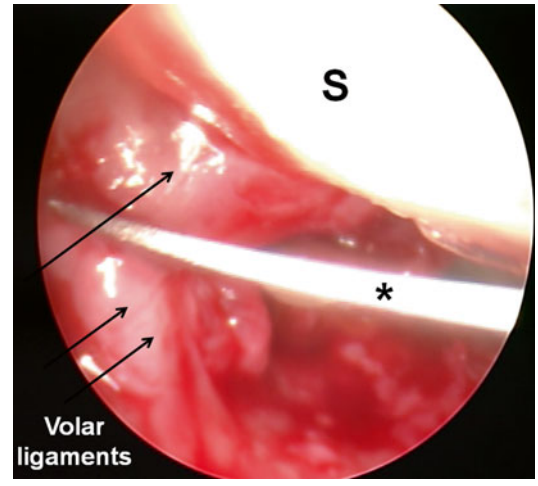

Fig. 76.12 Sectioning of the volar capsule using a miniscalpel (*) (*S* scaphoid) (Reproduced with permission from Springer Verlag)

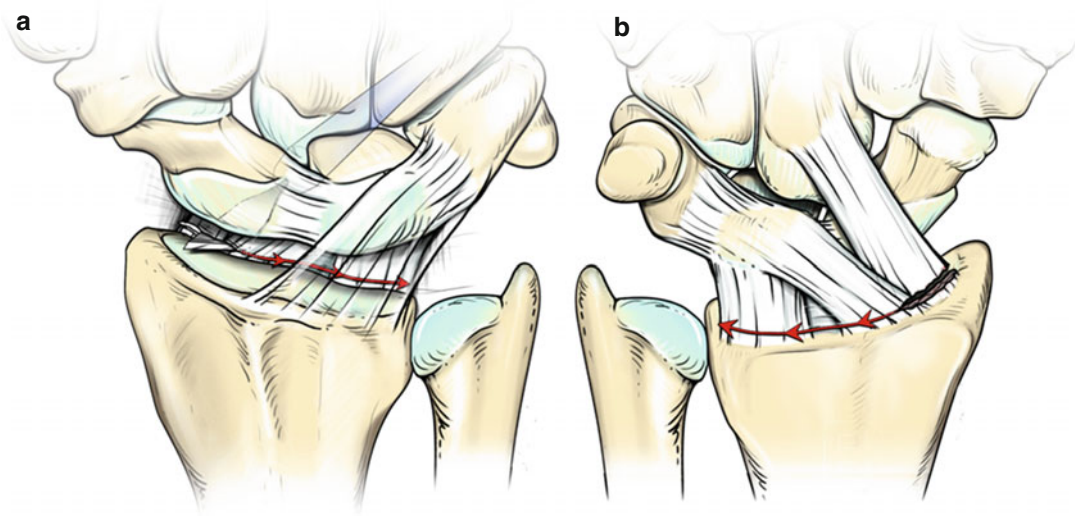

Fig. 76.13 Drawing illustrating the site of sectioning of the volar capsule and ligaments of the wrist (*red arrows)*: (**a**) dorsal view; (**b**) palmar view (Reproduced with permission from Springer Verlag)

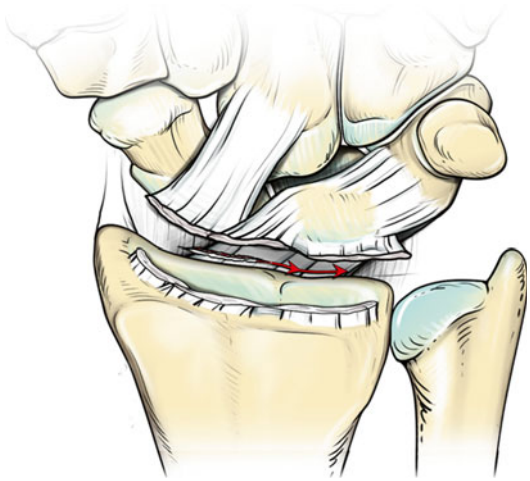

Fig. 76.14 Drawing illustrating the site of section of the dorsal capsule and ligaments (*red arrows*) (Reproduced with permission from Springer Verlag)

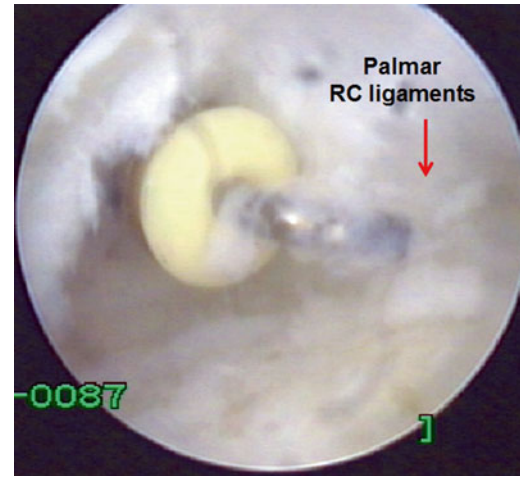

Fig. 76.15 Use of a hook tip of a radiofrequency device to section the dorsal capsule. Care should be taken to avoid injury to the structures dorsal to the capsule

Traction is now reapplied and the procedure continues with resection of the dorsal wrist capsule (Fig. 76.14). This is performed with the scope through the 1–2 portal and the instruments through the 6R portal. The dorsal central part of the capsule is sectioned first. By switching the scope to the 6R portal, the capsule can be further resected by introducing the instruments through the 1–2 portal. The intra-articular position of the 3–4 portal is located, and from this point, the resection of the capsule starts by using a miniscalpel, shaver, or radiofrequency with a hook tip (Fig. 76.15). The radial part of the capsule is easily resected through the 1–2 portal with the scope in the 6R portal. The ulnar part of the dorsal capsule contains the strong dorsal radiocarpal ligament. Here, the procedure becomes more difficult due to the firm consistency of this ligament. In this case, a volar radial portal may be used [12, 23, 24]. Bain et al. have described a safe method

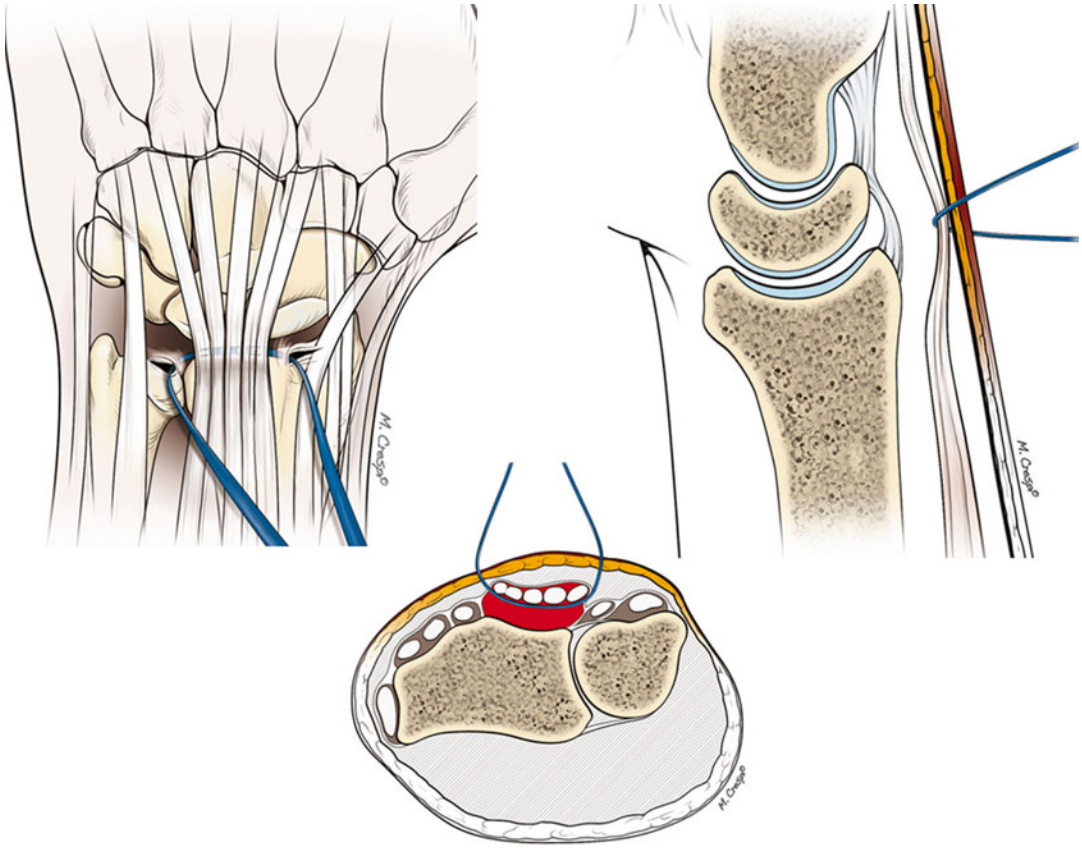

Fig. 76.16 Drawings illustrating the use of nylon tape to retract the extensor tendons during dorsal wrist capsule resection

to resect the dorsal capsule with minimal risk to the extensor tendons [3, 4]. This technique involved the use of an intracapsular nylon tape that is used as a retractor to pull the extensor tendons out of harm's way (Fig. 76.16).

It is very important to remember that the volar UC ligaments and dorsal capsule of the UC joint must not be resected (Fig. 76.17). The dorsal capsule of the UC joint is without a proper ligament but is reinforced by the floor of the ECU tendon sheath. The two volar UC ligaments are the ulnolunate and the ulnotriquetral ligament. Moritomo et al. showed that the volar UC ligaments insert into the volar aspect of the TFCC ligament, and both run proximally attaching to the ulnar head [20]. He demonstrated that a TFCC detachment produces both DRUJ and UC instability. Viegas reported that sectioning the radioscaphocapitate and radio-lunate ligaments does not lead to

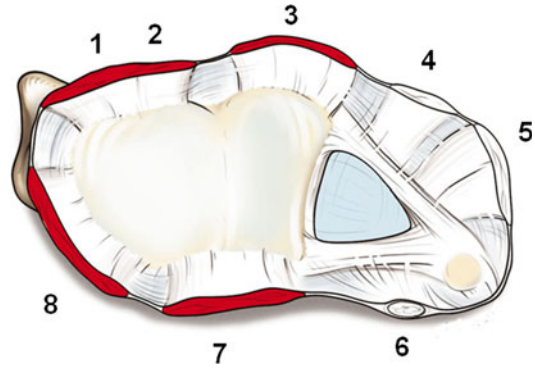

Fig. 76.17 Schematic drawing showing the extrinsic ligaments of the radiocarpal joint. (*1*) Radioscaphocapitate, (*2*) long radio-lunate, (*3*) short radio-lunate, (*4*) ulnolunate, (*5*) ulnotriquetral, (*6*) ECU tendon, (*7*) dorsal radiocarpal, (*8*) dorsal capsule. The ligaments (*1–2–3–7*) that can be sectioned during the arthroscopic volar and dorsal capsulotomy are shown in *red* (According to Verhellen and Bain [26]). The ulnocarpal ligaments (*4* and *5*) must be preserved (Reproduced with permission from Springer Verlag)

significant ulnar translation of the carpus and that either the volar ulnar ligament or the dorsal ulnar ligament complex alone can prevent ulnar translation [27]. The arthroscopic capsulotomy leaves the volar ulnar ligament and dorsal ulnar ligament complex intact.

Resection of a portion of the dorsal rim of the distal radius is mandatory when wrist extension is limited due to dorsal radiocarpal impingement secondary to malunion of a distal radius fracture (Fig. 76.1). This may be performed arthroscopically and improves wrist extension. After dorsal capsule resection, the dorsal rim of the distal radius is resected by using a 2.9–3.2 mm burr introduced through the 6R or 1–2 portal. Sometimes a volar radial portal is used but the ulnar-most side of the dorsal rim cannot be completely reached due to the carpal bones even if wrist distraction is increased. Therefore, the ulnar-most side of the dorsal rim of the distal radius is resected mostly through the 6R portal.

76.3.1.3 Ancillary Procedures

During arthroscopy, one may identify other occult articular, DRUJ, or carpal bone pathologies. Some of these may be treated during the same procedure, but others may need to be treated later due to different rehabilitation programs, in order to avoid postoperative immobilization.

Small articular steps (<1 mm) of the distal radius may be addressed (Fig. 76.18). A 2.9–3.2 mm burr is used at 500 revolutions per second introduced through the 6R portal with the scope in the 3–4 or 1–2 portal. Larger steps can also be treated but this often results in fibrotic band recurrences and ongoing wrist pain.

Central TFCC tears are debrided: the flap is removed and the edges are resected. Peripheral TFCC lesions or foveal detachments must be treated later because of the necessity for postoperative immobilization. Positive ulnar variance may be treated with arthroscopic wafer resection. Loose bodies, an extremely rare occurrence, should be removed if they are found. Fluoroscopy can be used in order to verify the articular step and dorsal/volar rim resection and position of the instrumentations.

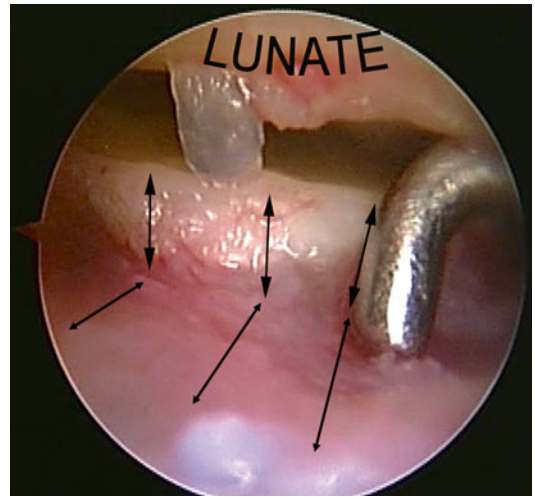

Fig. 76.18 Arthroscopic view showing an articular step of the distal radius that became evident during arthrolysis (Courtesy of Francisco del Piñal and reproduced with permission from Springer Verlag)

This concludes the RC arthroscopy and at this point the ROM should be assessed before proceeding to the MC joint. Traction is temporarily removed and passive wrist ROM is evaluated.

76.3.2 Midcarpal Joint

If there is no appreciable change in passive wrist ROM after the RC arthrolysis, a MC arthroscopy should be carried out. The approach for this articulation is via the two portals (RMC and UMC), but if needed, more portals can be used [scapho-trapezio-trapezoid (STT) and triquetrohamate (TH)]. Arthroscopy of this joint is much easier to perform and synovitis is the most frequently found pathology. It is usually localized at the level of the STT and TH joints. Commonly, one tends to see cartilage degeneration between the capitate and hamate. This may well be responsible for wrist pain. Debridement of the MC joint is performed and may improve pain and ROM. MC joint arthroscopy does not require any ligament resection. The triquetrohamate ligament must be preserved: its resection can produce a midcarpal instability.

Dorsal radio-midcarpal impingement is suspected when wrist extension is limited and

painful, with the pain localized to the capitate and with radiographs demonstrating deformity of the dorsal rim of the radius. The degree of chondral damage to the capitate due to impingement may be assessed. After a synovectomy and debridement, a burr is used to remove excess bone from the dorsum of the neck of the capitate to facilitate acceptance of the remodeled dorsal rim of the distal radius during wrist extension. The procedure is similar to that performed in the elbow for humeral-olecranon impingement in which osteophytes on the tip of the olecranon and the olecranon fossa are arthroscopically removed.

76.3.3 Distal Radioulnar Joint

A prerequisite to ensure a good outcome for the DRUJ is the preservation of a normal articular surface (sigmoid notch and ulnar head). Malunion of the sigmoid notch due to fracture of the ulna aspect of the distal radius should be treated by osteotomy if there are no signs of arthritis [9]. Salvage procedures are recommended for DRUJ incongruity with secondary arthritis of the joint.

Arthroscopy of the DRUJ is difficult. It is very unusual to have good visibility in the DRUJ even in normal conditions. Stiffness of this joint is due to capsular contraction, intra-articular fibrosis, and synovitis, which makes arthroscopy more difficult.

DRUJ arthroscopy is performed through distal and proximal portals. The scope is introduced in the proximal portal and the instruments in the distal portal. Normally, fibrosis does not permit any visualization. Fluid is constantly used to try to expand the joint and improve visualization. Once visualization is achieved and the tips of the instruments are seen, fibrosis is progressively removed using a full radius or aggressive resector.

From an arthroscopic point of view, the DRUJ comprises two spaces (Fig. 76.19), that between the TFCC ligament and the ulna head and the other between the ulna head and the radius (sigmoid notch). In posttraumatic conditions, both spaces are involved. Fibrosis under the TFCC precludes any visualization by arthroscopy, and in the absence of a central perforation of the TFCC, good visualization is difficult. In these cases, we suggest introducing a blunt dissector between the TFCC and the ulnar head and gently

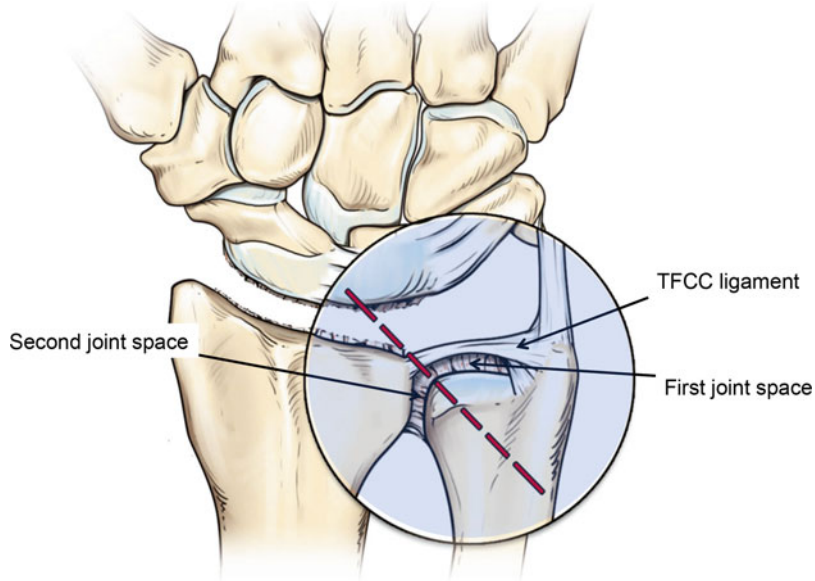

Fig. 76.19 Drawing showing the localization of fibrosis in the DRUJ. This joint is divided into two parts for the sake of the arthroscopic procedure (Reproduced and modified with permission from Springer Verlag)

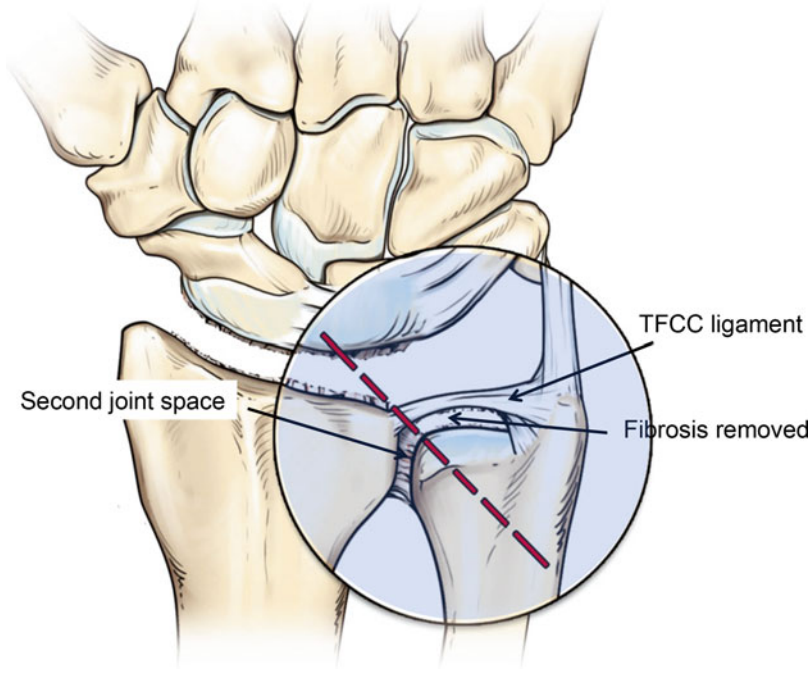

Fig. 76.20 Drawing showing removal of the fibrosis under the TFCC (Reproduced and modified with permission from Springer Verlag)

dissecting the adhesions. It can also be done using an arthroscopic chondrotome through the traditional DRUJ portals or just below the 6U portal (direct foveal portal) or lateral to the 6U portal. Fibrosis can be completely removed through these portals (Fig. 76.20) and it is also possible to perform a wafer resection.

The second space, lying between the ulnar head and radius in the sigmoid notch, is affected by contraction of the volar and dorsal capsule, causing a restriction in pronation and supination. Arthroscopic arthrolysis of this space starts with the scope in the distal portal and instruments in the proximal portal. It is difficult to visualize the tip of the instrument introduced in the DRUJ proximal portal. The dorsal and the volar capsule must be detached and/or resected (Fig. 76.21). Volar capsulectomy would improve the supination, and dorsal capsulectomy the pronation. To improve the visualization and speed of this last part of the procedure, a curved dissector is introduced into the joint from the proximal portal. By passing from dorsal to volar, it is possible to detach the ligament from the sigmoid notch

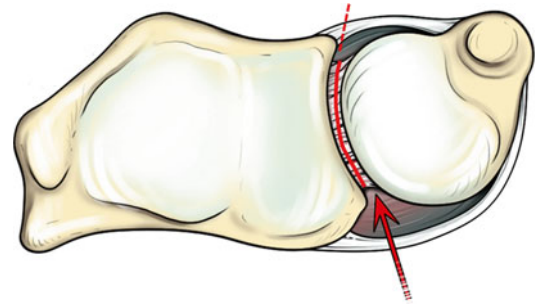

Fig. 76.21 Drawing showing an axial view of the DRUJ. Dorsal and volar capsules are sectioned (*red arrows* and *red line*) (Reproduced with permission from Springer Verlag)

(Fig. 76.22). The volar and the dorsal parts of the TFCC ligament must not be detached from the bony origin (radius and ulnar fovea). If this happens, DRUJ instability will follow. The articular surface of the ulna head and sigmoid notch must not be damaged. Dry arthroscopy is rarely used for the DRUJ. Finally, out of the traction, gentle pronation and supination maneuvers are performed to evaluate the improvement in ROM.

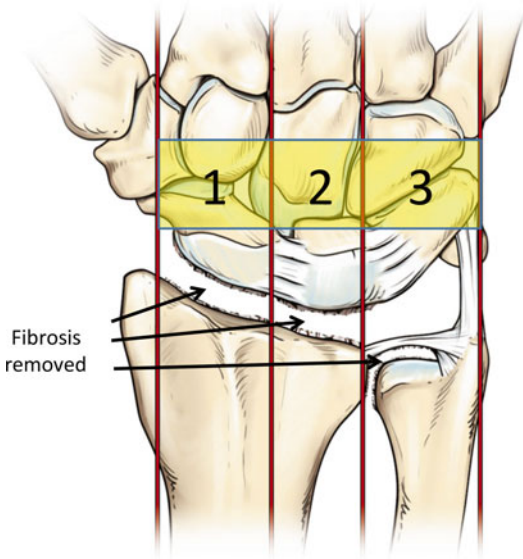

Fig. 76.22 Drawing showing complete removal of fibrosis in the DRUJ and radiocarpal joint (Reproduced and modified with permission from Springer Verlag)

76.3.4 Postoperative Rehabilitation

Rehabilitation is started immediately after surgery [25]. Routine analgesics are used for postoperative pain control. Active and passive pronation-supination and flexion-extension exercises are performed, gradually increasing the passive mobilizing force, under the guidance of a therapist.

Return to work is delayed up to 3 months as per the work requirements of the patient. A volar wrist splint is used for protection while performing heavy activities. Endurance and strengthening exercises using isokinetic and isotonic rehabilitation equipment can be initiated 1 month after surgery under the strict supervision of a physical therapist. The patient protocol is individualized depending on strength requirements for each individual patient and their job requirements [25].

76.4 Complications

Unfortunately, it may happen that the surgeon is unable to perform a wrist arthroscopic arthrolysis due to the presence of an osteofibrotic band (RC septum) that is too thick and dense and obstructs the field of view. This may result in a radio-lunate ankylosis (Fig. 76.19). These are the types of cases that should not be treated arthroscopically since they tend to end up with residual wrist stiffness.

Radiographs may not demonstrate all of the pathology, and when the surgeon sees a preserved joint space, they tend to be eager to perform an arthroscopic arthrolysis. Unfortunately, the underlying difficulties become quite evident during the surgery, and if one is able to perform the wrist arthrolysis, they have to first detach the adherent bands and the osteofibrotic band in order to improve the visual field and ultimately ROM. At the same time osteochondral lesions may become evident. In these cases, even if a proper physical therapy protocol is followed, it is quite common that fibrotic bands reform and result in partial or complete RC ankylosis.

Extra-articular wrist stiffness due to CRPS is a difficult problem to manage. In these cases, wrist arthrolysis must be performed with release of extra-articular soft tissue adhesions. Surgery in these cases must be planned with extreme caution since the root of the wrist stiffness is much more complex than just a localized articular dysfunction.

When the patient reports that wrist pain has recurred or never completely disappeared after surgery, the surgeon should take note that there can still be an underlying articular pathology that has not been diagnosed. Often the pain can be due to intrinsic ligament tears (scapholunate or lunotriquetral) which have not been identified pre- or intraoperatively.

The surgeon should exercise caution with the use of intra-articular instruments that can cause osteochondral damage or ligament injury, which may manifest postoperatively in the form of pain or instability.

76.5 Summary

Arthroscopic wrist arthrolysis is a difficult and time-consuming procedure. Occasionally the technique requires mini-open surgery or con-

version to an open procedure to obtain the best result. This is particularly true for the DRUJ where resection of the volar and dorsal capsule is difficult to perform arthroscopically. However, arthroscopic arthrolysis is a suitable and effective surgical option for the treatment of wrist stiffness after trauma or surgery. It is a safe and minimally invasive procedure and allows the surgeon to identify the intra-articular pathology.

Arthroscopy may identify associated lesions that contribute to the patient's pain. Loose bodies, arthrofibrosis, radiocarpal septae, arthritis, partial or complete tears of the inter-carpal ligaments and TFCC, and articular incongruity that may not have been evident on radiographs or MRI may also be identified arthroscopically. This is one of the advantages of performing this procedure arthroscopically [8, 29]. Moreover, it is often possible to treat all the pathologies at the same time, thereby improving outcomes.

Conversion to open surgery is only indicated when it is necessary to surgically treat the DRUJ and when difficulty is encountered during arthroscopy. Other surgical procedures may be performed at the same time to treat associated pathologies, such as carpal tunnel syndrome and partial or total wrist denervation.

Based on our experience, we suggest that TFCC tears type 1B or a complete tear of the SL ligament must not be treated simultaneously with arthrolysis since they require prolonged postoperative immobilization and the rehabilitation protocol is contrary to that of arthrolysis. Therefore, before arthroscopy, it is important to discuss with the patient the surgical procedure indicated based on a thorough clinical evaluation and to plan the optimal timing of the surgery. It is mandatory that the wrist is mobilized and that the patient initiates rehabilitation immediately after an arthroscopic arthrolysis procedure.

One must remember that if there is an underlying SL ligament tear, in addition to the presence of wrist stiffness, the surgeon may not be able to obtain a good result by performing an arthroscopic arthrolysis. The injury to this ligament is often concealed by the wrist stiffness, and only after wrist arthrolysis has been performed, will instability due to ligament injury be manifested. The improvement in pain and ROM that is obtained following wrist arthrolysis may be inconsistent.

It may be seen that an intraoperative increase in wrist flexion-extension ROM is followed by a temporary decrease soon after surgery but is regained over time. On the contrary, pronation-supination improvement that has been obtained during surgery is almost always maintained postoperatively [22].

DRUJ (pronation-supination) stiffness is more frequently encountered than RC stiffness and may be isolated or in conjunction with RC joint stiffness. When DRUJ stiffness is isolated, ROM recovery after surgery is easier to obtain than when it is associated with RC stiffness, and this improvement is maintained.

76.5.1 Patient Information Before Surgery

Based on these concepts, it should be ideal to inform the patient of this chapter before of surgery (arthrolysis) of the possible different scenarios that may be encountered within the joint, the possible treatment options, and likely outcomes that can occur.

76.6 Literature Overview

Various authors have reported that wrist stiffness that is a residual complication due to a traumatic capsular wrist contracture can improve with wrist arthroscopy because it permits selective resection of the volar and dorsal radiocarpal joint [13]. Verhellen and Bain [26] reported that arthroscopic arthrolysis is unlikely to risk the median nerve and radial artery because these structures are 5–6 mm from the volar ligaments. A comparison of previous publications following arthroscopic wrist arthrolysis is reported in Table 76.3. Compared with the reports of Verhellen and Bain [26] and Osterman et al. [21], Luchetti et al. [14] had greater preoperative wrist ROM, but the final

Table 76.3 Comparison between studies in literature

Publications	Cases no.	F-up months	Preop flex/ext (mean degrees)	Postop flex/ext (mean degrees)
Pederzini et al. [22]	5	10	44/40	54/60
Verhellen and Bain [26]	5	6	17/10	47/50
Osterman and Culp (2000) [21]	20	32	9/15	42/58
Luchetti et al. [14, 17]	19	32	46/38	54/53
Hattori et al. [13]	11	Unsure	29/47	42/56

results regarding wrist motion were almost the same. This is due to the fact that Luchetti et al. [14] were extremely selective in choosing appropriate participants for this study. However, the final results of this series showed that the best recovery parameters were achieved. The small number of cases in Luchetti et al.'s [14] paper resulted from their selective inclusion and exclusion criteria based on the patients' condition after fracture. Although not all patients obtained complete wrist ROM, they all confirmed that they were satisfied with the obtained results, as shown by the Mayo wrist score ($P = 0.0001$) and DASH questionnaire results.

76.7 Future Direction

Based on our experience, we can confirm that the method of arthroscopic wrist arthrolysis is now a standardized, repetitive, and reliable procedure. The results depend mainly on the preoperative condition of the articular surface of both the radius and carpus, which can be assessed with preoperative imaging and intraoperatively with arthroscopy. A preexisting poor articular surface may be responsible for recurrence of stiffness despite arthrolysis and despite the immediate rehabilitation of the wrist. Research needs to be aimed at prevention of the recurrence of arthrofibrosis. This may include introduction of substances that can be introduced into the joint to prevent the formation of fibrous tissue or allow articular tissue regeneration.

Hyaloglide® is an anti-adhesive absorbable hyaluronan-based gel, which has been tested for prevention of adhesions with tendon and nerve surgery. We have introduced it into the wrist joint via an arthroscopic portal, with the aim of preventing adhesions and fibrosis [19]. Results were positive, but there were no differences demonstrated when compared with traditional arthroscopic arthrolysis. The same product has been used in the elbow and shoulder, but the results are conflicting.

The concept of using a similar product to lyse fibrotic bands is inviting; however, if the underlying articular surface is poor, then there will be persistence of pain, dysfunction, and rigidity.

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Part VII

Ankle

Niek Van Dijk

Anterior Ankle Arthroscopy: General Setup and Portal Options

77

K.T.M. Opdam, R. Zwiers, and C.N. van Dijk

77.1 Introduction

In the early 1930s, the ankle joint was thought to be unsuitable for arthroscopy because of its typical narrow anatomy [1]. Nevertheless, in 1939 Tagaki was the first to describe the systematic arthroscopic assessment of the ankle joint and later on many followed [2–6]. In the past 30 years, significant progress in ankle arthroscopy has been made for diagnosis and treatment of a large range of ankle pathologies [4, 7, 8]. Indications for anterior ankle arthroscopy include anterior impingement, osteochondral lesions, ankle instability, and removal of loose bodies or fragments [3, 9]. Anterior pathology can be treated by means of an anterior 2-portal approach [5, 10]. In this chapter the general setup of this technique is discussed.

77.2 Fixed Distraction or Dorsiflexion?

Historically, orthopedic surgeons routinely used fixed distraction for ankle arthroscopy. With invasive distraction two pins are placed, one in the distal tibia and one in the calcaneus. Currently, invasive distraction is rarely used. It has been replaced by continuous noninvasive distraction or by a technique in which distraction is only applied when needed.

In case of fixed distraction, the distraction device is fixed to the side of the operating table. The surgeon has to stand beside the patient. In case of using a technique without distraction, the surgeon stands at the end of the operating table, and by leaning against the foot sole of the patient, the ankle is brought in a maximal dorsiflexed position (Fig. 77.1). This dorsiflexed position creates an anterior working space. In case distraction is needed, a soft tissue distractor device can be applied at any time during the procedure [11]. Leaning against the sole of the foot (Fig. 77.2) places the foot in a dorsiflexed position. The articular cartilage is thus protected from potential cartilage injury caused by the introduction of the instruments. It also prevents loose bodies to transfer from the anterior to the posterior compartment of the ankle. A disadvantage of continuous distraction of the joint is that it creates a tightening of the anterior capsule and thus creates a reduced anterior working area (Fig. 77.3a). A reduced working area makes it more difficult to identify anterior osteophytes and soft tissue impediments. Arthroscopic treatment of ankle instability cannot be performed with joint distraction, since distraction prevents adequate visualization of the fibula tip and ATFL. Distraction counteracts tightening of the ATFL. When the ankle joint is distracted, the anterior neurovascular structures are more at risk

K.T.M. Opdam • R. Zwiers • C.N. van Dijk (✉)
Academic Medical Center Amsterdam, Orthopaedic Research Center Amsterdam, Milan, Italy
e-mail: c.n.vandijk@amc.uva.nl

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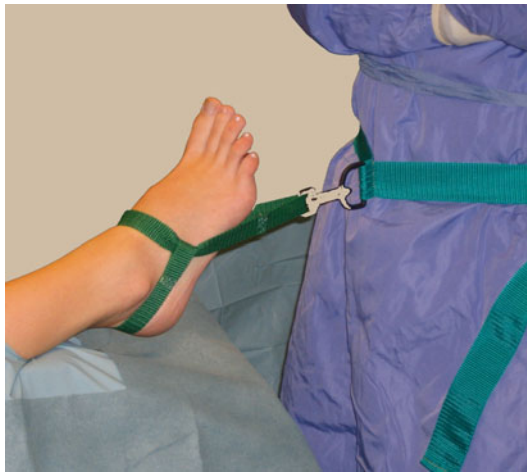

Fig. 77.1 Placement of noninvasive ankle distraction device. The device is attached to a belt around the surgeon's waist

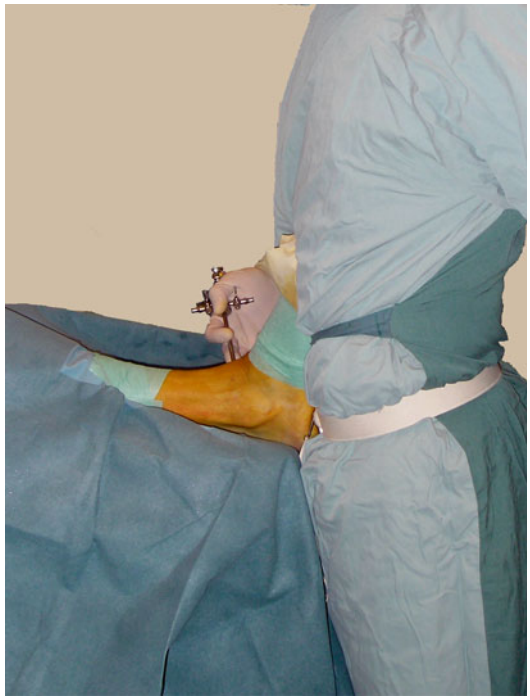

Fig. 77.2 By leaning against the foot sole of the involved foot, the ankle is brought into dorsiflexion, thereby creating an anterior working space (see also Fig. 77.3c)

for iatrogenic damage with introduction of instruments [12, 13].

The increased working area in dorsiflexion allows the surgeon to use a larger-diameter arthroscope which gives the advantage of an increased inflow of saline, thus allowing the use of a large-diameter shaver (Figs. 77.3c and 77.4).

77.3 Dorsiflexion Method: General Setup

Anterior ankle arthroscopy is performed as outpatient surgery under general anesthesia or spinal anesthesia. The patient is placed in a supine position with a folded sheet under the ipsilateral buttock which causes a slight elevation and endorotation (Fig. 77.5). A tourniquet is placed around the upper thigh of the affected side. It is important that the heel of the affected foot is located on the end of the operating table, allowing the surgeon to fully dorsiflex the ankle by leaning against the sole of the foot.

77.4 Instruments

For anterior ankle arthroscopy, a 4.0 mm ankle arthroscope can be used. An alternative is a 12 cm long 2.7 mm scoop with a 4.6 mm high volume sheath. A large-diameter arthroscope sheath can irrigate a larger amount of fluid per time which is beneficial when large-sized motorized instruments are used. For irrigation several fluids can be used such as saline, glycine, or Ringer's lactate. When using a 4.0 mm arthroscope, gravity fluid is adequate, although use of a pump system can also be applied.

77.5 Portal Placement

Appropriate portal placement is important. The two portals used for anterior ankle arthroscopy are placed anteromedial and anterolateral at joint line level. Initially, the anteromedial portal is created because it is easy to access in dorsiflexion. This portal is placed just medial from the anterior tibial tendon. If needed it is possible to create an accessory anteromedial portal which is located approximately 1 cm in front of the tip of the medial malleolus. Some surgeons favor the use of

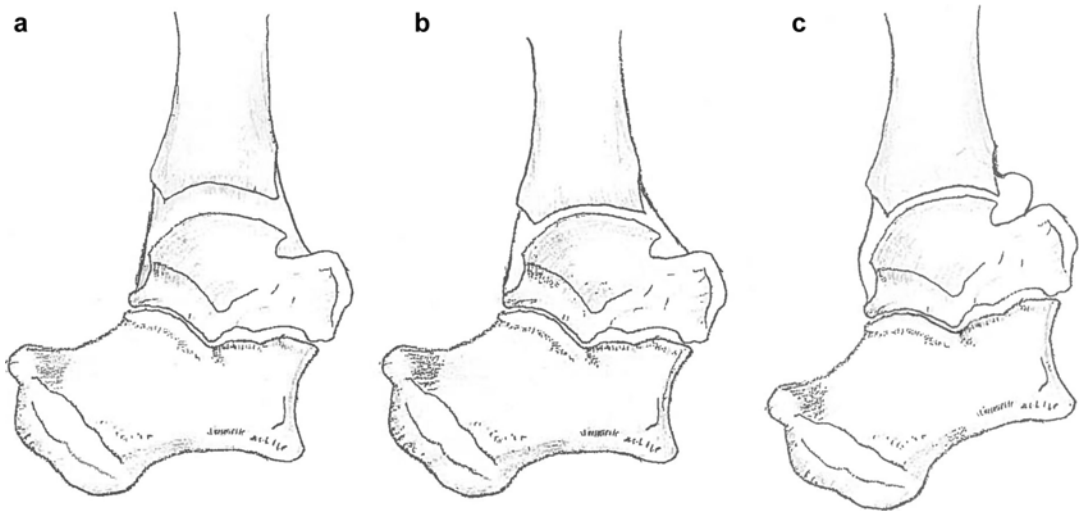

Fig. 77.3 Ankle joint with distraction (**a**), in neutral position (**b**) and in dorsiflexion (**c**)

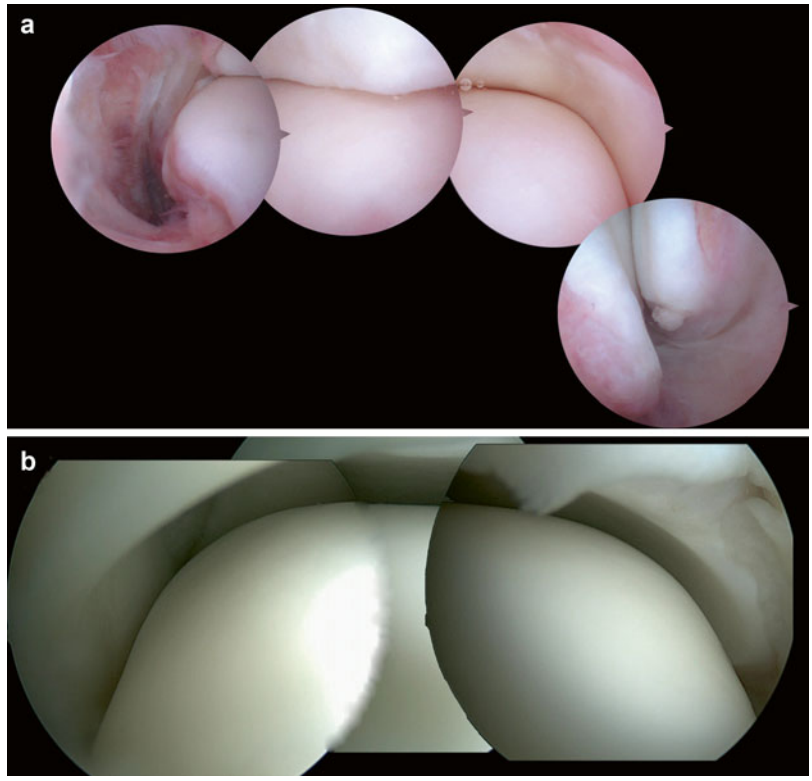

Fig. 77.4 (**a**) Anterior view in a right ankle without distraction. Inspection of the complete anterior joint compartment is thus possible. (**b**) Distraction creates intra-articular workspace. Distraction is only needed in case of treatment of symptomatic osteochondral lesions

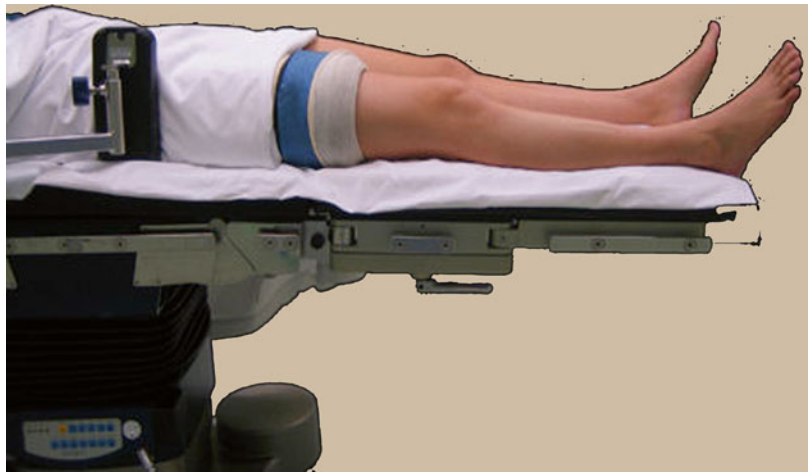

Fig. 77.5 Routine supine position for anterior ankle arthroscopy

a posterolateral portal. Some surgeons advocate an anterocentral portal which is located over the common extensor tendon. Anterocentral portal has some risk to impair the neurovascular structures. Transtibial and transmalleolar portals have also been described.

77.6 Anteromedial Portal

The anteromedial portal is created first and is located just medial to the anterior tibial tendon at the level of the joint line (Fig. 77.6). The distal tibia can be palpated as a prominence and distal to this prominence the so-called soft spot is located (Fig. 77.7). In the horizontal plane, this soft spot is located between the anterior tibial tendon and the medial malleolus, while in the vertical plane, this depression is located between the anterior tibial rim and the talus. By dorsiflexing the ankle, the palpating thumb gets locked into this soft spot. The portal is created in dorsiflexion. The anteromedial portal must be placed as central as possible, thus allowing inspection of the lateral talofibular space as well as the ATFL and the tip of the fibula. Dorsiflexion allows the surgeon to create this portal 1 cm more central when compared to the position in plantar flexion (see Fig. 77.7). When creating the portal in plantar-flexed position, the anterior tibial tendon is located approximately 1 cm more medial than when created in dorsiflexion. This is a disadvantage since from this more medial portal it is not possible to inspect the talofibular space. After a small skin incision has been made, the subcutaneous layer and the capsule are bluntly dissected with a curved mosquito forceps (Fig. 77.8a). The arthroscopic shaft with blunt trocar is introduced in the hyperdorsiflexed position (Fig. 77.8b). When it is felt that the trocar makes contact with the underlying bone, the shaft and the blunt trocar are carefully pushed further into the anterior working area toward the lateral side. Now, the trocar is exchanged for an arthroscope; a 4.0 mm, 30° angle arthroscope is routinely used (Fig. 77.8c). Saline solution is then introduced into the joint and the anterior compartment is inspected. Following this, under arthroscopic control, the anterolateral portal is made.

77.7 Anterolateral Portal

The anterolateral portal is made under direct vision by inserting a spinal needle at the joint line lateral to the peroneus tertius tendon and the common extensor tendons (Fig. 77.8d1, 2). In that area runs the superficial peroneal nerve subcutaneously and has to be avoided. By placing the foot in forced plantar flexion and supination, the superficial peroneal nerve and thereby the intermediate dorsal cutaneous nerve can be made visible, and damaging the branch can thus be avoided (Fig. 77.9). Depending on the location of the pathology in the

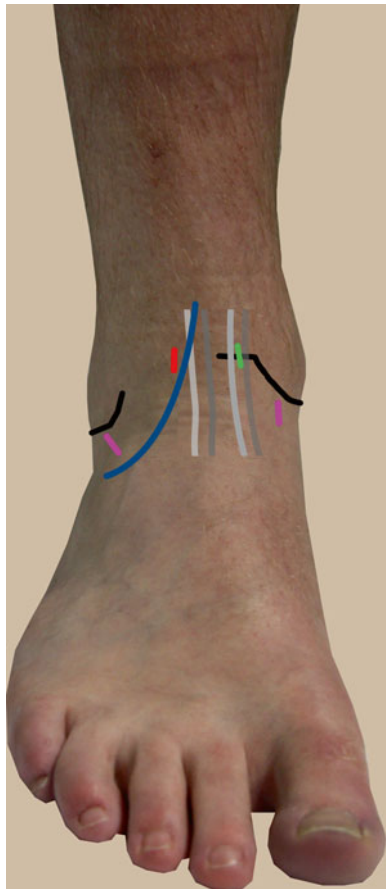

Fig. 77.6 *Black lines* = medial and lateral malleolus. *Dark gray lines* = anterior tibial tendon. *Light gray lines* = anterior tibial tendon palpated in dorsiflexion. *Blue line* = lateral border peroneus tertius tendon. *Green line* = anteromedial portal. *Red line* = anterolateral portal. *Pink lines* = accessory anteromedial and anterolateral portals

ankle, the location of the anterolateral portal can vary. For treatment of anteromedial pathology, the anterolateral portal is located between the lateral branch of the peroneal superficial nerve and the peroneus tertius tendon as central as possible. For treatment of lateral pathology, the anterolateral portal can be placed more lateral. After a small skin incision has been created, the subcutaneous layer and the capsule are blunt dissected with a curved mosquito forceps, and surgical instruments are introduced under direct vision (Fig. 77.8e1, 2). The surgical instrument and the scope can be changed between the anteromedial and anterolateral portals depending on the operative procedure.

77.8 Medial Midline Portal

Buckingham et al. first described the medial midline portal which is located between the anterior tibial tendon and the extensor hallucis longus tendons. This portal is similar to the anterocentral portal, but with lower risk of damage to neurovascular structures.

77.9 Accessory Anteromedial and Anterolateral Portals

The inferior anteromedial portal is placed 1 cm anterior to the tip of the medial malleolus. A spinal needle is introduced under vision and an incision through the skin is made in line with the deltoid ligament fibers (Fig. 77.6).

The inferior anterolateral portal is placed just below the anterior talofibular ligament and 1 cm anterior to the tip of the lateral malleolus. Under direct vision a spinal needle is introduced and an incision in the skin is made in line with the anterior talofibular ligament (Fig. 77.6).

77.10 Posterolateral Portal

The posterolateral portal is placed just lateral to the Achilles tendon. With the ankle in a plantigrade position, it is located 1 cm proximal to the tip of the lateral malleolus. It is possible to palpate the posterior talar process with the blunt trocar and then introduce the trocar just lateral and proximal to the posterior talar process. Note that a posterolateral inflow portal is not necessary for anterior ankle arthroscopy when a 4.6 mm sheath is used since this sheath ensures sufficient inflow.

77.11 Anterocentral Portal

The anterocentral portal is created at the level of the ankle joint between the extensor digitorum longus tendons [14]. This portal makes passage of instruments in anteroposterior direction possible, but it has a high risk to damage neurovascular structures [15].

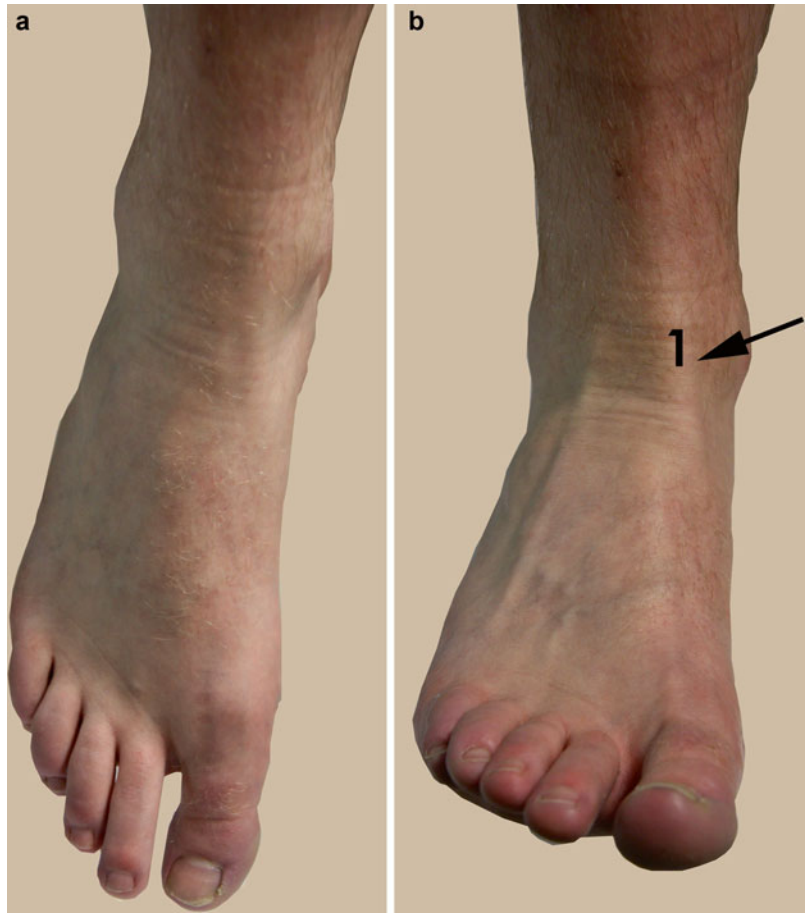

Fig. 77.7 The ankle in plantar flexion (**a**) and in dorsiflexion (**b**). Number 1 marks the anterior tibial tendon. The *arrow* marks the soft spot

77.12 Transtibial and Transmalleolar Portals

For debridement and drilling of talar dome lesions, a transmalleolar portal can be used, often in combination with ankle distraction to create more work space, but this portal has the disadvantage of causing cartilage damage to the medial malleolus opposite the lesion. Transtibial or transmalleolar drilling with the use of a special guiding system, which facilitates portal and K-wire placement, is useful especially for lesions in the tibial plafond.

77.13 Complications

Since its introduction, arthroscopy of the ankle has been going through a number of positive developments due to new techniques and improvement of arthroscopic instrumentation. In the pre-distraction period, the reported complication rate by Sprague et al. was 24.6 % [16]. The complication rate decreased to 13.6 % when routine fixed distraction was used [15, 16]. The complication rates for continues noninvasive distraction and are varying from 6.8 to 20 % with an average rate of 10.3 % [17–22]. In a

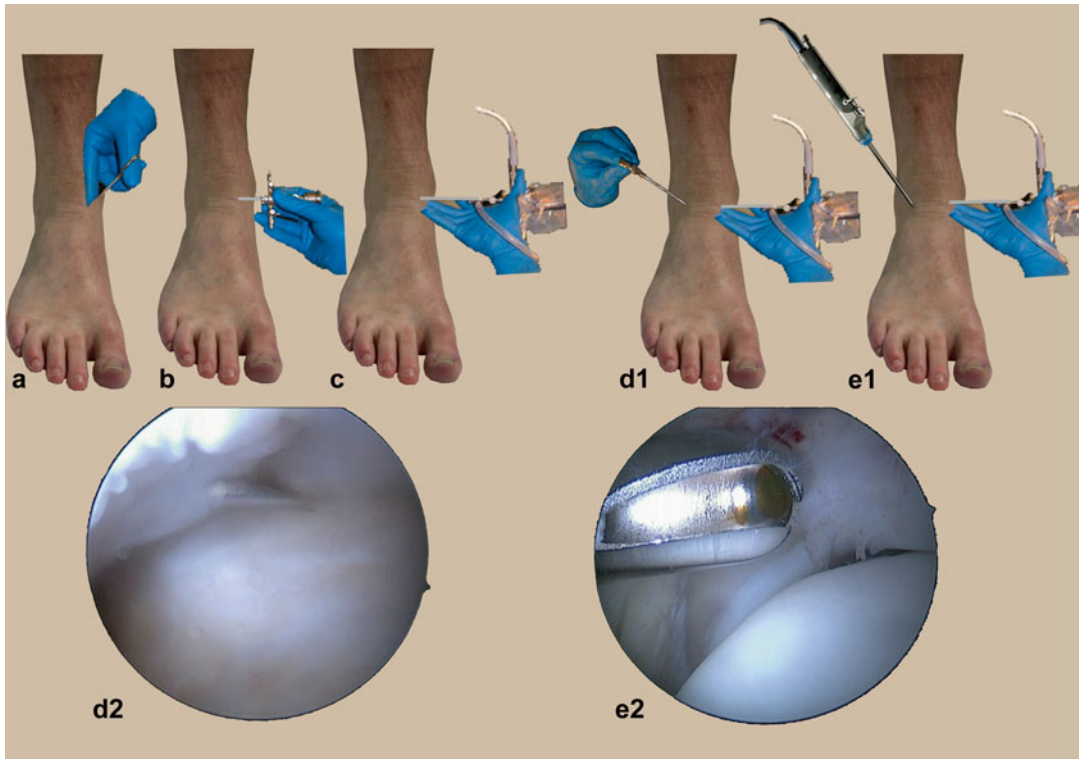

Fig. 77.8 Systematic representation of the anterior 2-portal approach. (**a**) Introduction of the mosquito clamp in dorsiflexed position. (**b**) The arthroscopic shaft with the blunt trocar is introduced in dorsiflexed position. (**c**) The trocar has been exchanged for the arthroscope. (**d**1) A spinal needle is introduced for location of the anterolateral portal. (**d**2) Endoscopic view after introduction of the spinal needle. (**e**1) A bonecutter shaver is introduced through the anterolateral portal. (**e**2) Endoscopic view after the introduction of the shaver

recent study by Zengerink et al., an overall complication rate of 3.5 % in 1,305 procedures was reported which use of the dorsiflexion method without distraction [11, 12, 17]. The dorsiflexion method without routine distraction currently seems to be the safest approach. The most likely explanation is the fact that nerves and vessels are not under tension in this position. They can thus more easily move out of the way when a blunt instrument is introduced through the portal.

The most common complication of anterior ankle arthroscopy is neurological damage. Ferkel et al. reported that 49.1 % of all complications consisted of neurologic damage [23]. The superficial peroneal nerve is the most at risk because of the anterolateral portal placement. Less common injured nerves reported by Deng et al. are the deep peroneal, saphenous, and sural nerves (0.77 %, 0.38 %, and 0.38 %, respectively) [19].

Other reported potential complications are vascular injury, infection, synovial fistulas and less commonly the complex regional pain syndrome, instrument breakage, thromboembolic complications, and painful scars [9, 17].

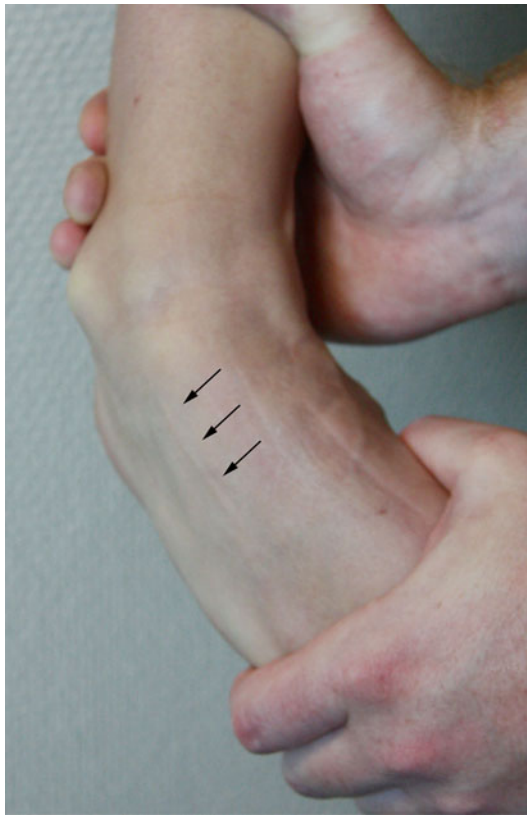

Fig. 77.9 Visualization of the intermediate dorsal cutaneous nerve by placing the foot in forced plantar flexion and supination of the foot. The *arrow* marks the nerve, which is important to identify

Conclusion

In ankle arthroscopy, significant progress has been made for treatment of a diverse range of ankle pathologies. The standard anterior ankle arthroscopy technique with the optional use of an intermittent soft tissue distraction provides save access to the ankle joint.

The dorsiflexion method has demonstrated to be associated with the lowest complication rate, while it gives improved access for treatment of anterior joint pathology like osteophytes, soft tissue impingement, ossicles, loose bodies, and treatment of instability. OCD can be treated with the ankle in forced plantar flexion. In some cases soft tissue distraction can assist the surgeon for treatment of posterior OCDs. As an alternative, posterior OCDs can be treated by means of a 2-portal hindfoot approach in the prone position.

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Anterior Ankle Impingement

78

R. Zwiers, K.T.M. Opdam, and C.N. van Dijk

78.1 Introduction

Anterior ankle impingement is a pain syndrome, characterized by pain at the anterior aspect of the ankle with or without restricted dorsiflexion [1–4]. Symptoms are caused by impingement of soft tissue or bony spurs. Soft tissue impingement is one of the most frequent causes of chronic anterior ankle pain after ankle sprain [5]. Anterior impingement is particularly common in athletes that sustain repetitive dorsiflexion movements, like ballet dancers and soccer players [2, 6, 7]. Anterior ankle impingement accounts for 3 % of all ankle injuries in professional football players. The incidence in the general population is unknown [8]. Historically, in the first descriptions, these lesions were referred to as "athlete's ankle" and "footballer's ankle" [9, 10]. Since then, these terms has been replaced with "anterior ankle impingement syndrome" [11–15]. Based on etiology, bony and soft tissue impingement can be distinguished. Additionally, impingement lesions can be classified based on location of pathology and symptoms in anterolateral, anteromedial, and anterocentral impingement [1–3, 16].

R. Zwiers • K.T.M. Opdam • C.N. van Dijk (✉)
Academic Medical Center Amsterdam, Orthopaedic Research Center Amsterdam, Milan, Italy
e-mail: c.n.vandijk@amc.uva.nl

78.2 Etiology

Anterior ankle impingement is thought to be a result of mechanical factors, traction, trauma, recurrent microtrauma, and chronic ankle instability [11, 17]. Anterolateral ankle impingement symptoms are believed to be the result from entrapment of hypertrophic soft tissues or torn and inflamed ligaments at the level of the anterolateral ankle joint. Several types of soft tissue impingement have been reported, including a "meniscoid" lesion, impinging distal fascicle of the anterior inferior tibiofibular ligament (AITFL), intra-articular bands (web impingement), or hypertrophied synovium [16, 18].

The primary etiology of this condition is injury to the ligaments with microtrauma or tearing due to inversion sprains. Another hypothesis is that the reactive synovitis is a result of hematoma reabsorption after ankle sprain. Ankle sprains lead to inflammation of torn ligaments after repetitive motion, thereby causing hypertrophic synovitis and scar tissue.

It was hypothesized that bony impingement was elicited by repetitive capsuloligamentous traction, by, for instance, repetitive kicking with the foot in full plantar flexion. This traction was thought to cause traction spurs [10]. The fact that these spurs were frequently found in athletes, who repetitively force their ankle in hyperplantar flexion, supported this theory [11, 19, 20]. Another explanation for the spur-formation process is direct mechanical trauma or recurrent

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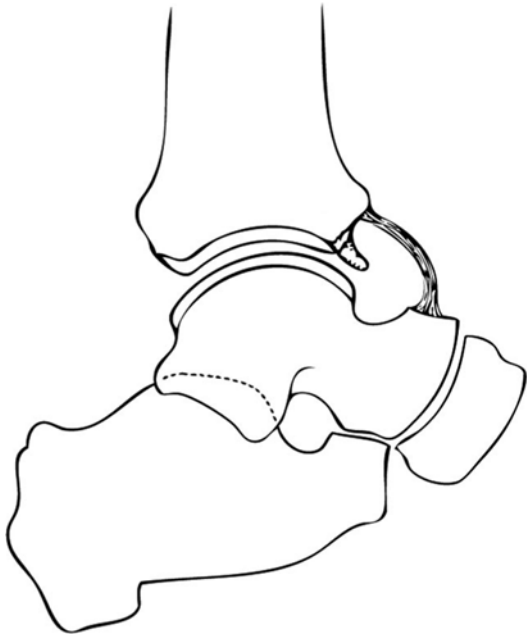

Fig. 78.1 Schematic drawing to show the attachment of the anterior joint capsule and the location of the osteophyte on the distal tibia

microtrauma associated with impingement of the anterior articular border of the tibia and the talar neck during forced dorsiflexion.

However, studies have shown that the anterior joint capsule inserts in the distal tibia on an average of 6 mm proximal to the anterior tibial cartilage rim. On the talar site, the capsule inserts approximately 3 mm from the distal talar cartilage border. Based on these anatomic observations, the hypothesis of formation of talotibial spurs due to recurrent traction to the joint capsule (traction spurs) is probably not correct. In patients with bony impingement, the location of tibial spurs is reported to be at the joint level and within the joint capsule [21] (Fig. 78.1).

78.3 Clinical Features

Patients are typically young and athletic and present with chronic ankle pain, limited dorsiflexion, and swelling, thereby reducing activity [22]. The patient may have a history of recurrent ankle inversion injuries. They have pain during dorsiflexion movement or in soccer players during kicking a ball. A recognizable tenderness on palpation of the anteromedial or anterolateral ankle joint line is present. Pain on forced hyperdorsiflexion can be present. A negative impingement test does not rule out an anterior impingement test [4]. Plantar flexion can induce pain by stretching the joint capsule over the osteophytes. After reproducible symptoms are identified, diagnosis can be further established with imaging.

78.4 Imaging

Standard weight-bearing lateral radiographs are useful in the initial assessment of anterior ankle impingement. Osteophytes that can be seen on the lateral radiograph are located on the lateral part of the joint line. The anterolateral border of the distal tibial rim is more prominent than the anteromedial tibial border [15]. Radiographs allow for the assessment of both talar and tibial osteophytes, as well as the tibiotalar joint space. However, anteromedial tibial or talar osteophytes are over-projected by the anterolateral border of the distal tibia or by the lateral part of the talar neck and body in standard lateral radiographs. With an oblique AMI view, the beam is tilted in a 45° craniocaudal direction with the leg in 30° external rotation and the foot in plantarflexion in relation to the standard lateral radiograph. The oblique AMI view has been reported to have a higher sensitivity for detecting anteromedial osteophytes [23] (Fig. 78.2).

Magnetic resonance imaging (MRI) is useful to rule out other pathology, like osteochondral lesions or stress fractures. Nowadays, MRI is widely used as an additional diagnostic tool; however, results are conflicting and diagnostic accuracy varies widely [24].

The results of using diagnostic tools, such as ultrasound and computed tomography (CT) arthrography, have also been studied. Ultrasound has been shown to have a high correlation with arthroscopic findings to detect soft tissue pathology [25, 26]. However, it is of limited diagnostic use due to an inability to assess intra-articular

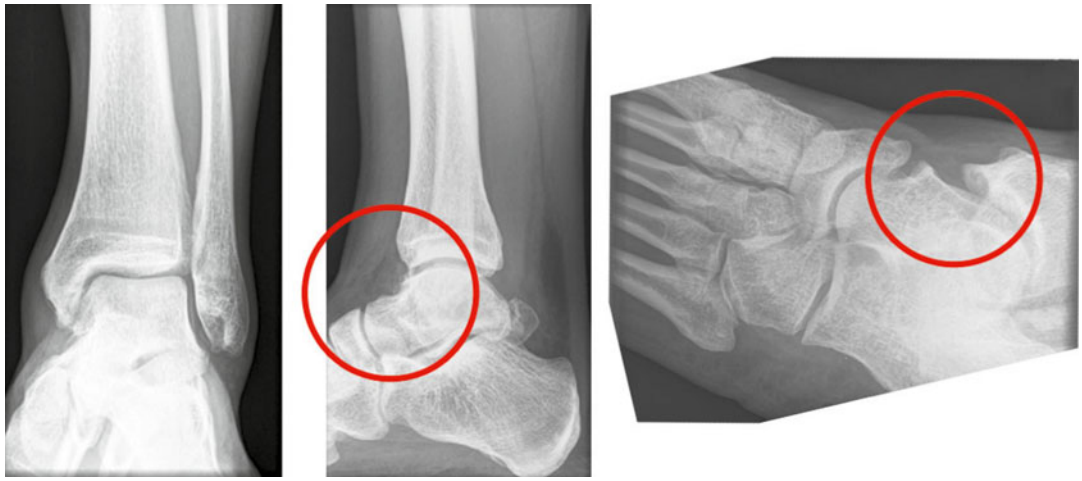

Fig. 78.2 AP, lateral, and AMI view of patient with anteromedial impingement. The osteophytes on the anterior medial malleolus and medial talar neck are clearly seen on the AMI view

pathology. CT arthrography has been reported to have a high sensitivity and moderate specificity in the diagnosis of anterolateral impingement. Nevertheless, CT arthrography is an invasive procedure and cannot accurately assess soft tissue pathology.

78.5 Classification

There is no widely used classification for anterior ankle impingement. Three classifications have been proposed. Scranton-McDermott et al. classified impingement based on the size of bone spurs [27]. Parma et al. based their classification on the size and distribution of spurs and general cartilage status [28]. Van Dijk et al. used a score to assess the severity of OA to predict outcome after surgery in anterior impingement patients [15]. The OA classification and Scranton-McDermott were compared, and it was concluded that only the OA classification by van Dijk was of prognostic value [28].

78.6 Treatment

Anterior impingement symptoms may respond to rest, activity modifications, nonsteroidal anti-inflammatory medications (NSAIDs). Physical therapy modalities or intra-articular cortisone injections may also relieve symptoms. In case conservative treatment fails, surgical intervention is indicated [11, 19].

A number of authors have reported good results with traditional open arthrotomy, but the procedure is associated with significant complication rates [22, 29–31]. Arthroscopic surgery of the ankle was considered technically demanding and had complication rates as high as 26.4 %. However, as arthroscopic techniques and equipment have become more sophisticated, published complication rates after arthroscopic surgery in the ankle are reported as low as 3.5 % [18, 32]. The most important progress toward a lower complication rate has been to abandon fixed distraction [33]. The most commonly reported complication is neurological injury. Other reported complications include vascular injury, infection, and synovial fistula. Complications such as stress fracture, pin track infection, and ligament injury have occurred with use of invasive distraction [5].

78.7 Surgical Technique

A skin incision is made through the skin only and the subcutaneous layer is bluntly divided with a hemostat. A probe is introduced to palpate the

anterior border of the distal tibia and talar neck. The ankle is brought in a dorsiflexed position (Fig. 78.3). In this position the anterior working area opens up. The probe can be used to elevate the capsule when necessary. A large-diameter aggressive synovater is used for removal of the osteophytes. We prefer to use the 5.5 mm bonecutter shaver blade. This aggressive instrument is capable of removing synovial tissue as well as bony spurs. The contour of the anterior distal tibia is identified first by shaving away the tissue just superior to the osteophytes (Fig. 78.4). The osteophyte subsequently can be removed either by shaver or by means of a 4 mm chisel. When a chisel is used, it has the advantage of removing the osteophyte in one piece. The talar cartilage must be protected by positioning the chisel just above the joint line. The detached fragment is removed by grasper. Any remnants are removed by means of the shaver. An advantage of the dorsiflexed position is the fact that the talus is concealed in the joint, thereby protecting the weight-bearing cartilage of the talus from potential iatrogenic damage.

78.8 Rehabilitation

The patient can be discharged the same day of surgery with a compression bandage applied around the operated ankle. Active range of motion exercises are encouraged, and patients are instructed to repetitively dorsiflex the affected ankle several times an hour. Anterior ankle arthroscopy for an osteophyte allows the patient to fully bear weight within 5 days.

78.9 Results

A recent systematic review shows that after arthroscopic treatment high percentages of good to excellent satisfaction are described (74–100 %).

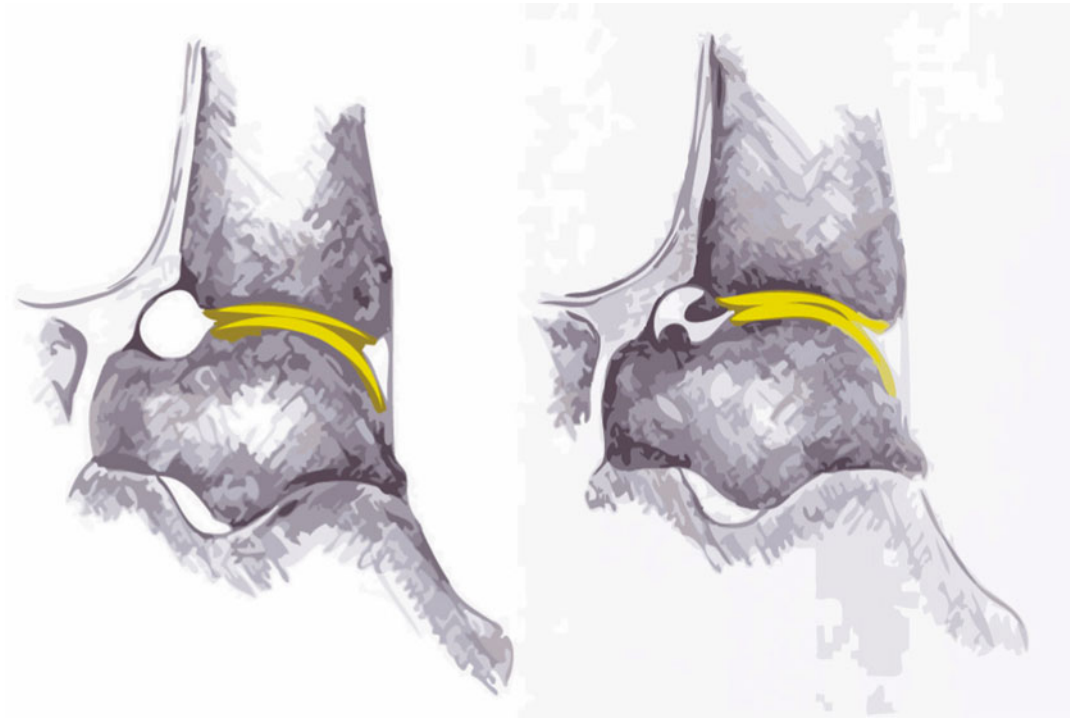

Fig. 78.3 In the fully dorsiflexed position the anterior working area opens up, thus making it possible to identify the osteophyte more easily. Another advantage of the fully dorsiflexed position is that the joint is "locked" and the talus is concealed in the joint, thereby protecting the weight-bearing cartilage of the talus from potential iatrogenic damage

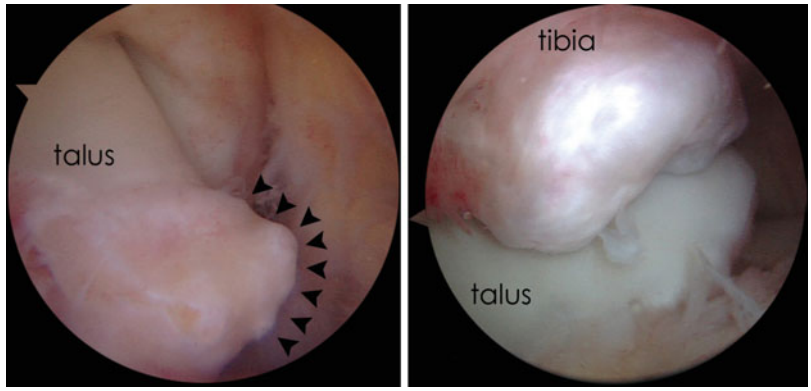

Fig. 78.4 Arthroscopic view with scope in the anterolateral portal. The anteromedial osteophyte is clearly visible (*arrowheads*). Behind the osteophyte we see the medial malleolus. Arthroscopic view with the scope in the anterolateral portal showing the osteophyte on the distal tibia. Below the osteophyte the talar cartilage is visible

The percentages of patients who would undergo the same procedure again under the same circumstances were also high (94.3–97.5 %). Complication rates were low (4.6 %), particularly with respect to major complications (1.1 %). The high heterogeneity of the included studies made it impossible to compare the results of the studies [18].

Three studies compared two subtypes of impingement. Baums et al. reported no difference between bony and soft tissue impingement in the VAS score for pain and rate of return to preinjury level of sports [34]. In their study on 280 patients, Cavallo et al. found anterolateral bony impingement to have better outcomes based on the AOFAS score compared with anteromedial bony impingement and found bony and soft tissue to have similar results [35]. The location of the bony impingement and extension of the fibrous impingement showed a significant correlation with clinical outcome. Van Dijk et al. described, among 62 patients, better outcomes as measured by the Ogilvie-Harris score for patients treated for anteromedial impingement compared to patients with anterolateral impingement [15].

Conclusion

Anterior ankle impingement is characterized by anterior ankle pain on activity, with recognizable tenderness on palpation at the joint line. Pain is caused by compression of synovial tissue. The anteromedial impingement view is recommended for detection of anteromedial osteophytes. Arthroscopic treatment yields good outcomes, with low complication rates.

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Soft Tissue Impingement of the Ankle

79

G. Cordier and S. Guillo

79.1 Introduction

Soft tissue impingement is a common cause of ankle pain. ISAKOS defined it as anterior print pain during physical activity [47]. It is generally seen in patients with a history of multiple ankle sprains [13, 14]. This explains the higher incidence among sports associated with a high frequency of inversion traumas. Soft tissue impingement is often located in the anterolateral compartment of the ankle, whereas osseous or bony impingement mostly affects the medial compartment [49]. Although diagnosis is based on clinical presentation and examination, additional diagnostics may help guide treatment.

79.2 Aetiology

The first description of conflicting tissue found in literature dates from 1950 [50]. Wolin describes a conflict of soft tissues of the ankle joint and describes it as a meniscoid lesion. Several articles followed pointing out the role of anterolateral synovitis and ligamentous hypertrophy in soft tissue impingement [7, 11, 12, 20, 24, 27, 43]. More recently involvement of the anteroinferior tibiofibular ligament (AITFL) was described as a conflict between the talar dome and the AITFL [5].

Differentiation can be made between three types of soft tissue impingement [43]:

- Anterolateral synovitis with ligamentous hypertrophy (Figs. 79.1 and 79.2)
- Meniscoid lesion of a fibrous type filling the anterolateral gutter (Fig. 79.3)
- Conflict between the talar dome and the AITFL (Fig. 79.4)

Mostly soft tissue impingement is the result of a lesion of the anterior talofibular ligament (ATFL). After an inversion trauma, fibrotic scar tissue may form around the ligament [11, 12]. This can lead to a hypertrophic, although functional, ligament, filling the anterolateral gutter [24]. As this lesion can look like a meniscoid lesion [10, 50] and the meniscoid and hypertrophic lesion have the same origin, differentiation is not needed [39].

The AITFL, also known as the Bassett ligament, can present a more distally located cause for impingement with the talar dome [1, 31]. Bassett was the first to describe this type of impingement [5]. This bundle lies separate from the principal part of a fibro-fatty septum and is located inside the capsule but outside the synovium [2, 15, 16] (Fig. 79.5). Contact between the talar dome and the AITFL is normal when the ankle is in neutral position [1]. Impingement between the AITFL and the talar dome may occur in dorsal flexion. Anatomical variation of the

G. Cordier (✉) • S. Guillo
Clinique du sport de Bordeaux-Mérignac, Mérignac, France
e-mail: docteurcordier@yahoo.fr

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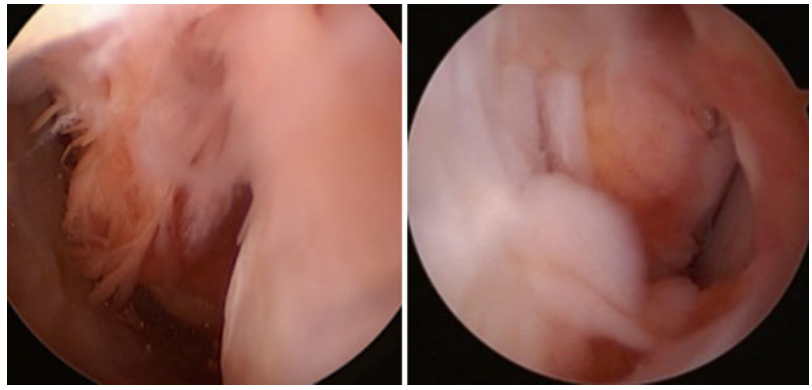
Figs. 79.1 and 79.2
Synovitis anterolateral



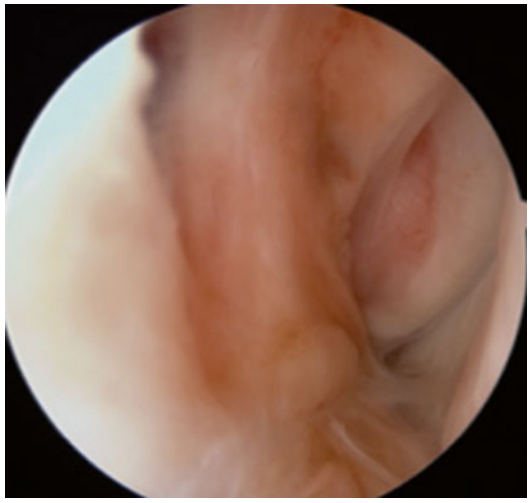


Fig. 79.3 Meniscoïd lesion

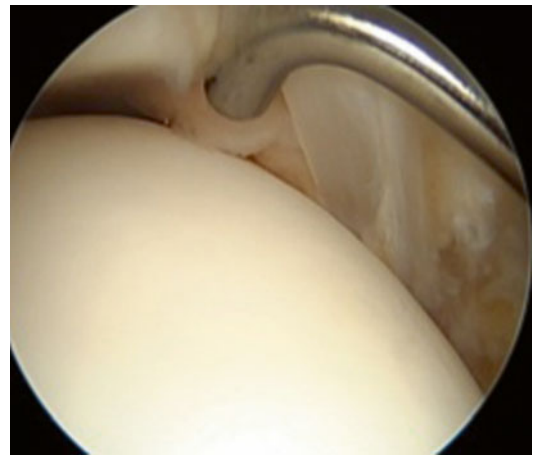


Fig. 79.5 Fibro-fatty septum back to the AITFL

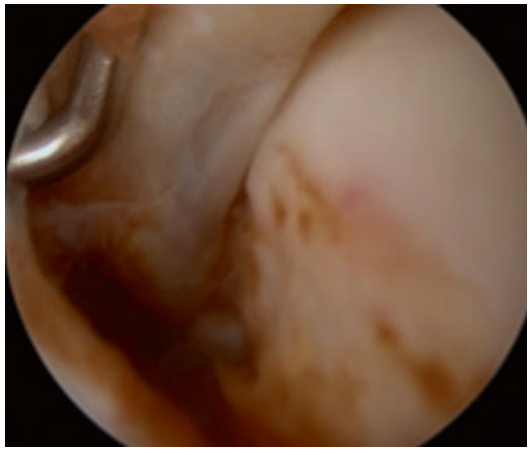


Fig. 79.4 Conflict between talus and Bassett ligament

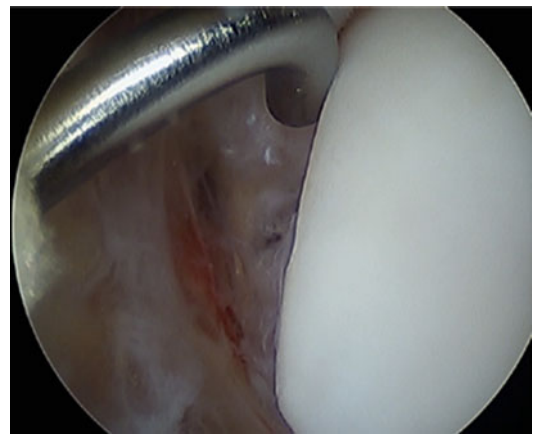


Fig. 79.6 The palpator shows a chondromalacia under the ligament

AITFL may explain impingement without a history of trauma [20, 33]. This type of impingement may also result from lateral ligament laxity, as an anterior shift (as seen in the anterior drawer test) increases the contact between the AITFL and the anterolateral part of the talar dome. This hyperpressure may cause chondromalacia underneath the ligament (Fig. 79.6), causing pain [1]. As a solution this ligament may be resected, without modifying articular biomechanics [15].

Other causes of soft tissue impingement may be fibrous bands, which are generally post-traumatic [23, 40]. After trauma fibrosis may be formed with synovial hypertrophy and may limit plantar flexion. More rarely it is caused by congenital plicae (Fig. 79.7) [3, 38, 42]. Additional causes of soft tissue impingement may be inflammation of the tibiotalar ligament [21], capsule-synovial thickening with involvement of the anterior part of the ATFL [34] and the presence of a synovial fringe at the posterior part of the syndesmosis[15], which may cause implied pain of impingement during movements of the ankle joint (Figs. 79.8 and 79.9).

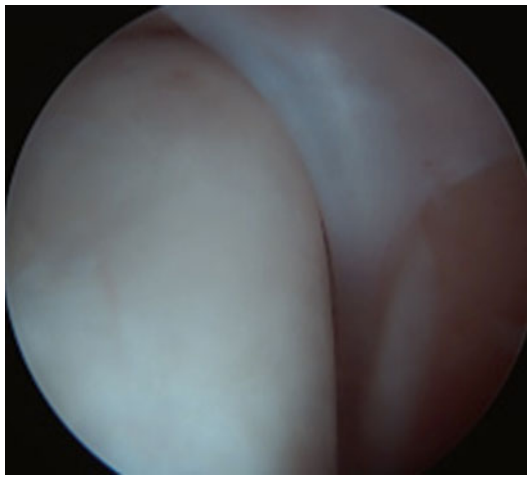


Fig. 79.7 Plicae anteromedial

79.3 Physiopathology

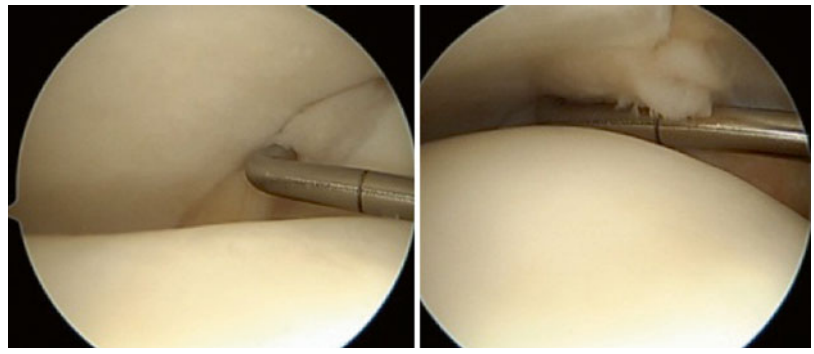
The presence of a hypertrophic soft tissue involves with repeated movements will end up with an inflammatory reaction with a production of granulation tissue. This explains the symptomatology of pain. This explanation is also worth for the bone impingement where the soft tissue comes to be wedged even more easily with the lack of space.

79.4 Diagnosis

79.4.1 Clinical Examination

Anamnesis should focus on a history of ankle sprains or other previous traumas. Chronic pain is a classical symptom. Pain generally occurs during repeated and maximal dorsiflexion. Clinical examination should mainly focus on:

- Joint swelling after activity
- Articular stiffness with limitation of dorsiflexion
- Anterolateral pain with a positive Molloy sign [29]: pain at palpation of the anterolateral gutter with forced dorsiflexion
- Absence of pathological ligamentous laxity; patients may, however, report functional instability



Figs. 79.8 and 79.9 Synovial fringe at the posterior part of the syndesmosis

79.4.2 Radiographic Assessment

Standard radiographs and an AMI view are used to exclude bony impingement [46]. Echography may be useful if it is wielded by an experienced operator. It may help diagnose a mass or hypertrophic tissue filling the anterolateral gutter [26]. Inflammation of a mass may be detected using a colour Doppler [32]. An MRI [8, 11] may also confirm the diagnosis by showing a mass, filling the anterolateral gutter. An arthro-MRI has a sensitivity of 96 % and a specificity of 97 %. Images of synovitis and abnormal ligaments, however, can also be found in asymptomatic subjects [35]. The arthro-CT cannot be used to diagnose soft tissue impingement. It can, however, assist in eliminating differential diagnoses, like an osteochondral lesion. Nevertheless, it may show an irregular aspect of the anterolateral gutter [19].

There is no radiologic classification for soft tissue impingement of the ankle. A topographic description is often used instead. Scranton et al. described four types of impingement but included osseous lesions [36].

79.5 Treatment

79.5.1 Conservative

Anterior ankle impingement is initially treated conservatively, consisting of rest, physiotherapy, shoe adaptation and bracing. In absence of improvement, a local injection of corticosteroids is proposed to reduce pain and inflammation of soft tissue in the lateral gutter. This treatment is done for a minimum of 3 months [49].

79.5.2 Surgical

79.5.2.1 Introduction

Generally, arthroscopy is performed out under loco-regional anaesthesia and as outpatient procedure [48]. Arthroscopic synovectomy is the treatment of choice in case conservative treatment fails [2]. Although it is not preferred, this treatment can also be used in teenagers [9, 17, 22]. Because of the high risk of complications, the open procedure should be avoided.

79.5.2.2 Operative Technique

Instruments

A standard arthroscope (4 mm, 30°) and a 4.0 mm shaver are used. This allows excision of fibrotic tissue around the ligament and excision of synovitis (Fig. 79.10).

The patient lies in prone position, with tourniquet around the upper thigh. The foot exceeds the table. When needed the dorsiflexion is performed by pressure of the surgeon's abdomen against the bottom of the foot. Distraction is not used.

Initially two standard portals are used.

- The anteromedial portal is the viewing portal. It is located on the medial side of the tibialis anterior at the level of the joint line. The surgeon places the ankle in dorsal flexion while palpating the soft spot. This portal is created in the direction of the middle of the joint line and allows the introduction of a trocar, which will subsequently be replaced by the arthroscope [49].
- The anterolateral portal is used to introduce instrumentation. The ankle is maintained in dorsal flexion. The portal is created just lateral to the peroneus tertius tendon. The main risk

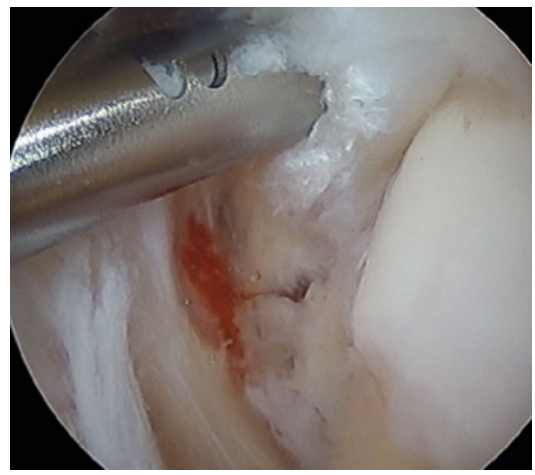


Fig. 79.10 Use of the shaver to remove the inferior part of AITFL

creating the lateral portal is damaging the lateral branch of the superficial fibular nerve. The nerve needs to be located, easiest done in inversion, before creating the portal. Sometimes it is possible to palpate it [49].

After the portals are created, the first step is articular exploration and the search for associated lesions. Additionally cartilage, possible syndesmotic laxity and the possible presence of bony impingement should be assessed. Subsequently, the lateral gutter is assessed. Possible findings could include a gutter filled with tissue, an impingement between the AITFL and the talar dome, as well as synovitis behind the ligament (Fig. 79.11). Indications for resection of the AITFL are [43]:

- AITFL/talus contact at the beginning of plantar flexion/inversion
- An increase in contact with dorsiflexion, combined with a cartilaginous abrasion under the ligament
- Elongation of the AITFL on the lateral side of the talus in dorsiflexion and flexion/inversion
- Location of the AITFL close to the ATFL
- Presence of a plica

Complete assessment of the ATFL is important. Finally, the last step is arthroscopic debridement. The opening of the shaver is always directed toward the bone and is performed in dorsiflexion to protect the cartilage. The lateral gutter is completely cleaned. After debridement, the edge of the malleolar tip, the distal insertion of the AITFL and the proximal insertion of the ATFL are visualized and checked (Figs. 79.12, 79.13 and 79.14). If the impingement is medial, portals are reversed.

79.5.2.3 Postoperative Care

Postoperatively the patient has to wear a walking boot or aircast splint is used for 10 days. Mobility training is begun immediately.

79.5.2.4 Result

Arthroscopic debridement with synovectomy and/or resection of fibrotic tissue provides good to excellent results in 84–96% of cases [4, 7, 11, 27, 51]. Literature also confirmed the indication for debridement in post-traumatic cases [28, 43–44].

Impingement related to AITFL ligament provides good to excellent results in 89–100% of cases after 3 years [2, 5]. Patients return to their preoperative level of sport [6, 7, 18].

Complications

Complications reported after surgery of anterior ankle impingement can be divided in minor and major complications. Minor complications

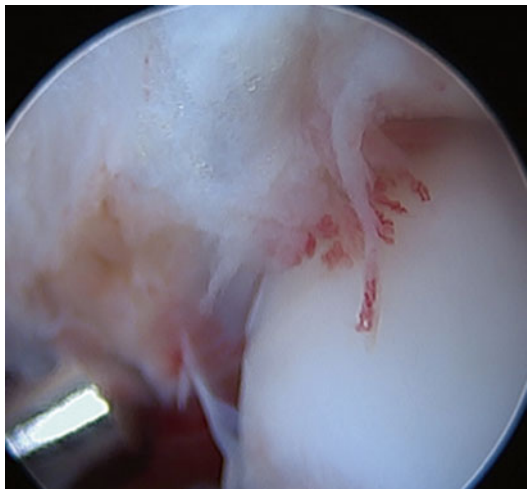


Fig. 79.11 Exploration confirms synovitis behind AITFL

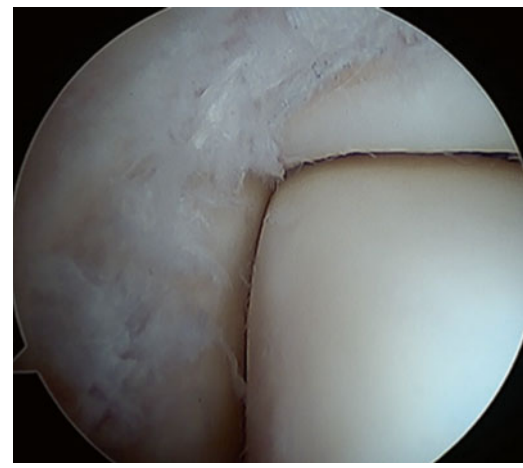
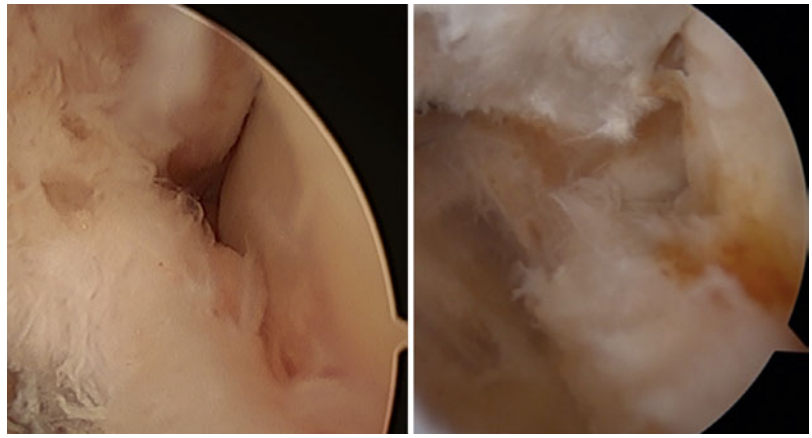


Fig. 79.12 Anterolateral gutter after removal inferior bundle of AITFL



Figs. 79.13 and 79.14 Final aspects after resection of the granulation tissue of ATFL

reported are nerve injury and infections. Major complications reported mainly contained a neuroma of the superficial peroneal nerve [37].

Prognosis Factors

The existence of associated lesions, mainly chondral lesions, seems to be the main negative predictive factor [5, 7, 11, 25, 30, 41, 44, 45].

Conclusion

The improvement of anatomical knowledge makes it possible to specify the various aetiologies of soft tissue impingement. The main cause remains the lesion of the ATFL. Less frequently, impingement is caused by a conflict between the AITFL and the talar dome. Searching for associated lesions (particularly ligament lesions) or other causes explaining the ankle pain is very important. The comprehension and treatment of associated lesions may improve the results.

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Anterior Bony Ankle Impingement

80

Daniël Haverkamp

80.1 History

Anterior ankle impingement syndrome is defined by recognizable pain on palpation and worsening with dorsiflexion. The underlying pathology is often a bony impingement caused by hypertrophic bone in the anterior compartment of the tibiotalar joint.

This concept of anterior bony impingement was recognized early and named as athlete's ankle in 1943 by Morris, as footballer's ankle in 1950 by McMurray, and later by a more correct descriptive term by O'Donoghue as impingement exostoses [1–3]. Although McMurray claimed that the condition is specific for male soccer players over the age of 25, we now know that it can occur in many types of athletes at all ages.

Anterior bony impingement is in the meantime reported in runners, ballet dancers, high jumpers and volleyball players, and other sporting activities. It is therefore more correct to name it the anterior ankle impingement syndrome instead of footballer's ankle. The term syndrome is added to state that only those impingements which cause pain are considered and are of interest; it is not unusual to find bone spurs on routine X-rays which do not cause any complaints [4, 5].

Many authors describe the structures causing the impingement as osteophytes, which might cause confusion. Talking about osteophytes is perhaps not the best term, since osteophyte formation is coupled to osteoarthritic changes, while in anterior ankle syndrome, it is not the case. Of course real osteophytes in osteoarthritic ankles also can cause impingement; the etiology and treatment results differ. In anterior ankle impingement syndrome, it is best to use the term "bone spurs" [6].

80.2 Etiology

One of the mechanisms that can cause bone spurs is repetitive forced dorsiflexion, which results in anterior compression of the tibiotalar joint. The repeated direct contact at the anterior chondral margin of the tibiotalar junction has been shown to induce bone formation. Over time, attempted repair, including fibrosis and fibrocartilage proliferation, leads to the bone spur development [7]. The same mechanism occurs in ankle instability, which creates a repetitive force on the anterior chondral margin of the ankle joint, leading to the same bone spur-forming pathway.

A biomechanical study of Tol et al. showed in elite soccer players that while kicking the ball in hyperplantarflexion, an enormous impact occurs in the anteromedial corner of the ankle joint. Of

D. Haverkamp, MD, PhD
Slotervaart Center of Research and Education (SCORE), PO Box 90440, Amsterdam 1006BK, The Netherlands
e-mail: daniel@drhaverkamp.com

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the 150 analyzed kicking actions, in 76 % there was a direct contact between the ball and the anterior part of the medial malleolus with an average impact of 1025 N. In these soccer players, the forced kicking in hyperplantarflexion can cause the same cascade leading to bone spurs on the anteromedial side [8].

The location of the bone spurs is important in understanding the etiology (and also in choosing the treatment). Both tibial and talar bone spurs are located in the joint inside the capsular attachment; they are not a part of the capsule. The original thought that the bone spurs are formed by traction on the capsule in hyperplantarflexion, as proposed by Morris and McMurray, is therefore not correct. The bone spurs are clearly free from capsular attachment [1, 2, 9].

Anterolateral bone spurs differ from the ones causing anteromedial impingent. Anterolateral impingement occurs less frequent and is mainly caused by trauma. The anterolateral osteophytes occur outside of the capsule and should be classified as enthesophytes caused by capsular or ligamentous traction [10]. In this chapter, we focus on the anterior ankle impingement syndrome caused by intra-articular bone spurs occurring most frequently in the anteromedial corner of the joint.

80.3 Clinical Investigation

The patient usually complains of pain in the front of the ankle, worsening with dorsiflexion and weight-bearing activities. It is important to discriminate between deep and superficial pain, since deep pain on weight bearing is more likely to be caused by osteochondral defects. Symptoms may increase after activity, but can also be present at rest. Most often it is mentioned as a dull ache, but can also be described as a more acute sharp pain. Often swelling of the ankle is reported by the patient.

Since the definition of anterior ankle impingement syndrome consists of recognizable pain/tenderness at palpation on the anteromedial corner of the joint, worsening on dorsiflexion, the range of clinical test is obvious. Simply palpate the anteromedial corner and verify that this is the pain that bothers the patient. Forced dorsiflexion may provoke the recognizable pain; however, this test has many false negatives.

80.4 Radiology

The normal weight-bearing AP and lateral X-ray often fail to show the bone spurs, since they are just around the anteromedial corner which is obscured on the lateral X-ray by the larger lateral/anterior aspect of the tibia. When clinical suspicion is raised by physical examination and history taking, the best option is to request an anteromedial impingement (AMI) view (Fig. 80.1).

The AMI view is a lateral view with double obliquity (craniocaudal inclination of 45° with the foot in plantarflexion and external rotation of 30°), which provides a correct visualization of the anteromedial aspect of the joint, evidencing possible bone proliferations [6, 11]. A study of Tol et al. showed that the sensitivity of detecting spurs on the tibia or talus is 40 and 32 % on conventional X-rays; however, on the AMI view, this increases to 85 and 73 %.

For detecting the bone spurs, (3D) CT is the gold standard; however, it should be mentioned that with clinical suspicion and AMI view,

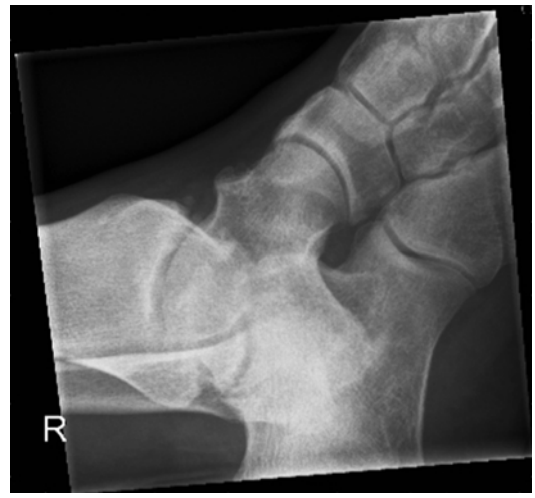

Fig. 80.1 AMI view showing clearly the bone spur on the tibia and talus

additional imaging is only reserved for those cases where there is doubt on the correct diagnosis.

In cases where there is doubt on the diagnosis or other talar lesions like OCDs are suspected, MRI may be the correct investigation besides the AMI view. MRI can rule out other causes of chronic pain, and MRI with intravenous contrast may be helpful to detect the synovial lesions causing soft tissue impingement [12] (Fig. 80.1).

80.5 Classification

Several classification systems are coined. The importance in classifying is either to help in choosing the appropriate treatment or to predict the outcome of the specific case. In treating bony impingement, treatment is identical for all subgroups, so the important aspect of the classification system should be to help predict the outcome. The classification system, from van Dijk, is based on appearance of osteophytes and joint space narrowing of the ankle from plain radiography [13]. Grades 0 and I both indicate no manifestation of osteoarthritis. While grade 0 signifies a normal joint or subchondral sclerosis, grade I denotes bone spurs without joint space narrowing. Grade II represents a joint space narrowing with or without bone spurs. Grade III describes (sub) total disappearance/deformation of the joint space. The series on which this score is based showed good results in grades 0 and 1, with 85 % good to excellent results. In these cases, a normal joint remains after removal of the bone spurs. In grades 2–3, the main cause is a degenerative process and perhaps osteophytes instead of bone spurs. The results in these groups may be good but are unpredictable (50 % good/excellent results).

80.6 Treatment

Since the bone spurs are an intra-articular entity free from the joint capsule, they can be removed arthroscopically. Although open techniques can be used, arthroscopic techniques have a faster recovery and return to sport with less morbidity for the patient [14].

Two main techniques of anterior ankle arthroscopy exist, the distraction method and the dorsiflexion method [15]. In the distraction method, a small-diameter arthroscope is used, and the joint is opened with some form of distraction. This allows a perfect intra-articular view. However, the bone spurs that need to be removed are outside of the joint, but inside the capsule. Using the distraction technique, the joint capsule is tight over the bone spur, limiting visibility and making it harder to remove completely. The dorsiflexion technique is introduced and described by van Dijk [15]. In this dorsiflexion technique, the joint is closed by forced dorsiflexion, and a normal-size arthroscope and shavers are used. Since the capsule relaxes on dorsiflexion, it is easier to reach the bone spur and to remove it from the top down (Fig. 80.2) [15]. By starting on the top of the bone spur with shaving instead of starting at the side of the joint, it is easier to visualize and control complete removal under arthroscopic vision (Fig. 80.3). An anatomical study from de Leeuw et al. showed that the anterior working space is significantly increased in the dorsiflexion method compared to the distraction method. This study also showed that the anterior neurovascular bundle is more at risk in the distraction method since it is pulled toward the joint line by tension on the soft tissue, whereas in the dorsiflexion method, it moves away from the joint due to relaxation of the soft tissue [16].

The most recent systematic review on the treatment of anterior ankle impingement syndrome by arthroscopic resection by Zwiers et al. showed overall good results with high percentages of good to excellent satisfaction (74–100 %). The included 20 studies showed the procedure to be safe with low complication rates (4.6 %), particularly with respect to major complications (1.1 %) [17].

80.7 Prognosis and Return to Sports

The overall prognosis of isolated anterior impingement syndrome is good when treated with arthroscopic removal of the bone spurs.

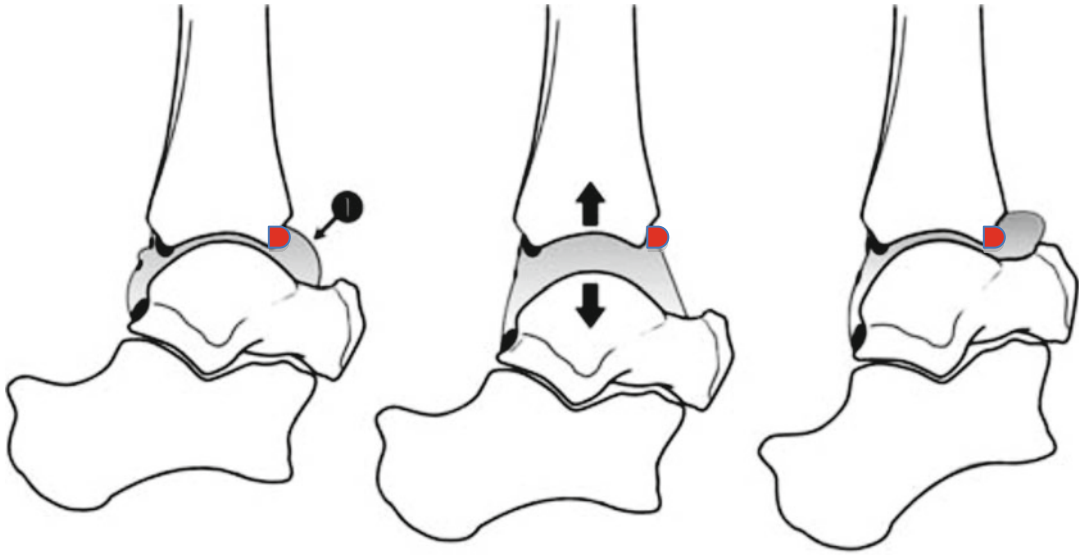

Fig. 80.2 Schematic difference in reachability of the bone spur in the dorsiflexion and distraction technique. (**a**) neutral position (**b**) distraction (**c**) dorsiflexion (Image adapted from de Leeuw et al. [16])

Fig. 80.3 Arthroscopic image after resection of the anteromedial impingement

Good to excellent results are reported in 74–100 % in various studies. The long-term outcome is reported to remain good over time [16, 18].

Parma et al. showed good and consistent results from an 8-year follow-up of arthroscopic treatment of anterior ankle bony impingement. However, in those cases with chondral lesions, the long-term outcome is impaired by the severity of the chondral damage [19].

Return to sport is mentioned in a few studies. Baums et al. report on 26 top athletes with anterior ankle impingement syndrome for more than 6 months; the return to sport is high with 25 returning to their previous level with an average Tegner score of 8 [20].

A similar series of Murawski et al. showed a return to the previous level of sport in 42 of 43 patients [21].

Conclusion

Based on the existing literature, it can be stated that arthroscopic bone spur removal in anterior ankle impingement syndrome provides excellent functional outcomes and allows the athlete to return to his previous level of sport.

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Osteochondral Defects of the Ankle

81

Gwendolyn Vuurberg and C. Niek van Dijk

81.1 Introduction

Osteochondral defects (OCDs) are also known as osteochondritis dissecans. OCDs are lesions involving articular hyaline cartilage and subchondral bone. These lesions may cause pain and disability and offer a challenge to foot and ankle surgeons.

OCDs can occur in every joint and are most common in the knee and the elbow. Of all OCDs, only 4 % occurs in the ankle joint, with a peak incidence in 20–30-year-old males [1, 2]. In the general population, little is known on the incidence of OCDs. Although, Orr et al. [3] showed an increase in incidence in military personnel corresponding with an increase in physical activity.

OCDs occur in most cases in the talar dome, but may also occur in the tibial plafond. Most often the OCDs are located at the posteromedial (58 %) or anterolateral (42 %) side of the talar dome [4].

Ankle sprains are the most common cause of OCDs. Treatment of these sprains is mainly conservative. Residual symptoms occur in up to 40 % of patients after an ankle sprain. In case of residual symptoms, an OCD must be considered as the cause of symptoms [5, 6].

G. Vuurberg (✉) • C.N. van Dijk
Department of Orthopaedic Surgery, Orthopedic Research Center Amsterdam, Amsterdam Medical Centre, Amsterdam, The Netherlands
e-mail: g.vuurberg@amc.nl

81.2 Aetiology

Ankle trauma is reported as the main etiologic factor for developing an OCD [7]. Not all patients, however, describe a history of ankle trauma. Therefore, OCDs are categorized as traumatic or non-traumatic defects [5, 6].

Previous trauma is reported in 98 % of laterally located OCDs and in 70 % of medially located OCDs [8–10]. Ankle sprains play the most important role in developing a traumatic OCD [5, 6]. A severe ankle sprain may cause a small fracture in the talus and subsequently impaired vascularization. This, in turn, may lead to the formation of an OCD [10]. Microtraumas, caused by repetitive articular cartilage surface loading or excessive stress, can lead to cellular degeneration or necrosis. This is due to disruption of the collagen fibril ultrastructure and thickening of the subarticular spongiosa [10, 11].

OCDs occur in up to 70 % of sprains and fractures involving the ankle and up to 7 % of supination trauma and acute ankle ligament ruptures [9]. These traumatic events can lead to partial or complete detachment of an osteochondral fragment, with or without necrosis [7, 12]. Of all OCDs, 93 % is located laterally and 61 % is located medially [7].

Inadequate treatment of OCDs may lead to osteoarthritis of the ankle [10, 13]. In case of non-traumatic OCDs, genetic, metabolic, vascular, endocrine and degenerative factors, as well as morphologic abnormalities, ligamentous laxity,

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spontaneous necrosis, steroid treatment and embolic disease, may contribute to the development of an OCD [9, 14, 15]. A significantly higher incidence of OCDs found in siblings and bilateral lesions also suggests a congenital or hereditary cause [13, 16].

81.3 Injury Mechanism

Lateral OCDs are mainly caused by a combination of inversion and dorsiflexion, whereas medial lesions are caused by a combination of inversion, plantar flexion and internal rotation [7, 14].

In case of an inversion trauma, the talus twists inside its box-like housing formed by the calcaneus, tibia and fibula, and the lateral part of the talar dome is compressed against the fibula (Fig. 81.1). Forces are released when the lateral ligaments rupture, which may cause an avulsion of the lateral talar border [17]. Traumas may lead to bone bruises and softening of cartilage. Cracks in the cartilage may occur with subsequent delamination. Shear forces may also damage subchondral bone, creating subchondral lesions. Fragments may remain partially attached to the talus or completely detach and become loose bodies.

Fig. 81.1 Inversion of the talus, an injury mechanism leading to a lateral osteochondral defect

In case of microfractures in the subchondral plate and subarticular spongiosa, caused by trauma, fluid from the damaged cartilage may be forced into the subarticular spongiosa during loading [10]. The smaller the diameter of the lesion, the higher the fluid pressure. The intermittent local rise in high fluid pressure may cause osteolysis and eventually formation of a subchondral cyst. The intermittent flow of fluid and pressure build-up in the joint through the damaged subchondral bone plate into the spongiosa may prevent healing of the lesion [10, 18].

Overall medial lesions are more frequent compared to lateral lesions. Lateral lesions are typically shallow and wafer shaped, caused by a shear injury mechanism. Medial lesions are generally deep and cup shaped, indicating torsional impaction injury. Lateral lesions are more often displaced compared to medial lesions, which can be explained by their shape, location and trauma mechanism (Fig. 81.2) [17].

81.4 Clinical Presentation

After a traumatic incident, a talar OCD of the talus may remain unrecognized, due to pain and swelling from the soft-tissue injury. Standard radiographs taken at the emergency unit may also fail to reveal an OCD. Size increase enhances the chance of visibility on an X-ray (Figs. 81.3 and 81.4). After a few weeks, symptoms of soft-tissue injuries have resolved, and patients experience persistent or intermittent deep ankle pain during weight bearing and during or after activity. Sometimes this is accompanied by swelling and limited range of motion [7]. Symptoms of isolated ligamentous ankle injury should have resolved within 2–3 weeks after conservative treatment. If symptoms still persist after 4–6 weeks, a

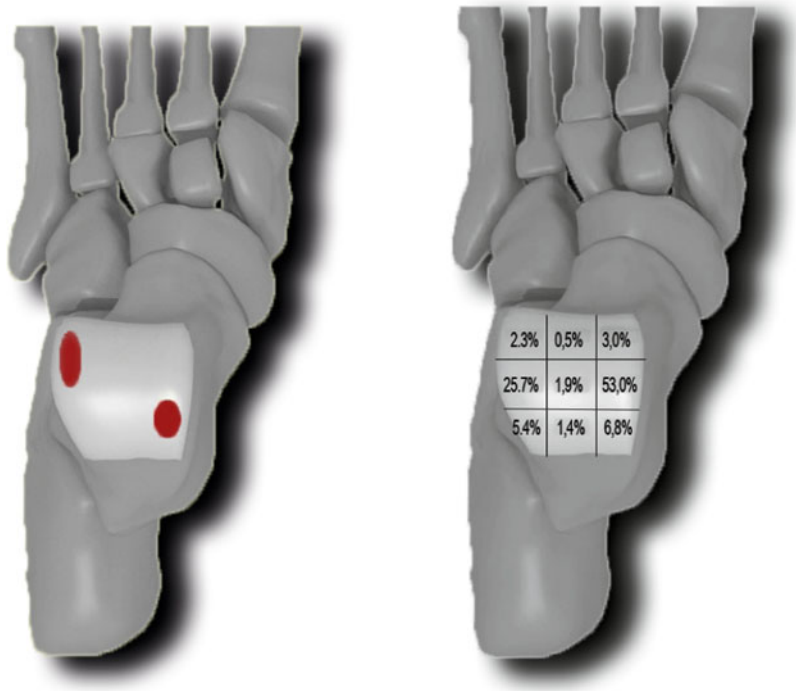


Fig. 81.2 Main shape and locations of the talus [17]

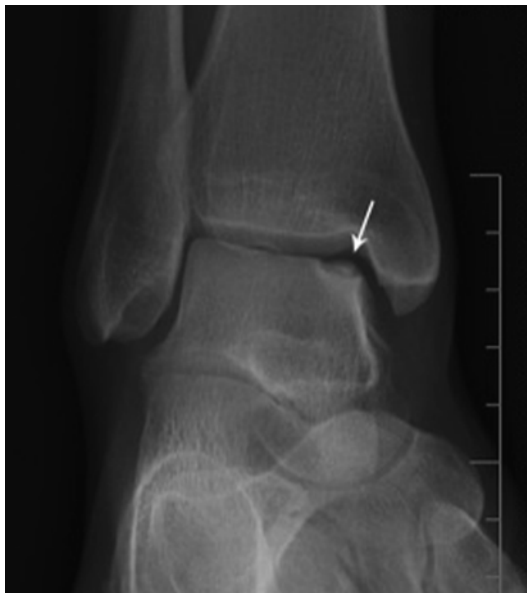


Fig. 81.3 Radiolucency of the medial talar dome indicating an osteochondral defect

talar OCD should be suspected. Locking and catching of the ankle joint can give rise to high suspicion of an OCD with a displaced fragment.

Differentiation must be made between acute and chronic lesions. Chronic lesions classically present as deep lateral or medial ankle pain associated with weight bearing. Reactive swelling and diminished range of motion can be present. Absence of swelling, locking or catching does not rule out an OCD. Generally, no recognizable tenderness is found on palpation, but may be present in case of secondary synovitis [7, 19, 20].

81.5 Clinical and Diagnostic Examination

In case of an ankle injury, evaluation generally consists of taking a medical history and performing regular physical examination. On clinical examination, few abnormalities can be found. Affected ankles may be presented with a normal range of motion, absence of swelling and no recognizable tenderness on palpation [7, 19, 20].

For diagnostic examination, often, routine radiographs of both ankles are taken, consisting of a weight-bearing anteroposterior and

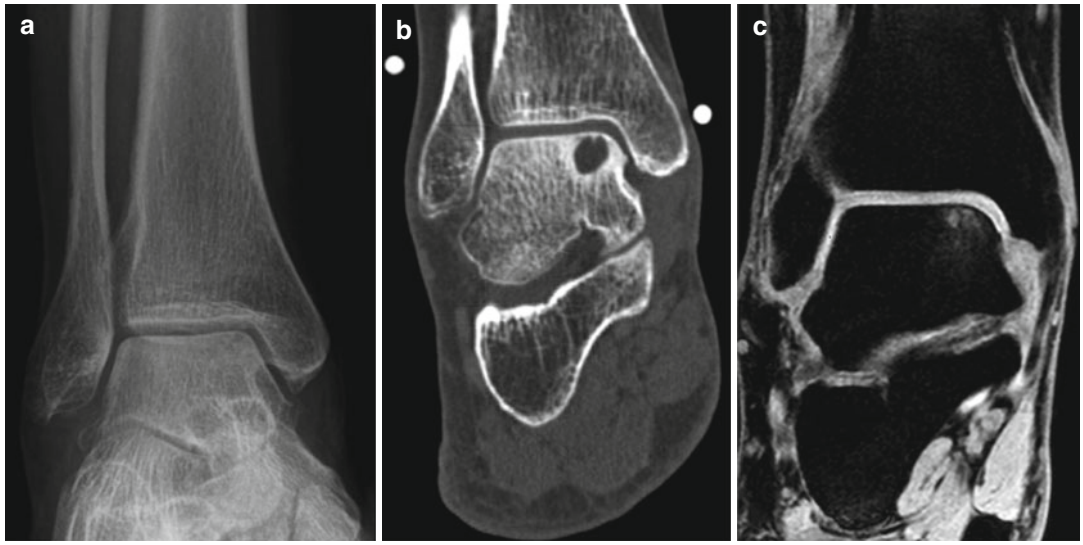


Fig. 81.4 (**a**) X-ray. (**b**) CT scan. (**c**) MRI of a medially located OCD. On the X-ray the OCD is not clearly visible and will be missed by routine screening. On the CT scan, a subchondral cyst is visible, secondary to the OCD. The MRI image is inconclusive in regard to the diagnosis of OCD. The image may also be indicative of a bone bruise. For surgical planning, the CT scan gives essential information on location and size of the defect

Box 81.1: Differential Diagnoses
- Posttraumatic synovitis
- OCD of tibial plafond
- Sinus tarsi syndrome
- Ligament laxity
- Osteoarthritis
- Subtalar joint pathology

lateral view [7]. OCDs may be visible as an area of radiolucency. Conventional radiography, however, only has moderate sensitivity (0.50–0.75) for these lesions, and visualization may be difficult (Fig. 81.4) [21]. In case of fragment displacement, it is more likely lesions will be visible. Routine radiographs fail to detect 30–50 % of OCDs [21]. Using a heel-rise view, developed to visualize the posterior lesions, instead of standard radiographs doubles the chance of diagnosing an OCD [22, 23].

The sensitivity and specificity for detecting an OCD using a helical CT scan, respectively, 0.81 and 0.99, are high, especially compared to standard radiographs [22]. A CT scan cannot visualize cartilage. The relevance of detecting the exact extend of damage to the cartilage, however, is unclear. Pain in OCDs is caused by involvement of bony tissue. Without bone involvement, lesions remain asymptomatic [21]. Additionally, a CT scan is used for preoperative planning. A CT helps determine the extent of the injury, detection of bony fragments, and in plantar flexion, assessment of the accessibility of the OCD can be made [24].

An MRI has shown to have a high accuracy for diagnosing OCDs. Verhagen et al. [22] showed a sensitivity and specificity of 0.96. Mintz et al. [25] reported a sensitivity of 0.95 and a specificity of 1.00 in patients after performing both an MRI and arthroscopy. It has to be taken in consideration the true lesion can be overestimated using an MRI, due to bony oedema, as lesion size is important for the treatment decision. Additionally, an MRI can give information concerning vascularization, healing and cartilage [26]. Using a stronger magnetic field may improve visualization of subchondral defects and cartilage [27].

81.5.1 Classification and Staging

In 1959, Berndt and Harty were the first to suggest a classification system to stage OCD

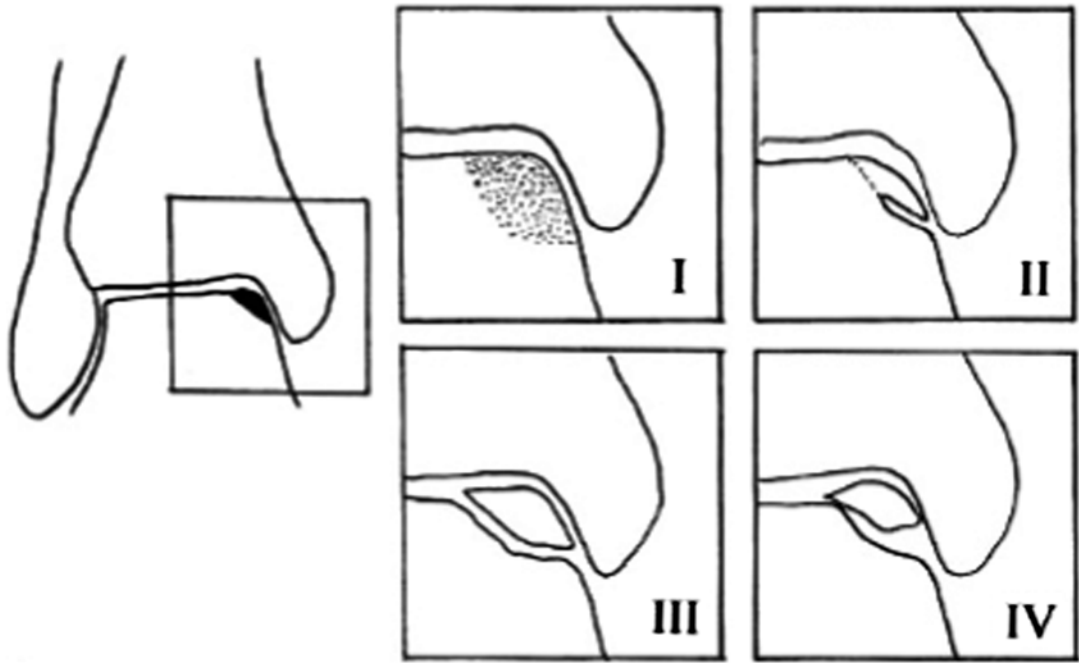


Fig. 81.5 Classification of osteochondral ankle defects by Berndt and Harty [14]

lesions at the time of surgery based on plain radiographs and surgical exploration of the ankle (Table 81.1, Fig. 81.5) [14, 21]. As this classification is based on both radiographic findings and surgical exploration, these findings might not fully correspond. Grade I, for example, describes local compression of cartilage and subchondral bone, which is usually not visible on conventional radiographs. Scranton and McDermott [28] added stage V: cystic lesions.

Ferkel et al. [29] developed a CT-based staging system that corresponds to the Berndt and Harty classification, emphasizing bony characteristics and the cystic component of the defect (Table 81.2). Additionally, to the classification system designed by Berndt and Harty, Ferkel et al. consider fragment separation, the presence of subchondral cysts and the extent of osteonecrosis. Loomer et al. [30] later included stage V: subchondral cysts.

Hepple et al. [31] created an MRI classification to grade OCDs, resembling the classification designed by Berndt and Harty (Table 81.3). None of these current grading systems is sufficient to direct treatment choice [7].

Table 81.1 Classification and staging of lesions according to Berndt and Harty [14]

Stage	Description
I	Small compression fracture
II	Incomplete avulsion of a fragment
III	Complete avulsion of a fragment without displacement
IV	Displaced fragment

Table 81.2 CT staging system according to Ferkel and Sgaglione [29]

Stage	Description
I	Cystic lesion within dome of talus with an intact roof on all views
IIa	Cystic lesion communication to talar dome surface
IIb	Open articular surface lesion with overlying non-displaced fragment
III	Non-displaced lesion with lucency
IV	Displaced fragment

In 1986 Pritsch et al. [32] were one of the first to grade talar OCDs according to cartilage quality assessed by arthroscopy. Cheng et al. [33] later further developed the arthroscopic staging of OCDs (Table 81.4).

Table 81.3 MRI staging system according to Hepple et al. [31]

Stage	Description
I	Articular cartilage damage
IIa	Articular cartilage damage with underlying fracture and bony oedema
IIb	Articular cartilage damage with underlying fracture without bony oedema
III	Detached, but undisplaced, osteochondral fragment
IV	Displaced fragment
V	Subchondral cyst formation

Table 81.4 Arthroscopic staging system based on cartilage quality according to Pritsch et al. [32] and Cheng et al. [33]

Stage	Description
A	Articular cartilage smooth and intact, but soft
B	Articular cartilage surface is rough
C	Fibrillation or fissuring of the cartilage present
D	Present osteochondral flap or exposed bone
E	Detached, but undisplaced osteochondral fragment
F	Detached and displaced osteochondral fragment

81.6 Treatment Strategy

Various treatments, both conservative and surgical, have been published for the treatment of symptomatic OCDs. Surgical techniques are mainly based on (1) debridement and bone marrow stimulation (microfracturing, drilling, abrasion arthroplasty), (2) securing a lesion to the talar dome (fragment fixation, retrograde drilling, bone grafting) or (3) development or replacement of hyaline cartilage (autologous chondrocyte implantation (ACI), osteochondral autograft transplantation (OAT), mosaicplasty, allografts). The preferred treatment depends on the patient's age, symptoms, duration of complaints and location and size of the lesion, as well as whether it concerns a previously treated OCD [7, 15].

81.6.1 Nonoperative Treatment

Asymptomatic or non-severe lesions are primarily treated conservatively for a period of 6 months, consisting of rest, ice, temporarily reduced weight bearing, restriction of (sporting) activities, use of non-steroidal anti-inflammatory drugs (NSAIDs) and, in case of giving way, an orthosis [9, 15]. Conservative treatment yields a success rate of 45 %. Nonoperative treatment may relieve symptoms for a short term; however, they often recur due to inadequate healing of the lesion. A trial period of nonsurgical treatment does not adversely affect surgery outcome. The treatment aims to unload the damaged cartilage, so oedema can resolve and necrosis is prevented [4, 9, 34, 35].

81.6.2 Debridement and Bone Marrow Stimulation

Surgical treatment may include excision of a (partially) detached fragment, leaving the defect untreated, excision and debridement or excision, debridement and bone marrow stimulation (BMS) using either an open or arthroscopic technique [36].

Symptomatic lesions are primarily treated by debridement and BMS in adolescents and in children if conservative treatment fails [37]. During debridement unstable cartilage is removed, including underlying necrotic bone, and cysts are opened and curetted. The mostly present sclerotic-calcified zone is perforated by drilling or microfracturing into the vascularized subchondral bone (Fig. 81.5). As the underlying intraosseous blood vessels are disrupted and growth factors are released, a fibrin clot is formed in the created defect. Formation of new blood vessels is stimulated, marrow cells are introduced into the OCD and multiple connections with the subarticular spongiosa are formed [36, 38]. In case of a cystic defect of ≥15 mm in diameter, a cancellous bone graft may be placed in the defect [39].

Transmalleolar antegrade drilling can be considered in case the OCD is difficult to reach because of its location on the talar dome. The defect can be drilled through the malleolus using a Kirschner (K)-wire about 3 cm proximal to the tip of the medial malleolus. The K-wire is

directed through the medial malleolus into the lesion, through the intact cartilage [36]. Whenever possible, transmalleolar drilling should be considered due to damage to the tibial plafond cartilage opposite the talar OCD [10].

Treatment by debridement and bone marrow stimulation is, with 78–86 % of good or excellent results, superior to other techniques for treating an OCD and is the current treatment of choice. Even though OAT showed similar results in an RCT, microfracture and chondroplasty are preferred because of less postoperative pain, lower costs, comparable results and avoidance of donor site morbidity [4, 39–41] (Fig. 81.6).

81.6.3 Securing a Lesion to the Talar Dome

Fragment fixation with one or two lag screws is preferred in an acute or semi-acute situation with a fragment ≥15 mm. Materials that can be used for fixation are Herbert screws, K-wires, absorbable fixation and fibrin glue [36]. Following failure after a period of 6 months of conservative treatment, fixation of an OCD in adolescents should always be considered [7].

In case of intact cartilage with a large subchondral cyst in primary OCDs, retrograde drilling, combined with cancellous bone grafting when necessary, may be the treatment of choice [7]. Retrograde drilling is also used in lesions that are hard to reach through the standard anterolateral and anteromedial portals. For medially located lesions, arthroscopic drilling can be done through the sinus tarsi, and for lateral lesions, the cyst is approached from anteromedial. By drilling through the posterior talar process, a posterior arthroscopic approach is possible. The aim of retrograde drilling is to induce revascularization of subchondral bone and subsequently stimulate formation of new bone. Here as well a graft may be placed in the defect. Retrograde drilling is the treatment of choice in case of large subchondral cysts with healthy overlying cartilage [36, 42].

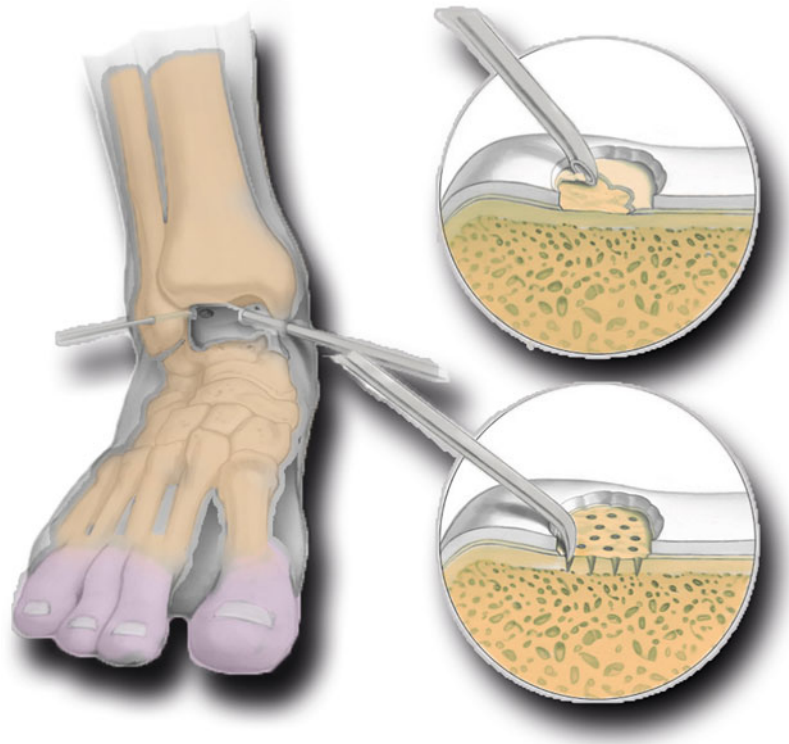


Fig. 81.6 Microfracture of an OCD

81.6.4 Development or Replacement of Hyaline Cartilage

When primary treatment fails, OAT and ACI are the options. For both techniques good results have been reported [39, 43, 44].

OAT has been introduced as an alternative to allografts in the treatment of OCDs. Two procedures have been developed: mosaicplasty and osteochondral autograft transfer system (OATS). These are reconstructive bone grafting techniques that consist of harvesting one or more osteochondral plugs from a lesser weight bearing area of the knee and transplanting them into the talar defect [45]. The grafts are subsequently transplanted into the prepared defect site on the talus. These techniques aim to reproduce (bio) mechanical and structural properties of the original hyaline cartilage. This procedure as well can be performed through an open approach and an arthroscopic procedure. The main indications for OAT involve large, often medial lesions, sometimes with a cyst underneath [36, 42]. OAT yields good to excellent results in 90–94 % at intermediate follow-up. However, this technique is associated with donor site morbidity, and often a medial osteotomy is required [39, 45–47].

ACI is the implantation of in vitro-cultured autologous chondrocytes, using a periosteal tissue cover after expansion of isolated chondrocytes. This technique aims to regenerate tissue with a high percentage of hyaline-like cartilage. Cultured chondrocytes are placed under a periosteal patch that covers the lesion. The technique is applied in lesions >1 cm^3 and no generalized osteoarthritic changes. Chondrocytes are harvested from either the knee or the region on the perimeter of the talar lesion. After the cells have been cultured for 6–8 weeks, a second procedure is performed. A stable border is created by curettage of the damaged articular surface and a periosteal patch is harvested from the tibia. The periosteal patch is sutured to the defect and sealed with fibrin glue. Subsequently the cultured chondrocytes are injected under the periosteal patch [39, 44, 48]. Matrix-based chondrocyte implantation (MACI) is also used. It differs from standard ACI in chondrocytes being embedded in a type I/III collagen membrane bilayer. The membrane is placed in the defect, as with ACI, but MACI requires no sutures. The membrane is secured using fibrin sealant. MACI is technically easier compared to ACI and does not require an osteotomy [49]. Disadvantages include the two-staged surgery, high costs and donor site morbidity [39, 44, 48].

81.6.5 Treatment Choice

Surgical treatment of talar OCDs remains controversial among orthopaedic surgeons. None of the current grading systems is sufficient to direct treatment choice [22]. Treatment should be graded by size of the lesions, location of the lesions and whether it concerns primary or secondary treatment. Age also plays a role. We tend to be more conservative in young patients [10].

In case of pure cartilage lesions, asymptomatic and low symptomatic lesions, conservative treatment is started for 6 months. Surgical treatment should be considered in case of failure of conservative treatment, or continuing or exacerbation of symptoms after 6 months, or in case of residual symptoms after previous surgical treatment (Table 81.5). Arthroscopic BMS is the treatment of choice in primary OCDs <15 mm. Defects of >15 mm have shown less good results compared to OCDs <15 mm [10, 36].

81.7 Surgical Technique BMS

The size and location of an OCD determine whether a standard 4.0-mm arthroscope is used during an anterior approach combined with maximal plantar flexion of the ankle or if a 2.7-mm arthroscope is used in combination with

Table 81.5 Best treatment options based on the talar OCD

Lesion type	Best treatment
Asymptomatic lesions	Conservative
Symptomatic lesions <15 mm	BMS
Symptomatic lesions >15 mm	Fixation
Talar cystic lesions	Retrograde drilling

mechanical distraction. In patients with unlimited plantar flexion, all anteriorly located lesions and lesions at the anterior part of the posterior half of the talus can be reached through an anterior approach [12, 50]. If lesions cannot be approached from anterior, a two-portal hindfoot approach or a medial malleolar osteotomy may offer a solution [34, 51].

The 4.0-mm scope is routinely used in combination with a 4.5- or 5.5-mm bone cutter shaver. In case of synovitis, a local synovectomy is performed with the ankle in dorsiflexion. The lesion is identified in forced plantar flexion by palpating the cartilage with a probe. A soft-tissue distractor can be applied if needed. The full-radius resector as bonecutter is introduced into the defect. In some cases, identifying the defect by introducing a spinal needle, probe or curette can be useful before introducing the resector. Identifying the anterior part of the defect and removing unstable cartilage and subchondral necrotic bone are important. Checking every step in the debridement procedure is done by regularly switching portals. After full debridement, the sclerotic zone is penetrated by a microfracture probe or a Kirschner wire. Postoperatively, a compression dressing is applied [7]. A hyaluronic acid injection after microfracture might improve clinical outcomes [52]. Overall arthroscopic treatment showed excellent to good results in 80–87 % of patients [22, 53].

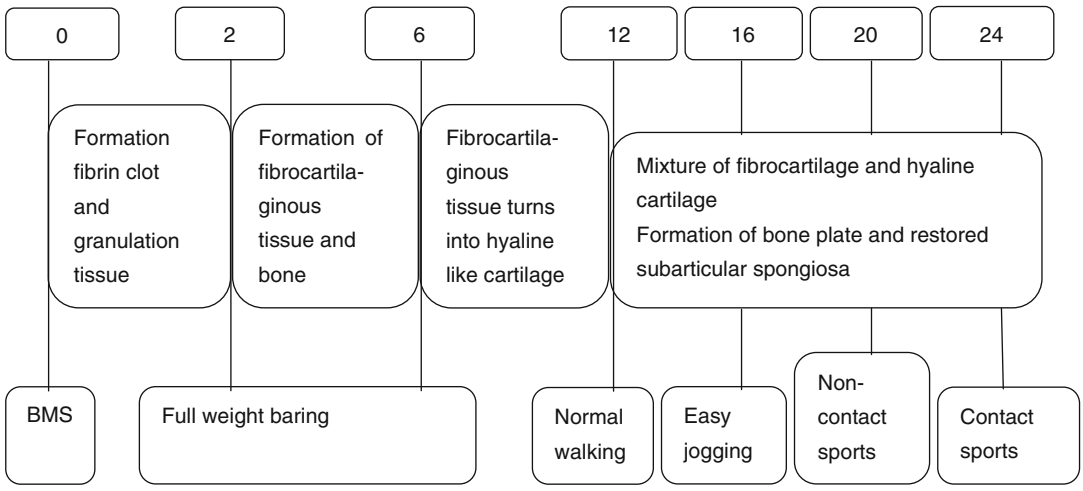
81.8 Rehabilitation

After BMS active plantar and dorsiflexion are encouraged. Partial weight bearing is allowed as tolerated. Progression to full weight bearing is allowed in 2–4 weeks in patients with central or posterior lesions up to 1 cm. Larger lesions and anterior lesions require partial weight bearing up to 6 weeks. Running on even ground is permitted after 12 weeks. Full return to normal and sporting activities is usually possible after 4–6 months of surgery [7]. A four-level activity scheme has been described (Table 81.6) [54].

The first phase aims to return to normal walking, which commences the day of the operation allowing partial weight bearing. Training active range of motion is important. Active plantar- and dorsiflexion is stimulated. Partial weight bearing provides nourishment by synovial fluid for chondrocytes. Full weight bearing stimulates osteoblasts in the formation of bone underneath the cartilage. At the end of the first phase, proprioception training is commenced to regain normal stability.

The second phase aims to resume running on even ground. Progression from walking to run-

Table 81.6 Rehabilitation scheme after bone marrow stimulation



ning on even ground is permitted between 12 and 16 weeks. Sometimes more proprioception training is needed. The range of motion should be normal. Controlled sideways movement is achieved by force, endurance and technical skill training. Pain and swelling should have ceased after 24 h of increased activity.

The third level of the activity phase is a return to non-contact activities. Full return to non-contact sports, depending on the size and location, is usually possible 20–24 weeks postoperatively. Training for speed, endurance, running and sprinting is continued. By the end of this phase, rope jumping, turning and twisting should be possible, without increased pain for more than 24 h.

Phase four is defined as a return to contact sports. Contact sports are permitted from 24 weeks and up. Final training for speed, muscle strength and endurance should enable running on uneven ground, generation of explosive force, changing direction and other sports-specific movements.

Rehabilitation after other treatment options, like fixation or OATS, is slightly different. After fragment fixation, the non-weight-bearing period is 6 weeks followed by another 4–6 weeks of controlled weight bearing to ensure proper fixation.

After medial malleolar osteotomy, weight bearing depends on the surgical treatment of the osteochondral lesion. After OATS, running is not permitted until the graft has been incorporated [54].

Conclusion

Osteochondral defects are defects involving hyaline cartilage and subchondral bone. The lesions can differ in size and location. In case of an ankle OCD, there is often a history of ankle trauma, reporting an inversion injury.

Performing clinical examination, an ankle with an OCD may show little abnormality. Physicians must be aware of reported deep ankle pain, which cannot be provoked by joint line palpation. Conventional radiographs might be insufficient to show the lesion, whereas a CT scan may show talar or tibial OCDs.

BMS provides the solution in lesions <15 mm. Lesions >15 mm have shown less good results and fixation is advised. In case of asymptomatic lesions or lesions in younger patients, a conservative approach is advocated.

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Mosaicplasty for Treatment of Osteochondral Defects of the Ankle

82

Tamás Gál, Ágnes Berta, and László Hangody

82.1 Introduction

An osteochondral ankle defect is a lesion involving talar articular cartilage and subchondral bone and mostly caused by a single or multiple traumatic events, leading to partial or complete detachment of the osteochondral fragment with or without osteonecrosis [1]. Many synonym terms are used, including osteochondral fracture, osteochondral lesion, osteochondritis dissecans (OCD), transchondral fracture, flake fracture, and intra-articular fracture. OCD defects are mainly located on the medial and lateral sides of the talar dome and less often centrally [2]. There exist many treatment possibilities, depending on the size and location of the osteochondral lesion, as well as the age of the patient and many other circumstances. One of these possibilities is mosaicplasty, which aims to replace the damaged hyaline cartilage and the underlying bone. This technique was originally developed for treating focal osteochondral lesions of the knee, by transferring multiple cylindrical osteochondral grafts from the less weight-bearing area of the knee to the defect on the weight-bearing surface, superimposing onto each other, thus allowing for 90–95 % coverage of the lesion. This technique was adapted to treating osteochondral defects in other joints, and mosaicplasty proved to be quite effective in the therapy of talar lesions.

82.2 Indications

Mosaicplasty as a treatment of osteochondral defects of the ankle is a relatively aggressive surgical procedure, since it requires the harvesting of a donor autologous osteochondral graft from a healthy knee joint and for medial side defects; a malleolar osteotomy is often required. For these reasons, indication of mosaicplasty is usually secondary, following a failed, less invasive, previous surgical treatment, such as debridement, curettage, or microfracture/drilling (bone marrow stimulation), etc. [3].

Before offering mosaicplasty, the size and location of the osteochondral lesion, blood supply of the talus, and associated pathologies must be identified using radiographs, CT scans, MRI, and/or bone scans. However, the final indication to perform mosaicplasty is based on the arthroscopic findings only after preparation of the lesion. The ideal indications for mosaicplasty include focal osteochondral lesion ≥10 mm in diameter, the location of the lesion on the medial or lateral dome, and detached osteochondral fragments, but otherwise normal articular surfaces of the ankle [4].

T. Gál, M.D., Ph.D., D.Sc. (✉) • Á. Berta, M.D.
L. Hangody, M.D., M. Sc., M. Res.
Department of Orthopaedics, Uzsoki Hospital, Budapest, Hungary

Department of Traumatology, Semmelweis University, Budapest, Hungary
e-mail: drgaltamas@hotmail.com

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Contraindications for this procedure are patients with ankle osteoarthritis and patients with pan-articular arthritis or cartilage thinning regardless of age or previous surgical history. Relative contraindications include patients over 50 years of age and patients who have had multiple previous surgeries (even though mosaicplasty is recommended as a second-line surgery).

82.3 Technique

The mosaicplasty technique for treatment of osteochondritis dissecans of the talus was reported by Hangody et al. in 1997 [5]. As a first step, an arthroscopic examination of the ankle joint is performed to check the intra-articular pathologies and other conditions. Standard anterolateral and anteromedial portals are recommended, but – in case of poor visualization – further additional portals can be added [2, 5]. If mosaicplasty has been decided, the surgery can be extended to an open procedure.

Considering the complex structure of the talocrural joint, the approach recommended is a mini-arthrotomy, combined with a medial malleolar osteotomy if the lesion is located on the medial talar dome, because it is of key importance that the grafts are placed perpendicularly to the articular surface (Fig. 82.1).

The cylindrical grafts are harvested from the less weight-bearing periphery (usually the medial femoral ridge) of the ipsilateral knee at the level of the patellofemoral joint; the lateral femoral ridge can serve as an additional harvest site. The quality of the hyaline cartilage of these grafts matches the requirements of the talar surfaces.

The surgical approach depends on the site of the lesion. In cases of medial osteochondral lesions of the talus, usually a medial malleolar osteotomy is required at the junction of the medial plafond, in order to ensure adequate exposure of the defect. Lateral lesions are most often located on the anterolateral surface of the talus, and since the lateral malleolus is in a relative retroposition, an osteotomy is usually not required; a vertical anterior lateral arthrotomy is sufficient (Fig. 82.2).

The foot is positioned in plantarflexion in order to achieve a perpendicular approach of the lesion. In cases of large lesions extended posteriorly, Gautier and Jakob recommend a lateral mal-

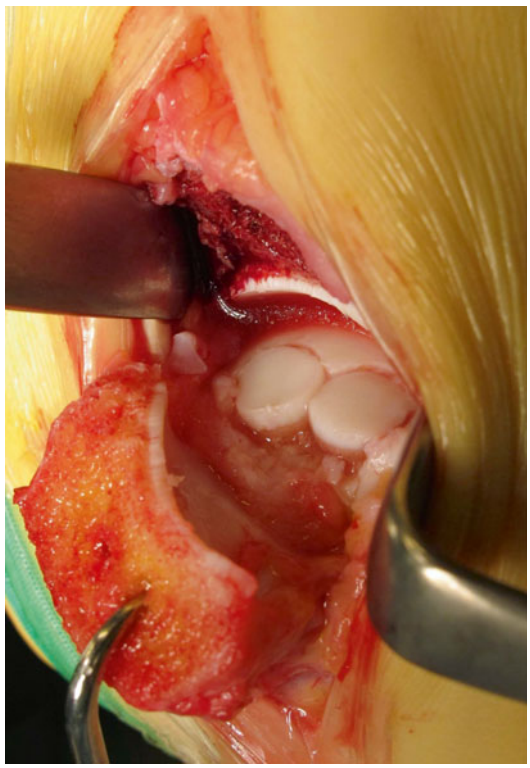

Fig. 82.1 Mosaicplasty on the medial talar dome – mini-arthrotomy approach, combined with a medial malleolar osteotomy

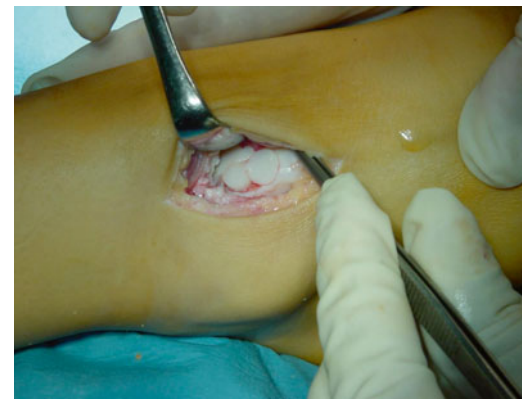

Fig. 82.2 Mosaicplasty on the lateral talar dome – no osteotomy is required for the surgical approach

leolar osteotomy, while Kish recommends exposure through an anterior fibular periosteal flap containing the origin of the anterior talofibular ligament and, if necessary, the calcaneofibular ligament. Then using a thick K-wire or a Steinmann pin tapped into the body of the talus (as a "joystick"), the talus can be drawn forward and rotated downward. In large, central defects, approach of the talus can be achieved by eversion of the ankle into a valgus position (if necessary, using a Steinmann pin as a joystick). The consequent twisting of soft tissues during surgery has not been shown to cause any negative postoperative side effect.

The following step is preparation of the recipient site. The lesion is exposed and after removal of the damaged cartilage, a sharp curette or abrader is used to refresh the bony surface until reaching the intact cartilage. Next, the graft sizes and number of grafts are measured using mosaicplasty instruments (Mosaicplasty™ Complete Instrumentation – Smith & Nephew Inc., Andover, MA) to be transferred to the recipient site. The drill guide is used to determine the diameter and locations of the intended drill holes. In the talus, the usual size of the drill holes is 6.5 and 4.5 mm in diameter. 8.5 mm diameter is recommended for defects not involving the convex dome area of the talus, while smaller sizes (3.5 mm in diameter) can be used to fill the remaining spaces between the implanted grafts. The depths of the defects are measured with the laser marks of the dilator.

The osteochondral grafts are then harvested from the peripheral, non-weight-bearing, medial upper part of the medial femur condyle of the ipsilateral knee. If necessary, the lateral supracondylar ridge can also be used to obtain additional graft through a mini-arthrotomy. By flexing the knee from 0° to 100°, three to four grafts can be harvested from each of the medial or lateral supracondylar ridges. Depending on the size of the lesion at the recipient site, the appropriate diameter tubular chisel is introduced with the harvesting tamp. The chisel is placed perpendicular to the articular surface and is driven by hammer to the appropriate depth (usually 15–20 mm). The taper design of the tubular chisel captures the graft. The chisel is then toggled – not rotated – causing the graft to break free. The chisel is then flipped upside down, and using a chisel guard, the graft is rejected from the cancellous bony side. All graft lengths should be recorded, and they should be stored in a saline solution until implantation. Grafts expand 0.1–0.2 mm in diameter after removal, which is a characteristic that adds to the press fit fixation of the grafts at the recipient site. After harvesting grafts, a suction drain is placed into the knee joint.

Following graft harvesting, implantation of the grafts are performed at the recipient site. The optimal position for the graft is found using the dilator, onto which we slide the universal drill guide, which has a sharp cutting edge. This is hammered in perpendicularly. The appropriate-sized drill bit is inserted and drilled to the proper depth (3–4 mm deeper than the selected graft). A conical dilator is used to enlarge the hole by 0.1–0.2 mm, which not only allows for easier graft insertion, but the dilation of the next hole also impacts the surrounding bone of the previously implanted grafts resulting in a secure press fit fixation. The osteochondral graft is then delivered to the recipient site by inserting the graft into the universal drill guide with the cartilage surface facing upward. The graft is then gently tapped into position. If the graft is proud, a tamp may be used to achieve congruency. The procedure of drilling, dilation, and delivery is repeated with each graft. Since the grafts superimpose onto each other, mosaicplasty allows for 90–95 % coverage of the defect (Fig. 82.3).

Finally, if an osteotomy was required, the medial malleolus is reduced back into position and the osteotomy is repaired with two malleolar screws. The ankle does not require drainage, and closure is of standard manner.

82.4 Complications

Analysis of clinical scores has shown good to excellent results in 93 % of talar mosaicplasties. Nevertheless, moderate and severe donor-site disturbances were present in 3 % of patients according to the Bandi score (evaluations were

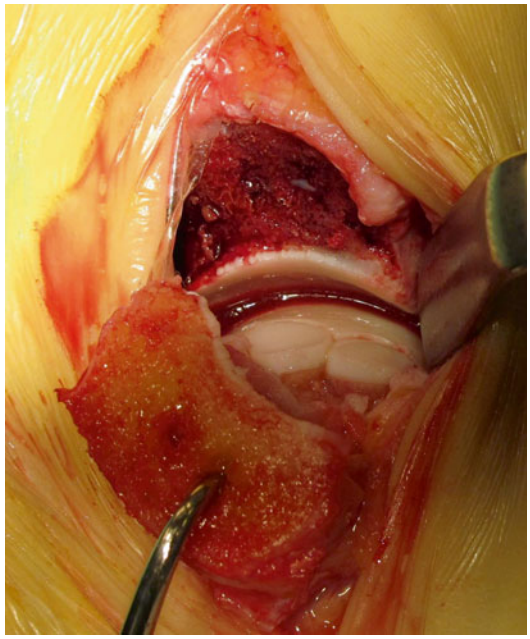

Fig. 82.3 Graft positioning during mosaicplasty – the surface of the graft is congruent with the surrounding cartilage

done in a 1–10-year interval) [6]. However, neither the number of osteochondral cylinders harvested, the total size of grafts harvested, nor the age of the patients has an effect on the donor-site morbidity; rather a higher body mass index of the patients resulted in poorer clinical outcomes [7]. Other complications include slight or severe degenerative changes at the recipient and/or donor sites and painful hemarthroses. In one case, Hangody reported limited range of motion of the ankle due to arthrofibrosis and three cases of incomplete incorporation of the graft on the follow-up MRI studies of over 80 patients who underwent talar mosaicplasty [4].

One of the technically demanding steps of mosaicplasty is the flush or congruent transplantation of the graft into the recipient site. Even if the graft is perpendicularly obtained from the medial or lateral femur condyle of the knee, it may not be completely congruent when transplanted into the medial or lateral dome of the talus. When contact pressures were measured in cadaver models, elevated grafts not only overloaded the cylindrical osteochondral plugs but also the surrounding area of the diseased talus; therefore, grafts should be placed congruent to the surrounding surface or slightly recessed when not possible [8].

General postoperative complications include deep infections and painful hemarthroses. Arthroscopic or open debridement may be necessary to resolve deep infections. Some cases of intra-articular hemorrhage also required arthroscopic or open debridement, but usually treatment by aspiration and cryotherapy is sufficient. Other general postoperative complications include thromboembolism. These general complications can be reduced by aseptic conditions, the administration of preoperative antibiotic prophylaxis, and postoperative thrombosis prophylaxis.

82.5 Results and Literature Overview

The treatment of cartilage and osteochondral defects of the ankle has gone through a significant development over the past two decades [2]. Osteochondral defects of the ankle comprise approximately 4 % of the total number of osteochondral defects [9]. These injuries often require surgical treatment, primarily debridement (removal of the fragment), curettage, and/or a bone marrow stimulation technique such as microfracture or Pridie drilling. If these primary techniques fail or if the lesion is larger or deeper in size, mosaicplasty may serve as a one-step operative osteochondral autograft transplantation procedure, aiming to promote a hyaline type of resurfacement of the defected area.

This technique was developed by Hangody et al. in 1992, originally for the treatment of osteochondral defects of the knee joint, and was first used to treat talar defects in 1993. Hangody et al. released a preliminary report in 1997, treating 11 patients with mosaicplasty, who suffered from osteochondritis dissecans of the talus. The average age of the patients was 25 years, and the average size of the defect was 1 cm^2, and the average number of grafts was 3. No graft loosening was observed, and they reported excellent

results based on clinical evaluation, radiography, follow-up arthroscopy, and biopsy [5].

In a more recent study involving two institutes with 121 patients, the researchers evaluated 21 years of clinical experience with autologous osteochondral mosaicplasty on the talus. One hundred and ten patients were followed for an average of 12 years (range, 1–20 years). The average age of patients was 21.8 years (range, 12–43), and the average size of the defect on the talus was 16.2 ± 10.1 mm^2. Except for two cases, all lesions were on the medial talar dome. The American Orthopaedic Foot and Ankle Society (AOFAS) scoring system was used to assess the patients, which increased from the preoperative value of 65 ± 3.1 points to 90.0 ± 8.3 points postoperatively (mean AOFAS improvement was 16 ± 8.1 points). The donor site had 90 % good results according to the Bandi score. One case of malunion and two cases of deep venous thrombosis occurred [10].

In another study group, similar results were reported, involving 2-year short-term outcomes of open mosaicplasty of large osteochondral lesions of the talus accessed via medial malleolar osteotomy in 32 patients. The mean age of the patients was 27.5 years (range, 20–47 years). Follow-up imaging of the patients included radiographs and MRI. The AOFAS score preoperatively was 59.12 ± 7.72 points and increased over the postoperative 2 years to 87.94 ± 3.55 points [11].

In 2011, Imhoff et al. evaluated the long-term results of osteochondral transplantations of the talus using clinical examinations and magnetic resonance imaging (MRI). They performed either mosaicplasty or Osteochondral Autograft Transfer System (OATS) transplantations in 26 cases. The average follow-up time of the study was 7 years (range, 53–124 months). The average body mass index (BMI) of the patients was 25. They observed an improvement in AOFAS score from 50 preoperatively to 78 points postoperatively and Tegner activity score improvement from 3.1 to 3.7, and pain intensity on the visual analog scale (VAS) decreased from 7.8 to 1.5. They also observed that patients with congruent or just slightly incongruent cartilage surfaces on the MRI had better AOFAS scores, but they found no other significant correlations between MRI findings and other criteria. They did however find a significant difference in patients who had osteochondral transplantation as a first procedure compared to those who had first a drilling and then OATS as a second procedure. The AOFAS, Tegner, and VAS clinical results were poorer in the group who had osteochondral transplantation as a second procedure [12].

In yet another study, authors evaluated the clinical and radiologic outcomes of ankles treated with mosaicplasty with poorer results. Although patients had a 92 % satisfaction rate of good to excellent and AOFAS score significantly increased from 45.9 to 80.2 points, while the VAS pain score decreased from 5.9 preoperatively to 3.9 following the operation, they reported significantly decreased sports activity levels, reduced ankle dorsiflexion, knee pain, recurrent lesions, and some degree of cartilage degeneration and discontinuity of the subchondral bone plate [13]. The study group however consisted of 21 patients, of which only 12 were available for the latest follow-up (mean, 72 months). They recommended the careful indication of mosaicplasty from the knee to the ankle joint.

Conclusion

In conclusion, the correct indication of mosaicplasty as a second surgery for osteochondral lesions of the talus, along with the careful selection of patients based on the size and location of the defect, patient age, and condition of the surrounding cartilage, offers a one-step, but two-incision, treatment technique providing hyaline resurfacement of the defects.

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Scaffolding as Treatment for Osteochondral Defects in the Ankle

83

Alberto Gobbi, Celeste Scotti, and Giuseppe M. Peretti

83.1 Introduction

The talar dome is the second most common site, after the knee, affected by traumatic osteochondral lesions (OCL) and by osteochondritis dissecans (OCD) [38]. Frequently, these lesions are unrecognized mainly due to lack of specific symptoms or signs and difficulty to detect early changes on plain radiographs [35]. For this reason, their true incidence is unknown. Because of the limited vascularity and limited reparative potential of the talus, inappropriate treatment of OCL and OCD may lead to early cartilage degeneration and development of disabling osteoarthritis, characterized by chronic pain, recurrent swelling, and instability [2, 24, 29]. Once the lesion is detected, there are many treatment options, ranging from nonsurgical to arthroscopic, minimally invasive, or open surgical procedures. The decision is based on size and location of the osteochondral defect [33]. Thanks to the recent advancements in the field of tissue engineering and biomaterial science, scaffolds are currently available for articular surface lesions involving the subchondral bone. These implants are typically easy to handle and can be implanted in the defect area, through arthroscopic or open procedures, in order to support neocartilage formation at the defect site. These scaffolds can be utilized both in two-step techniques, such as the matrix-induced autologous chondrocyte implantation (MACI), and in one-step techniques such as the Bone Marrow Aspirate Concentrate (BMAC)-based procedures or scaffold-augmented microfractures. Both these surgical techniques demonstrated promising preliminary and midterm results [1, 12–14]. In this chapter, the scaffolds typically used and current surgical scaffold-based procedures will be discussed.

A. Gobbi, MD (✉)
Orthopaedic Arthroscopic Surgery International (O.A.S.I.) Bioresearch Foundation, Gobbi Onlus, Milan, Italy
e-mail: gobbi@cartilagedoctor.it

C. Scotti, MD
IRCCS Istituto Ortopedico Galeazzi, Via R Galeazzi 4, Milan 20161, Italy

G.M. Peretti, MD
IRCCS Istituto Ortopedico Galeazzi, Via R Galeazzi 4, Milan 20161, Italy

Department of Biomedical Sciences for Health, University of Milan, Milan, Italy

83.2 Scaffolds

83.2.1 General Concepts

Recent advancements in biomaterial science allowed for the development of several scaffolds with the potential to host and support regeneration of the articular cartilage tissue. Substantial differences regarding the biomaterial, its macro- and

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microarchitecture, and its physical form (i.e., fibers, meshes, and hydrogels) make the available options for the surgeon very heterogeneous. Based on their physical structure, solid scaffolds provide a substrate onto cells can adhere, whereas hydrogel scaffolds physically entrap the cells [9, 30]. This difference influences the cytoskeleton and, therefore, cell differentiation. The biomaterials that are used to manufacture scaffolds can be classified as natural or synthetic (polymers and ceramics). Synthetic matrices present mechanical properties and degradation rates that can be more easily tuned as compared with that of natural polymers. However, some biocompatibility concerns might be raised owing to their degradation products, as they can determine local inflammation and recruitment of inflammatory cells, and potential detrimental effects on native tissue and implanted cells. However, innovations in chemistry and materials science addressed these issues by improving their biocompatibility and tailoring their degradation process. Among the natural (gellan gum, alginate, silk fibroin, chitosan, collagen, hyaluronic acid), the synthetic materials (polyesthers such as the polyglycolic acid, PGA, and the polylactic acid, PLA), and the ceramics (hydroxyapatite, aragonite, and calcium triphosphate) that have been investigated in osteochondral regeneration studies, only few of them have been used in ankle lesions. As a matter of fact, few clinical trials have been performed to assess the potential of scaffolds for the regeneration of osteochondral tissue in the ankle joint with both one- and two-step procedures [19, 34, 37]. Almost all procedures were developed for an application in the knee joint [23] and have been secondarily applied also in other joints such as in the ankle, where often technical difficulties render more challenging the surgical procedure, especially for the type of lesion which appears often unshouldered, making the stability of the implant more difficult.

83.2.2 Scaffold Characteristics

Typical characteristics of scaffolds for tissue regeneration are as follows [9]:

1. *Biocompatibility*: Both the intact scaffold and its degradation products must produce breakdown products that elicit the minimal immune response.
2. *Porosity*: Sufficient enough to allow ingrowth of host tissue of circulation of anabolic and catabolic molecules.
3. *Mechanical strength*: To withstand the implantation procedure and the compressive and shear mechanical forces acting at the joint surface.
4. *Retain ability*: Primary stability of the scaffold in the defect site is of paramount importance in order to support tissue growth.

These scaffolds can be divided according to their chemical nature: into protein-based polymers, carbohydrate polymers, and artificial polymers. Combinations of these different polymers are also available. Among the natural and synthetic materials that have been investigated, few have been used in ankle lesions, probably due to the lack of studies in the field of ankle tissue regeneration. Most importantly, all these features are capable to influence both cell survival and proliferation and cell differentiation that are considered the two key points for successful cartilage repair. In the following paragraph, the scaffolds most frequently used for cartilage repair are discussed.

83.2.3 Scaffolds for Cartilage Repair

Hyaluronan (hyaluronic acid, HA) is a natural and highly conserved glycosaminoglycan, which is ubiquitous in the human body. It has been proven to be a very versatile biomaterial for cartilage tissue engineering, thanks to its both bioactive and structural activity. Hyaluronan-based scaffolds for cartilage repair, both cell-free and cell based, are entirely based on the benzylic ester of hyaluronic acid and consist of a network of 15–20 μm thick fibers, with interstices of variable sizes. This macro- and microscopic organization has been demonstrated to be a suitable physical support to allow cell survival, cell to cell contact, cluster formation, and extracellular

matrix deposition. In particular, a two-step autologous chondrocyte implantation technique based on *HYAFF® 11* (Hyalograft C, Anika Therapeutics Inc., Massachusetts, USA), a derivative of HA, has been shown to provide successful tissue-engineered repair of cartilage [18, 25]. In addition, Giannini et al. reported 81 patients treated for traumatic OCL with implantation of bone marrow-derived cells (BMDCs) seeded on a HA (HYAFF®-11) scaffold supplemented with autologous platelet-rich fibrin. In this study, improvement in AOFAS score and MRIs was demonstrated, suggesting restoration of the cartilage layer and subchondral bone at average follow-up of 59.5 ± 26.5 months [11].

Chondro-Gide (Geistlich Biomaterials, Wolhusen, Switzerland) is a type I/III collagen bilayered matrix that has been widely used for cartilage repair purposes and has been also demonstrated to improve results of first generation ACI [26]. In addition Chondro-Gide has been used in the Autologous Matrix-Induced Chondrogenesis (AMIC®) procedure also for the treatment of OCL of the talus with overall good MRI and clinical results [32].

BioSeed C (BioTissue Technologies GmbH, Freiburg, Germany) scaffold is composed of fibrin, polyglycolic/polylactic acid, and polydioxanone. It is a tissue-engineered graft that combines autologous chondrocytes, embedded in fibrin, with a 2 mm thick porous gel-like matrix in a bioresorbable polymer scaffold, and has been applied in clinical practice since 2001 [27]. However, probably because of its particular surgical technique, requiring pin fixation or interference sutures, it has never been reported for the treatment of OCL of the talus.

NeoCart (Histogenics Corporation, Waltham, Massachusetts) consists of a three-dimensional type I collagen scaffold seeded with autologous chondrocytes and then cultured in a proprietary bioreactor system which duplicates some features of the joint environment [7, 8]. The tissue resulting after the dynamic culture process is a viable proteoglycan and glycosaminoglycan-rich hyaline-like-engineered tissue, which is secured into the defect with a collagen bioadhesive. NeoCart is currently undergoing a phase III clinical trial for the treatment of articular cartilage defects of the knee.

Novocart 3D (B. Braun-Tetec, Reutlingen, Germany) comprises autologous chondrocytes embedded in a 3D collagen-chondroitin sulfate scaffold [36]. Patients' chondrocytes are typically isolated and then expanded in monolayer culture without being passaged and then seeded onto the scaffold in a density of $1.45 \times 10^6/cm^2$. To date, no report of Novocart 3D for cartilage lesions to the talus is present in literature.

CaReS (Ars Arthro, Esslingen, Germany) consists of autologous chondrocytes seeded on 3D type I collagen gel. The cells are isolated, mixed with collagen, and after complete gelling and 2 weeks of culturing, the chondrocyte-loaded gel is available for transplantation [28]. This scaffold is also available as cell-free material for one-step procedures.

Cartipatch (TBF Tissue Engineering, Mions, France) is used as two-step procedure for autologous chondrocyte implantation on a vegetal hydrogel made of agarose and alginate. Autologous chondrocytes are suspended within the hydrogel, and the resulting materials can be shaped in any form at 37 °C and then solidified at approximately 25 °C. This feature makes it a very easy-to-handle material [31].

MaioRegen (Fin-Ceramica Faenza SpA, Faenza, Italy) is an osteochondral nanostructured biomimetic scaffold with a porous, trilayered structure duplicating the morphology of the osteochondral unit. This scaffold has been also used for the treatment of OCL of the talus, with significant clinical improvement but limited tissue regeneration [5]. A larger experience have been reported for OCL of the knee, with a 5-year follow-up study demonstrating good clinical results but only partial osteochondral regeneration [21].

Agili-C (CartiHeal, Kfar Saba, Israel) is a recently developed, rigid biphasic implant composed of biocompatible and biodegradable aragonite-hyaluronate. The bone phase of the implant is composed of calcium carbonate in the aragonite crystalline form, a well-known biomaterial that enhances bone formation. The cartilage phase is a composite of modified aragonite and

hyaluronic acid (HA). Preclinical evaluation in a caprine model demonstrated cartilage and subchondral bone regeneration at 6- and 12-month follow-up [22]. Preliminary clinical experience for the treatment of OCL of the knee is ongoing.

83.3 Surgical Procedures

83.3.1 Matrix-Induced Autologous Chondrocyte Implantation (MACI)

Among the two-step procedures available, MACI demonstrated satisfactory results in both the knee joint and the ankle. Thanks to the use of a scaffold, on which autologous chondrocytes are seeded, the surgical procedure is easy, and the chondrocytes are able to reacquire and maintain their original chondrogenic phenotype, which is typically lost upon 2D expansion, and synthesize an extracellular matrix rich in type II collagen and glycosaminoglycans, which are essential components of the hyaline cartilage [18, 25]. As mentioned above, the use of a three-dimensional scaffold for autologous chondrocyte culture was introduced with the aim of improving both the biological performance of chondrogenic autologous cells as well as making the surgical technique easier, by securing the chondrocytes in the defect site. In fact, a properly sized scaffold can be placed directly into the articular defect under a mini-open approach or through arthroscopic guidance. The latter offers the great advantage of an all arthroscopic surgery, since there is no need for harvesting the periosteal flap as it was needed in the first-generation ACI technique. However, some technical limitations exist, especially for the treatment of posterior lesions. It must be emphasized that this is common to all arthroscopic procedures and that it could be solved by with the development of new arthroscopic tools or by using a dedicated distractor capable to open the joint space. Currently, the main indications for second-generation cartilage transplantation are symptomatic focal, full-thickness cartilage lesions (ICRS Grades III–IV), larger than 1 cm^2, in the absence of significant arthritis, malalignment, and joint instability in adults (15–50 years). The main limitations to this procedure include (i) the high costs related to the two surgical procedures required and the autologous cells processing in Good Manufacturing Practice (GMP) laboratory and (ii) the still debated benefit compared to simpler procedures (e.g., microfractures).

83.3.2 Bone Marrow Aspirate Concentrate (BMAC) Procedures

Despite the satisfactory results, cost-effectiveness of autologous chondrocytes implantation techniques has been questioned. For this reason and in order to streamline treatment of articular surface lesions, cell-based one-step procedures have been developed [6, 15]. The use of autologous bone marrow-derived cells (BMDCs) and growth factors offers the benefit to avoid the first surgery for the biopsy and subsequent chondrocyte isolation and expansion. Previous animal and laboratory studies have shown that bone marrow-derived mesenchymal stromal cells (MSCs) have a high proliferation and multi-lineage differentiation potential into adipogenic, osteogenic, and chondrogenic cells, representing an ideal candidate for cell-based regenerative therapies [3, 4, 10, 16, 17, 20]. However, despite the body of literature supporting their use, very few clinical studies have been performed. We have been using BMAC combined with various scaffolds for the treatment of full-thickness cartilage defects of ankle since 2006 (Figs. 83.1 and 83.2) with satisfactory clinical and MRI (Fig. 83.3) results [16, 17, 20]. In details, approximately 60 mL of bone marrow is harvested from the iliac crest using a dedicated aspiration kit and centrifuged using a commercially available system (BMAC Harvest Smart PreP2 System, Harvest Technologies, Plymouth, Massachusetts, USA) to obtain a concentration of bone marrow cells 4× to 6× the baseline value. With the use of Batroxobin enzyme (Plateltex Act, Plateltex SRO, Bratislava, Slovakia), the bone marrow concentrate is activated to produce a sticky clot

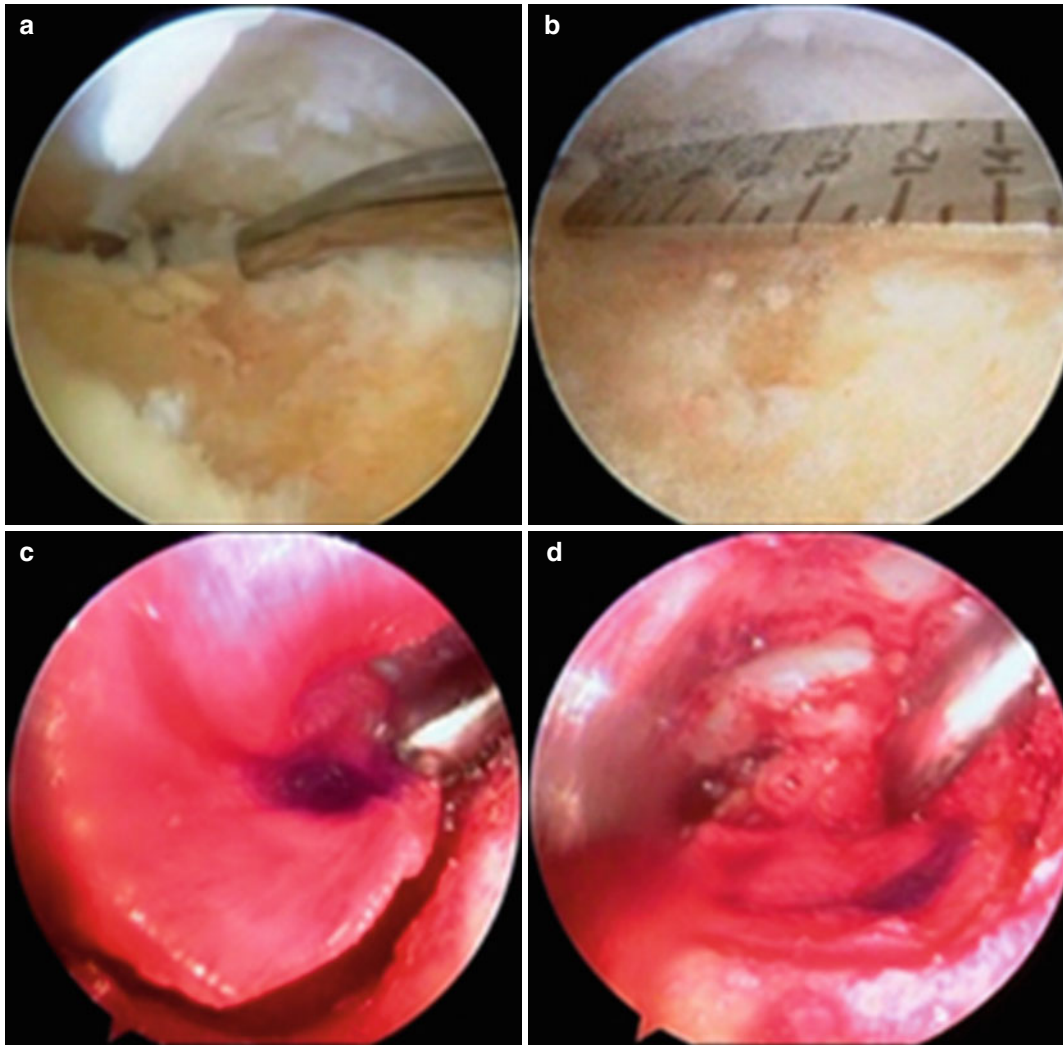

Fig. 83.1 (**a**) Arthroscopic debridement. (**b**) Arthroscopic templating. (**c**) Arthroscopic placement of the scaffold containing BMAC and (**d**) sealing of scaffold with fibrin glue

material that makes it easier to handle and apply into the cartilage defect. The ankle joint is approached either using an arthroscopic or mini-arthrotomy technique, depending on the location of the lesion, and the scaffold is tailored according to the defect size and shape. Finally, the previously prepared BMAC clot is implanted into the prepared cartilage defect and covered with the scaffold, which is secured to the surrounding cartilage using a polydioxanone suture (PDS II 6-0, Ethicon, Somerville, New Jersey, USA) and sealed with fibrin glue (Tissucol, Baxter Spa, Rome, Italy).

83.3.3 Scaffold-Augmented Microfractures

Another valuable option for the treatment of OCL of the talus is represented by the application of a chondrogenic scaffold after performing microfracture. As a matter of fact, this procedure further streamlines the process, being not only one step but also cell-free. In details, this procedure combines debridement of the lesion and microfracturing with a scaffold capable to stabilize the clot within the defect and provide a suitable environment capable to promote chondrogenic differen-

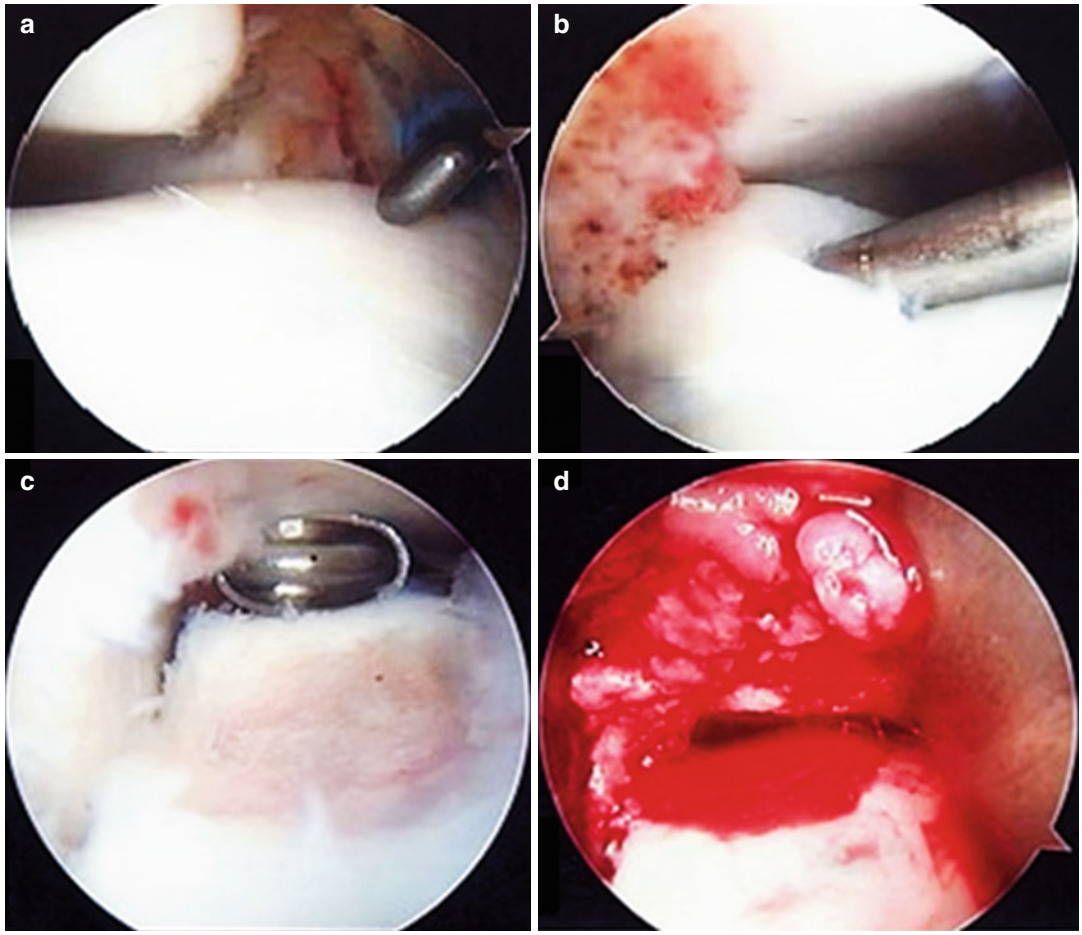

Fig. 83.2 (**a**) Arthroscopic evaluation. (**b**) Arthroscopic debridement. (**c**) Arthroscopic curettage, defect preparation, and (**d**) BMAC with scaffold transferred over defect area

tiation of progenitor cells coming from the subchondral bone. In case of large osseous defect, an autologous bone graft can be performed prior to scaffold application [32]. Both Chondro-Gide® and HYAFF®-11 have been reported for this technique with favorable clinical results despite the suboptimal tissue regeneration shown at MRI. Comparative studies are desirable in order to demonstrate the benefit of these techniques compared to the simpler microfractures.

83.3.4 Postoperative Treatment and Rehabilitation

Continuous passive motion is begun the day after surgery and is used intermittently throughout the in-hospital stay, usually for 2 or 3 days. The patient is then recommended to continue with active range of motion (ROM) exercises. A brace is placed in order to allow motion of 15° plantar flexion and 15° dorsal flexion for 6 weeks. In addition, the patient is allowed to use crutches with limited weight bearing (20 kg) for the first 6 weeks. Gradual increase in weight bearing is then commenced every week until full weight bearing is allowed in week 8–10. Once the brace is removed, pool exercises are recommended; as full weight bearing is reached, gait training is started along with walking and bicycling. Functional exercises in closed chain are also incorporated in the rehabilitation program. Motion and proprioceptive training is continued throughout the rehabilitation; running and plyometric exercises are allowed only after 6 months.

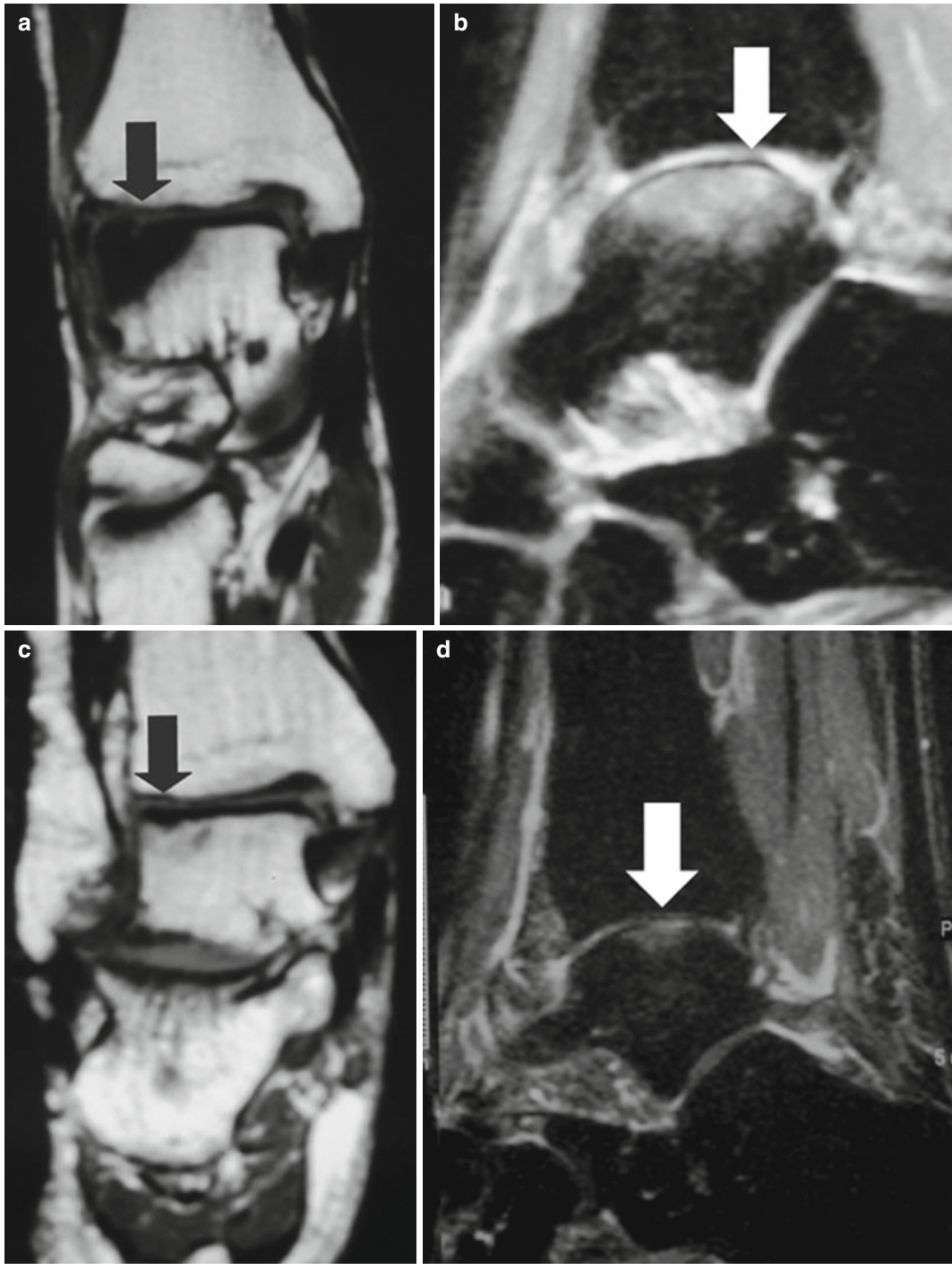

Fig. 83.3 Preoperative T1-weighted (**a**) and STIR (**b**) MRI images of a large osteochondral lesion (*arrow*) of the lateral aspect of the talus treated with BMAC and scaffold. Two-year post-operative T1-weighted (**c**) and STIR (**d**) showing reduction of the subchondral bone edema and satisfactory regeneration of the articular surface (Courtesy of Dr. Francesca Vannini (Istituto Ortopedico Rizzoli, Bologna, Italy))

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HemiCAP for Secondary Treatment for Osteochondral Talar Defects

84

Mikel L. Reilingh, Christiaan J.A. van Bergen, Rogier M. Gerards, Inge C.M. van Eekeren, and C. Niek van Dijk

84.1 Introduction

In the eighteenth century, Monro was the first to report the presence of cartilaginous bodies [18]. In 1888, König used the term osteochondritis dissecans to describe loose bodies in the knee joint and suggested that these were the result of spontaneous necrosis [16]. It was not until 1922 that the first report on osteochondritis dissecans in the ankle was published [14]. Since then, several etiologies for these lesions have been suggested. Trauma is known to be the most important etiologic factor [37], but ischemia and idiopathic osteochondral ankle lesions do occur [26]. The most common location of osteochondral defects (OCDs) is in the knee, followed by the talar dome [42]. OCDs of the talus are located in 62 % on the medial talar dome [7]. These medial defects are generally deep and cup shaped [5]. An OCD may sometimes heal and stabilize, but often progresses to a cystic lesion causing deep ankle pain on weight bearing, prolonged swelling, diminished range of motion, and synovitis [23, 37].

Arthroscopic debridement and bone marrow stimulation is considered the primary treatment and yield 85 % success [41], lasting over the years to have a 76 % satisfactory outcome at the long term [31]. In case of failure of the primary treatment, current secondary treatment options include osteochondral autograft transfer, autogenous bone graft, and autologous chondrocyte implantation [4, 9, 11, 30]. However, these techniques are sometimes associated with donor-site morbidity and involve two-stage surgery or poor graft integration [3, 19–21].

For treatment of large lesions of the medial talar dome or after failed primary treatment, a contoured articular inlay implant (HemiCAP®, Arthrosurface Inc., Franklin, MA, USA) with a fixed diameter of 15 mm has been developed [36]. Its goals are to offer relief of pain, return to activity, and prevent degeneration/further cyst formation. There are two components: a cobalt-chromium articular component and a titanium screw. Fifteen articular component offset sizes are available, based on the surface geometry of the medial talar dome. The offset sizes have been found appropriate for a variety of talar specimens in a cadaveric study [36]. Since October 2007, this implant has been used in our institution in patients with persistent complaints more than

M.L. Reilingh, MD (✉)
Department of Orthopaedic Surgery,
Orthopaedic Research Center Amsterdam,
Academic Medical Center, University of Amsterdam,
PO Box 22660, 1100 DD Amsterdam,
The Netherlands
e-mail: m.l.reilingh@amc.uva.nl

C.J.A. van Bergen, MD, PhD • R.M. Gerards, MD
I.C.M. van Eekeren, MD • C.N. van Dijk, MD, PhD
Department of Orthopaedic Surgery, Orthopaedic Research Center Amsterdam, Academic Medical Center, Amsterdam, The Netherlands

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1 year after primary surgical treatment of a large osteochondral defect of the medial talar dome (anterior-posterior or medial-lateral diameter >12 mm on CT) [35]. Contraindications of this procedure are age <18 years, OCD size >20 mm, ankle osteoarthritis grade II or III [38], concomitant ankle pathology (tibial OCD, instability, fracture less than 6 months old, tendinopathy), diabetes mellitus, advanced osteoporosis, infection, and a known allergy to the implant material. However, these indications/contraindications are not strict because the HemiCAP is still in the experimental stage.

84.2 Surgical Technique

The procedure is carried out under general or spinal anesthesia. The patient is placed in the supine position with a tourniquet applied around the upper leg and a rolled-up apron underneath the lateral malleolus to facilitate eversion of the foot and improve exposure of the talus. A curved skin incision of approximately 7 cm is made over the medial malleolus. The anterior skin is mobilized using a scalpel and forceps, and a skin retractor is placed to retract the skin. A Hohmann retractor is placed over the distal tibia. A small anterior arthrotomy exposes the anteromedial talar dome. The level of this anterior superior border of the talar dome will later in the procedure act as a guide to identify the level of the posterior ankle joint. Next, the sheath of the posterior tibial tendon is incised, and another Hohmann retractor is placed posterior to the medial malleolus and anterior to the posterior tibial tendon. The posterior capsule of the ankle joint can be visualized now and incised. The posterior intersection between the medial malleolus and tibial plafond is identified using an arthroscopic probe. The surgeon carefully inserts the 5-mm tip of the probe in the posteromedial joint space by sliding along the posterior aspect of the distal tibia at the intersection with the medial malleolus and gently pulls in an oblique craniomedial direction [33]. This maneuver identifies the posterior part of the intersection between the tibial plafond and medial malleolus. The periosteum at the level of the intended osteotomy is marked. Next, the probe is placed in the anteromedial tibial notch and pulled in an oblique craniomedial direction, identifying the anterior part of the intersection. The anterior intersection is marked, and this is connected to the posterior intersection as a reference guide to the osteotomy. Before creating the osteotomy, two screw holes are predrilled and tapped in the medial malleolus, using a cannulated drill. An oscillating saw is placed on the incised periosteum and directed at the marked intersection of the tibial plafond and medial malleolus. The osteotomy is created up to approximately 2 mm above the articular cartilage, while two Hohmann retractors protect the adjacent soft tissue. The optimal angle for the osteotomy has determined to be at a mean angle of 30° relative to the long tibial axis [34]. The osteotomy is completed with the use of an osteotome. This way, the surgeon controls the osteotomy of the articular surface and minimizes the risk of damaging the talar cartilage. After the osteotomy has been completed, the surgeon manually retracts and everts the medial malleolus using gauze. Optionally, the distal part is temporarily transfixed by drilling a large diameter K-wire into the talus through one of the predrilled holes. Exposure of the talar dome is improved by forced eversion of the heel. The fibula is hereby used as a fulcrum (take care not to use too much force), and the talus is tilted.

The necrotic fragment of the defect can now be identified and debrided (Fig. 84.1a). Utilizing a drill guide, a guide pin is placed into the center of the defect, perpendicular to the curvature of the medial talar dome. The guide pin ensures that a perpendicular direction is maintained throughout the procedure. The titanium screw of the metal implant is inserted after drilling a pilot hole (Fig. 84.1b). A contact probe is used to determine the radius of curvature in the sagittal and coronal planes to allow for a precise fit of the articular component to the existing articular surface. A matching reamer prepares the site for placement of the articular component. The reamer is a cannulated instrument used over the guide pin with a diameter of 15 mm. A sizing trial with corresponding offsets allows for final verification of

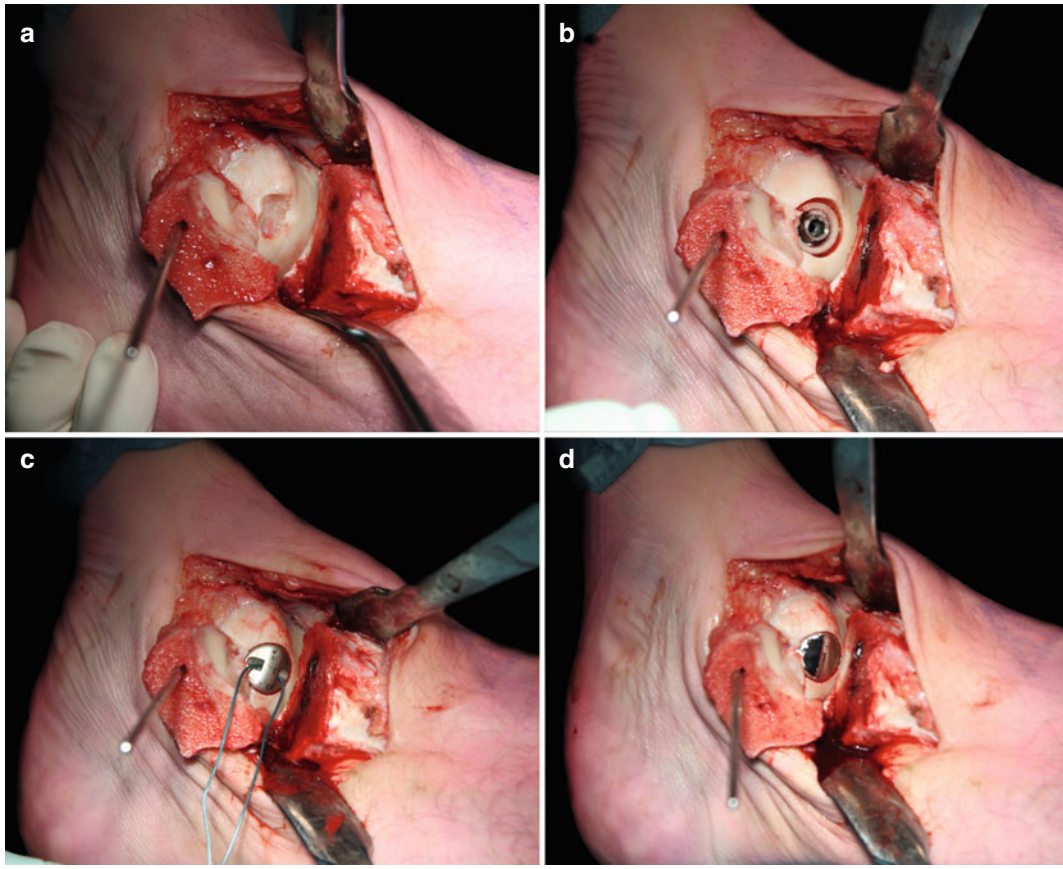

Fig. 84.1 Intraoperative photographs of a right ankle showing (**a**) the OCD debrided following a medial malleolar osteotomy, (**b**) the screw inserted in the center of the OCD, (**c**) a trial articular component in place on the screw, and (**d**) the definitive resurfacing implant engaged on the screw

proper fit (Fig. 84.1c). The selected articular component is oriented into the correct planes and is placed on the screw. It is impacted with a gentle hammer stroke on an instrument with a plastic tip, thereby engaging the taper interlock (Fig. 84.1d). After the confirmation of slightly recessed implant edges, the osteotomy is reduced. Initially, large diameter K-wires are placed through the predrilled screw holes to confirm correct alignment. A Weber bone clamp can be placed for initial compression. Placement of the proximal leg of the Weber clamp is facilitated by creating a small hole in the distal tibial cortex proximal to the osteotomy using a 2.5-mm drill. We routinely use two 3.5-mm cancellous lag screws with a length of 40 or 45 mm. The posterior tibial tendon sheath is not repaired, and the wound is closed with Ethilon 3.0 sutures using a vertical mattress (Donati) technique.

84.3 Results

We prospectively studied 20 consecutive patients with a mean age of 38 years (20–60) after failed prior surgical treatment of a large OCD of the medial talar dome [35]. The patients were assessed preoperatively and at 2 and 6 weeks, 3 and 6 months, and annually postoperatively. Various outcome measures were recorded prospectively, including numeric rating scales (NRS) of pain at rest, walking, climbing stairs, and running [25], the American Orthopaedic Foot and Ankle Society (AOFAS), ankle and hindfoot

clinical rating System [13, 15], Foot and Ankle Outcome Score (FAOS) [24], and Short-Form 36 (SF-36) [1]. Weight-bearing radiographs (antero-posterior (AP) mortise and lateral views) were obtained at all follow-up visits including and after 6 weeks post-surgery.

Statistical analyses were performed with the use of SPSS software v19.0 (SPSS Inc., Chicago, Illinois). One-way repeated-measures analyses of variance (ANOVA) were performed to determine differences in mean scores at different time points for the outcomes with a normal distribution. When a p-value <0.05 was found, post hoc pairwise comparisons were performed using a Bonferroni correction. The assumptions of normality and sphericity were checked with the use of the Shapiro-Wilk test and Mauchly's test, respectively. Skewed distributions were analyzed using the Friedman's two-way analysis of variance by ranks. Post hoc pairwise comparisons of these outcome measures were performed with the use of Wilcoxon signed-rank tests with Bonferroni correction to adjust for multiple comparisons. The SF-36 scales were compared with the normative data for the Dutch population with the use of the Student's t-test.

Currently, the mean duration of follow-up is 4.5 years (3–5). No patients were lost to follow-up.

The mean defect size was 15 mm (11–20) in the AP direction, 10 mm (8–14) in the mediolateral direction, and 9 mm (4–16) in depth. Radiologically, one defect was classified according to the modified Berndt and Harty classification as stage III (complete avulsion of a fragment), one as stage IV (displaced fragment), and 18 as stage V (cystic lesion) [27]. Sixteen defects were located on the centromedial talar dome and four on the posteromedial talar dome.

The NRS pain improved significantly during walking, climbing stairs, and running (Table 84.1 and Fig. 84.2). Repeated-measures ANOVA determined that the mean NRS walking differed significantly between time points ($F_{(4, 76)} = 13.5$, $p<0.01$). Post hoc pairwise comparisons using Bonferroni correction revealed that the NRS walking was significantly decreased at all post-operative time points compared with the preoperative situation ($p<0.001$ to $p=0.05$).

The median AOFAS improved from 62 (IQR, 46–72) preoperatively to 75 (IQR, 68–87) at 6 months, 87 (IQR, 76–94) at 1 year, and 85 (IQR, 75–99) at final follow-up ($p<0.001$; Friedman's two-way analysis of variance by ranks). Post hoc tests revealed significant differences at 1 year ($p<0.001$) and at the final follow-up ($p=0.001$) compared with preoperatively.

The FAOS improved significantly on subscale pain, function, sports, and quality of life (Fig. 84.3). Post hoc pairwise Bonferroni-adjusted comparisons revealed statistically significant differences between preoperative scores and most postoperative scores (Table 84.2).

Table 84.1 Numeric rating scale (NRS) for pain (IQR, interquartile range)

	Mean (range)						Median (IQR)	
Time point	NRS rest	p-value[b]	NRS walking	p-value[b]	NRS stair climbing	p-value[b]	NRS running	p-value[d]
Preoperative	3.6 (0–8)		6.7 (4–9)		6.6 (4–10)		10.0 (9–10)	
3 months	2.4 (0–8)	1.0	4.4 (1–8)	0.05	4.6 (0–8)	0.24	7.0 (5–10)	0.10
6 months	1.7 (0–6)	0.09	3.3 (0–9)	0.001	2.8 (0–7)	0.001	6.0 (3–10)	0.04
1 year	1.3 (0–7)	0.01	2.3 (0–7)	<0.001	2.2 (0–6)	<0.001	3.0 (0–10)	0.005
Final	2.1 (0–8)	0.50	2.8 (0–9)	<0.001	3.0 (0–8)	0.001	6.0 (0–10)	0.004
p-value	$F_{(4, 76)}=3.6$; $p=0.01$[a]		$F_{(4, 76)}=13.5$; $p<0.01$[a]		$F_{(4, 72)}=13.0$; $p<0.01$[a]		$p=0.08$[c]	

[a]Repeated-measures analysis of variance
[b]Bonferroni-adjusted p-value of pairwise comparison with the preoperative NRS
[c]Friedman's two-way analysis of variance by ranks
[d]Wilcoxon signed-rank test

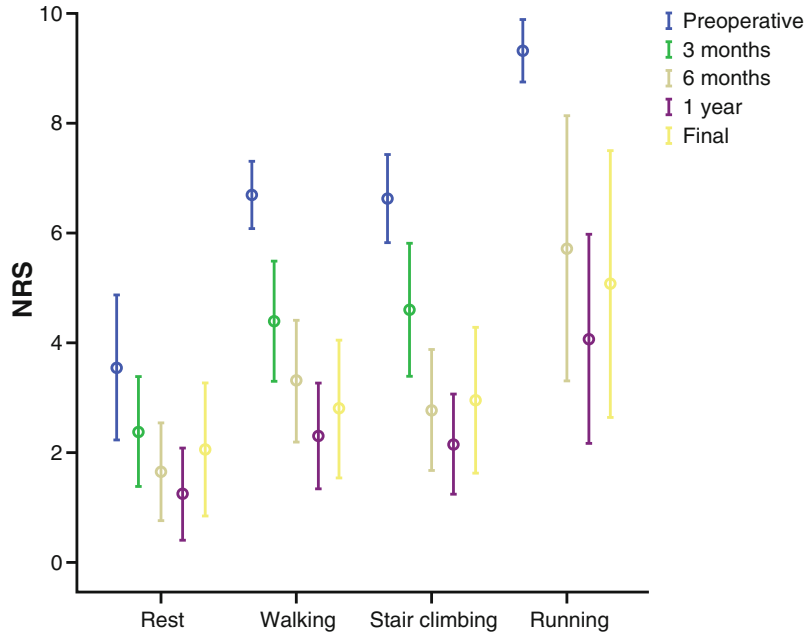

Fig. 84.2 Graph showing the mean numeric rating scale (NRS) for pain in rest, walking, stair climbing, and running situations across the follow-up. *p*-values for comparisons across time points are given in Table 84.1. The *error bars* denote the 95 % confidence intervals

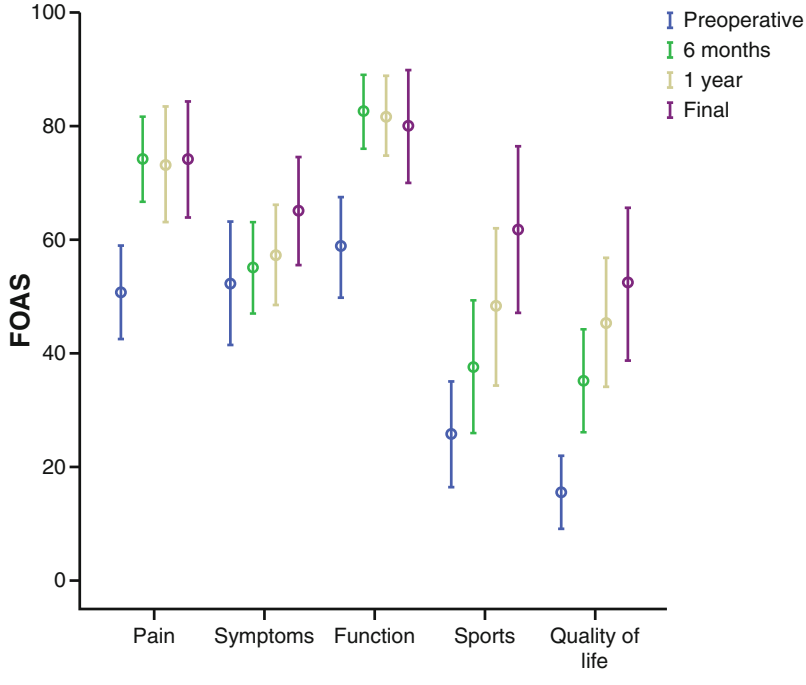

Fig. 84.3 Graph showing the mean Foot and Ankle Outcome Score (FAOS) by subscore across the follow-up. *p*-values for comparisons across time points are given in Table 84.2. The *error bars* denote the 95 % confidence intervals

The mean SF-36 physical component improved from 36.2 (22.8–50.3) preoperatively to 42.2 (21.0–52.3) at 6 months ($p = 0.05$), 44.0 (28.5–57.4) at 1 year ($p = 0.01$), and 45.1 (28.7–54.9) at final follow-up ($p = 0.004$) ($F_{(3, 51)} = 6.4$, $p = 0.001$; one-way repeated-measures ANOVA). The SF-36 mental component did not change significantly; the mean score was 53.0

Table 84.2 Foot and ankle outcome score (FAOS) (*ADL* activities of daily living)

	Mean FAOS subscore (range)									
Time point	Pain	*p*-value[b]	Symptoms	*p*-value[b]	Function (ADL)	*p*-value[b]	Sport	*p*-value[b]	Quality of life	*p*-value[b]
Preoperative	50.5 (14–78)		52.0 (11–96)		58.6 (15–85)		25.4 (0–70)		15.2 (0–44)	
6 months	74.1 (56–100)	0.001	54.9 (21–89)	1.0	82.5 (43–100)	0.001	37.2 (0–75)	0.20	34.8 (0–63)	0.001
1 year	73.1 (39–100)	<0.001	57.1 (25–91)	1.0	81.5 (54–100)	<0.001	48.0 (10–100)	0.002	45.1 (13–88)	<0.001
Final	74.0 (31–100)	<0.001	66.9 (29–100)	0.16	79.9 (25–100)	0.01	61.5 (5–100)	<0.001	52.1 (0–100)	<0.001
p-value	$F_{(3, 54)} = 10.1$; $p < 0.01$[a]		$F_{(3, 54)} = 2.3$; $p = 0.09$[a]		$F_{(3, 54)} = 11.2$; $p < 0.01$[a]		$F_{(3, 54)} = 9.5$; $p < 0.01$[a]		$F_{(3, 54)} = 18.6$; $p < 0.01$[a]	

[a]Repeated-measures analysis of variance

[b]Bonferroni-adjusted *p*-value of pairwise comparison with preoperative score

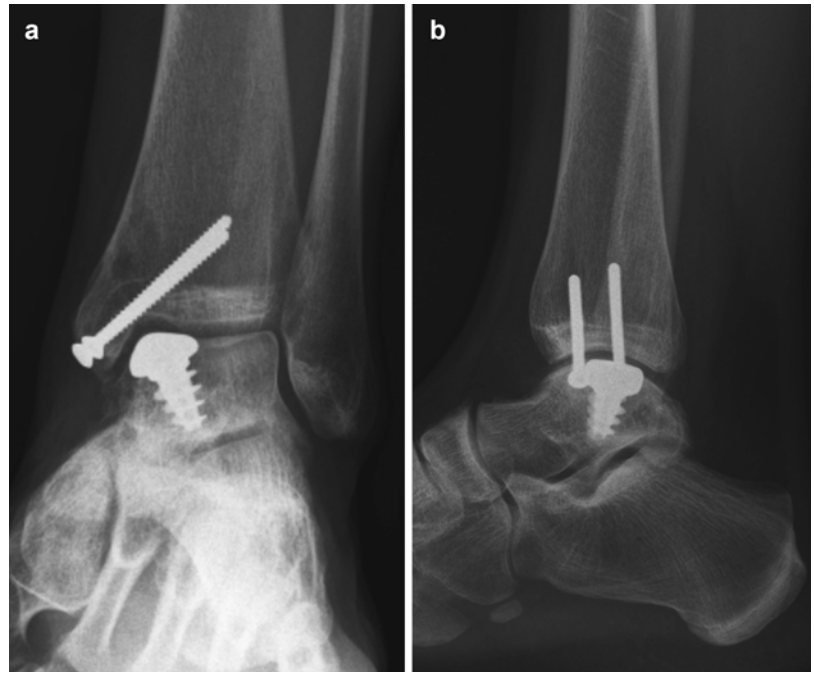

Fig. 84.4 Mortise (**a**) view and lateral (**b**) weight-bearing radiographs of a left ankle 5 years postoperatively showing correct positioning of the implant

(21.9–67.9) preoperatively, 50.6 (34.7–62.1) at 6 months, 52.8 (39.8–60.3) at 1 year, and 54.1 (24.7–66.5) at final follow-up ($F_{(3,\ 51)}$ = 2.5, $p = 0.07$). Neither the final physical nor the mental component differed significantly from the population norm [8].

There were four minor complications that resolved within the study period. Three patients reported an area of numbness about the scar, which resolved within the postoperative year. Another patient had a superficial wound infection, which was effectively treated by oral antibiotics. The medial malleolar osteotomy healed in all cases, and no signs of prosthetic loosening were seen on radiographs (Fig. 84.4). In two patients joint space narrowing was seen during follow-up. Eleven reoperations were performed in eight patients. Hardware removal was performed in seven patients and arthroscopic removal of anterior impingement in three patients, and one patient had a lateralizing calcaneus osteotomy to unload the medial facet of the ankle because of persisted deep ankle pain.

84.4 Postoperative Management and Rehabilitation

The postoperative management consists of a plaster cast for 1 week. A functional non-weight-bearing brace (Walker) or a detachable plaster cast can be applied for another 5 weeks. During this period, non-weight-bearing sagittal range-of-motion exercises are allowed, i.e., 15 min twice daily. After these, 6 weeks radiographs of the operated ankle are obtained to confirm consolidation of the malleolar osteotomy. Subsequently, physical therapy is prescribed to assist in functional recovery and facilitate the return to full weight bearing over approximately 1 month. Return to normal weight bearing and walking should thus be accomplished 10 weeks after surgery. Impact activities, such as running, are allowed when no signs of prosthetic loosening and migration are seen after 6 months of follow-up. Non-contact sports are allowed after 9 months of follow-up and contact sports 1 year after surgery. However, the risk of periprosthetic

fracture during contact sports should be discussed with the patient. We reported the first clinical case report of the talus implant in which the patient was able to play korfball (contact sports) at the preinjury level after 1 year and continued to play at this level at 4 years follow-up [32].

84.5 Discussion

Treatment of osteochondral lesions or osteonecrosis by means of metal resurfacing implants is relatively new [6, 12, 28, 39]. Two biomechanical cadaveric studies provided foundations for the use of a metal resurfacing implant in the talus [2, 36]. The results of our prospective case series show that patients with talar OCDs generally benefit from the procedure. Almost all outcomes demonstrated statistically significant improvements. Satisfaction was high, with 18 patients indicating that they would undergo the procedure again.

We believe that the effectiveness of the resurfacing implant is simply based on the mechanism of filling and coverage of the defect. Increased fluid pressure from the joint into the subchondral bone has been described as the cause of pain and subchondral cyst formation [22, 37]. Filling and resurfacing the defect will possibly stop this process.

Alternative current treatment methods for large or secondary lesions are osteochondral autograft transfer system (OATS), cancellous bone grafting, osteochondral allograft transplantation, ankle arthrodesis, or ankle arthroplasty. Although excellent results of OATS have been published [27], the risk of donor-site morbidity in the knee is worrisome [29]. An additional disadvantage of osteochondral autografts is difficulty in matching the talar surface geometry and poor graft integration [19]. Limited availability and donor-site pain are also disadvantages of cancellous bone grafting [3]. Osteochondral allografts can be used for massive defects but are not recommended for localized OCDs because of the loss of viability and stability in approximately one-third of the grafts [10]. Ankle arthrodesis or prosthesis is a definite solution for a recurrent OCD but is not preferable in young patients.

The surgical approach is an important part of the implantation technique because the accuracy of implantation of this device strongly depends on the approach and quality of exposure. If the osteotomy is created too medially, i.e., in the articular facet of the malleolus, exposure of the talar dome may be insufficient for adequate treatment. Furthermore, a small distal fragment may be prone to fracture when fixed at the end of the procedure. Conversely, if the osteotomy is created too laterally, it will exit in the tibial plafond. This is undesirable because the medial tibial plafond directly articulates with the medial talar dome [17, 36], and damage to this weight-bearing area might lead to secondary osteoarthritis [8]. We therefore routinely use a probe to determine the intersection of the tibial plafond and the articular facet of the medial malleolus when performing the osteotomy [33].

The surface of the prosthetic device should be placed slightly recessed relative to the surrounding surface of the talar cartilage because talar cartilage deforms during weight bearing while the implant does not. Wan et al. measured a peak cartilage deformation of $34.5 \pm 7.3\,\%$ under full body weight in persons with a medial talar dome cartilage thickness of 1.42 ± 0.31 mm [40]. We therefore aim at an implantation level of 0.5 mm below the adjacent cartilage. This implantation level was found appropriate in a previous cadaveric study [36]. When the prosthetic device is correctly implanted, excessive contact pressures of the implant on the tibial plafond are avoided [36].

In conclusion, this technique is a promising treatment for OCDs of the medial talar dome after failed previous treatment. Although the results of this study are encouraging, more patients, longer follow-up, and preferably a control group may determine the place of this implant in the treatment of these defects.

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85 Retrograde Drilling for the Treatment of Osteochondral Lesions in the Ankle

Adam Lomax and James Calder

85.1 Introduction

The primary aim when treating osteochondral lesions (OCL) in the ankle is to promote healing through revascularization [3]. In most cases, this involves debridement of the damaged chondral surface and removal of any underlying soft, necrotic bone. Bone marrow stimulation through microfracture or drilling can then be performed to encourage the ingress of multipotent stem cells and growth factors into the lesion. The desired end result is healing of the defect through bony ingrowth with an overlying fibrocartilaginous articulating surface.

Less commonly, however, the lesion is limited to involving only the subchondral bone, with the overlying cartilage remaining intact. Debriding this intact hyaline cartilage layer in order to access the bony component of the lesion, with the subsequent healing potential to form only a fibrocartilage replacement layer, does not seem intuitive. In 1981, Lee and Mercurio proposed that these lesions might be best managed by treating the bone pathology whilst preserving the overlying intact cartilage [17]. Using a technique also later described by Guhl and Stone, and subsequently popularized by Conti and Taranow, a method of drilling the bone in a retrograde fashion was proposed [5, 9]. By retrograde drilling (RD), access can be gained to the subchondral bone without the need to disturb the overlying cartilage, as is mandatory when using an anterograde approach. Any remaining necrotic bone can be removed by curettage through the drill tract, with the residual defect filled with bone graft when necessary, using the same approach. The sclerotic zone of the lesion at its periphery is perforated to encourage revascularization, and the bony defect then heals with its overlying hyaline cartilage surface left undamaged. By this means, a more normal articulating surface within the ankle joint may be preserved.

85.2 Indications

The concept behind RD for the management of OCL of the talar dome is based on the following assumptions, as proposed by Conti and Taranow [5]:

1. Most are caused by trauma and follow a pattern of bone injury followed by an increased local intra-osseous pressure with subsequent bone necrosis and attempts at repair.
2. The bone lesion identified on magnetic resonance imaging histologically is a combination of necrotic bone and fibrous tissue.
3. The discomfort is caused by the bone lesion, which does not support the overlying subchondral bone.

A. Lomax, MBBS, FRCS (Tr & Orth) (✉)
J. Calder, MD, FRCS (Tr & Orth), FFSEM (UK)
Department of Orthopaedics, The Fortius Clinic, London, UK
e-mail: 1adamlomax@gmail.com

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4. Soft hyaline cartilage is better than fibrocartilage or eburnated bone.
5. Arthroscopic treatment has a better result than open treatment.

This technique is only suitable for those lesions in which the osteochondral fragment remains undetached [17]. It is the treatment of choice when there is a large subchondral cyst with overlying intact healthy cartilage, where it is theoretically advantageous that this hyaline cartilage is preserved [5, 26]. Confirmation that the cartilage remains intact should be achieved by arthroscopic assessment. Any damage visualized on the surface must be limited to softening with only minor fibrillation. There must not be any areas of cartilage fissuring if this technique is to be performed [1, 26]. With cystic lesions, it is critical that the structural integrity of the lesion is addressed with bone graft or synthetic bone substitute after debridement, to prevent subsequent subchondral collapse [14, 18].

85.3 Operative Technique

Initial ankle arthroscopy is performed to ensure that the lesion remains suitable for RD, as previously described. Once the lesion is located, its centre is estimated using a combination of arthroscopic examination and intraoperative fluoroscopy, with the prior knowledge gained from preoperative imaging. A guide wire is then placed in a retrograde fashion, terminating with its tip in the centre of the damaged bone, resting up against the subchondral bone but not perforating the overlying articular cartilage. Traditionally, the wire is guided into this position by the surgeon using intraoperative fluoroscopy. To improve ease and accuracy of wire placement, many surgeons will also use an aiming device (Fig. 85.1). The tip of the aiming device is placed arthroscopically onto the area of softened cartilage overlying the lesion (Fig. 85.2), and the aiming device is positioned in preparation for the passage of a guide wire. The wire entry point must be carefully selected to ensure that it is placed away from any articular cartilage (Fig. 85.3). Passage of a guide wire into the centre of the lesion can then be carried out (Fig. 85.4) and this can be checked on intraoperative x-ray (Figs. 85.5 and 85.6). With the wire now positioned in a satisfactory location within the lesion, a drill can be passed over the wire (Fig. 85.7), ensuring that it remains within the subchondral bone (Fig. 85.8) and does not penetrate through the articular cartilage as the drill is advanced. Once the cyst has been decompressed, if required, it is possible at this stage to introduce an arthroscopic burr into the tract formed by the drill to perform an additional debridement of debris from within the osseous cavity (Fig. 85.9).

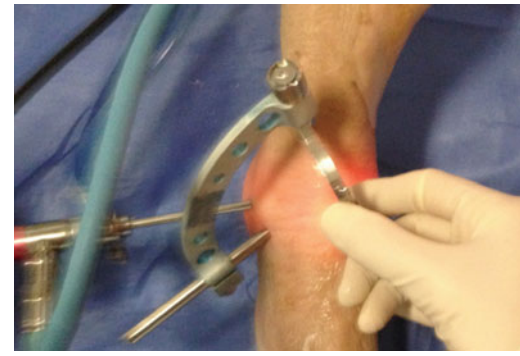

Fig. 85.1 Clinical photograph of an anterior ankle arthroscopy performed for retrograde drilling of a medial-sided osteochondral lesion of the talus. The aiming device is introduced through the medial portal and viewed with the arthroscope introduced from the lateral side

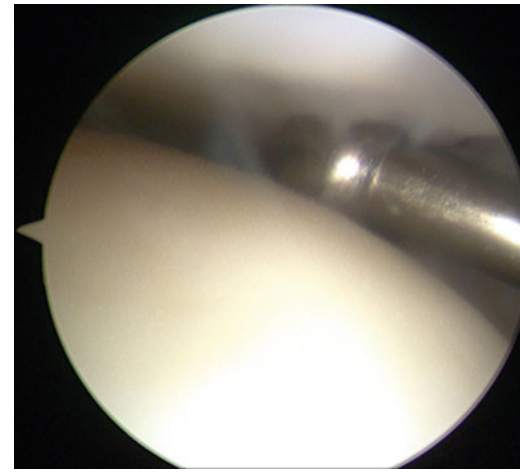

Fig. 85.2 Arthroscopic view of the ankle showing the tip of the aiming device placed on the overlying cartilage of an osteochondral lesion of the medial dome of the talus

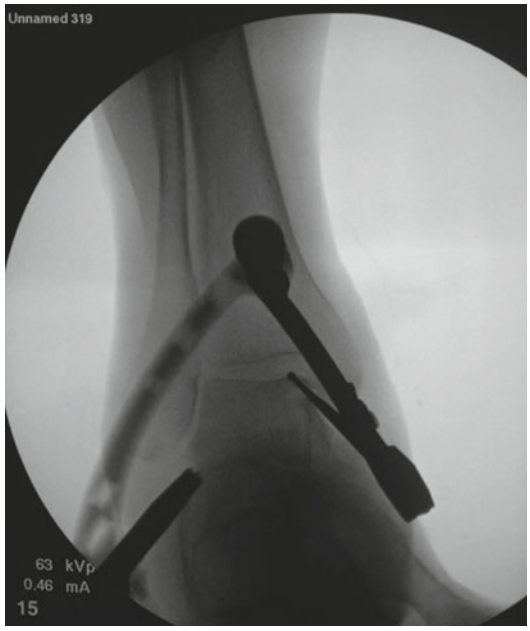

Fig. 85.3 Intraoperative anteroposterior ankle x-ray showing correct placement of the aiming device

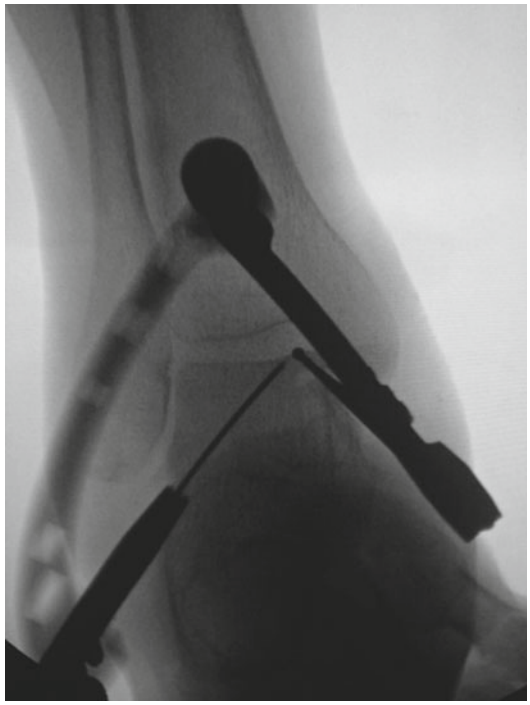

Fig. 85.4 Intraoperative anteroposterior ankle x-ray showing passage of the guide wire through the aiming device. The guide wire is positioned accurately within the osteochondral lesion, abutting against but not perforating through the subchondral bone

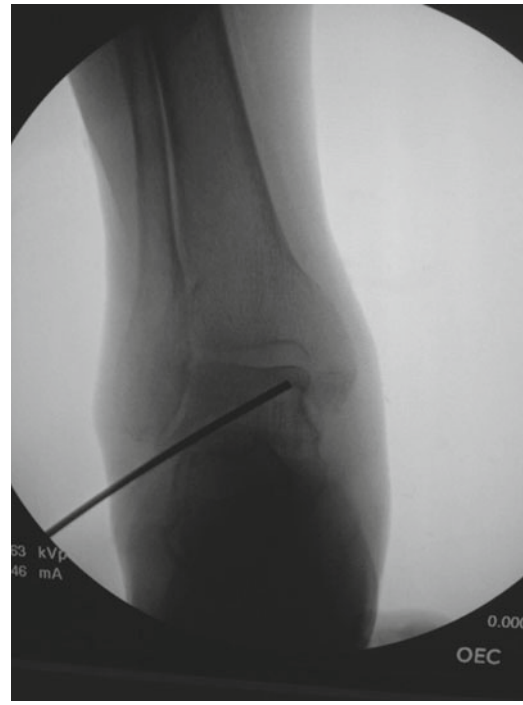

Fig. 85.5 Intraoperative anteroposterior ankle x-ray showing the final position of the guide wire

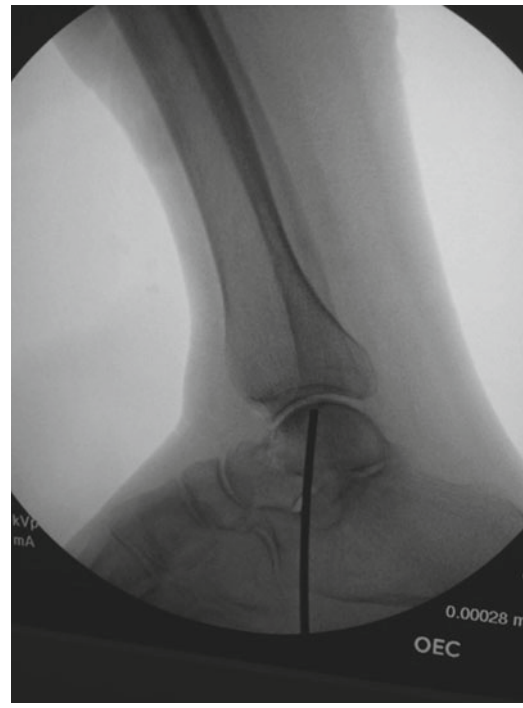

Fig. 85.6 Intraoperative lateral ankle x-ray showing the final position of the guide wire

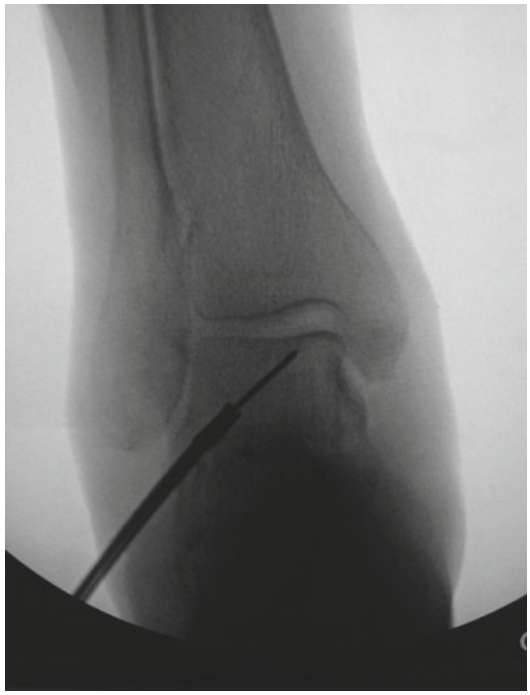

Fig. 85.7 Intraoperative anteroposterior ankle x-ray showing the cannulated drill being carefully advanced over the guide wire. Intraoperative x-ray is performed at this stage to ensure that the guide wire or drill does not perforate through the subchondral bone and into the articular cartilage

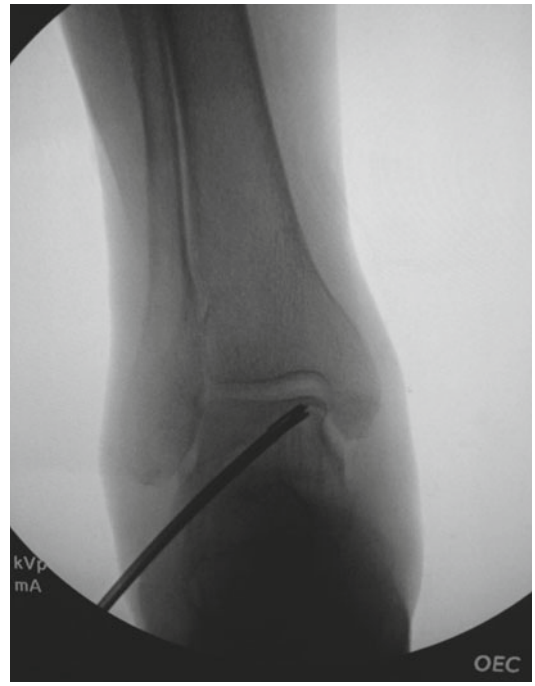

Fig. 85.8 Intraoperative anteroposterior ankle x-ray showing the final position of the drill up against the subchondral bone

More recently, a number of computer-assisted techniques have been described to allow for computer-navigated guide wire placement into the centre of the OCL. The use of this technology is discussed later within this chapter.

Lesions that are located in the medial side of the articulating dome of the talus can be approached through an entry point made in the sinus tarsi. Lateral-sided lesions may be approached through the antero-medial side of the talus [26]. A posterolateral approach has also been described to access both medial- and lateral-based lesions [16]. Articulating cartilage at the entry point on the talus is always avoided by careful wire placement.

Once the wire has been directed into the desired location and this is confirmed on intraoperative imaging, an appropriately sized cannulated drill is passed over the wire and into the lesion. Care is taken not to advance either the guide wire or the drill beyond the subchondral

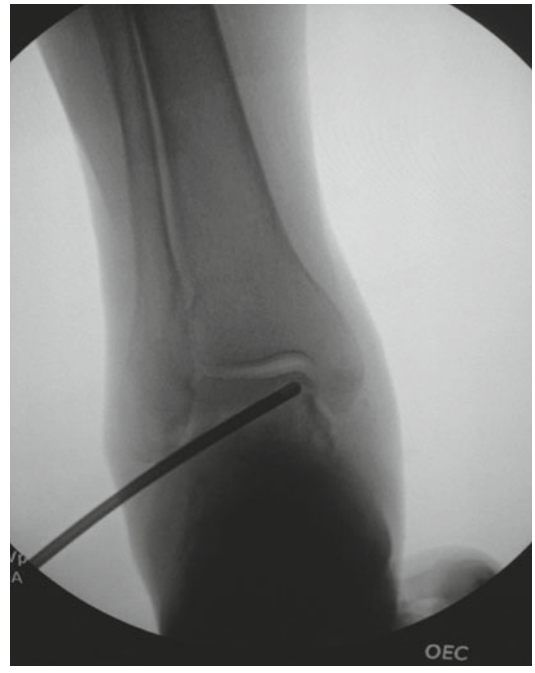

Fig. 85.9 Intraoperative anteroposterior ankle x-ray showing the use of an arthroscopic burr, introduced into the drill tract to further debride the debris from within the osseous cavity of the osteochondral lesion

bone of the talar dome so as not to penetrate the overlying cartilage. Intraoperative fluoroscopy in combination with direct arthroscopic visualization is used as the drill is carefully passed.

Once a drill hole has been created, a small-angled curette may be passed along the tract to allow for the careful removal of any additional debris that may remain in the lesion after drilling. If required, the lesion may subsequently be packed with graft deposited along the drill tract up to the subchondral region, using autologous bone or synthetic bone graft substitute.

Post-operatively, early active ankle motion is recommended, but weight bearing is prevented up to approximately 6 weeks, to ensure structural stability is regained in the lesion prior to loading [5, 9].

85.4 Clinical Evidence for Retrograde Drilling

In the single case presented by Lee and Mercurio in 1981, the lesion in the talus showed evidence of healing on x-ray taken at 6-month follow-up [17]. This is perhaps the first description of RD for an osteochondral lesion in the ankle.

Conti and Taranow in 1996 described the technical details of a similar procedure that they had performed [5]. Presenting no clinical results on this occasion, they subsequently presented their outcomes in a case series of 16 patients [24]. They carried out RD and autologous bone grafting through a sinus tarsi approach for medial-sided OCL of the talus with intact overlying cartilage. After surgery, active ankle range of motion exercises was commenced and a strict non-weight-bearing regime was followed until 6 weeks post-surgery. At a mean of 15 months after RD, there was evidence of healed lesions on MRI scan in 88 % of cases. AOFAS scores improved from a mean of 53.9–83.6 at mean follow-up of 24 months (range, 19–38 months). They conclude that the short-term clinical results of this technique compare favourably with those of anterograde drilling, and there are high rates of radiological bone healing.

In a subsequent cohort, Rosenberger presented the results of 15 cases treated with RD without additional bone grafting [22]. Patients were allowed to partial weight bearing during the initial week after surgery and then fully weight bearing after this. On follow-up MRI scans at 1-year post-surgery, there was an improvement in Berndt and Harty staging in 46.7 % of cases, with worsening occurring in 13.3 %. When questioned about pain, 26.7 % had no pain, 66.7 % had mild pain and 6.6 % had moderate pain at 1-year post-surgery. AOFAS scores averaged 88.9 post-operatively, although no preoperative scores were obtained for comparison.

In a larger cohort of 48 cases, Anders et al. performed RD in 7–14 mm-sized lesions with subsequent autologous bone grafting [1]. Patients were left free of immobilization post-operatively and allowed a full range of motion, but they were kept partial weight bearing for a period of 6 weeks. At a mean follow-up of 29 months (range, 12–54 months), there was a significant improvement in the AOFAS scores. It was noted however that the results were poorer in those cases where there were fissures in the overlying cartilage of the OCL. Consequently, the authors recommend this technique for stable midsize OCL of the talus with an intact cartilage surface, carried out after failure of all conservative treatments.

Kono et al. performed the only comparative study of RD for the management of OCL with intact overlying cartilage [16]. They compared RD with trans-malleolar drilling (TMD) in a case control study of 30 patients (11 RD, 19 TMD). Post-surgery, patients were allowed a full range of ankle movement and were kept partially weight bearing for 4 weeks. At 1-year post-surgery, the MRI along with the ankle arthroscopy was repeated and the lesion was regraded. The RD group achieved greater improvement in their articular cartilage condition, according to the modified Pritsch classification, than did the TMD group [19]. In the TMD group, 11 lesions (58 %) were unchanged and eight lesions (42 %) had deteriorated. In the RD group, three lesions (27 %) had improved and eight lesions (73 %) remained the same. All patients in the TMD

group showed signs of cartilage deterioration in the tibial side cartilage after TMD compared to none in the RD group. In both groups the AOFAS scores at 2 years improved significantly but without any difference between groups. Both groups showed improvement in bony healing classified on MRI appearance, but there was no significant difference between groups. The authors conclude that compared with TMD, RD can improve the arthroscopic assessment of the articular cartilage condition in these lesions at short-term follow-up. This may have an impact on the longer-term outcome after this procedure but this is currently unknown.

The use of bone graft into the cystic component of the lesion is recommended to prevent subsequent collapse after RD and curettage [18]. In cases where the insertion of autologous bone graft into the drill hole is difficult or when parts of the cavity are not in direct alignment with the drill hole (such as when the subchondral cyst is saucer shaped), Kennedy et al. recommend the use of an injectable bone graft substitute [14]. A calcium sulphate paste is injected into the lesion through the drill hole and is used to fill the residual cavity. This has the additional advantage of providing rapid stability to the overlying cartilage to resist compressive load once the injectable material has hardened (approximately 5 min). The bone substitute is then reabsorbed and replaced by host bone over a period of 8 weeks. Hyer et al. presented a small case series of nine cases using RD and subsequent void filling with an injectable demineralized bone matrix gel, for cystic subchondral lesions with intact overlying cartilage [13]. In these cases, AOFAS scores improved by a mean of 34 points at mean 24 month follow-up (range, 8–44 months). Not all cases had a post-operative MRI scan, but in those who did, there was evidence of cystic repair with maintenance of the overlying cartilage.

Yasui et al. reported their experience of RD performed in combination with lateral ligament reconstruction of the ankle [25]. The talus lesions were limited to those with only subchondral marrow oedema without evidence of cyst formation. After surgery, patients were mobilized in a soft ankle orthotic for 6 weeks. Partial weight bearing was enforced for 4 weeks. The size of the lesion on MRI scanning performed at 1-year post-surgery improved significantly in all cases. There was a significant improvement in the AOFAS scores at mean follow-up of 29 months (range, 24–46 months). The authors conclude that RD in conjunction with lateral ligament reconstruction is a promising procedure for patients with non-cystic OCL of the talus with intact overlying cartilage, when present in conjunction with chronic lateral ankle instability.

85.5 Retrograde Drilling Using Computer-Assisted Surgery

Placement of the initial guide wire to within the centre of the bony lesion is of paramount importance for the accuracy of RD of the lesion and the subsequent success of this technique. The use of intraoperative fluoroscopy for anteroposterior and lateral x-rays is the most common method of achieving this. This is often used in conjunction with targeted aiming devices placed arthroscopically to guide the wire tip to the lesion, using the overlying softened articular cartilage as an indicator for the location of the damaged bone. However, there are potential drawbacks with these techniques. Intraoperative fluoroscopy provides only two-dimensional imaging, and therefore multiple images taken by rotating the C-arm in 90 ° planes are required to confirm pin placement. This is often accompanied by multiple attempts at pin repositioning, resulting in radiation exposure to both the patient and to the theatre staff.

Targeting devices themselves also have potential drawbacks. When the overlying cartilage is intact, it may be difficult arthroscopically to locate the true centre of the lesion by cartilage probing alone. This can be even more challenging when the bony lesion itself is not easily apparent on intraoperative fluoroscopy, for example, when there is no sizeable cystic component. In addition, the distance between the entry point into the bone and the targeting device tip is sufficiently large for small deviations in wire trajectory, caused, for example, by sclerotic bone, to

result in malpositioning of the wire tip. Computer-assisted surgery (CAS) has more recently been trialled by some authors in an attempt to improve the accuracy of the guide wire and drill placement.

In 2001, Bale et al. developed a CAS device that they trialled for accuracy on ten cadavers and subsequently used for RD in four patients [2]. Using preoperative computer tomography (CT) scanning, data specific to the three-dimensional location of the OCL was transferred to computer navigation software. A patient-targeting device, fixed to a premoulded cast taken from the ankle, was then used with a preprogrammed drill trajectory to angle a guide wire into the lesion. The accuracy of wire placement was then assessed by subsequent anatomic dissection in the cadavers and intraoperative fluoroscopy combined with post-operative CT in the four patients. The accuracy of wire placement from the defined centre of the OCL showed a mean distance of 2.05 mm. This ranged from 1.0 to 3.5 mm in the cadavers and from 2.5 to 3.5 mm in the patients. In a study of the same technique performed on 39 patients, Rosenberger et al. showed that the drill accurately penetrated the OCL in 100 % of cases as proven by post-operative MRI [22]. They had technical difficulties resulting in abandonment of the navigated technique in two cases.

Intraoperative three-dimensional imaging modalities have also been employed by a number of authors [4, 6, 20, 21]. This technique involves the use of a motorized fluoroscopic C-arm capable of producing three-dimensional intraoperative images, coupled to a computer-assisted navigated drilling system. In two initial patient case reports, the lesion was successfully targeted when performing RD using this technique [20, 21]. In a comparative cadaveric trial performed by Citak et al., three-dimensional fluoroscopic imaging with navigation improved the accuracy of guide wire placement to within the lesion when compared to traditional two-dimensional fluoroscopy (7/7 vs. 5/7 successful wire placement) [4]. The radiation dose was noted, however, to be significantly higher in the three-dimensional imaging group. Geerling et al. published a case series of 19 patients treated with navigated three-dimensional image-based RD [6]. They had 100 % accuracy of guide wire and drill placement, determined on intraoperative three-dimensional imaging. There were no cases of penetration of articular cartilage as judged by intraoperative arthroscopy. Clinical outcomes at mean follow-up of 25 months (20–34) showed a significant improvement in both ankle-hindfoot and visual analogue scores. The post-operative MRI showed improvement in the grade of the lesion, measured by the Hepple score, in 80 % of patients [10].

O'Loughlin et al. trialled a navigation system using arthroscopic assistance and two-dimensional fluoroscopic imaging in a single patient case report [18]. The site of the lesion was identified arthroscopically and marked with a spinal needle. Intraoperative two-dimensional fluoroscopic images were then taken in three planes (anteroposterior, lateral and oblique x-rays) and transferred to computer navigation software. Using a pin placed in the talar neck that was attached to reflective marker balls for referencing, the guide wire trajectory was determined and pin placement was navigated to the pre-marked lesion. Post-operative MRI scan confirmed that the lesion was accurately targeted.

Gras et al. presented a similar technique for navigation using reflective marker ball technology, but in their technique, no intraoperative fluoroscopy is required [7]. The softened cartilage overlying the lesion is located using arthroscopy. The tip of a navigation pointer, equipped with reflective markers, is then placed at the centre of this cartilage, and the computer software stores the tip's location. A drill equipped with navigation, again using reflective marker balls, is used to insert the wire on a trajectory that is aimed at the stored location for the tip of the probe. They performed 29 drillings in lesions within the talus and the femoral condyles, with an accuracy of 93 %. Gras et al. have also performed a comparative study of this technique versus traditional two-dimensional intraoperative fluoroscopy on 16 sawbones [8]. They found that there was no statistically significant difference in the accuracy of the drill position between the groups. The accuracy of the two-dimensional

fluoroscopic technique has mean of 1.14 +/– 0.15 mm compared with 1.07 +/– 0.11 mm in the navigated group. There was, however, a significant reduction in the operative time within the navigation group, and there was also no requirement for intraoperative radiation in that group.

Hoffmann et al. utilized a similar fluoroscopy-free navigation system based around an electromagnetic drill-targeting device, aimed at a probe placed arthroscopically at the level of the lesion [11, 12]. In a laboratory-based cadaveric study of 32 retrograde drillings, they found that when using their navigation-based drilling system compared to traditional two-dimensional fluoroscopic-guided drilling, the success rate for targeting the lesion was improved (16/16 vs. 12/16). There was also a significant improvement in the accuracy of drill placement measured from the centre of the lesion in the navigated group (mean, 0.88 mm vs. 2.5 mm). Operative time was reduced in the navigated group (308 vs. 660 s), and there was a significant reduction in the need for drill readjustment. There was no difference between the proximity of the drill tip to the cartilage surface between groups.

Seebauer presented a technique of MRI-guided RD that they performed on 16 cadavers [23]. Drilling accuracy was 1.38 mm +/– 0.9 in the coronal plane and 2.67 mm +/– 1.8 in the sagittal plane. However, partial cartilage perforation occurred in four cases, although this did not perforate through the entire cartilage thickness and into the ankle joint itself. Kerimaa et al. have also used an MRI-assisted RD in a small case series of four patients [15]. The lesion was successfully targeted in all cases and without any incidence of overlying cartilage penetration.

85.6 Complications

Rates of drill accuracy for successfully entering the OCL of between 71% and 100% have been reported, suggesting a potential failure rate of up to 29% when attempting to target an OCL using RD [4, 7, 11, 22]. Wire penetration through the overlying cartilage and into the joint has been reported in a single case along with four cases of partial thickness penetration during drilling [7, 23].

Although some authors report no complications with this technique [6, 13, 16, 18, 24, 25], others have reported evidence of "cortical damage" to the talar neck during drilling (one case) [22], osteomyelitis of the talus (one case) [22], delayed wound healing (one case) [1] and hyperesthesia in the forefoot (two cases) [1].

85.7 Summary

OCL in which the overlying cartilage remains intact can be successfully treated using RD, with good clinical outcomes and rates of healing on post-operative imaging. Arthroscopic assessment of the ankle joint must be performed prior to the procedure to ensure that the overlying cartilage is intact and is not damaged or fissured. Accurate placement of the guide wire and drill must be ensured and a variety of techniques have been described for this purpose. CAS is a promising new development with the potential for improvements in drilling accuracy, surgical efficiency and a reduction in radiation exposure. Drilling of the lesion to perforate through the sclerotic zone is followed by curettage of any residual necrotic and fibrous material from the lesion. Care should be taken to avoid perforation of the intact overlying cartilage, both when placing the guide wire and when drilling the lesion. Supplementation with autologous bone graft or injectable bone graft substitute should be performed for subchondral stability when a cystic defect remains.

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Osteoarthritis of the Ankle

86

Milan Handl

86.1 Introduction

Osteoarthritis of the ankle involves the tibia, the fibula, and the talus. This degenerative process involves at least two of these bones. Osteoarthritis can appear as primary disease or secondary due to posttraumatic changes, rheumatoid inflammations, tumors, and other general reasons. The term "arthritis" means "joint inflammation," so the word "osteoarthrosis" is more correct to describe the pathology. Osteoarthrosis (OA) is a common problem for many people of the middle and higher age. But it may also occur in younger persons mostly as a sequela of an ankle fracture or an ankle sprain [27, 28, 33].

Dislocations and intra-articular fractures that damage the joint surface can lead to posttraumatic OA. Other reasons for developing OA in the ankle are inflammatory diseases like rheumatoid arthritis. Septic inflammation can destroy the cartilage in the joint very rapidly (Fig. 86.1a, b). Although osteochondritis dissecans belongs to the relatively frequent diagnosis, it is a rare cause for osteoarthritis [2, 9, 11, 14, 34].

M. Handl, MD, PhD
Dubai Bone and Joint Center, Al Jalila Foundation, Mohammed Bin Rashid Al Maktoum Academic Medical Center, Dubai Healthcare City,
Al Razi Building No. 64, DHCC, P.O.Box 118855, Dubai, United Arab Emirates

Orthopaedic Clinic, 2nd Faculty of Medicine, Charles University, Prague, Czech Republic
e-mail: milan.handl@dbaj.ae

The reason of osteoarthritis is the change of cartilage quality in the structure and properties. Similarly the cartilage wears away gradually over the years after the injury as well as after the inflammation process. When becomes fibrillated frayed, and rough, the height of the cartilage layer decreases. Painful osteophytes (bone spurs), subchondral sclerosis, and incongruence in the intra-articular surface can develop [13, 17, 38] (Fig. 86.2a–c).

86.2 Anatomy of the Ankle

The ankle joint is formed by the lower end of the tibia, the fibula, and the talus, which fits into the socket formed by the former two. The talus is located on top of the calcaneus. Its main function is to move in one direction, causing "a hinge" that allows the ankle to move in dorsal and plantar flexion. The ligaments on both sides of the ankle joint act as stabilizers of the joint. Tendons crossing the joint enable to move the ankle [23–25, 42, 45].

86.3 Symptoms

End stage of osteoarthritis is characterized by the deconfiguration or malalignment of anatomic shape, tenderness or pain, stiffness or limits in ROM, and swelling. Usually this occurs at first only related to activity. With the progress of

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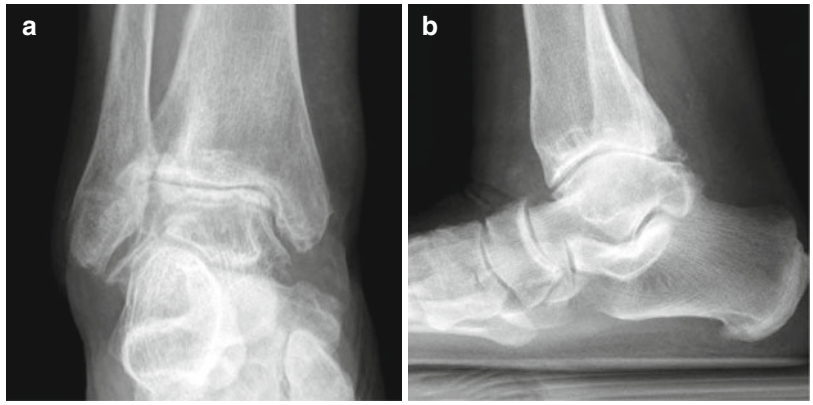

Fig. 86.1 (**a**, **b**) Postinflammatory osteoarthritis

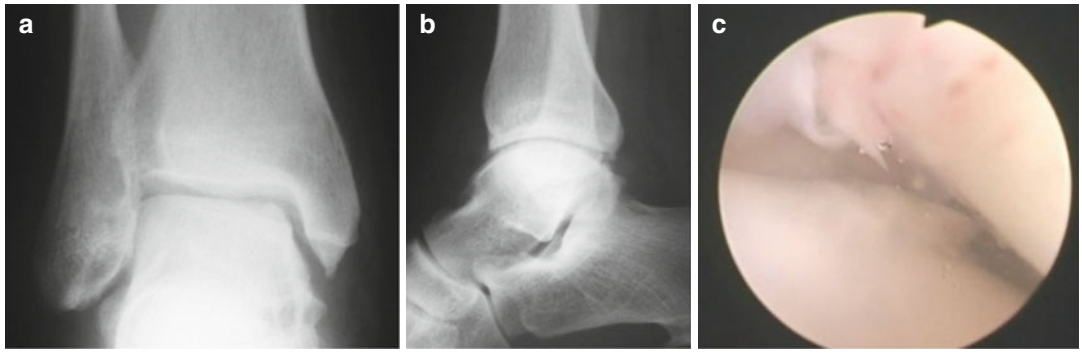

Fig. 86.2 (**a**–**c**) Early onset of osteoarthritis – X-ray and arthroscopic view

disease, pain may be present also at rest, at night interfering sleep or as a "starting pain" at walking in the morning. With increasing daily activity, the joint may swell. Crepitation may be described. In these stages, OA may affect the motion of a joint, which loses flexibility. The movements become painful which affects the gait, and finally it can lead to the loss of control of the body position [5, 6].

86.4 Diagnosis

The diagnosis of ankle osteoarthritis is most likely done by the following:

86.5 Standing X-ray

This imaging provides a detailed picture of shape and density of bone structures. In cases of osteoarthritic changes, they may show narrowing of the joint space, indicating cartilage loss, changes in the bone structure or the formation of bone osteophytes, subchondral sclerosis, irregularity in the joint surface, and cyst formation [4].

Weight-bearing X-rays are taken at standing position which can be helpful in diagnosing the severity of OA. It is valuable also to know how much osteoarthritic changes are present and where it is mainly located in the joint (Fig. 86.3a, b).

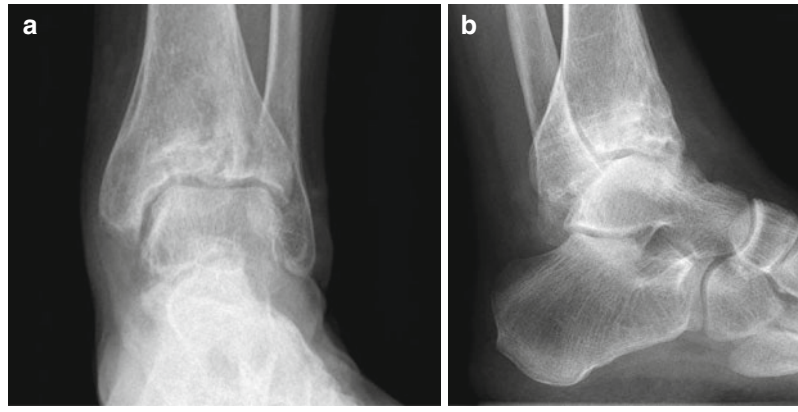

Fig. 86.3 (**a**, **b**) Posttraumatic osteoarthritis

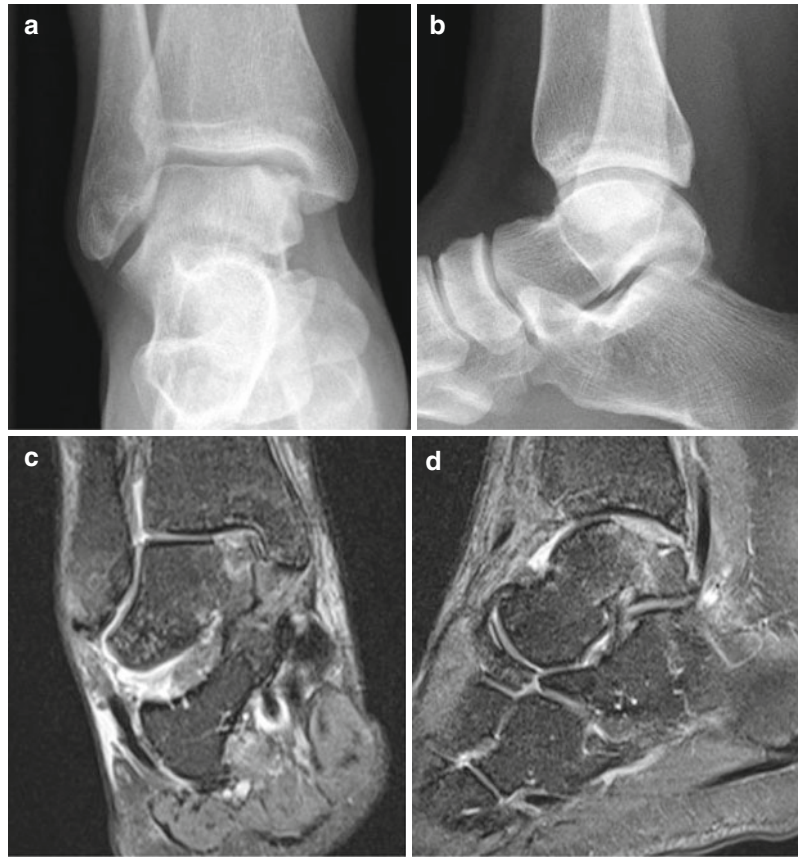

Fig. 86.4 (**a**, **b**) Osteochondritis dissecans – diagnosis in X-ray. (**c**, **d**) Osteochondritis dissecans – diagnosis in MRI

86.6 MRI

Magnetic resonance imaging (MRI) scan can be indicated for the determination of the conditions of the cartilage, bone quality in cases of local osteonecrosis, cyst formation, and other participating soft tissues (joint capsule, ligaments) [31] (Fig. 86.4a–d).

86.7 CT Scan

This imaging is important for the analysis of the bone structure and possible changes inside of the bone.

86.8 Laboratory Tests

With some types of arthritis, including rheumatoid arthritis, blood tests are important for an accurate diagnosis. In degenerative osteoarthritis, usually the laboratory tests are not significant.

86.9 Treatment

The treatment of OA of the ankle can be divided into conservative and surgical procedures. Surgery is usually indicated in case of failure of conservative treatment.

86.10 Conservative Treatment

There are several steps in the conservative treatment of OA. Weight reduction belongs to the first step, because it means a decrease in weight on the ankle joint. Activity modification is also helpful; it causes interruption of the symptoms. The next steps involve anti-inflammatory drugs, pain relievers, pads or arch supports, inserts that support the ankle and foot, physical therapy, and steroid medications injected into the joint. Medications such as glucosamine and chondroitin sulfate or viscosupplementation by hyaluronic acid derivates are being used more commonly today. We do not recommend the use of glucosamine and chondroitin sulfate due to lack of evidence. In cases when these steps are no longer successful, surgery may be indicated.

86.11 Rehabilitation

Physiotherapy plays an important role in the treatment of the ankle osteoarthritis. The main goal is to help how to control pain and symptoms. Rest, heat, or topical rubs are used to improve flexibility, balance, and strength. Training is performed in order to walk smoothly and without a limp. Various kinds of physiotherapy are utilized for this purpose.

86.12 Surgery

The type of surgery depends on the severity of the osteoarthritis. Which procedure is recommended may be determined by many factors. These include desired activity level of the patient, age, and comorbidity.

86.13 Arthroscopic Surgery: Arthroscopic Debridement

Debridement is a procedure to remove loose bodies, inflamed synovial tissue, and bone osteophytes from the joint. There is an indication for removal of osteophytes in case the patient presents with localized tenderness on palpation without deep ankle pain. Removal of these osteophytes, loose bodies, and inflamed synovium results in 50 % of good or excellent results [20, 22, 36, 37, 39, 40, 43, 44] (Fig. 86.5a–c).

86.14 Open Surgery

There are several surgical treatment options [12, 15, 16, 19, 21, 41, 44].

The main options are arthrodesis, ankle prosthesis, or correction osteotomy [1, 3, 7, 8, 10, 26, 30, 46].

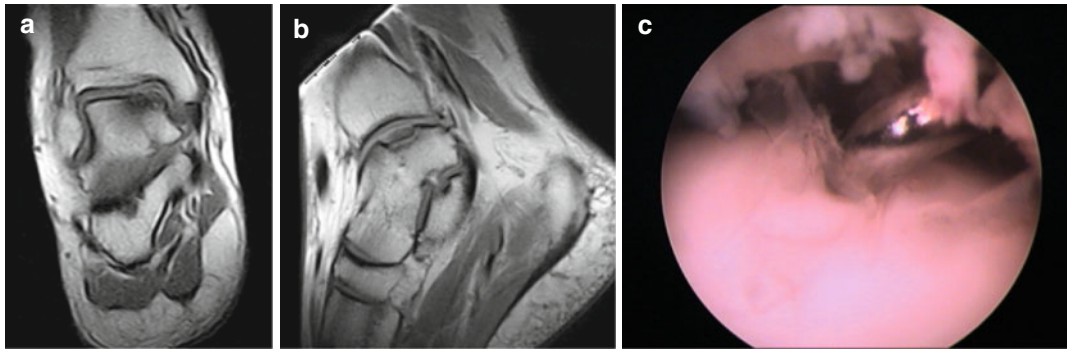

Fig. 86.5 (**a**–**c**) Osteochondritis dissecans – diagnosis in MRI and in arthroscopy

86.15 Arthrodesis: Fusion Surgery

This kind of surgery involves fusing bones together with the use of pins, screws, rods, plates, or external fixators. The advantage is that with a successful fusion the pain is gone. Most patients after this surgery are able to walk without much trouble. Shoe adaptations more often are not needed. The ankle fusion is commonly indicated especially for young, active persons mostly for posttraumatic OA of the ankle. The procedure can be carried out by means of arthroscopy. Arthroscopic ankle arthrodesis has demonstrated superior results over open surgery in terms of time to fusion, fusion rates, and complications [1]. The procedure can be performed by means of a two-portal anterior approach or by means of a two-portal hindfoot approach. Arthrodesis can be also done in case of the final solution, when total ankle replacement has failed [29, 35, 44] (Fig. 86.6a–d).

86.16 Osteotomy

Osteotomy can be indicated in case of malalignment and unicompartmental osteoarthritis. Depending on the joint axis, the procedure can be performed as a supramalleolar correction osteotomy or by means of calcaneal osteotomy. Medializing or lateralizing calcaneal osteotomy has gained popularity due to its simplicity and reliable results even in cases with non-horizontal ankle joint line [44].

86.17 Total Ankle Replacement (Arthroplasty)

Total ankle replacement is not as common as total hip or total knee replacement. This procedure is most commonly indicated for severe OA destruction of the ankle or in cases with aggravated pain that interferes with daily activities. The main goal of TAR is a relief of the pain while preserving more mobility than fusion (Fig. 86.7a–d). The other advantage that less stress is transferred to the adjacent joints and thus lowering the chance of developing adjacent joint osteoarthritis [18, 32]. The results of TAR thus far have not been superior to arthrodesis. Within 10 years after TAR, 15 % of patients need revision surgery.

86.18 Summary

Osteoarthritis of the ankle is a disease involving the synovium, cartilage, and bone. In most cases, it is a result of injury, wear and tear, deformity, or the inflammation process. Conservative therapy is used in the early stages. When the disease does not respond to nonsurgical management and dependent on the progress of osteoarthritic changes, surgery may be indicated for the treatment. In case of painful osteophytes with recognizable tenderness on palpation and without deep ankle pain, arthroscopy treatment can be indicated. In advanced ankle arthrosis, the options are correction osteotomy in case of malalignment, arthrodesis, or prosthesis.

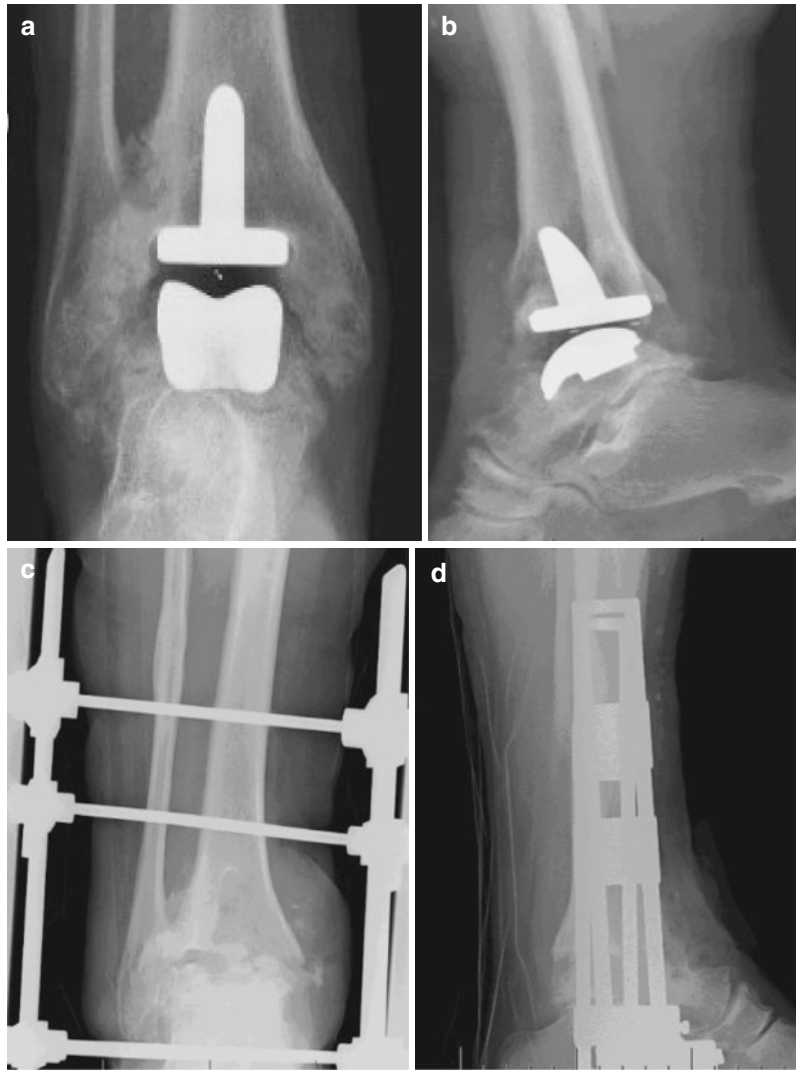

Fig. 86.6 (**a**, **b**) Total ankle replacement – before removal. (**c**, **d**) Arthrodesis of the ankle – external fixation

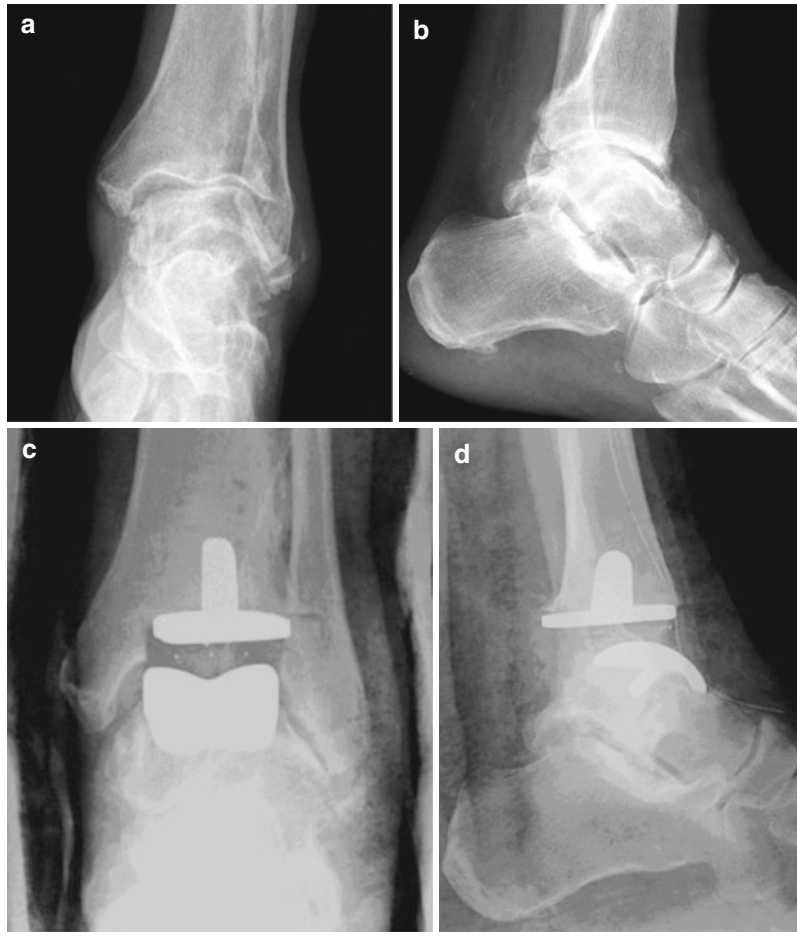

Fig. 86.7 (**a**, **b**) Osteoarthritis of the ankle. (**c**, **d**) Total ankle replacement

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Arthroscopic Ankle Arthrodesis

87

Richard P. Walter and Ian G. Winson

87.1 Introduction

Arthrodesis of the ankle joint is an established treatment for end-stage arthritis, with the aim of achieving a stiff but pain-free and well-aligned ankle. Traditional open arthrodesis has been performed through various surgical approaches, although significant complication rates in terms of nonunion, delayed wound healing and infection have been reported [4, 5]. The rationale for arthroscopic ankle arthrodesis is to minimise surgical insult to the soft tissue envelope with the aim of decreasing complication rates, time to union, length of hospital stay and overall recovery time [9, 11].

87.2 Anatomy and Pathogenesis

The ankle joint is a highly congruent articulation involving the tibia, talus and fibula. The mortise shape created by the interaction between the tibia and fibula, held by the inferior tibiofibular ligaments, closely contains the talus and confers significant bony stability. Further static constraint is offered by the joint capsule and medial and lateral ligament complexes, and dynamic stability is provided by the surrounding musculotendinous units, not least the peroneal muscles. In comparison to other large joints, the articular cartilage of the ankle is thinner, and less prone to age-related changes, therefore remaining stiffer and of higher tensile strength in patients over 40 years of age [1, 6]. For this reason, primary osteoarthritis is rare. More commonly, patients requiring surgery for ankle arthritis have a history of posttraumatic (fracture or significant ligament injury) arthritis, inflammatory arthritis or significant hindfoot deformity, resulting in abnormal loading of the ankle joint.

87.3 Symptoms, Signs and Imaging

Patients with end-stage ankle arthritis experience stiffness, swelling and severe pain localised over and deep to the anterior ankle joint line, initially on weight bearing and later also at rest. Often there is a history of a significant ankle injury or preceding ligamentous instability. A detailed past medical history will reveal alternative causes of arthritis (such as inflammatory arthritides, haemophilia and diabetic neuropathy) and also factors that influence suitability for surgery (such as severe peripheral vascular disease).

R.P. Walter (✉)
Consultant in Trauma and Orthopaedics, Department of Trauma and Orthopaedics, Royal Cornwall Hospitals NHS Trust, Truro, UK
e-mail: richwalter55@googlemail.com

I.G. Winson
Consultant in Trauma and Orthopaedics, Department of Trauma and Orthopaedics, North Bristol NHS Trust, Bristol, UK

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During clinical examination, it is important to carefully assess the vascular status of the limb and the condition of the soft tissue envelope. Inspection of the overall limb, ankle and hindfoot alignment will yield information regarding the requirement for and anticipated effects of ankle deformity correction during surgery. Careful palpation and movement of the neighbouring joints can reveal arthritis and guide surgical decision-making. For example, in some patients with ipsilateral subtalar arthritis, ankle arthroplasty might be discussed as a reasonable alternative to arthrodesis with the aim of avoiding a completely stiff tibiotalocalcaneal segment.

Weight-bearing mortise and lateral views will help to confirm the diagnosis of osteoarthritis, with loss of joint space, sclerosis, subchondral cysts and osteophyte formation. Ankle joint alignment is also assessed with these views. If there is reason to suspect significant bone loss, avascular necrosis or large cyst formation, then computed tomography is used to localise and quantify the defect, which may need to be grafted.

87.4 Nonoperative Management

By the time of first presentation to an orthopaedic surgeon, patients will have typically exhausted nonoperative management without success. This includes simple analgesics, non-steroidal anti-inflammatory drugs, modification of footwear (walking boots with ankle support and rocker-bottom soles) and intraarticular injection of local anaesthetic and corticosteroid. This means that posttraumatic arthritis is more likely to be associated with poor soft tissues, increasing the need for fusion methods which protect them.

87.5 Surgical Management

Various surgical procedures have been used to treat ankle arthritis. In the setting of localised degeneration associated with malalignment either side of the ankle joint, periarticular osteotomies can be used to relieve symptoms and prolong the life of the native ankle joint. Distraction arthroplasty using external fixation devices has been used as an alternative joint-preserving treatment, but has not gained widespread popularity. For end-stage ankle arthritis, this leaves the options of implant arthroplasty or arthrodesis. Whilst outcomes from total ankle arthroplasty have been improving in recent years, ankle arthrodesis remains the most reliable surgical procedure in terms of resolution of symptoms and reoperation rates.

87.6 Indications and Rationale for Arthroscopic Arthrodesis

The rationale for arthroscopic ankle arthrodesis is to minimise surgical insult to the soft tissue envelope with the aim of decreasing complication rates, time to union, length of hospital stay and overall recovery time [9, 11]. Indications are similar to those for traditional open ankle arthrodesis: end-stage ankle arthritis, including posttraumatic and inflammatory arthritides. Furthermore, avoiding the need for open approaches allows expansion of the indications to include patients with a relative compromise of the soft tissue envelope, such as patients with previous high-energy trauma or open fractures, and even a relative compromise of vascularity. It was previously believed that deformity could not be corrected during arthroscopic arthrodesis, although published work has since showed this not to be the case [2, 12]. Similarly, avascular necrosis of the talus is no longer considered a contraindication to an arthroscopic approach [7]. Relative contraindications include smoking and neuropathy (in particular in the early phase of Charcot neuroarthropathy), both of which carry an increased risk of surgical site infection and nonunion. Active infection is considered an absolute contraindication for this procedure.

87.7 Operative Technique

87.7.1 Position and Preparation

Figure 87.1 shows a recommended theatre floor plan. Note the ipsilateral arthroscopy stack and image intensifier, affording the surgeon access

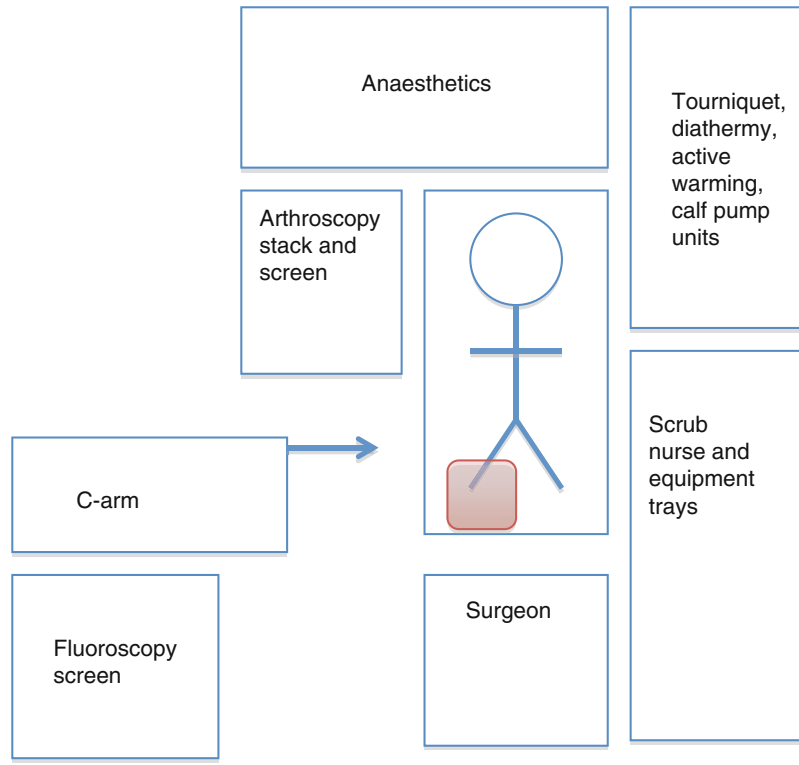

Fig. 87.1 Recommended theatre floor plan for arthroscopic ankle arthrodesis

to the medial aspect of the limb during screw insertion. General or regional anaesthesia is used. Antibiotic prophylaxis is administered prior to inflating a thigh tourniquet. The patient is positioned supine with a sandbag under the ipsilateral buttock to control limb rotation. A non-invasive ankle distractor is applied after skin preparation and draping (keeping the knee exposed to allow intraoperative assessment of limb rotation). The World Health Organisation safety checklist is completed before making an incision.

87.7.2 Surgical Approach

The joint is distended by injecting 20 ml saline, and standard "nick and spread" anteromedial (medial to the tibialis anterior tendon) and anterolateral (lateral to extensor digitorum longus tendons) portals are established, taking care not to injure branches of the superficial peroneal nerve.

87.7.3 Preparation of Joint Surfaces

A 30° 4.5 mm "knee" arthroscope is introduced into the anteromedial portal, and the anterolateral portal is used as a working portal, through which curettes and then a 4.5 mm full-radius soft tissue resector are introduced to remove remaining articular cartilage, hypertrophied synovium and intraarticular scar tissue. A barrel-shaped burr is used to remove the anterior distal tibial osteophyte and to decorticate the tibial and talar articular surfaces, to reveal the punctate bleeding of subcortical bone. Care is taken to limit the resection to cortical bone, maintaining the congruous shape of the tibiotalar joint. The articular surfaces of the medial malleolus and medial facet of the talus are prepared in a similar fashion (typically requiring switching of portals to an anterolateral viewing portal and anteromedial working portal). Conversely, whilst obstructing osteophytes must be removed, articular surfaces of the lateral gutter do not need to be formally prepared

for arthrodesis. Finally, the suction-assisted soft tissue resector is used to empty the joint of loose debris.

87.7.4 Stabilisation

An image intensifier C-arm with a sterile cover is brought in from the lateral side. Two "nick and spread" incisions are made over the posteromedial aspect of the distal tibia. Whilst the ankle is held in position (neutral flexion, 0–5° hindfoot valgus and 0–5° external rotation), two parallel guide wires are passed from the posteromedial distal tibia into the talar body up to but not penetrating the far talar cortex. After image confirmation of wire position, countersinking, measurement (subtracting 5–10 mm length to allow for arthrodesis site compression) and drilling are followed by insertion of two short-threaded cannulated screws of at least 6.5 mm diameter. Wounds are closed using nonabsorbable sutures. Sterile dressings and a below-knee plaster splint are applied.

87.8 Postoperative Care and Rehabilitation

In our unit, patients are admitted for one night postoperatively. The splint is changed for a full below-knee cast prior to discharge home. Patients remain non-weight bearing for the first 2 weeks, after which sutures are removed and a new cast applied. For the following 6 weeks, patients are allowed to partial weight bear in cast, as comfort allows. From 8 weeks postoperatively, full weight bearing commences in a removable boot. Radiographs are performed at 12 weeks postoperatively, and the boot is left off at this stage.

87.9 Outcomes

Published outcomes of arthroscopic ankle arthrodesis are summarised in the table below.

	Study design	*n*	Union rate (%)	Mean time to union (week)	Mean hospital stay (day)	Mean follow-up (month)	Comments	*P* value AAA vs. OAA
Abicht and Roukis [10]	Systematic review	244	91	8	Not stated	24	Included 7 original articles	
Dannawi et al. [2]	Case series	55	91	10	Not stated	63		
Gougoulias et al. [3]	Case series	78	97	12	3.7	21		
Winson et al. [12]	Case series	105	92	12	4	65	Union rate 95% excluding first 8 cases	
Comparisons AAA vs. OAA								
Townshend et al. [11]	Case series: AAA	30	97	Not stated	2.5	24		
	OAA	27	96	Not stated	3.7	24		<0.05 (reduction in mean hospital stay)
Nielsen et al. [13]	Case series: AAA	58	95	90%<12 weeks	6.6	>12		
	OAA	48	83	57%<12 weeks	8.9	>12		<0.01 (for both time to union and hospital stay)
O'Brien et al. [14]	Case series: AAA	19	84	Not stated	1.6	Not stated		
	OAA	17	82	Not stated	3.4	Not stated		<0.05 (for mean hospital stay)
Myerson and Quill [8]	Case series: AAA	17	94	9	1.5	23		
	OAA	16	100	15	4	23		<0.04 (for mean time to union)

87.10 Pearls and Pitfalls

- A small fusion site gap on intraoperative imaging is acceptable. This represents surface irregularities, and in our experience, the gap is filled with new bone as fusion progresses.
- A relatively posterior-to-anterior orientation of screws can help to avoid an anteriorly translated talus, which is not well tolerated and can cause compensatory knee hyperextension.
- Immobilise patients until 12 weeks postoperatively (initially in a plaster, followed by a removable boot), but allow early weight bearing in cast. Results showed improved union rates with this duration of immobilisation.
- The lateral gutter does not need to be prepared for fusion, but may need to be debrided to allow a tilted talus to be accurately reduced.
- It is important to make sure the screws are seated fully home to ensure good rigidity, which is the key to union rather than compression per se.
- Resection of the posterior malleolus effectively allows a posterior release of the ankle without actually releasing soft tissues. Sometimes however a percutaneous Achilles tendon lengthening is necessary to bring the foot from equinus to a plantigrade position.

Conclusions

An arthroscopic approach to ankle arthrodesis minimises the soft tissue injury of surgery, with the aim of speeding recovery.

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Posterior Ankle Arthroscopy: General Setup and Portal Options

88

K.T.M. Opdam, R. Zwiers, and C.N. van Dijk

88.1 Introduction

Over the last decades, numerous arthroscopic approaches have been described for accessing the ankle joint [1–3]. Because of the deep location and the close relation of the anatomical structures in relation to each other, knowledge of the anatomy is important for save access to the posterior ankle. Golano et al. showed in an anatomical study of the posterior ligaments that a posterolateral portal can always be created between the transverse ligament and the posterior intermalleolar ligament [4]. With the ankle in dorsiflexion, these ligaments in combination with the tibia mark out a triangular area to safely establish the portal.

In 2000, van Dijk first described a two-portal endoscopic approach to the hindfoot [3, 5]. This approach allows better access to the posterior ankle compartment, flexor hallucis longus, os trigonum, and the subtalar joint. In this chapter, this two-portal approach is described.

K.T.M. Opdam (✉) • R. Zwiers • C.N. van Dijk
Academic Medical Center Amsterdam, Orthopaedic Research Center Amsterdam, Milano, Italy
e-mail: K.t.opdam@amc.uva.nl

88.2 Two-Portal Endoscopic Hindfoot Approach: General Setup

Posterior ankle arthroscopy is performed as outpatient surgery under general anesthesia or spinal anesthesia. The patient is placed in a prone position (Fig. 88.1). A tourniquet is placed around the upper thigh of the affected side, and a triangular cushion is placed under the affected lower leg, making it possible to move the ankle freely. When indicated, a soft tissue distraction device can be used to create more work area (Fig. 88.2). This device is connected to a belt around the waist of the surgeon.

88.3 Instruments

For posterior ankle arthroscopy, a 4.0 mm with a 30° ankle arthroscope is routinely used. Also, it is possible to use a 2.7 mm arthroscope of 11 cm in length in combination with a 4.6 mm high-volume sheath. For irrigation, saline is mostly used; however, several fluids can be used like glycine or Ringer's lactate. When using a 4.0 mm arthroscope, gravity fluid is adequate.

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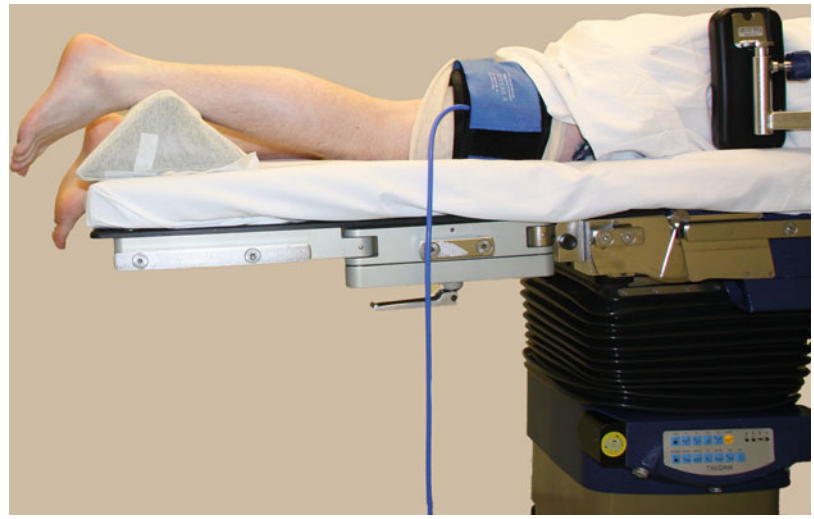

Fig. 88.1 Routine prone position for posterior ankle arthroscopy

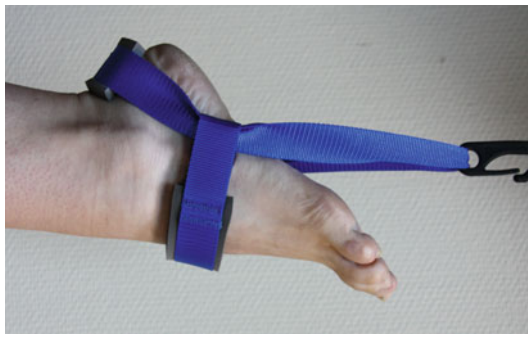

Fig. 88.2 Soft tissue distraction device. The distraction device is connected to a belt around the waist of the surgeon

88.4 Portal Placement

To perform a posterior arthroscopic procedure, appropriate portal placement is extremely important. The landmarks for posterior arthroscopy are the lateral malleolus, the medial and lateral border of the Achilles tendon, and the sole of the foot (Fig. 88.3). The two portals used for posterior ankle arthroscopy are placed both lateral and medial from the Achilles tendon.

First, the ankle is brought in a neutral position, which means in a 90°° angle. Following this, a line (white dotted line in Fig. 88.3) is drawn from the tip of the lateral malleolus to the lateral border of the Achilles tendon parallel to the sole of the foot (Fig. 88.3). The posterolateral portal (red line in Fig. 88.3) is created just above this line and just lateral of the Achilles tendon. A small vertical stab incision is made, and the subcutaneous layer is bluntly dissected with a curved mosquito forceps (Fig. 88.4a). When introducing the curved mosquito forceps, it is directed anteriorly and pointing in the direction of the interdigital web space between the first and second toe. When the tip of the mosquito forceps touches the bone, it is exchanged for a 4.6 mm arthroscopic shaft with the blunt trocar pointing in the same direction (Fig. 88.4b). By palpating in the sagittal plane, the posterior talar process can be felt as a prominence between the ankle joint and the subtalar joint, which can help by distinguishing between both joints. At this point, it is not necessary to enter the joint capsule, and the shaft and trocar are still situated extra-articular at the level of the ankle joint. Now, the trocar is exchanged for the arthroscope and saline solution is introduced (Fig. 88.4c). Then, under arthroscopic control, the posteromedial portal is made.

This posteromedial portal is made at the same level, opposite the posterolateral portal just anterior to the Achilles tendon (Fig. 88.4d1, 2). First, a small vertical stab incision is made. Then a mosquito forceps is introduced and directed toward the arthroscope shaft in a 90° angle (Fig. 88.4d). When touching the shaft, the shaft is used as a guide to

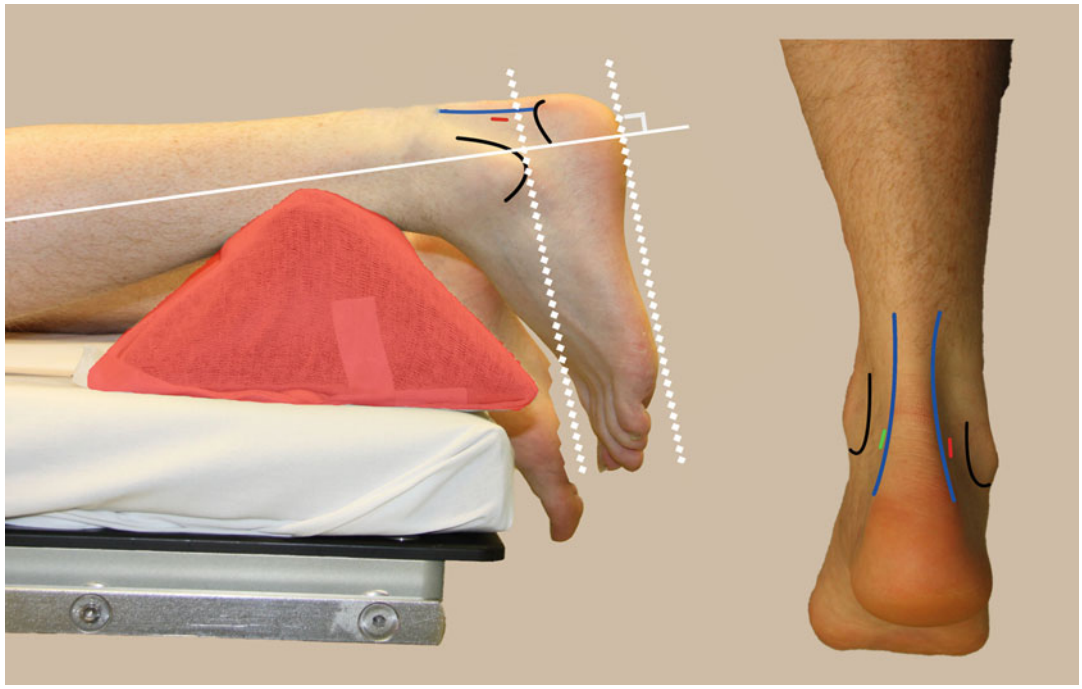

Fig. 88.3 The landmarks for posterior arthroscopy with the ankle in a 90° angle. The *blue lines* represent the borders of the Achilles tendon, the *black lines* the medial and lateral malleolus, the *red line* the posterolateral portal, and the *green line* the posteromedial portal

move anteriorly in the direction of the ankle joint (Fig. 88.4d1, 2). The mosquito forceps keeps touching the shaft all the way until the bone is reached. Thereafter, the arthroscope is slightly pulled backward so that the mosquito forceps is used as a guide to travel back over the top of the forceps until the tip of the mosquito forceps comes to view. The extra-articular soft tissue in front of the scope is spread with the mosquito forceps. Subsequently, the mosquito forceps is exchanged for a 5.5 mm bonecutter shaver (Fig. 88.4 e1, 2). When exchanging for a bonecutter shaver, the scope is brought back into the starting position pointing in the direction of the interdigital web space between the first and second toe, with the tip of the arthroscope touching the bone. The bonecutter shaver is introduced in the posteromedial portal and is directed in a 90° angle toward the arthroscope. To move the bonecutter shaver or any other surgical instrument, the above described manner is used to pass the neurovascular bundle without damage.

88.5 Visualization of Structures

The Rouvière ligament and the fascia are covering the underlying structures. The fatty tissue and the joint capsule can be removed by means of a shaver. At the level of the ankle joint, the posterior tibiofibular ligament and the posterior talofibular ligament can be identified (Fig. 88.5). After removal of the thin subtalar joint capsule, the posterior compartment of the subtalar joint can be visualized. Scar tissue around the posterior talar process can then be removed (Fig. 88.6), and the flexor hallucis longus tendon can be identified. The identification of the flexor hallucis longus (FHL) tendon is important to prevent damage to the more medially located neurovascular bundle. To prevent injury to the FHL, it is possible to place a loop around the FHL (Fig. 88.7). With a little traction on the loop, the FHL is secured and damage can be avoided.

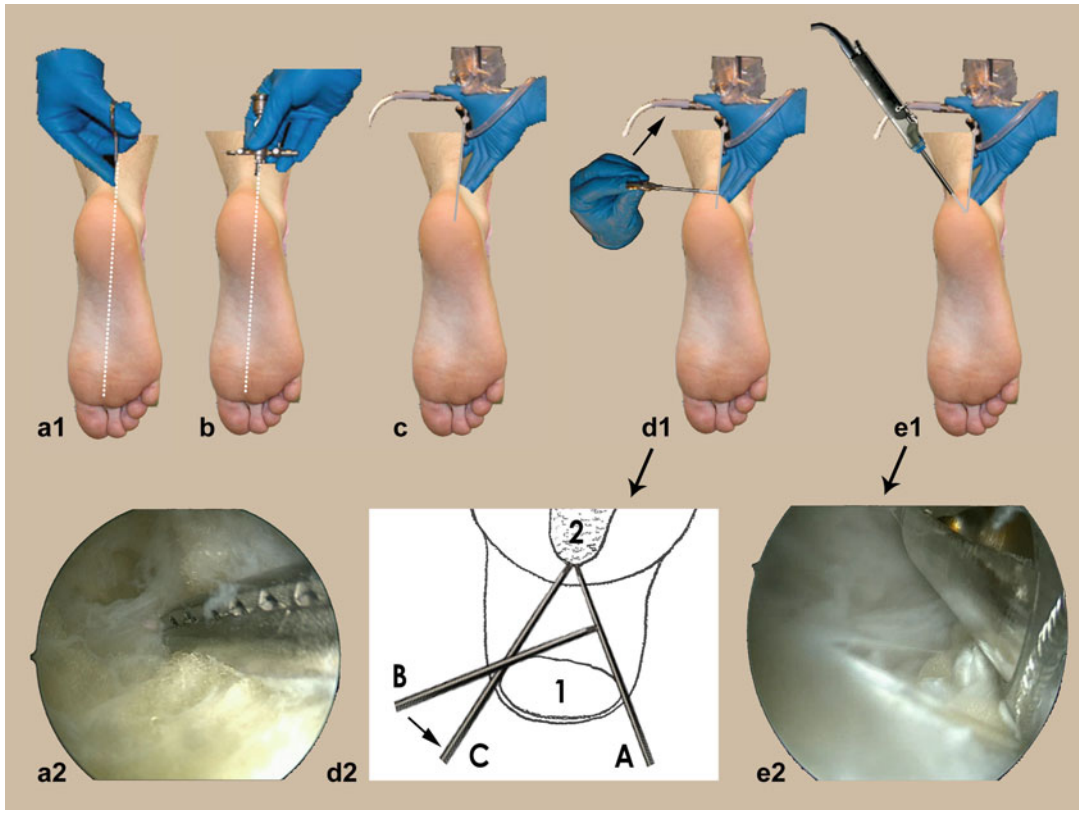

Fig. 88.4 Systematic representation of the two-portal hindfoot approach. (**a**) The mosquito forceps is directed anteriorly and is pointing toward the interdigital web space between the first and second toe. (**b**) The arthroscopic shaft with the blunt trocar is introduced, pointing into the same direction. (**c**) The trocar has been exchanged for the arthroscope. (**d1**) Mosquito forceps is introduced through the medial portal at a 90° ankle with the arthroscope. (**a2**) Endoscopic view after introduction of the mosquito forceps. (**d2**)The mosquito forceps (**b**) is guided anteriorly by the arthroscopic shaft (**a**) and then brought forward till it reached the bone (**c**). (**e1**) The scope is brought back to the starting point (directed to the web space between the first and second toe), and the shaver is introduced as seen in D2. (**e2**) Endoscopic view after introduction of a shaver

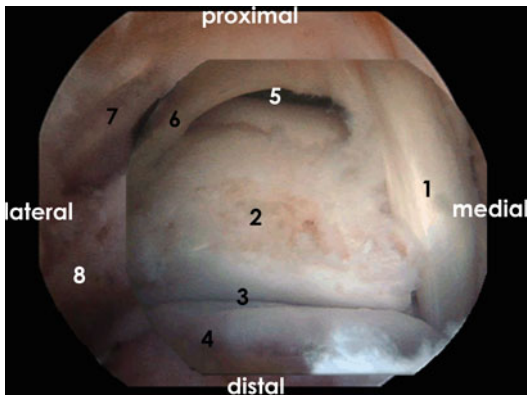

Fig. 88.5 Endoscopic view of the posterior compartment of a left ankle. *1* FHL, *2* talus, *3* subtalar joint level, *4* calcaneus, *5* ankle joint level, *6* tibial slip, *7* transverse ligament, *8* posterior talofibular ligament

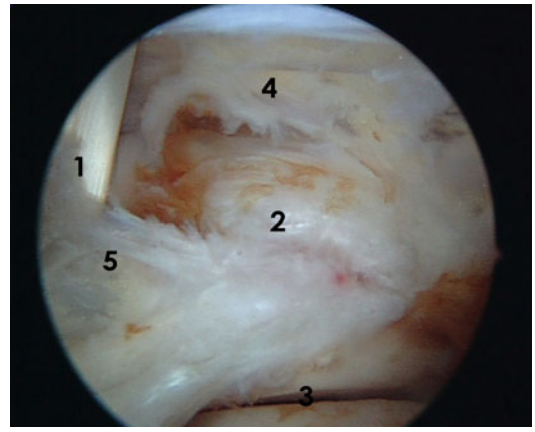

Fig. 88.6 Endoscopic view of a right ankle. *1* Flexor hallucis longus, *2* posterior talar process, *3* subtalar joint, *4* ankle joint, *5* flexor hallucis longus retinaculum

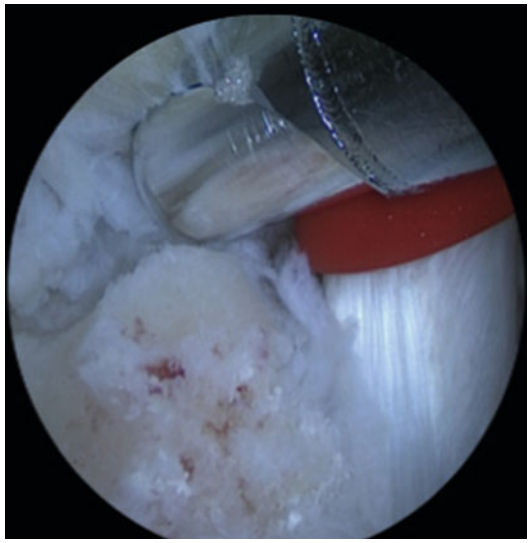

Fig. 88.7 A loop is placed around the FHL to avoid iatrogenic damage

On the medial side, the tip of the medial malleolus and the deep portion of the deltoid ligament can be identified. The talar dome and the tibial plafond can be inspected, posterior syndesmotic ligaments can be visualized, and on the lateral side, the peroneal tendons can be visualized.

88.6 Complications

The incidence of complications with an open posterior ankle approach is known to be 10–24 % [6, 7]. The largest cohort reported by Zengerink et al. showed an overall complication percentage of 2.3 % for hindfoot endoscopy which is lower than the complication rate for anterior ankle arthroscopy [8]. The complications that have been described are infection, complex regional pain syndrome, reoperation, temporary or persistent nerve symptoms, and persistent portal leakage [9–15].

Conclusion

The two-portal endoscopic hindfoot approach for posterior ankle arthroscopy provides save access to the posterior ankle compartment, the subtalar joint, and extra-articular structures. Treatment using this technique yields good results, with early return to activity and low complication rates.

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Posterior Impingement

89

Tahir Ögüt

89.1 Pathoanatomy

The normal anatomy of the posterior ankle and hindfoot along with overuse of the region contributes to the development of posterior impingement [37]. The main structures involved in PAIS can be divided into osseous and soft tissue components.

89.1.1 Bony Anatomy and Impingement

The osseous components include the posterior distal tibia, the talus, and the superior calcaneum. The posterior aspect of the talus has two spurs: the posteromedial process and posterolateral process. These processes are divided by a groove containing the FHL tendon. When the posterolateral process remains separated from the talus, it is called the os trigonum or trigonal process [21] (Fig. 89.1). The os trigonum is a secondary ossification center of the talus, which arises between the ages of 8 and 11 years posterior to the lateral tubercle and in 85 % fuses with the posterolateral process within 1 year of its appearance. In cases in which the posterolateral process of the talus projects more posteriorly than normal, it is referred to as a Stieda process [24]. It may remain as a separate accessory bone in 7–14 % of people and it is often bilateral [17]. The os trigonum has three surfaces: anterior (synchondrosis), inferior (calcaneus), and posterior (ligamentous attachment) [21]. This structure is usually asymptomatic. Typically, to produce symptoms, an os trigonum must be disturbed by some traumatic event, such as a supination or forced plantar flexion injuries, dancing on hard surfaces, or pushing beyond physiologic limits [49, 52]. Posterolateral ankle impingement is often associated with an os trigonum or trigonal process.

The first clinical description of bony posterior ankle impingement was by Howse [14] in 1982. He described posterior ankle pain in dancers secondary to the presence of an os trigonum. Later, Brodsky and Khalil also emphasized the etiological role of the *en pointe* and *demi-pointe* positions in ballet [4].

Posterior talar anatomy variations are the principal predisposing osseous factors in PAIS. In an anatomic study, a significantly downward sloping posterior tibial lip was found to be responsible for posterior impingement [33]. Skaf et al. presented five cases with posterior ankle impingement due to osseous abnormalities at the posteromedial process of the talus, including the presence of an ossicle or a prominent posteromedial process, without any history of local trauma [41]. Dysplasia

T. Ögüt, MD
Department of Orthopaedics & Traumatology,
Istanbul University Cerrahpasha Medical School,
Istanbul, Turkey
e-mail: drtahirogut@gmail.com

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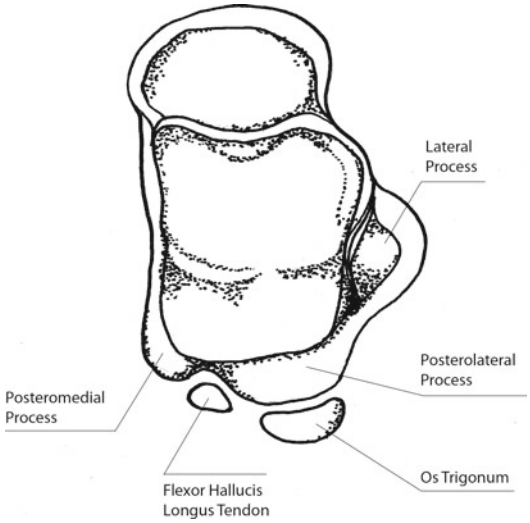

Fig. 89.1 Superior view of the talus and posterior talar anatomy

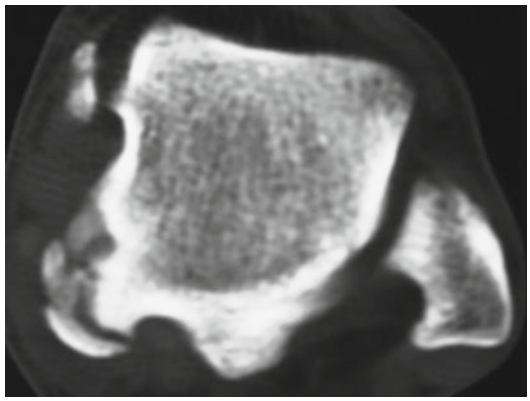

Fig. 89.2 One of our cases with posteromedial ankle tenderness. Posterior impingement test was negative. CT scan represented prominent posteromedial talar process

epiphysealis hemimelica of the talus, which is a rare skeletal developmental disorder representing an osteocartilaginous tumor arising from epiphyses during childhood, has also been reported as a cause of PAIS due to bony impingement [39]. Mann and Myerson reported five adolescents with a bipartite talus and a large posteromedial fragment with resulting posteromedial impingement symptoms. It was secondary to an unossified posteromedial talar tubercle [20] (Fig. 89.2).

89.1.2 Soft Tissue Anatomy

The bony anatomy and restricted space in the posterior recesses of the ankle and subtalar joints do not accommodate abundant soft tissues well, especially in the positions of forced plantar flexion. For this reason, the normal anatomic soft tissue structures of the posterior ankle can easily contribute to the onset of posterior ankle impingement [37].

The key soft tissue structures involved in PAIS include the flexor hallucis longus (FHL) tendon, the ligaments of the posterior ankle, and the joint capsule and synovium.

89.1.3 Posteromedial Soft Tissue Impingement

Most posteromedial ankle impingement is caused by soft tissues, usually by entrapment of fibrotic scar tissue in this region [16, 19]. Inversion injury with the ankle plantar flexed is the most common reason of posteromedial impingement [50]. With this, the fibers of the posterior tibiotalar ligament are compressed between the medial malleolus and talus and subsequently hypertrophy. Initially, this injury is often unnoticed because lateral ligamentous disruption dominates the clinical presentation [7]. The hypertrophied ligament may come into contact with the flexor tendons and partially encase the tibialis posterior (40 % of cases), the flexor hallucis longus (16 %), or the flexor digitorum longus (8 %) [7, 16].

Injury to the FHL tendon is another cause of posteromedial impingement. The FHL tendon is most frequently affected in athletes, such as runners, tennis players, and those involved in repetitive push-off maneuvers, such as ballet dancers [21]. Additional pathologies such as os trigonum, cysts, flexor digitorum accessorius longus muscle, and dorsal talar exostoses can also lead to FHL tenosynovitis [1, 3, 10, 29]. The FHL passes through a fibro-osseous tunnel behind the talus between the medial and lateral tubercles to the level of the sustentaculum tali like a rope through a pulley. As it passes through this pulley, it is easily strained. Frequent, prolonged repetitive

push-off maneuvers can lead to irritation and swelling of the FHL tendon. Chronic inflammation and hypertrophy of the musculotendinous unit within this tunnel can lead to painful stenosing tenosynovitis, like de Quervain disease in the wrist. FHL tendinopathy has only rarely been reported at sites other than the posteromedial ankle. However, immunohistochemical studies have suggested an avascular zone of the tendon in the segment of tendon that passes behind the talus [11, 26, 35].

89.1.4 Posterolateral Soft Tissue Impingement

Occasionally, posterolateral ankle pain can be caused by soft tissue entrapment between posterior lip of the talus and the os calcis. Posterolateral soft tissue impingement is usually caused by an accessory ligament, the posterior intermalleolar ligament (PIML) [7] (Fig. 89.3).

The PIML was described by Rosenberg et al. [38] in 1995, who identified it in 56 % of cadaver specimens. Although the presence of a PIML is common in the general population, posterolateral impingement related to the PIML is rare. This ligament, also called the tibial slip or marsupial meniscus, is a structure with consistent location but varying size and width. It is distinct from the posteroinferior tibiofibular ligament and separated from it by a small gap filled with synovial tissue [8]. It spans the posterior ankle between the posterior tibiofibular and posterior talofibular ligaments, from the malleolar fossa of the fibula to the posterior tibial cortex. The PIML may protrude further into the joint during plantar flexion, becoming entrapped and torn. The PIML is likely to be compressed and torn during an initial inversion injury with marked plantar flexion and subsequently hypertrophy. The resulting impingement syndrome consists of ankle locking and pain [7].

The posterior inferior tibiofibular ligament (PITFL) is a thick, stout band running posterior to the interosseous tibiofibular ligament, with which it partly blends. This ligament can normally form a labrum of the ankle joint by projecting inferiorly to the distal tibia, effectively deepening the tibial articular surface. PITFL is often in contact with the talar articular surface and can potentially split longitudinally or hypertrophy causing labral and synovial impingement [37] (Fig. 89.3).

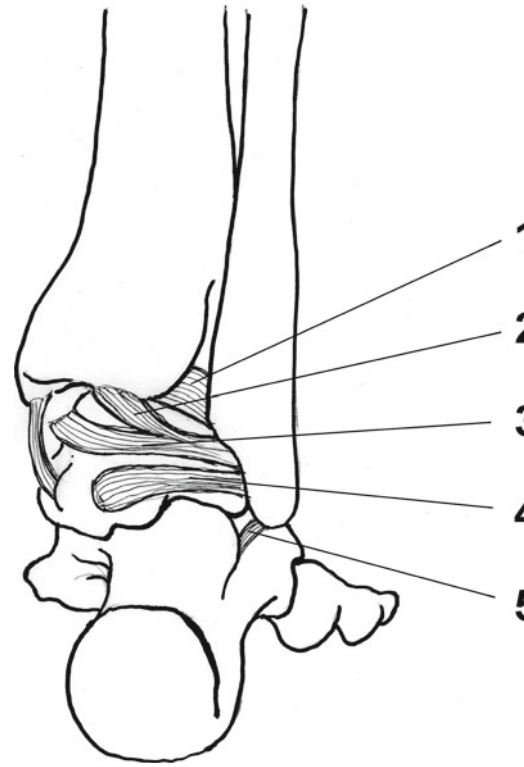

Fig. 89.3 The posterior ankle ligaments with the ankle in dorsiflexion position. (Flexor hallucis longus tendon is removed.) *1* posterior inferior tibiofibular ligament, *2* tibial slip of the intermalleolar ligament, *3* intermalleolar ligament, *4* posterior talofibular ligament, *5* calcaneofibular ligament

89.2 Clinical Presentation

89.2.1 Natural History

Os trigonum is a benign condition and usually is asymptomatic. The diagnosis of posterior ankle impingement is based primarily on the clinical history. Clinical diagnosis can be difficult compared with anterior ankle impingement, because posterior impingement is less common and the

affected structures of posterior ankle are much deeper. Patients experience chronic or recurrent deep pain in the posterior aspect of the ankle joint, mainly with forced plantar flexion. Although PAIS has several causes, the symptoms on presentation can be similar for the different diseases. A thorough history and detailed physical examination with intimate knowledge of the anatomic locations of posterior ankle structures and appropriate imaging as discussed later are essential for differential diagnosis. During examination, the ankle should also be checked for ligamentous instability.

Posterior ankle impingement can be caused by overuse (chronic pain) or trauma (acute pain). It is important to differentiate between these two, because posterior impingement from overuse has a better prognosis [49]. Overuse injuries typically occur in ballet dancers, soccer players, downhill runners, and high heel wearers [11, 46]. In ballet dancers, the increased range of motion and joint mobility can decrease the distance between the calcaneus and talus, particularly when a dancer is performing the en pointe technique. Soccer players may develop posterior impingement symptoms due to repetitively striking the ball with the foot in plantar flexion, exposing the hindfoot to excessive force [43]. In chronic conditions, stenosing tenosynovitis of the FHL tendon may coexist with os trigonum syndrome, which leads to poorer outcome if surgical treatment is delayed [15].

Despite the presence of an acute injury, the onset of symptoms of posterior ankle impingement may be delayed by 3–4 weeks [36]. This delay is most likely because in the early inflammatory phase of the injury, the athlete is unable to adopt the positions of plantar flexion because of pain, swelling, or hemarthrosis and as the patient recovers and regains motion, the impingement is apparent with either soft tissue hypertrophy or avulsion fragments of bone such as a fracture through an os trigonum synchondrosis [37].

89.2.2 Physical Findings

On examination, there is pain on palpation of the posterior aspect of the talus, posterolateral, posteromedial, or both. For accurate diagnosis, it is important to differentiate the anatomic location of most painful posterior ankle structure. Passive range of motion is a useful examination. During the passive forced plantar flexion test, the investigator can apply a rotational movement on the point of maximal plantar flexion, thereby "grinding" the posterior talar process or os trigonum between the tibia and the calcaneus [48]. Recognizable pain during this examination means a positive "posterior impingement test." Usually the patients also have tenderness behind the peroneal tendons deep in the back of the lateral malleolus (often mistaken for peroneal tendinitis) [53]. A positive "posterior impingement test result" in combination with pain on posterolateral palpation indicates posterior ankle impingement. To confirm the diagnosis, the examiner can perform a diagnostic infiltration of an anesthetic into the posterolateral talar region.

In patients with posteromedial soft tissue impingement, physical examination often reveals localized fullness and tenderness at the posteromedial aspect of the ankle. Posteromedial tenderness with passive ankle inversion and plantar flexion is a reliable and consistent finding [7, 32].

Localized tenderness and swelling over the musculotendinous junction and tendon sheath of the FHL behind and lateral to the medial malleolus is diagnostic for FHL tendinitis; pain can be elicited by forced simultaneous ankle and first MTP joint dorsiflexion [11, 26, 53].

"Pseudo-hallux rigidus" may coexist with posteromedial ankle pain: hallux dorsiflexion may be limited with ankle dorsiflexion but restored with ankle plantar flexion. This exam finding/phenomenon has been reported to be secondary to nodular thickening of the proximal FHL that impinges within the fibro-osseous tunnel on the posteromedial ankle [26]. In those patients with low-lying muscle bellies, the muscle can become trapped between the tubercles during motion and cause posteromedial ankle pain [11].

It is now accepted that syndromes related to FHL tendon are more frequent than previously reported and are not necessarily chronic [1]. Hamilton et al. [11] reported FHL tenosynovitis

in 85 % of patients in their series with posterior ankle pain. They concluded that primary FHL tenosynovitis can clinically mimic PAIS, and the tendon also can be secondarily involved. Similarly, Scholten et al. [40] found FHL tenosynovitis in 63 % of their patients with PAIS. They attributed this phenomenon to slight displacement of os trigonum, reactive synovitis, capsular hypertrophy, or scar tissue in that area.

The differential diagnosis of posteromedial ankle pain is hypertrophied posterior tibiotalar ligament impingement, FHL tenosynovitis, soleus syndrome, posterior tibial tendinitis, and posteromedial fibrous tarsal coalition [7, 53].

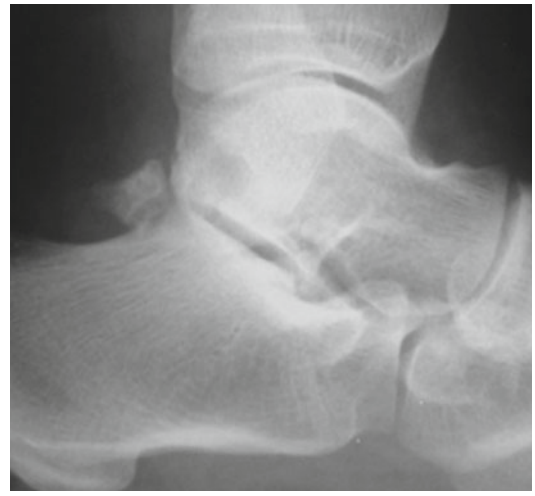

Fig. 89.4 Lateral x-ray representing an os trigonum

89.3 Radiological Examination

89.3.1 Radiograph

Direct radiographs should be used as a first-line radiologic investigation. In patients with posterior ankle impingement, the anteroposterior (AP) ankle view is typically unnecessary because it fails to demonstrate abnormalities (Fig. 89.4).

On the lateral view, a prominent posterior talar process or os trigonum can sometimes be recognized. As the posterolateral located posterior talar process or os trigonum is often superimposed on the medial talar tubercle, detection of an os trigonum on a standard lateral view is often not possible. For the same reason, calcifications can sometimes not be detected by this standard lateral view. Van Dijk recommends rotating the ankle into 25^0 external rotation to uncover the posterolateral tubercle [47, 56].

89.3.2 Computed Tomography Scan

Computed tomography (CT) is an often overlooked modality of imaging for investigation of ankle impingement [37]. It proves its worth when radiographs fail to diagnose bony impingement lesions even with rotated views and MRI is unable to diagnose subtle, small lesions such as avulsion fragments or irregularities of the surface of the bone [23, 37].

89.3.3 MRI

Magnetic resonance imaging (MRI) is useful for detection of bone contusions/edema, posterior capsular or ligament thickening, talar osteochondral lesions, and FHL tenosynovitis, which are the findings of a PAIS [5]. MRI has been reported to accurately identify FHL tendinitis in 82 % of patients, represented by intermediate or low signal intensity on T2-weighted images [15, 26]. At least, fat-suppressed T2-weighted or proton density images in the sagittal plane and imaging of the ankle in three planes should be requested from the radiologist [37]. Contrast-enhanced scans with gadolinium can add subtle detail to differentiate between, for example, synovitis and joint effusion, which have treatment implications [18].

MR imaging was found as an effective means of investigating the PIML as a potential cause of posterior impingement. The identification of a prominent PIML in the absence of another structural cause of PAIS indicates that impingement of the PIML is the most likely cause of PAIS. For optimal visualization and evaluation of the PIML, a high-field MR scanner is required [45].

Fluid in the FHL tendon sheath is frequently seen in MRI without clinical signs of an FHL tendinitis. Fluid in the tendon sheath of the FHL must be combined with changes in the tendon itself in order to be a sign of a tendinitis.

Bone edema in the os trigonum is an important diagnostic finding. It is a sign of chronic compression of the os trigonum between the distal tibia and calcaneus. It can be a sign of degeneration of the cartilage of the undersurface of the os trigonum. In these cases, the bone edema is combined with bone edema of the calcaneus. Lastly, it can be a sign of movement between the os trigonum and the talus. In these cases, there is bone edema in the posterior talus as well. These cases represent a pseudoarthrosis type of lesion [48] (Figs. 89.5 and 89.6).

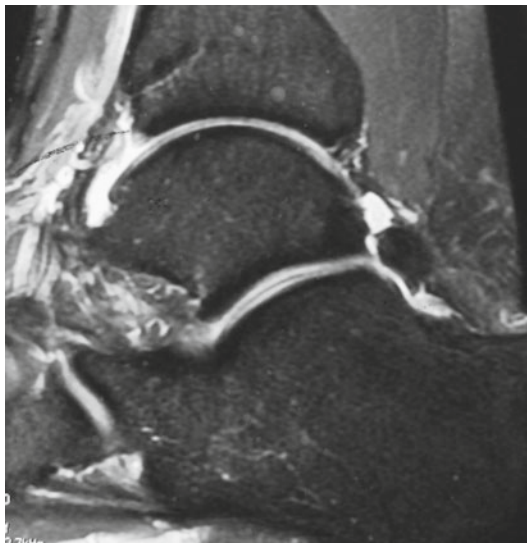

Fig. 89.5 MR image of an os trigonum which causes no pain, no complain

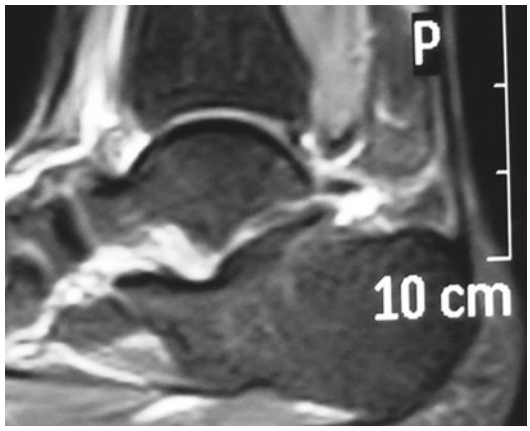

Fig. 89.6 MR image of an os trigonum with bone edema and posterior ankle synovitis

89.3.4 Ultrasonography

It is generally used for targeted injections with steroid and local anesthesia around the posterior ankle to relieve symptoms [25, 34, 36]. It seems that availability and accuracy of MRI have limited the use of ultrasonography for the investigation of PAIS.

89.4 Treatment

89.4.1 Nonoperative Management

Initial treatment of PAIS consists of rest, ice, anti-inflammatory medication, avoidance of forced plantar flexion, and, occasionally, ankle immobilization for 4–6 weeks. If there is an established nonunion, immobilization with casting is not recommended [21]. Physical therapy, such as progressive resistive exercises and strengthening, may also be helpful [21]. Such nonoperative treatment has a reported success rate of 60 % [12]. Image-guided steroid and local anesthetic injection into areas of focal inflammation provides diagnostic confirmation and long-lasting symptomatic relief in most patients [36]. Injections can often help athletes to finish a season and in some cases obtain cure, unless there is a large osseous lesion causing the impingement [25, 36].

89.5 Surgical Treatment

Operative treatment is indicated if symptoms persist despite 3–6 months of nonoperative care. Until recently open approach was the only option for surgical intervention. In 2000 van Dijk and associates [51] described the two portal posterior endoscopic approach to the hindfoot with the patient in prone position. Because this technique offered excellent access to the posterior compartment of the ankle and subtalar joints, the FHL tendon, and the os trigonum, it became very popular by the surgeons in a relatively short time. It caused less morbidity and facilitated a quick recovery.

89.5.1 Open Surgery

The orthopedic surgeons who are not familiar with arthroscopic surgery may still prefer the open surgery. The approach may be either posterolateral or posteromedial. Posterolateral approach is not recommended because of the high rate of sural nerve injury (reported to be up to 20 %) [1, 37, 54]. Damage to the posterior tibial nerve and peroneal tendinitis are also reported through this posterolateral approach [12, 22]. A symptomatic os trigonum can be removed through both approaches, but the advantages of the posteromedial approach are that one can address the FHL tendon and sheath and the posterior tibial neurovascular bundle can be visualized easily as well. With open debridement, 70–88 % of good or excellent results are reported in literature; but the complication rate was found between 12 % and 24 % and mean time to return to sporting activities or dancing was reported as 3–6 months [1, 11, 12, 22, 44]. In a systematic review on the surgical treatment of posterior ankle impingement, comparing open technique with the endoscopic one, the complication rate (16 % vs. 7 %) and time to return to full activity (16 weeks vs. 11 weeks) differed between the two groups, both favoring endoscopic surgery [58].

89.5.2 Endoscopic Surgery

Endoscopic decompression has first been described for the treatment of posterior ankle impingement by Dr. van Dijk et al. [51]. It improves the success rate and has a shortened recovery time and a decreased complication rate [6, 28, 42, 51, 55, 57, 58].

The aim of surgery is to resect inflammatory soft tissues and bone spurs to allow complete plantar flexion without impingement. The ossicle itself can be excised easily by open surgery; however, the inflammatory tissue extending locally cannot always be completely debrided by open surgery, thus contributing to postoperative symptoms in some patients [1, 30]. Also, FHL tenosynovitis usually coexists with os trigonum syndrome, and this leads to poorer outcomes if surgical treatment is delayed [1]. In addition to os trigonum excision, hindfoot endoscopy allows simultaneous observation and treatment of FHL tenosynovitis, as well as debridement of the local synovitis and hypertrophied structures which may lead to impingement [30]. Regardless of indication, inspection of the FHL tendon for tenosynovitis meticulously in every hindfoot endoscopy procedure is recommended [30] (Figs. 89.7, 89.8, 89.9, and 89.10).

In a series of 16 posterior ankle arthroscopies evaluated at a mean follow-up of 32 months, all patients had good to excellent health-related quality of life and functional outcome scores, with a high rate (93 %) of return to preinjury athletic level [57]. In another series of 36

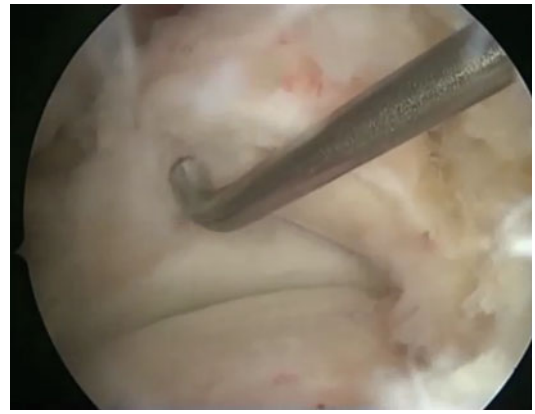

Fig. 89.7 The os trigonum, causing posterior ankle impingement

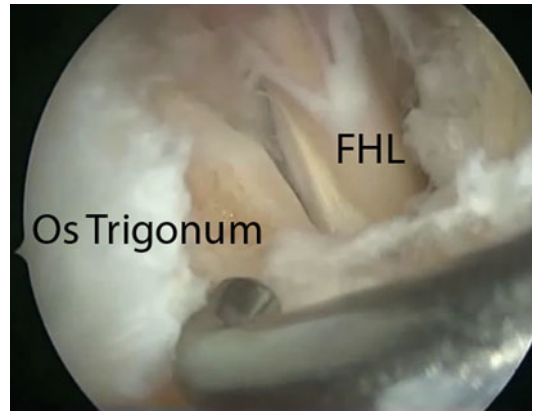

Fig. 89.8 Inspection of the stenosed FHL tendon

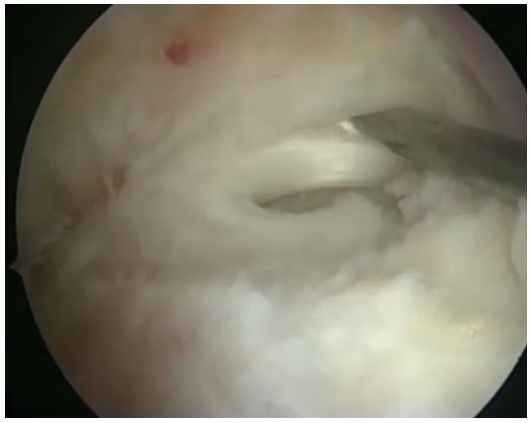

Fig. 89.9 Palpating the posterior ankle ligaments

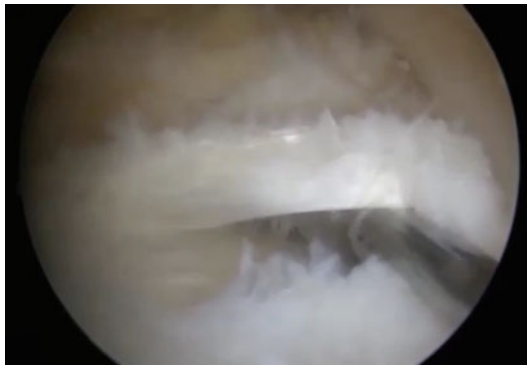

Fig. 89.10 Hypertrophied tibial slip of intermalleolar ligament

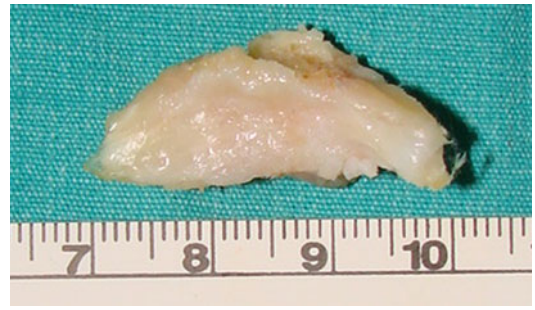

Fig. 89.11 An os trigonum removed arthroscopically

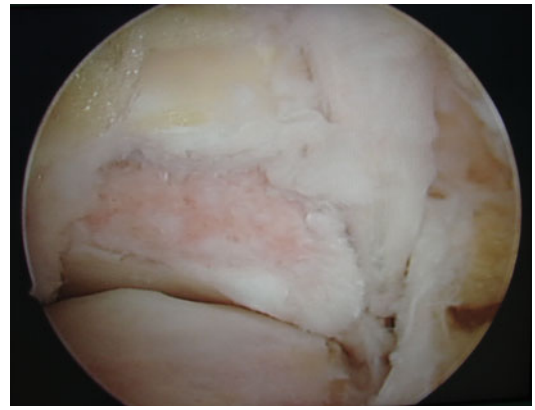

Fig. 89.12 Arthroscopic view after removal of os trigonum and FHL tendon release

patients treated by hindfoot arthroscopy for symptomatic os trigonum or osteophytes, scores on a visual analog scale for pain improved significantly from 7.2 points to 1.3 points, although impaired sensitivity of the sural nerve was reported in two cases [6].

In addition to the removal of an os trigonum (Fig. 89.11), posterior ankle arthroscopy has been used to resect a prominent calcaneal tuberosity [51], for tendoscopy of the FHL [30, 51], for debridement of pigmented villonodular synovitis [30], and for debridement followed by grafting of the intraosseous talar cysts [31] (Fig. 89.12). In their series of 60 ankles in 59 patients treated with hindfoot endoscopy, Ogut et al. [30] reported 13 cases with osteochondral lesion of talus which were treated with this technique in order to treat the accompanying soft tissue impingement at the same time. The author of this chapter believes the formation of excessive scar tissue posteromedially, in chronic and/or neglected osteochondral lesions located at posterior half of talus, which scar tissue leads to FHL tenosynovitis and/or posteromedial soft tissue impingement [30, 31].

The overall results for bony impingement appear to be better than those for soft tissue impingement [53].

The rate of complications seen in published series of posterior ankle arthroscopy is generally low. Wound infection rates are usually 0–5 % [2, 9, 13, 27], and injury to the sural nerve is reported in a few studies as up to 8 %. When injury occurs, it is usually a transient neuropraxia; however, it can be persistent in some cases [6, 28]. In their series of 189 ankles in 186

patients treated with hindfoot endoscopy, Nickisch et al. [27] reported four plantar numbness, three sural nerve dysesthesia, four Achilles tendon tightness, two complex regional pain syndrome, two infection, and one cyst at the posteromedial portal. They stated that one case of plantar numbness and one case of sural nerve dysesthesia failed to resolve.

To prevent sural nerve injury, it is important to create the posterolateral portal as described previously, close to the Achilles tendon, first making a stab incision and then continuing with blunt dissection by a mosquito clamp. Precise control of the aspirator and shaver is mandatory to prevent tibialis posterior nerve and vessel injury and to prevent damaging the FHL tendon. In areas close to the neurovascular bundle, the aspirator should be set to the degree of a minimum amount of suction. Since 1994 van Dijk applied this technique without any complications other than two patients who experienced a small area of diminished sensation over the heel pad of the hindfoot [48].

Conclusion

Posterior impingement syndrome and FHL tendinitis are common reasons of posterior ankle pain. They are not only specific to the dancers. For an experienced arthroscopic surgeon, hindfoot endoscopy is a safe, effective, and attractive procedure for the treatment of several identified hindfoot pathologies which cause posterior ankle pain.

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Hindfoot Endoscopy for Posterior Ankle Impingement

90

P.P. d'Hooghe and C.N. van Dijk

90.1 Introduction Including Epidemiology

Posterior ankle impingement syndrome is a common cause of chronic ankle pain in athletes. The overall percentage of ankle injuries in, e.g., football is 19 % [1, 2], but the exact prevalence and incidence for posterior ankle impingement has not been documented. The typical clinical features are posteriorly located ankle pain, which increases with forced hyperplantar flexion. The cause can either be soft tissue or bony impingement. In the early 1930s and mainly because of its anatomic features n the ankle joint was found unsuitable for arthroscopy. Decades later, considerable contributions were made to the arthroscopic surgery of the ankle by mainly Asian and Dutch schools.

Over the last three decades, arthroscopy of the ankle joint has become a standardized and important procedure, with numerous indications for both anterior and posterior intra-articular pathology, as well for tendinous problems around the ankle.

The advantages of ankle arthroscopy are the direct visualization of the structures, improved assessment of the articular cartilage, faster rehabilitation, and earlier resumption toward sports.

There is nowadays enough evidence that there is only a limited value in performing a diagnostic arthroscopy because of the increased imaging modalities in ankle pathology.

However, because of the lack of direct access, the nature, and deep location of its hindfoot structures, posterior ankle problems still pose a diagnostic and therapeutic challenge nowadays.

Historically, the hindfoot was approached by a three-portal technique, i.e., the anteromedial, anterolateral, and posterolateral portals, with the patient in the supine position. It is known that the traditional posteromedial portal is associated with potential damage to the tibial nerve, the posterior tibial artery, and its surrounding tendons locally.

Therefore, a two-portal endoscopic technique was introduced in 2000 by Van Dijk et al. [3, 12], and since then, this technique has shown to give a safe [4, 12] and excellent access to the posterior ankle compartment, the subtalar joint, and the surrounding extra-articular posterior ankle structures.

Posterior ankle arthroscopy has shown the need for specific anatomical knowledge, has modified classic arthroscopic tools and skills, and has introduced a broad spectrum of new indications in posterior ankle pathology.

P.P. d'Hooghe (✉)
Department of Orthopaedic Surgery,
Aspetar Hospital, Aspire Zone, Sportscity street,
PO BOX 29222, Doha, Qatar
e-mail: pieter.dhooghe@aspetar.com

C.N. van Dijk
Department of Orthopaedic Surgery,
AMC University, Meibergdreef 9,
Amsterdam, AZ 1105, The Netherlands
e-mail: c.n.vandijk@amc.uva.nl

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90.2 Functional Anatomy

As for any pathology, anatomical knowledge is essential in the understanding and treatment of this impingement syndrome. The anatomical knowledge is particularly important in ankle arthroscopy due to the potential risk of associated complications, which can be prevented or decreased only by profound familiarity with the anatomy of the region and its anatomical variations.

The main anatomical structure for the orientation and to determine the safe working area is the flexor hallucis longus (FHL) tendon. Just medial to this tendon runs the posterior neurovascular bundle (tibial nerve and posterior tibial artery and veins).

The posterior ankle arthroscopy should therefore routinely be performed lateral to the FHL tendon. Proper positioning of the ankle and the hallux results in better visualization of the tendinous portion of the FHL muscle and avoids unnecessary resection of some of the muscle fibers that reach the lateral tendinous border in a semipenniform morphology.

Plantar flexion of the ankle or hallux flexion facilitates visualization of the FHL tendon proximal to the lateral talar process.

Also obligatory for the orientation during posterior ankle arthroscopy are the posterior ankle ligaments. The most distal and vertically orientated ligament is the talocalcaneal ligament, originating from the posterior talar process to the calcaneus. Superior to this ligament, also originating from this process, is the posterior talofibular ligament (PTFL), running in a slight oblique orientation to insert in the medial border of the posterior distal fibula. Both the posterior talocalcaneal ligament and the PTFL need to be (partly) released in case of removal of a symptomatic os trigonum/hypertrophic posterior talar process.

The posterior talofibular ligament, component of the lateral collateral ligament, originates from the malleolar fossa, located on the medial surface of the lateral malleolus, coursing almost horizontally to insert in the posterolateral surface of the talus. This ligament is also an important reference in posterior ankle arthroscopy.

Superiorly to the PTFL, the posterior intermalleolar ligament – also called the tibial slip in the arthroscopic literature – is recognized (Fig. 90.1). Proximal to this ligament is the posterior tibiofibular ligament which consists of a superficial and deep component or transverse ligament. A distinction between the transverse and intermalleolar ligament can easily be made by dorsiflexion of the ankle [5].

In order to gain arthroscopic access to the talocrural joint, the posterior intermalleolar ligament and the transverse ligament need to be lifted and/or partly excised. Up to the present, no literature

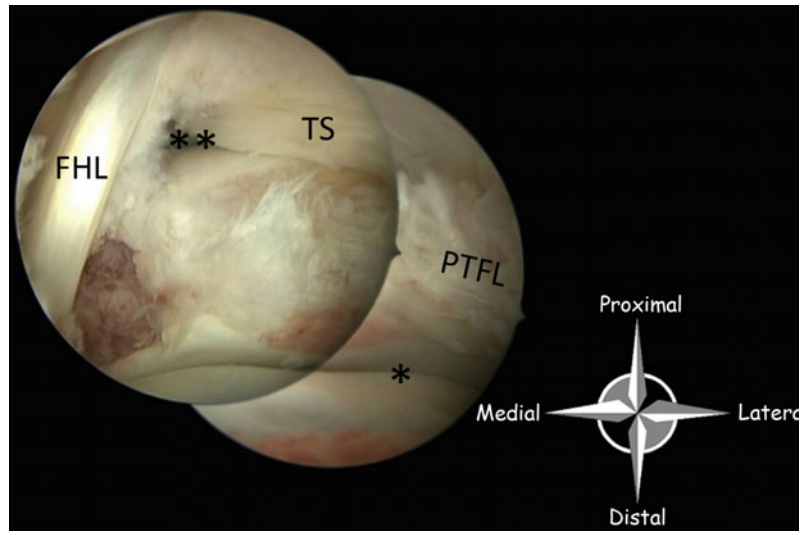

Fig. 90.1 Arthroscopic images indicating the important anatomical landmarks during posterior ankle arthroscopy in a right ankle. Superior to the subtalar joint (*), the posterior talofibular ligament is orientated and proximally to this ligament is the tibial slip (*TS*). By elevation of the TS, the ankle joint (**) can be entered. Prior to treatment of any pathology, the flexor hallucis longus (*FHL*) must be identified

is present on the function of these ligaments, but most probably these can be at least partly removed without significant consequences.

90.3 Etiology and Injury Mechanism

Posterior ankle impingement syndrome is a clinical pain syndrome that reflects the most common cause of posterior ankle pain, and it can be provoked by a forced hyperplantar flexion movement of the ankle [6–8]. In the event of a soft tissue or bony posterior impingement of the ankle, plantar flexion induces a conflict between the posterior malleoli of the distal tibia onto the posterosuperior calcaneal bone. A bony prominent posterior process of the ankle occurs in almost 7 % of the sports population and can present itself as a hypertrophic posterior talar process or as an os trigonum. Although apparent posterior bony prominences caused by acute or repetitive overload (micro-) trauma can induce posterior ankle pain, it is not necessarily associated with the posterior ankle impingement syndrome.

In the ankle, the posterior area is mostly well protected from trauma, and posterior impingement complaints therefore mostly originate from repetitive strains or overuse as is seen in professional (ballet) dancers. In contrast, in football players, for example, the main cause is a trauma to the posterior part of the ankle joint; this can be an inversion injury with an additional injury to the posterior ligaments or a direct trauma from a football shoe into the posterior area, causing a fracture of the posterior talar process, an avulsion fracture of the posterior ligament complex, or an instability in the pseudo-joint of the os trigonum.

The latter will then remain symptomatic in most cases because there is now instability in this joint, allowing (painful) motion of the os trigonum in relation to the posterior talar process (Fig. 90.2). The pain in posterior impingement syndrome can originate from a number of causes, as mentioned above already: a traumatized os trigonum, a fracture of posterior talar process, an avulsion fracture of the posterior ligament process, a tear in the posterior ligament process, a flexor hallucis longus tendinopathy, and an impingement of a bulky distal flexor hallucis

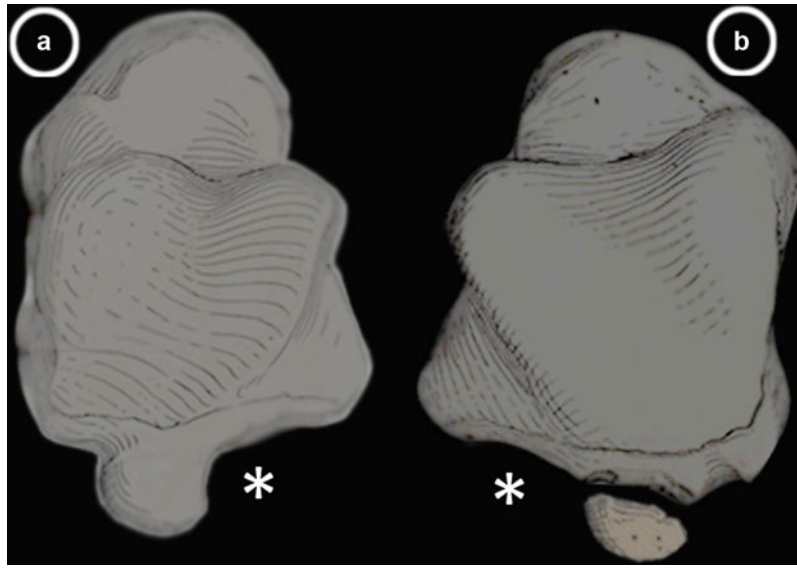

Fig. 90.2 Schematic drawings of the talus. (**a**) At the posterolateral aspect of the talus, the posterolateral talar process can be identified. This bony prominence, forming the groove for the flexor hallucis longus (*) together with the posteromedial talar process, can be enlarged (hypertrophic) and can subsequently cause a posterior ankle impingement. (**b**) In case the posterolateral talar process is not fused after the ossification is finished, it is called an os trigonum and could also become symptomatic

longus tendon in the flexor retinaculum in dorsal flexion of the hallux.

Typically in football, pain is experienced on kicking, when the posterior structures are crushed in the little posterior space between Achilles tendon, talus, and distal tibia. Recurrent trauma to the soft tissue component can lead to hypertrophy of the synovial layer, subsynovial fibrotic tissue formation, and infiltration of inflammatory cells and can thus cause a posterior soft tissue impingement.

90.4 Clinical Features

Since an acute forced hyperplantar flexion movement on the ankle or a repetitive overload induces the bony or soft tissue conflict in the posteriorly located components of the ankle joint, we mainly see these lesions in a sports-specific population.

The classical example of repetitive overload is seen in ballet dancers, where the forced plantar flexion during "en Pointe" and "demi Pointe" positioning induces repetitive impingement on the posteriorly located soft tissue components. Other types of sports, related to the posterior ankle impingement syndrome, include football, swimming, cycling, acro-gym, high jump, and any other sports in which the mechanism of injury is a repetitive forced plantar flexion or an acute setting (e.g., during a blocked kicking action in football). If the lesion occurs due to compression of the os trigonum between the distal tibia and calcaneal bone, it can lead to displacement of this os trigonum or even fractures of the processus posterior tali or distal tibia (Fig. 90.3).

Patients that suffer from posterior ankle impingement present with a posteriorly localized ankle pain during a (forced) plantar flexion movement.

Clinically it presents as a recognizable local pain on palpation along the posterior aspect of the talus. Since the neurovascular structures and tendons are localized in the posteromedial region of the ankle, this area is not always easily palpated when compared to the clinical examination of the posterolateral part of the ankle.

The posterior ankle impingement test is a pathognomonic test to identify the clinical diagnosis of posterior ankle impingement. To have a positive test, the ankle is passively and quickly forced from neutral to hyperplantar flexion position, and during this movement, the patients encounter suddenly recognizable posteriorly located ankle pain. To increase compression on the posterolateral structures of the ankle, plantar flex-

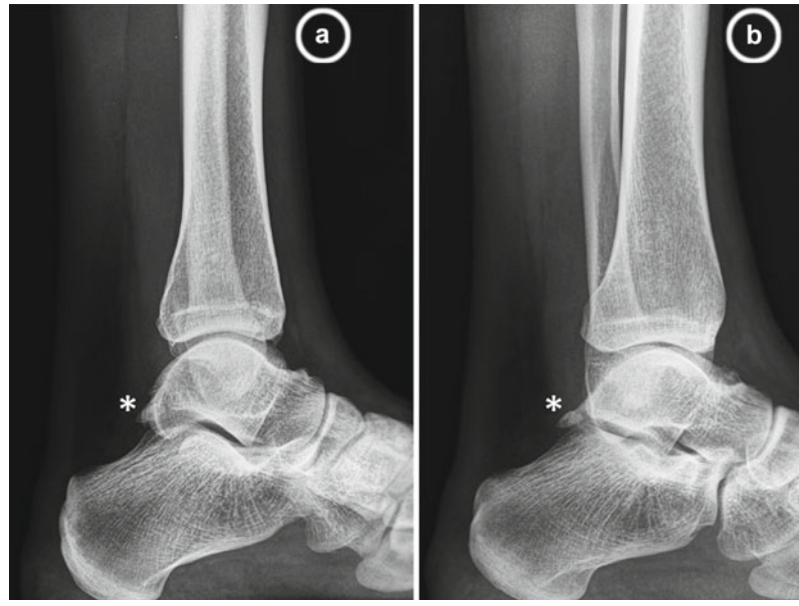

Fig. 90.3 (**a**) Standard lateral weight-bearing radiograph of the ankle can be negative in relation to a prominent posterior talar process/os trigonum (*). (**b**) By tilting the beam into a 90° craniocaudal direction with the leg in neutral position and the foot in neutral flexion, bony anomalies in the posterior ankle can more precisely be exposed (* os trigonum)

ion, external rotation, and eversion movements are considered during clinical testing.

Inversion and internal rotation movements of the ankle are being performed during the clinical setup while performing a posteromedial compression. In general, a diagnostic infiltration with bupivacaine is an excellent extra tool to diagnose posterior ankle impingement, since a positive local anesthetic injection can easily confirm the condition.

In football, the typical symptomatic athlete will present with a history of previous ankle injuries [3]. On history taking, the main symptoms are persistent posteriorly located ankle pain during plantar flexion movements or while kicking the ball, post-exercise ankle swelling, and restricted dorsal as well as plantar flexion. With an adapted training program, most players can continue playing. Sometimes taping the ankle joint can help.

The physical examination reveals recognizable pain on palpation along the posterolateral and/or posteromedial part of the ankle joint. The patient will recognize the pain on palpation or on provocation with plantar flexion provocation test. In plantar flexion, the flexor hallucis longus tendon is further entrapped in the retinaculum, and the posterior structures are crushed in the narrowed posterior ankle space, inducing pain and possible synovial swelling. The optimal palpation position is at slight ankle plantar flexion.

90.5 Diagnostic Imaging

Standard weight-bearing lateral and anteroposterior radiographs can detect a posteriorly located os trigonum, but might be false negative. Due to the posterior overlap with the fibula in the standard lateral radiograph, there is a possible over-projection, and an os trigonum or an elongated posterior talar process might be missed. The straight lateral ankle (posterior impingement) view is recommended to detect the posterior osseous structures causing impingement. As compared to the standard lateral projection, the beam is tilted into a 90° craniocaudal direction with the leg in neutral position and the foot in neutral flexion (Fig. 90.3). Routine computed tomography (CT) or magnetic resonance imaging (MRI) for the posterior impingement syndrome is not advised, although MRI has a high sensitivity to detect the (posteromedial) soft tissue impediments.

Ultrasound and conventional MRI have a debatable role in the athletic population.

A CT scan is most sensitive in detecting small calcifications in the posterior ligament complex or small loose bodies as well as a small os trigonum or even a Cedell (posteromedial tubercle) fracture. Ultrasound might be helpful, since hypervascularity of the synovial or meniscoid mass seems to depend on the repetitive injuries and the amount of the fibrosis in it. An additional advantage of ultrasonography over MRI is the possibility to directly infiltrate the inflamed tissue with steroids in a controlled manner, most suitable posterolaterally.

Although some authors have proposed MR arthrography enabling a high sensitivity and specificity as an additional diagnostic tool to diagnose posterior ankle impingement, no radiographic series have been published in the literature up to present. On an MR arthrography, an irregular or nodular contour of the posterior soft tissues is considered to be pathological and would be highly correlated to ankle scar tissue and synovitis at arthroscopy. Our conclusion is that posterior impingement is a clinical diagnosis and imaging assists in understanding the cause of the posterior impingement pain as well as in facilitating the meticulous preoperative planning that is the secret to success.

90.6 Classification

Up to the present, there is not a uniform classification system for posterior ankle impingement. However, a distinction between bony and soft tissue impingement is often made.

90.7 Treatment

90.7.1 Conservative Treatment

Conservative treatment, consisting of intra-articular injections and physiotherapy, is

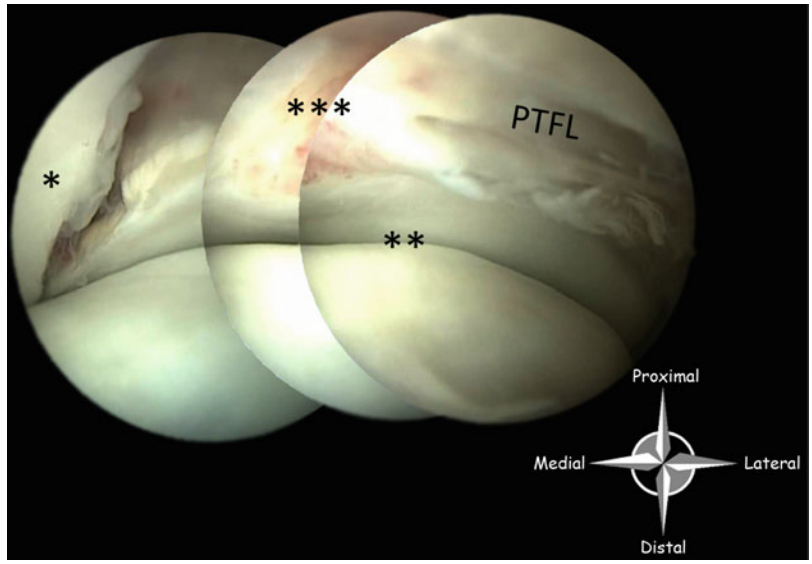

Fig. 90.4 Arthroscopic image of the posterior ankle compartment in a right ankle indicating the good exposure of the subtalar joint (**). Again proximally to the subtalar joint, the posterior talofibular ligament can be identified (*PTFL*), inserting in the posterior talar process (**). The flexor hallucis longus (*) should always be identified prior to treating posterior ankle pathology through posterior ankle arthroscopy

recommended in the early stages, but has never been systematically studied and might frequently be unsuccessful by itself.

90.7.2 Invasive Treatment

Hindfoot endoscopy enables the surgeon to more easily assess the posterior ankle compartment (Fig. 90.4), as compared to open surgery. Also it compares favorably to open surgery with regard to an overall lesser morbidity and quicker recovery [6, 7, 9].

In the initial description of the technique, the main indications to perform a posterior ankle arthroscopy were the treatment of an os trigonum and FHL pathology (Fig. 90.5). Nowadays however, numerous ankle pathologies in our athletes can be treated through this minimal invasive technique, and still indications are added.

The procedure is carried out in an outpatient setting under general or spinal anesthesia [3, 6]. The patient is positioned in the prone position with a tourniquet above the knee at the affected side. The affected ankle is positioned just over the edge of the operation table and is supported to allow free ankle movement (Fig. 90.6).

The anatomical landmarks for portal placement are the sole of the foot, the lateral malleolus, and the medial and lateral borders of the Achilles tendon. With the ankle in the neutral position (90°), a straight line, parallel to the sole of the foot, is drawn from the tip of the lateral malleolus to the Achilles tendon and is extended over the Achilles tendon to the medial side (Fig. 90.7). The posterolateral portal is located just proximal to – and 5 mm anterior to – the intersection of the straight line with the lateral border of the Achilles tendon (Fig. 90.8).

The posteromedial portal is located at the same level as the posterolateral portal, but on the medial side of the Achilles tendon.

Before addressing any pathology, the FHL tendon should be localized since, just medially to it, the posterior neurovascular bundle is located. Therefore the FHL tendon determines the working area, which is basically only laterally to this tendon. Once this working area is determined, the whole spectrum of posterior pathology can be treated supero-inferiorly from the talocrural over the subtalar joint toward the Achilles tendon insertion and mediolaterally from tarsal tunnel release toward the peroneal tendons (Fig. 90.9).

Now the pathology can be addressed, ranging from debridement of soft tissue to the removal of a hypertrophic posterior talar process (Fig. 90.10),

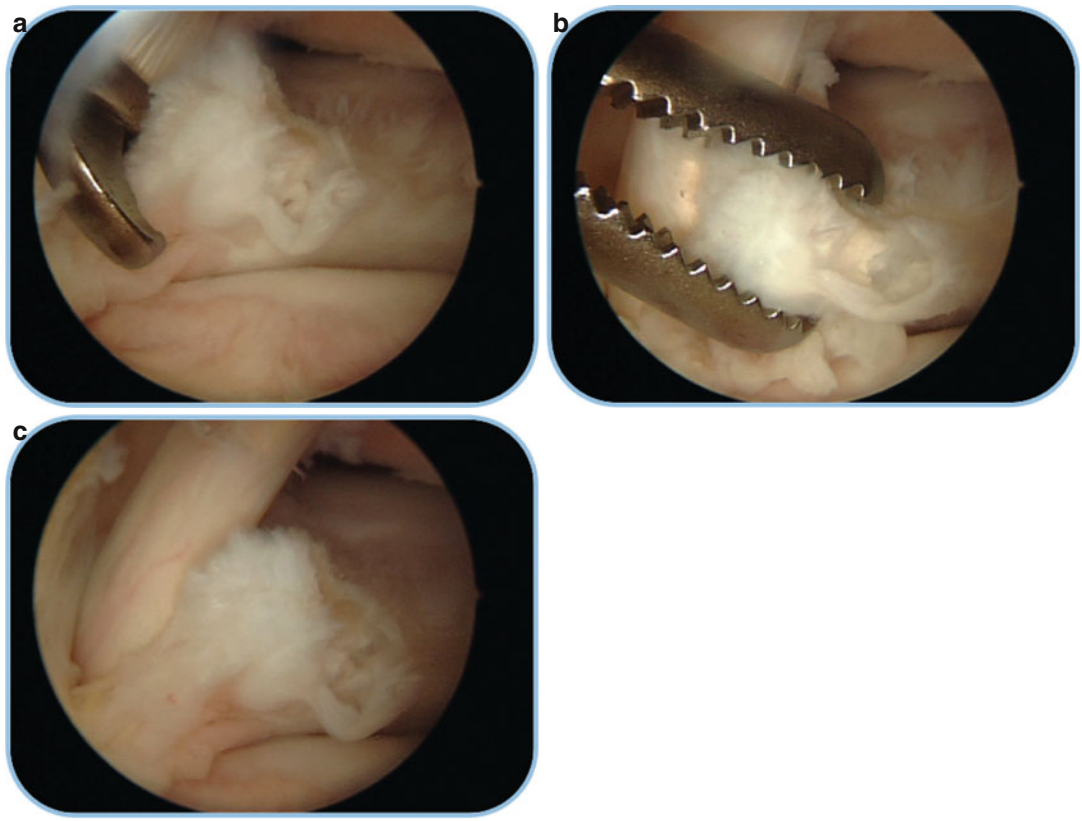

Fig. 90.5 Arthroscopic image in a right ankle treating the os trigonum pathology. (**a**) The os trigonum is released from the posterior talofibular ligament with the use of a punch. (**b**) Subsequently the os trigonum is removed with a grasper (* flexor hallucis longus). (**c**) Postoperative situation; fraying of the flexor hallucis longus (*) can be visualized, indicating the prior impingement by the os trigonum

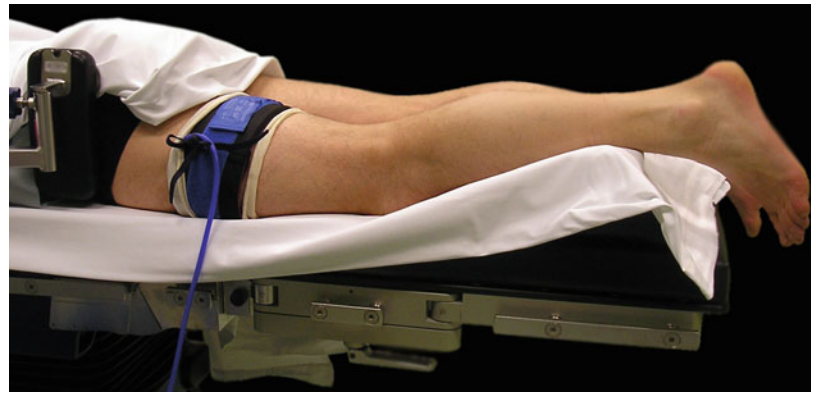

Fig. 90.6 Patient positioning in posterior ankle arthroscopy; the hip at the affected side is supported, a tourniquet is applied, and the lower leg is elevated allowing free ankle movement

an os trigonum, or the release of the FHL tendon from its adjacent structures.

Beyond the scope of this chapter are some other indications that can be addressed by the posterior endoscopic ankle technique:

- Fibular groove deepening in case of recurrent peroneal tendon dislocation
- Endoscopic tarsal tunnel release
- Addressing a Cedell fracture or prominent posteromedial talar tubercle

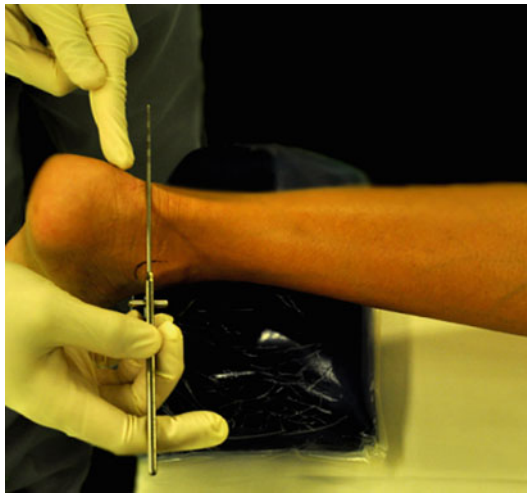

Fig. 90.7 The lateral malleolus is marked; a probe can be used to identify the level of the posterolateral and posteromedial portal. These are located at the level of the lateral malleolus, lateral and medial to the Achilles tendon

- Osteochondral defect treatment for a posteromedial/posterolateral talar dome lesion or talar cyst

Hindfoot endoscopy can be also used for the treatment of talar body fractures, intraosseous talar cysts (that are localized posteriorly in the ankle) and pigmented villonodular synovitis (PVNS). This is a condition that can be localized in the posterior ankle compartment, and it can invade the whole posterior part of the talus, extending proximally up to the FHL tendon sheath.

Furthermore, Achilles tendinopathy/denervation and Haglund's syndrome pathology in the ankle can nowadays also successfully be addressed by a posterior minimal invasive two-portal endoscopic technique in the sports population. This condition requires a more distally aimed two-incision technique that covers the pathology all the way up to the Achilles tendon insertion.

Significant advantages of the posterior ankle endoscopy include lower morbidity, shorter postoperative hospitalization time, and quicker return to full sports. It is a safe and effective method for treating posterior ankle pathology and is an attractive alternative to open surgery for experienced arthroscopic surgeons. The most influential indication to perform posterior ankle arthroscopy remains the treatment of os trigonum and FHL release.

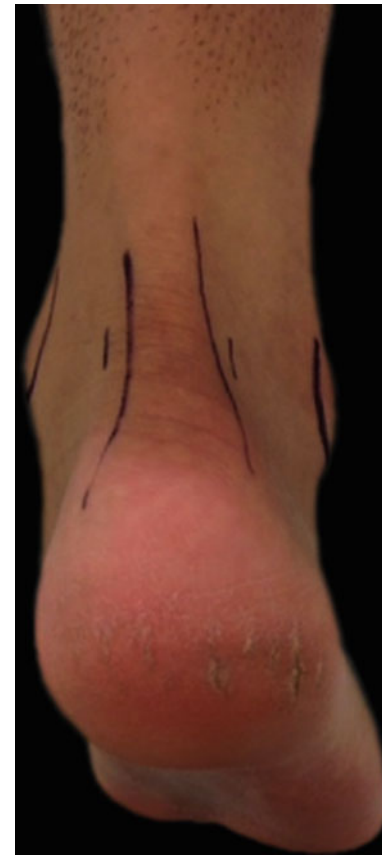

Fig. 90.8 Right ankle in which the posterolateral and posteromedial are marked

90.8 Rehabilitation

Postoperative rehabilitation treatment consists of a compression bandage and partial weight bearing for 3–5 days. The athlete is instructed to actively plantarflex and dorsiflex the ankle and foot upon awakening and to repeat this exercise a few times every hour for the first 2–3 days after

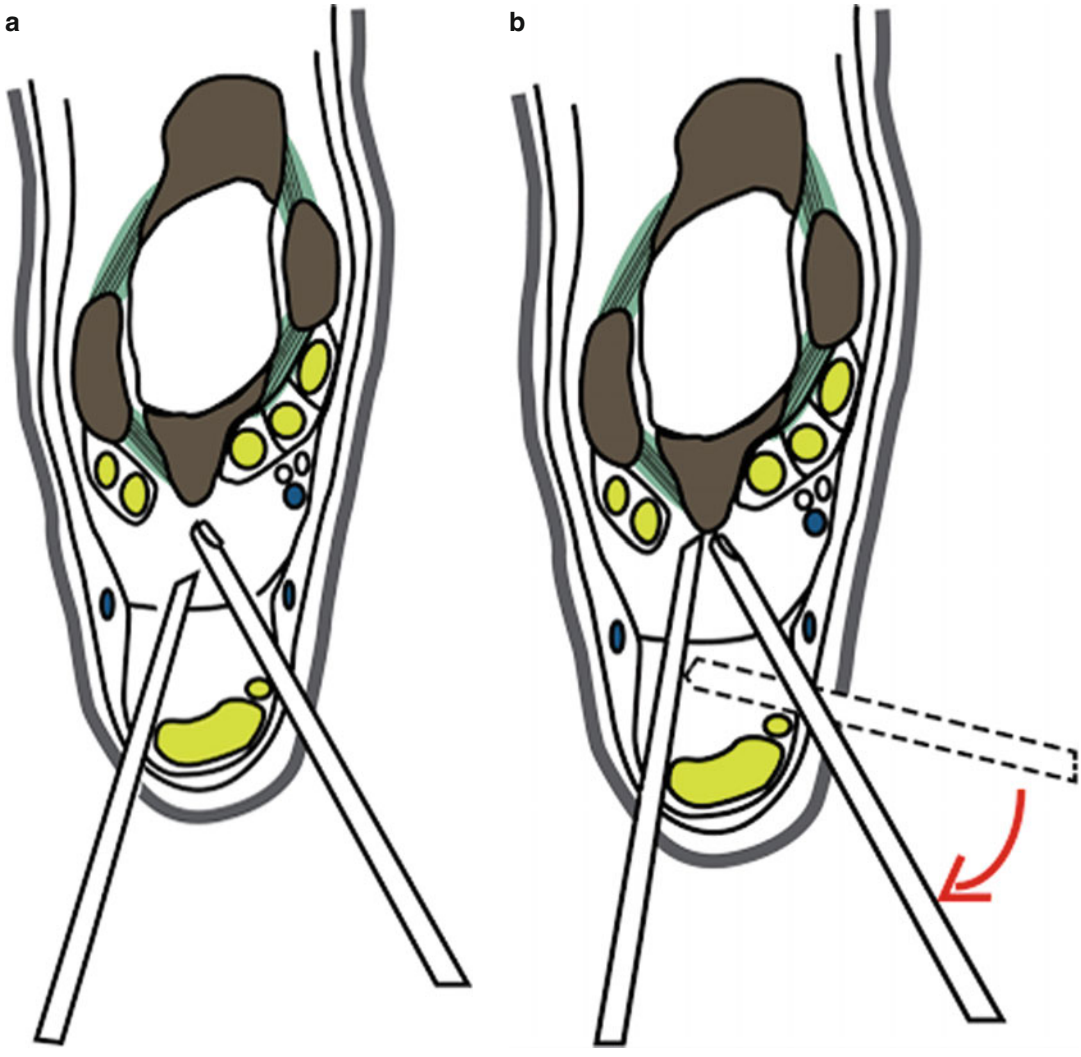

Fig. 90.9 Determining the working area for arthroscopy in posterior ankle pathology. (**a**) During the insertion, the arthroscope is aiming toward the first web space, in between the first and second toe. This enables the surgeon to determine the safe working area. (**b**) After insertion, the arthroscope is turned in a horizontal fashion to broaden the working area after identification of the flexor hallucis longus. Copyright: P. d'Hooghe

surgery [5, 10]. The added value of physical therapy has insufficiently been documented. A small retrospective series showed that patients receiving more than 1 month physical therapy scored better on a 7-point ankle scale as compared to the ones who were not treated with physical therapy [11]. In absence of high-level evidence, physical therapy with a focus on restoration of dorsiflexion, reduction of swelling, functional training, and supervised return to sports-specific training after 6–8 weeks is advised.

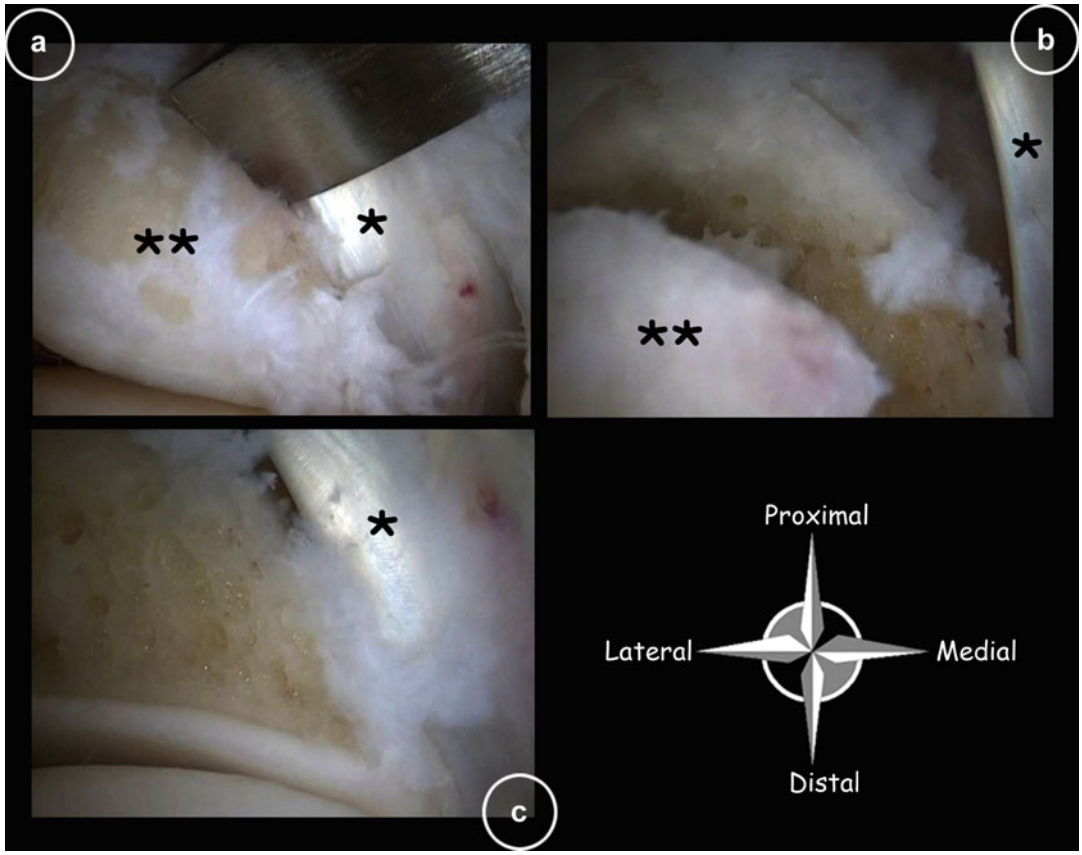

Fig. 90.10 Arthroscopic image of a left ankle indicating the removal of a hypertrophic posterior talar process. (**a**) With the use of a chisel, the hypertrophic part (**) can be removed, special attention to not damage the flexor hallucis longus (*) and to not remove too much bone, thereby damaging the subtalar joint

Conclusion

Posterior ankle arthroscopy is a challenging, safe, reliable, and effective technique in the treatment of posterior ankle impingement. Posterior ankle impingement is not always just a bony pathology. Frequently, it also presents as a soft tissue impediment with or without a bony component that needs consideration. Due to the improved functional outcome after surgery and a quicker rehabilitation time, athletes can hugely benefit from this technique. The initial indications include flexor hallucis longus and os trigonum pathology. Nowadays however, this technique can be used for an increasing amount of posterior ankle pathologies.

How to Diagnose Posterior Impingement of the Ankle

- Ask for sports-specific repetitive ankle movements.
- Perform a hyperplantar flexion movement of the ankle.
- Look for palpatory pain along the course of the flexor hallucis longus (FHL).

How to Treat Posterior Impingement of the Ankle

- Perform a diagnostic injection.
- Start with the standardized two-portal hindfoot technique after initial cadaveric training.

- Search for the flexor hallucis longus (FHL) tendon and the posterior talofibular ligament (PTFL) as these are the main anatomical landmarks.

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Arthroscopy of Subtalar Joint

91

Xavier Martin Oliva, Juan Manuel Rios,
and Matteo Guelfi

91.1 Subtalar Anatomy

The inferior side of the talus and the superior side of calcaneus form the surfaces of the subtalar joint. The talus is an irregularly shaped tarsal bone, covered by articular cartilage on more than 60 % of its surface and with no muscle insertions. The talus can be easily divided into three parts: the body, neck, and head.

The body of the talus is provided with the trochlea tali on its superior side, which is semicylindrical, [1, 2] wider in front than at the back (approximately 5–6 mm). On the bone's inferior side, three articular surfaces serve for the articulation with the calcaneus, and several variously developed articular surfaces exist for the articulation with ligaments. The posterior facet is a saddlelike joint and is also the largest of all three, with a concave shape in the long axis, and, unlike the anterior and middle facets, it is always by itself (Fig. 91.1).

When we examine the superior surface of the calcaneus, we find three articular facets that mirror those of the talus (Fig. 91.1). Another key structure of the calcaneus is the "sustentaculum tali" in which the talus leans over. This structure also provides a surface for the sliding of ankle flexor tendons [1, 3].

Between the articulation of the posterior and middle articular facets, we can find a deep groove, the sinus tarsi, which runs obliquely forward and lateralward. This structure is broader and deeper in front filled up in the fresh state by the interosseous talocalcaneal ligament [4].

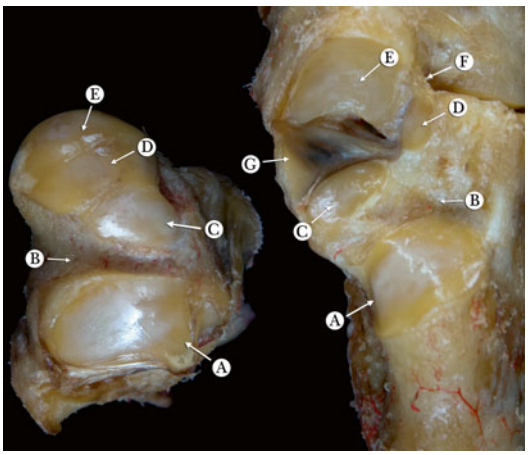

Fig. 91.1 Anatomy of the subtalar joint of a right foot. Superior view of the calcaneus and inferior view of the talus. The talus has been separated and overturned. (**a**) Posterior subtalar articular surface. (**b**) Sinus tarsi. (**c**) Middle subtalar articular surface. (**d**) Anterior subtalar articular surface. (**e**) Talonavicular surface. (**f**) Calcaneonavicular part of bifurcate ligament. (**g**) Spring ligament

X.M. Oliva (✉)
Medicine Faculty, Barcelona University,
Barcelona, Spain
e-mail: xmoliva@inbox.com

J.M. Rios
Foot and Ankle Unit Consultant,
Consorci Sanitari Integral, Barcelona, Spain

M. Guelfi
Orthopaedic and Traumatology Division,
University "G. d'Annunzio" of Chieti and Pescara,
Chieti, Italy

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In a thorough review of literature, it is hard to find a unique description about the sinus tarsi ligaments [5]. The first reference we find of a consensus on the three ligaments within the sinus tarsi comes from Smith [6], who describes an anterior band of the interosseous talocalcaneal ligament (the cervical ligament or the ligament of Fick), a posterior band of the interosseous talocalcaneal ligament (the interosseous talocalcaneal ligament or ligament of Farabeuf), and a cruciform ligament or "ligament of Retzius" (Fig. 91.2).

According to Maceira et al., the articular surfaces of the subtalar joint (STJ) are much like sections of cylinders [1]. The posterior STJ shows a concave facet at the talus, whereas the anterior STJ has a concave facet at the calcaneus.

In the STJ the articular contact pattern seems to be gliding, as opposed to rolling contact. In a gliding contact pattern, the axis of motion passes through the geometric center of the convex surface [1]. The center of rotation of the STJ passes through the geometric center of the talar head and the geometric center of the calcaneal posterior surface or thalamus.

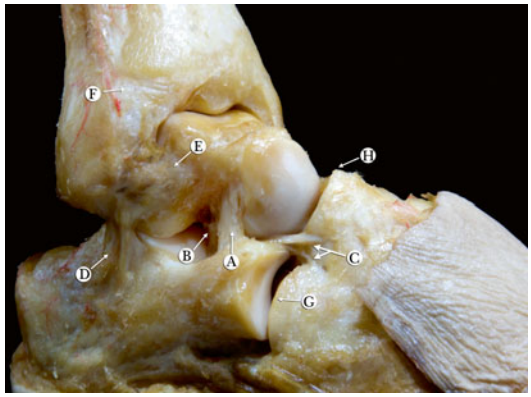

Fig. 91.2 Anatomy of the subtalar joint and its ligaments, lateral view of a right foot. Dorsal talonavicular ligament and dorsal calcaneocuboid ligament have been dissected, and forefoot is slightly adducted to better exposure of joint lines. (**a**) Cervical ligament. (**b**) Interosseous talocalcaneal ligament. (**c**) Bifurcate ligament with calcaneocuboid and calcaneonavicular part. (**d**) Calcaneofibular ligament. (**e**) Anterior talofibular ligament. (**f**) Anterior tibiofibular ligament. (**g**) Calcaneocuboid joint. (**h**) Talonavicular joint

Henke has already described the STJ axis going from anterior, dorsal, and medial to posterior plantar and lateral [7]. There is triplanar motion in the STJ axis occurring simultaneously.

91.2 Biomechanics of the Subtalar Joint

The subtalar joint acts as a hinge with beveled surfaces connecting the talus and the calcaneus. There is a cooperative function between the STJ and the ankle which allows some additional leg rotation that would not be possible by the sole obliquity of the ankle joint axis. Individual variations are extensive and impart variability to the behavior of this joint during locomotion.

If the axis of the hinge between the talus and the calcaneus is at 45°, a simple torque converter has been created. This explains how rotation of the talus can produce rotation of the calcaneus. We also have to take into account that a more horizontally placed hinge (pes planus) causes a greater rotation of the horizontal member for each degree of rotation of the vertical member; the reverse holds true if the hinge is placed more vertically (pes cavus) [8].

The two basic movements of the STJ during gait are pronation and supination. Pronation is a triplanar motion that includes dorsiflexion on the sagittal plane, abduction on the transverse plane, and eversion on the coronal plane. Supination is a triplanar motion combining adduction around a vertical axis, plantar flexion through a transverse axis, and inversion on the longitudinal axis [9].

Fusion of the talonavicular joint completely blocks motion at the STJ, but not oppositely; fusion of the STJ allows for significant motion at the neighboring joints [10].

91.3 Indications of Posterior Arthroscopic Procedures in the Subtalar Joint

Since the year 2000 when Van Dijk introduced the two-portal posterior approach for hindfoot arthroscopy with the patient in the prone

position, an important change has taken place in the surgical treatment of ankle and subtalar lesions [11].

There are general indications for an arthroscopy of the subtalar joint [12, 13]:

- Posterior ankle bone impingements (FHL tendinitis isolated or associated with trigonum or with mega Stieda process) [14]
- Posterior soft tissue impingement
- Subtalar arthrodesis
- Assisting fracture reduction

There are also contraindications that should be taken into account, for example, localized soft tissue infection (absolute), severe edema, and vascular disease, including diabetic vascular disease [15].

In the subtalar arthrodesis by posterior ankle arthroscopic procedures, the contraindications are:

- Severe deformities in varus/valgus of the hindfoot such as some sequels of calcaneal fractures [16, 17].
- Single- or multiplane deformities [18].
- Failed arthrodesis which requires an open approach and extended debridement [19].
- Valgus deformity secondary to coalition presents special difficulties when being corrected [20].

91.4 Posterior Impingement

Pain is caused by an abnormal movement between the os trigonum and talus or compression of a thickened joint capsule/scar tissue between the os trigonum and the posterior tibial rim.

The main procedures to be performed are resection of an os trigonum, reduction of a prominent posterior talar process, and resection of the intermalleolar ligament. All these conditions could be affiliated as probable cause and also related to a flexor hallucis longus (FHL) tendinitis [21].

Flexor hallucis longus tendinitis is often present in patients with posterior ankle impingement syndrome, with the pain located posteromedially.

During examination there is pain on palpation of the posterior aspect of the talus. The posterior talar process can be palpated posterolaterally between peroneal tendons and the Achilles tendon. On the posteromedial side, the neurovascular bundle and flexor tendons cover the talus. Posteromedial pain on palpation therefore does not automatically indicate impingement pain. The passive forced plantar flexion test is the most important. With this test the examiner performs repetitive quick passive forced plantar hyperflexion movements [22].

We always confirm the diagnosis with a posterolateral anesthetic infiltration and with an radiographie (XR) study.

Release of the FHL tendon can be performed by resection of the flexor retinaculum, removal of adhesions, and release of the flexor tendon sheath [21].

Overuse injuries associated with posterior impingement often occur in ballet dancers and runners, whereas acute symptoms result from a hyperplantar flexion or supination trauma, predominantly in soccer players. In one study posterior ankle impingement caused by overuse seemed to have a better prognosis [23]. An os trigonum is usually not the cause of impingement on its own. This anatomical anomaly must be combined with a traumatic event such as a supination trauma, dancing on hard surfaces, or pushing beyond anatomical limits to cause pain. Pain is caused by an abnormal movement between the os trigonum and talus (Fig. 91.3) and

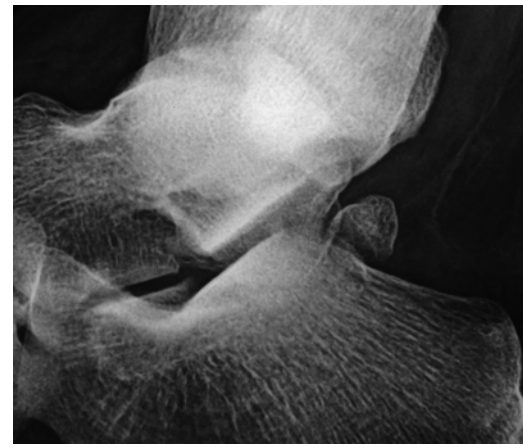

Fig. 91.3 XR of trigonum

compression of a thickened joint capsule or scar tissue between the os trigonum and the posterior tibial rim.

Van Dijk's group's research into retired dancers is interesting. They analyzed the average length of ballet dancers' careers that spanned 37 years. All of the dancers had been dancing en pointe. None of these dancers had suffered a posterior ankle impingement syndrome. A hypertrophic posterior talar process or an os trigonum was present in 18 of the 38 investigated ankle joints. The presence of an os trigonum itself therefore does not seem to be relevant. This anatomic anomaly must be combined with a traumatic event such as supination trauma, dancing on hard surfaces, or pushing beyond anatomic limits. The pain is caused by an abnormal movement between the os trigonum and talus or compression of a thickened joint capsule/scar tissue between the os trigonum and the posterior tibial rim [24].

Conservative treatment (physical therapy, anti-inflammatory drugs, local injection) is effective in approximately 60 % of the patients according to Hedrick and McBryde [25]. If, after 3 months, conservative treatment fails to correct the symptoms, the adequate choice would be hindfoot endoscopic surgery.

Besides ankle impingement treatment, subtalar arthroscopy has two excellent indications.

91.5 Degenerative Arthritis of Subtalar Joint

The arthroscopic treatment of this pathology can be done under the same indications as those mentioned in the literature for the open procedure, except in large deformities, and for female patients, arthroscopic access is not viable.

We could also delimitate the main indication for a posterior arthroscopic arthrodesis of the subtalar joint:

- Posttraumatic osteoarthritis (68 % sequels of calcaneal fractures)
- Painful talocalcaneal coalition
- Inflammatory and primary osteoarthritis of the subtalar joint

In patients with soft tissue problems, the arthroscopic arthrodesis is a very good option that almost completely avoids wound complications [22, 26].

91.6 Fractures

Literature has shown without doubt that anatomic restoration of the calcaneal shape and joint congruity predict greater functional scores [27, 28] and a lower incidence of posttraumatic subtalar arthritis [29].

There are common significant risks of wound problems with open reduction and internal fixation of a calcaneus fracture, with reported rates of deep infection of 8–25 %, with superficial infection occurring in 40 % and wound necrosis in around 14 %.

In calcaneal fractures with little displacement and a fragment that allows mobilization, an arthroscopic reduction and fixation with minimal incision can be attempted [30]. This can be achieved elevating the depressed posterior facet percutaneously under image intensifier guidance and at the same time performing an arthroscopy using two sinus tarsi portals and often a third posterolateral portal.

91.7 Surgical Technique and Our Tricks

We use the posterior ankle approach to perform the FHL and posterior impingement liberations and for the subtalar arthroscopic procedures.

The patient is placed in the prone position with the foot hanging off the operating table and a support under the tibia, to allow plantar and dorsal flexion and eversion and inversion of the ankle joint. This position is preferred to the lateral position. Skin traction is avoided.

The equipments necessary to complete the procedure are:

- 4-mm arthroscope
- 2.7-mm arthroscope for tight joints
- Curettes

- Chisels
- Drill
- Shaver

Two posterior arthroscopic portals are recommended, while other authors recommend three portals [31]. Precise placement of portals is important in order to avoid neurovascular bundle injury and to allow proper articular access. The tibial nerve and vascular structures are at an average distance of 6.8 mm from the FHL [32] (Fig. 91.4).

The posterolateral portal is first made 1 cm proximal to the distal point of the lateral malleolus and adjacent to the lateral edge of the Achilles tendon. The posteromedial portal is made at the same level on the medial edge of the Achilles.

The scope is introduced through the posterolateral portal directed toward the second metatarsal, until the posterior part of the talus bone can be felt. If the instruments are introduced through the posteromedial portal in the same direction, damage to the posterior tibial nerve is very probable. To avoid this complication, the blunt trochar is introduced through the posteromedial incision, and after reaching the Achilles tendon, it is turned 90° laterally, until the sheath of the optical device can be felt. Keeping this metallic contact, we slide the trochar along the sheath until reaching the posterior part of the tibiotalar articulation or the talus.

Clear vision of the posterior part of the ankle joint is often obstructed with abundant fatty tissue, and it is important to spend time clearing it away with a shaver and blunt trochar using gentle movements. The main objective is to visualize the FHL tendon, the posterior intermalleolar ligament, the posterior tibioperoneal ligament, and tibiotalar and subtalar articular surfaces. It is important to stay lateral to the FHL tendon because that way we can protect the posterior tibial neurovascular bundle.

The resection of the talocalcaneal ligament allows visualization of the subtalar articular surfaces.

Having identified the articular structures and the FHL, we are able to perform a careful resection of the trigonum (Fig. 91.5) and in other patients a resection of an enlarged Stieda process (Figs. 91.6 and 91.7). During these procedures, in some cases, we use an elastic vessel loop to separate the FHL tendon and avoid its lesion (Fig. 91.8).

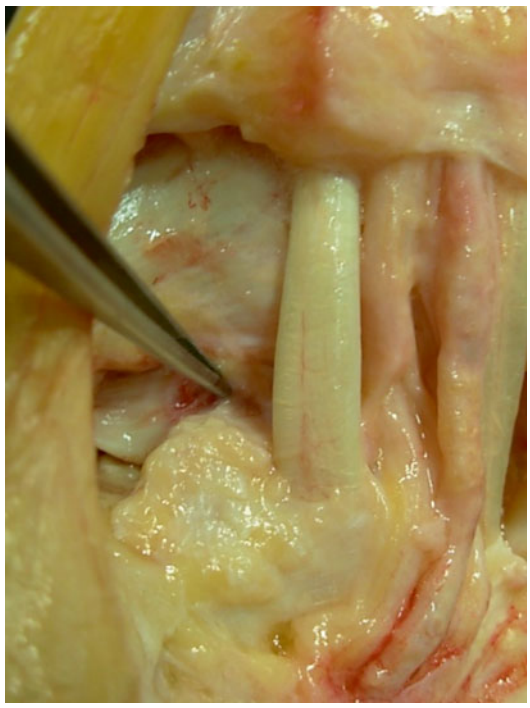

Fig. 91.4 We observe the distance between FHL and posterior tibial nerve

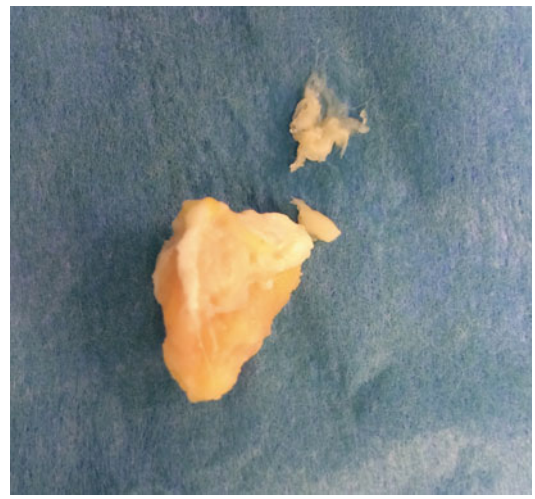

Fig. 91.5 Trigonum fragment after resection

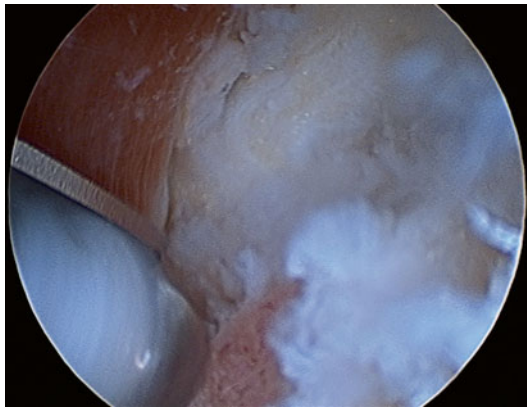

Fig. 91.6 We are using the burr during a resection of mega Stieda process

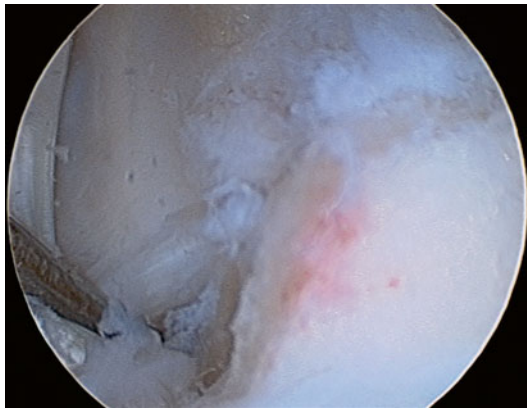

Fig. 91.7 We can observe the FHL completely liberated of the mega Stieda process

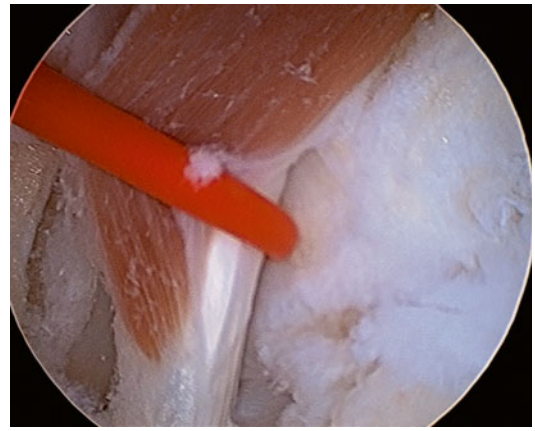

Fig. 91.8 In some cases we use a elastic vaselap to separate the FHL tendon and avoid its lesion during the resection of bone impingements

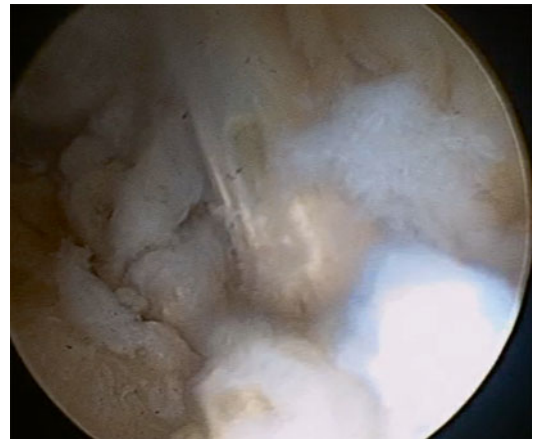

Fig. 91.9 Chronic FHL tendinitis. We can observe a fibrosis around the tendon

Also we perform with a radio-frequency wand a release of the FHL in cases of chronic tendinitis (sometimes the cause is posttraumatic), or we can also use a punch for the release (Figs. 91.9 and 91.10). Occasionally we resect the intermalleolar ligament in case it causes a conflict of space.

Another important indication is the fusion of the subtalar joint.

In patients presenting traumatic sequels, identification of the subtalar articulation may be difficult. To make this easier, the blunt trochar can be used to open the joint. In case of doubt, we can use image intensifier control.

If we perform a subtalar arthrodesis, we carry out the same approach that we described earlier. We start with the resection of the joint surfaces, using a shaver, burr, chisel, or curette. We start the resection of the articular surfaces with the shaver and also with chisel (Fig. 91.11), and when we have enough space, we use a burr or a curette and progress until we arrive to the anterior edge of the posterior subtalar facet (Fig. 91.12).

A complete cartilage resection of the articular surfaces must be carried out. The most critical part is the medial and lateral edges of the posterior subtalar joint in order to achieve optimum surface contact for the correct consolidation of the fusion. Finally, we place two cannulated screws in the posterior facet of the subtalar joint. We do not usually use bone graft owing to the

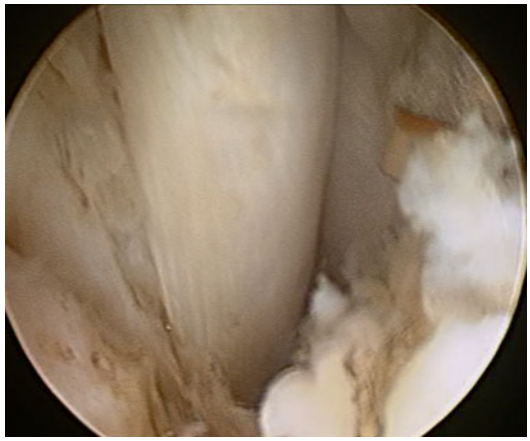

Fig 91.10 We can observe the FHL completely liberated after our release

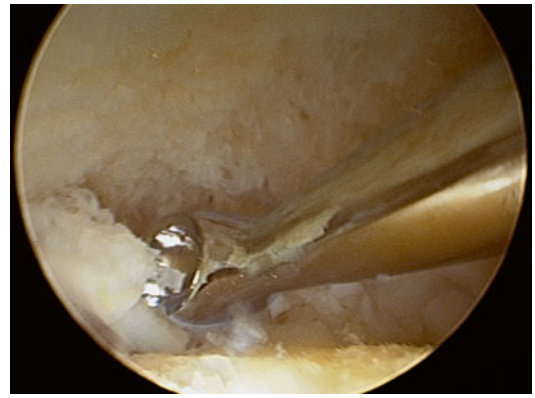

Fig. 91.12 During arthroscopic subtalar arthrodesis, when we have enough space, we use curette during the cartilage resection

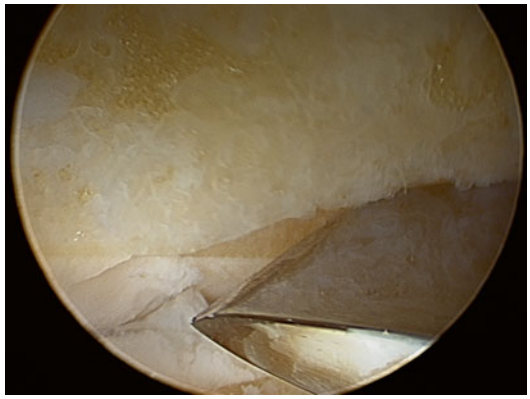

Fig. 91.11 During arthroscopic subtalar arthrodesis, often we start the resection of the joint surfaces using a chisel

fact that studies available do not show better results for the rate of fusion in comparison to patients not using bone graft [33].

Some authors recommend a lateral accessory portal, in order to introduce instrumentation with the aim of mobilizing the articulation and to facilitate the arthrodesis technique. We do not use this third approach because we do not consider it necessary [34].

Our postoperative protocol for arthroscopic subtalar arthrodesis consists of a 4-week immobilization of the ankle joint and nonweightbearing for approximately 6 weeks. After this period, the patient can start with partial and progressive weightbearing. In our series we have an average time until the complete fusion of 8–9 weeks (range of 7–15 weeks), similar to the publications of Tasto [35] and Perez Carro [36].

91.8 Complications

There are some common complications in the arthroscopic treatment of this joint. Nickisch and colleagues [37] studied 186 hindfoot arthroscopies with 8.5 % of complications that included four plantar numbness, three sural nerve dysesthesia, four Achilles tendon tightness, two complex regional pain syndrome and two infections, and one cyst at the posteromedial portal. Finally, one case each of plantar numbness and sural nerve injury could not be resolved. We are of aware of the incidence of nerve damage; to avoid it, we have to be especially careful with our approaches and maneuver in a delicate manner when performing articular resection and releasing structures [32].

In their systematic review, Donnenwerth and Roukis [38] reported complications in 3.8 % of 452 patients who underwent hindfoot endoscopy. These included wound-healing problems, recurrent symptoms, neuritis of the medial calcaneal nerve, transient incision anesthesia, traumatic sural neuroma, and transient superficial peroneal neuritis; only 1.8 % required additional treatment or operative intervention.

In a revision of our patients treated by posterior ankle arthroscopy, we found 3.4 % of complications. These included medial calcaneal nerve dysesthesia, spontaneously solved at 6 months, and wound-healing problems.

Zengerink reported 2.3 % complications in 315 consecutive hindfoot procedures [39].

All these studies revealed a low frequency of complications after hindfoot endoscopy. Neurologic injuries are the most important among the complications that occurred [40]. All these peripheral nerve complications could be avoided, by making a posterolateral portal just lateral to the Achilles tendon and being guided by a thorough understanding of the regional anatomy.

Conclusion

The arthroscopic approach to the ST joint allows good visualization of the articular surfaces. Advantages compared with the open approach are less soft tissue damage, a faster post-op recovery, and fewer complications. Union rates are comparable with the traditional open approach which has made this procedure the main technique for a lot of foot and ankle surgeons. Posterior tibial and sural nerve lesions are serious complications that are extremely rare due to the careful approach and maneuver used by foot and ankle surgeons. In summary, subtalar arthroscopy has become a safe and reproducible technique in the today's foot and ankle surgeon armamentarium.

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Subtalar Arthroscopic Arthrodesis 92

Peter A.J. de Leeuw and C. Niek van Dijk

92.1 Introduction

In 2009 Beimers et al. [1] described an arthroscopic technique for subtalar joint arthrodesis, based on the two-portal posterior approach for hindfoot arthroscopy [11, 12]. With the use of an additional portal, the subtalar joint can be distracted, and also this portal can be used for optimal joint debridement prior to the fusion [10].

Subtalar pathology can be divided into acquired and congenital deformities. (Post-traumatic) Osteoarthritis is the most frequent indication for arthrodesis of the subtalar joint. In the skeletal mature patients, the main congenital pathologies, requiring a subtalar arthrodesis, are coalitions. Subtalar coalitions can be either osseous, osteofibrous or cartilaginous. The coalitions around the subtalar joint predominantly cause pain due to the micromotions in the bar itself.

In this chapter the arthroscopic technique for subtalar arthrodesis based on hindfoot arthroscopy is presented.

P.A.J. de Leeuw, MD • C.N. van Dijk, MD, PhD (✉)
Department of Orthopaedic Surgery,
Academic Medical Center, University of Amsterdam,
PO Box 22700, Amsterdam 1100 DE,
The Netherlands
e-mail: p.a.deleeuw@amc.uva.nl;
m.lammerts@amc.uva.nl

92.2 History and Physical Examination

Patients with a (post-traumatic) osteoarthritis of the subtalar joint will present with the typical 'osteoarthritic' complaints. These include pain and swelling throughout the day and a diminished function. The pain frequently worsens during gait on uneven ground and depending on the degree of osteoarthritic changes; the walking distance is diminished due to the sensation of joint stiffness or pain. History taking includes asking for any trauma in the subtalar or ankle joint region; fractures of the talus, calcaneus or navicular bone are prone for the development of osteoarthritis in the subtalar joint.

In contrast to the osteoarthritic patients, patients with talocalcaneal coalitions usually present with specific hindfoot pain. In some patients complaints have started following an inversion ankle sprain resulting in (chronic) ankle instability [7]. The symptomatic coalitions mostly present in the adolescents [2]. Talocalcaneal and calcaneonavicular coalitions are the most common types of tarsal coalitions. Tarsal coalitions appear to be present in about 1 % of the population [3, 5, 7, 8].

Physical examination shows an abnormal gait and a reduced ankle inversion. Frequently, a greater or lesser degree of hindfoot valgus is seen. However, limitations in subtalar motion and valgus deformity vary in severity. The ankle and

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subtalar joint should be tested on stability. A lump may be present under the tip of the medial malleolus, which indicates the prominence of the talocalcaneal coalition. The coalition itself may be painful to pressure, specifically after a recent trauma. Finally, a tarsal tunnel syndrome may develop due to a large middle facet resulting in increased pressure on the median plantar nerve.

92.3 Diagnostic Imaging

Conventional weight-bearing radiographs in the anteroposterior and lateral direction should be made. Osteoarthritis can be detected with conventional radiographs; these may show narrowing of the joint space, loss of cartilage, subchondral sclerosis and osteophytes.

On the lateral weight-bearing radiograph, the so-called C-sign can be recognised in patients with a subtalar coalition (Fig. 92.1) [6]. The C-shaped line is formed by the medial outline of the dome of the talus and the posteroinferior outline of the sustentaculum tali [4].

A computed tomography, with reconstructions in the coronal and sagittal plane, is advised for preoperative planning.

92.4 Indications

Persistent subtalar joint pain secondary to osteoarthritis is the main indication for arthroscopic subtalar arthrodesis [9]. Another group of patients which can benefit from this procedure are those with subtalar coalitions. In general the amount of

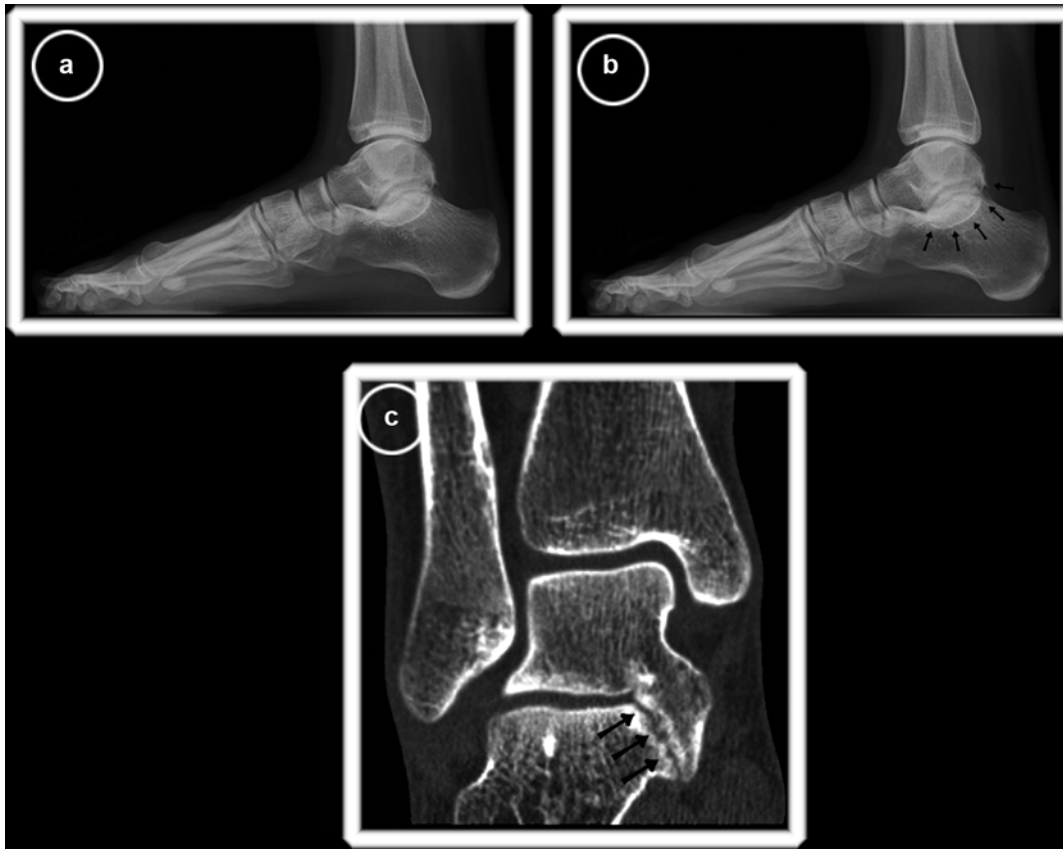

Fig. 92.1 On the lateral weight-bearing radiograph, (**a**) a talocalcaneal coalition can be recognised with the C-sign (**b**). For the preoperative planning, it is important to make a computed tomography; the location and extent of the coalition can be determined, in this case an osseous coalition (**c**)

bone loss and degree of joint deformity determine whether an arthroscopic subtalar arthrodesis can be performed. As for most orthopaedic pathologies, surgery is only indicated if the conservative treatment options have failed.

92.5 Contraindications

A contraindication for isolated arthroscopic subtalar arthrodesis is symptomatic osteoarthritis in the adjacent joints. Severe angular and rotatory deformities are also contraindications. Another contraindication is an acute or chronic infection of the joint. Relative contraindications are the diabetic- and the cardiovascular-compromised patients.

92.6 Operative Technique

92.6.1 Instruments

A solution of saline is used for irrigation during the procedure, and the flow is secured by the use of an arthroscopic pump; however, gravity with or without pressured saline bags can also be used. Routinely a 4.0-mm arthroscope is used with an inclination angle of 30°. Optimal visualisation can be obtained both because of the good flow through the cannula and the ability to change the angle in which the anatomy/pathology can be observed. Additionally a spinal needle, probes, the 5.5-mm bonecutter shaver, the large-diameter blunt trocar, small osteotomes, a mallet hammer, ring curettes and the 6.5-mm lag screws are used. At the end of the procedure, fluoroscopy is mandatory.

92.6.2 Patient Positioning

The arthroscopic subtalar arthrodesis is performed in an outpatient setting and can be performed both under general, spinal or local regional anaesthesia. The correct side is marked to prevent wrong side surgery, a tourniquet is applied at the upper leg and the patient is subsequently positioned in the prone position. Prophylactic intravenous antibiotics are given. At the level of the tourniquet, a support is placed. A second support is placed under the lower leg, just proximal to the ankle joint, to allow for a full range of ankle motion throughout the procedure (Fig. 92.2).

92.6.3 Portals

The standard portals for hindfoot arthroscopy are used. With the ankle in the 90° position, a line parallel to the sole of the foot is drawn from the distal tip of the lateral malleolus towards the Achilles tendon. The line is then extended over the Achilles tendon to the medial side, still parallel to the foot sole with the ankle in the 90° position. The posterolateral and posteromedial portal are located 1 cm anterior to the Achilles tendon and proximal to the previous drawn line. The additional third portal for arthroscopic subtalar arthrodesis is located at the level of the sinus tarsi (Fig. 92.3). The optimal location is determined intraoperatively with the use of a spinal needle. The sinus tarsi portal is used to distract the subtalar joint with the use of the larger-diameter blunt trocar. This portal is also used to debride the anterior part of the subtalar joint with the ring curettes or the bonecutter shaver.

92.6.4 Operative Technique

The posterolateral portal is made first as a vertical stab incision only affecting the skin, and a mosquito clamp is used to spread the subcutaneous layer. The foot is now in a slightly plantarflexed position. The clamp is directed anteriorly, towards the interdigital webspace between the first and second toes. When the tip of the clamp touches the bone, it is exchanged for a 4.5-mm arthroscopic cannula with the blunt trocar pointing in the same direction. The trocar is situated extra-articularly at the level of the posterior talar process and is exchanged for the 4.0-mm 30° arthroscope, directed laterally. At this time the scope is still outside the joint in the fatty tissue overlying the capsule.

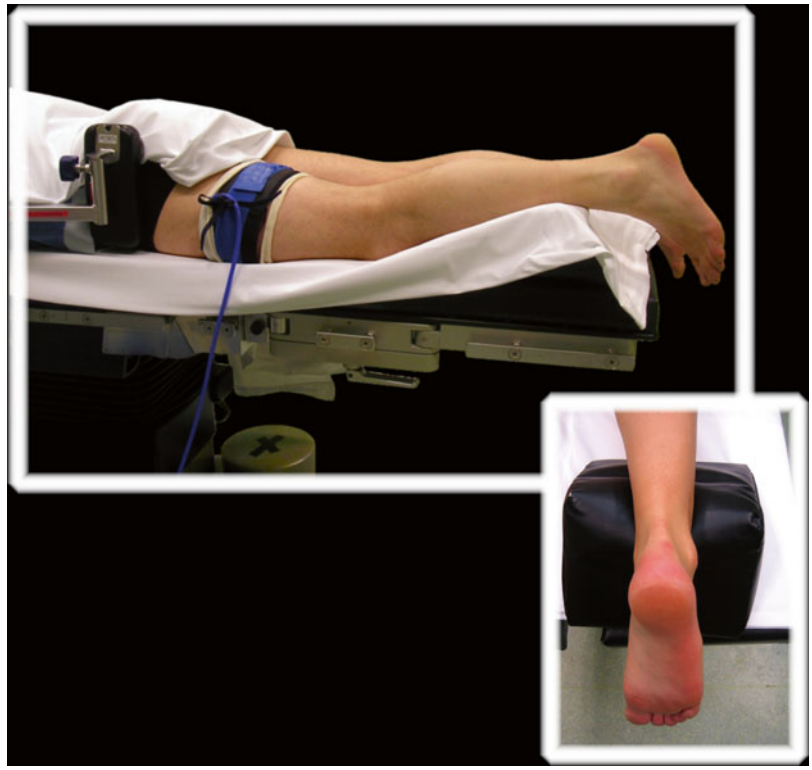

Fig. 92.2 The patient is positioned in the prone position with a tourniquet around the upper leg. Both the tourniquet and the ankle are supported, the latter to be able to move the ankle freely throughout the surgical procedure

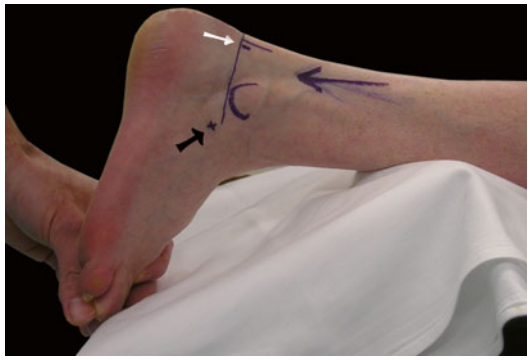

Fig. 92.3 The correct side is marked to prevent wrong side surgery (*blue arrow*). The posterolateral portal is situated at the level of the lateral malleolus, 1 cm anterior to the Achilles tendon (*white arrow*). The additional portal is located at the level of the sinus tarsi (*black arrow*)

Second the posteromedial portal is made with a vertical stab incision through the skin only, and a mosquito clamp is introduced through the posteromedial portal and is directed towards the arthroscope shaft at a 90° angle, until the clamp contacts the arthroscope. The ankle is still in a slight plantarflexed position and the arthroscope has remained in position. The arthroscope shaft is used as a guide for the mosquito clamp to travel anteriorly. While in contact with the arthroscope shaft, the clamp glides over the shaft towards the ankle joint until the bone is reached. Once the arthroscope and clamp are both touching the bone, the mosquito clamp is left in position, and the arthroscope is pulled slightly backward and tilted until the tip of the clamp comes into view. The soft tissue layer covering the joints consists of fatty tissue and the deep crural fascia. On the lateral side, a specific part of the crural fascia can be recognised, the Rouvière ligament.

The clamp is now directed to the lateral side in an anterior and slightly plantar direction. This movement creates an opening in the crural fascia just lateral to the posterior talar process. The fatty tissue and subtalar joint capsule are subsequently opened. The mosquito clamp is exchanged for a 5-mm full-radius shaver or bonecutter shaver

(Fig. 92.2). With a few turns of the shaver, the subtalar joint capsule and soft tissue are gently removed. The opening of the shaver blade is facing towards the bone. This part of the procedure is carried out in a blind fashion. The shaver is then retracted, and the scope is brought anteriorly through the opening in the crural fascia to visualise the posterolateral aspect of the subtalar joint. Once the joint is recognised, the opening in the crural fascia is enlarged to create more working area. The cranial part of the posterior talar process is freed from the Rouvière ligament and crural fascia to identify the flexor hallucis longus (FHL) tendon. The FHL tendon is an important safety landmark. The neurovascular bundle runs just medial to this tendon; therefore, the area lateral to the FHL tendon is regarded as being safe. After the identification of the FHL tendon, the specific pathology can be identified and addressed.

To ease access to the (osteoarthritic) subtalar joint, the sinus tarsi portal is now created. A spinal needle is introduced through the sinus tarsi, directed towards the tip of the lateral malleolus. At the level of the subtalar joint, the spinal needle is pointing posteriorly. The position of the needle is checked arthroscopically. If the correct position is confirmed, the portal is created. The large diameter blunt trocar (4.0 mm) is inserted through the sinus tarsi portal and is manoeuvred towards the posterior subtalar joint. The blunt trocar is now forced into the subtalar joint to open up the joint. Since the direction of the blunt trocar is almost parallel to the subtalar joint, it can be forced in a sideward direction into the joint. In case of a talocalcaneal coalition, the talus and calcaneus are connected by the talocalcaneal bar that is located at the medial side. A small-size chisel (4.0 or 6.0 mm) is placed through the posteromedial or posterolateral portal into the area of the bar. An attempt can be made to remove the bar by using the small-size chisel in order to further open up the joint. Removal of the articular cartilage of the posterior subtalar joint is performed with the shaver and the ring curettes. The different portals are interchangeably used for optimal debridement. After removal of all the articular cartilage, the subchondral bone is entered to expose the highly vascular cancellous bone. Using the small-size chisel, deep longitudinal grooves are made in the subchondral cancellous bone of the talus and calcaneus (Fig. 92.4). It is important to remove the dense subchondral bone plate and create a bleeding subchondral bone bed on both sides of the joint. A vertical skin incision is made at the tip of the heel for introduction of two lag screws. Using fluoroscopy, the 6.5-mm lag screws are placed across the posterior subtalar joint. The estimated length and direction of the two screws can be preoperatively planned on the lateral weight-bearing radiograph of the ankle. Before the insertion of the two screws, it is important to check the alignment of the hindfoot. Coaptation of the posterior subtalar joint surfaces can be checked arthroscopically when tightening the screws (Fig. 92.4f). The skin is closed using non-resorbable sutures.

92.7 Rehabilitation Protocol

A non-weight-bearing lower leg cast is provided for 4 weeks, followed by a walker boot for another 4 weeks. At 8 weeks following surgery, anteroposterior and lateral weight-bearing ankle radiographs are made. With radiographic signs of union of the subtalar arthrodesis, the patient is allowed full weight bearing without further support.

92.8 Pearls and Pitfalls

- The location of the posterolateral and posteromedial portals can precisely be determined with the use of an arthroscopic probe. By hooking the probe under the lateral malleolus and aiming it parallel to the sole of the foot with the ankle in a 90° position, a precise portal localisation can be achieved (Fig. 92.5).
- The FHL tendon must be identified prior to addressing pathology. This tendon is the important safety landmark and determines the working area; just medial to the FHL tendon, the neurovascular bundle is located.

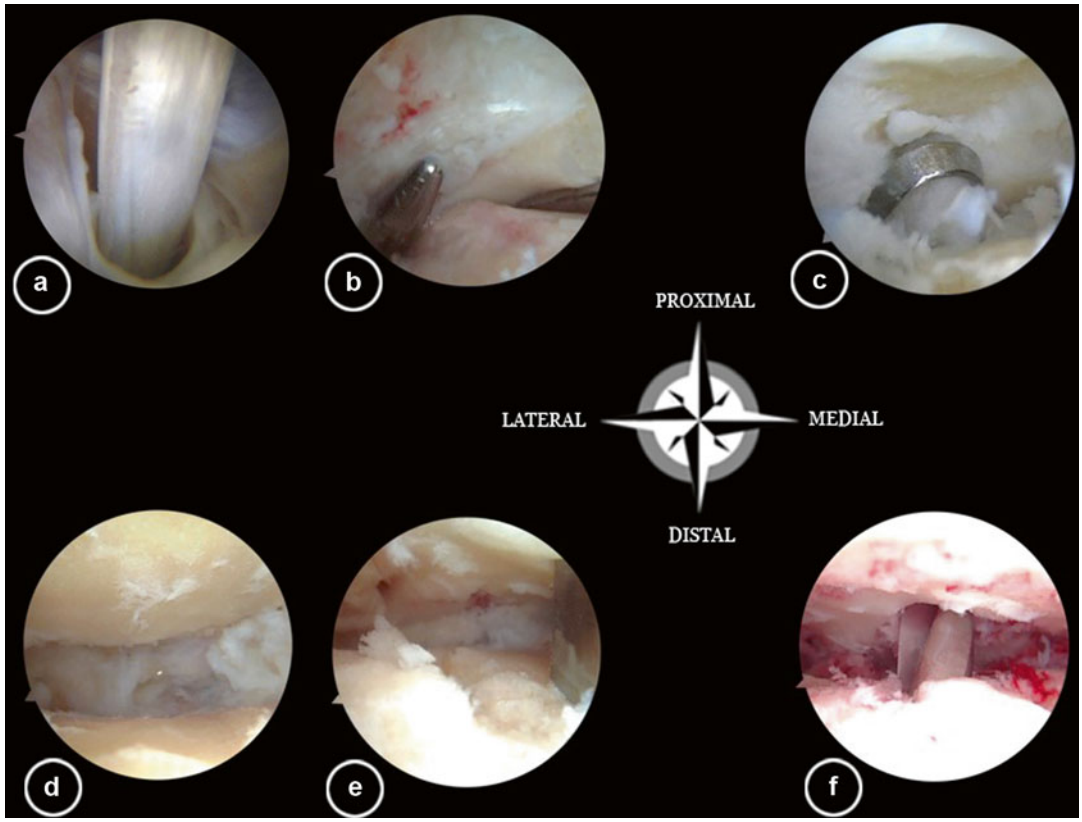

Fig. 92.4 Arthroscopic images describing the arthroscopic subtalar arthrodesis. (**a**) Before addressing the pathology, at first the flexor hallucis longus tendon must be identified to determine the safe working area. (**b**) Through the additional sinus tarsi portal, a large-diameter blunt trocar is inserted to distract the subtalar joint. (**c**) The ring curettes are very helpful for the debridement of the cartilage. (**d**) Debrided subtalar joint. (**e**) With the chisel longitudinal grooves are created to open the subchondral bone layer of both the talus and the calcaneus. (**f**) Arthroscopic assessment of the debrided subtalar joint while tightening the screws

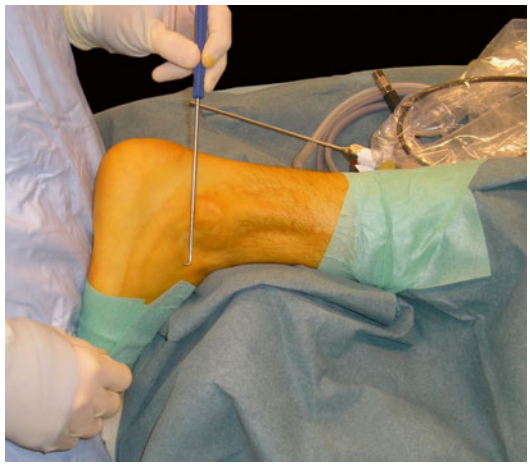

Fig. 92.5 The probe is a useful tool to determine the location of the posterolateral portal. The probe is hooked under the lateral malleolus, while the ankle is in the 90° position. The orientation of the probe is parallel to the sole of the foot. One centimetre anterior to the intersection of the probe with the Achilles tendon, the posterolateral portal is located

- The blunt trocar insertion through the accessory sinus tarsi portal is ideal for subtalar joint distraction, thereby optimising visibility to achieve a thorough joint debridement.
- Using dedicated arthroscopic instruments will ease the surgical performance [10].
- The ankle and subtalar alignment should always be checked prior to the insertion of the screws; also while tightening the screws, the alignment must constantly be checked and secured.

Conclusion

Indications for an arthroscopic subtalar joint arthrodesis can be divided in acquired and congenital deformities, (post-traumatic) osteoarthritis and coalitions, respectively. The presented technique to fuse the subtalar joint is based on the standard portals for hindfoot arthroscopy with the use of an additional sinus tarsi portal [10].

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Peroneal Tendoscopy

93

P.A. van Dijk, P.A. de Leeuw, and G.M. Kerkhoffs

93.1 Introduction

Peroneal tendon pathologies account for a great percentage of the (post-traumatic) posterolateral ankle complaints, and the symptoms can be very debilitating. Although post-traumatic lateral ankle pain seems a common clinical problem, peroneal tendon disorders are often misdiagnosed [9]. As in many injuries, adequate treatment in an early stage is essential to prevent further deterioration of tendon tissue and chronic pain complaints [7, 13, 22, 41]. Peroneal tendoscopy provides opportunities in the improvement of both diagnostics and treatment of peroneal tendon disorders. Over the decade, the procedure has become more and more appreciated [17, 27, 29, 42].

Recurrent ankle sprains due to chronic lateral ankle instability are considered a typical onset of peroneal tendon pathologies [8, 13, 29, 33]. With an important role in the lateral ankle stabilization, more strain is put on the peroneal tendons in chronic instability of the ankle resulting in hypertrophic tendinopathy, tenosynovitis, and ultimately in tendon tears [8, 29]. Peroneal tendon pathologies can be classified in three categories: (1) tendinitis, tenosynovitis, tendinosis, and stenosis, (2) subluxation and dislocation, and (3) (partial) ruptures [5, 8, 35]. The differential diagnosis for posterolateral ankle pain includes pathologies of the posterior talofibular ligament (PFTL), bony spurs, rheumatoid arthritis, calcifications or ossicles, disorders of the posterior compartment of the subtalar joint, and posterior ankle impingement [38]. Differentiation between posterolateral ankle pathologies can be challenging due to nonspecific symptoms and nonspecific MRI changes, and careful patient history and clinical examination are often the clue to a correct diagnosis [19]. Peroneal tendoscopy has been proposed as an adequate diagnostic method to confirm the clinical diagnosis or to provide insight when in doubt [27, 29, 39].

The primary indication of treating peroneal tendon pathologies is pain [31]. When conservative treatment is not effective, surgical

P.A. van Dijk • G.M. Kerkhoffs (✉)
Department of Orthopedic Surgery, Academic Medical Center, Meibergdreef 9, Amsterdam, AZ 1105, The Netherlands

Academic Center for Evidence based Sports Medicine (ACES), Meibergdreef 9, 1105, AZ, Amsterdam, The Netherlands

Amsterdam Collaboration for Health and Safety in Sports (ACHSS), Meibergdreef 9, 1105, AZ, Amsterdam, The Netherlands
e-mail: g.m.kerkhoffs@amc.uva.nl

P.A. de Leeuw
Academic Medical Center Amsterdam, Orthopaedic Research Center Amsterdam, Meibergdreef 9, 1105, AZ, Amsterdam, The Netherlands

Amsterdam Collaboration for Health and Safety in Sports (ACHSS), Meibergdreef 9, 1105, AZ, Amsterdam, The Netherlands

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intervention is recommended. Surgical treatment involves debridement and resection of a prominent distal muscle belly in cases of persistent tendinopathy or tendinitis, which locally can provoke impingement. Fibular groove deepening with or without a repair of the superior peroneal retinaculum is recommended in case of dislocation or subluxation of the peroneal tendons. Partial and total tears are treated with debridement and tubularization, tenodesis, or grafting, depending on the degree of damage to the tendons. Postsurgical scar formation, adhesions of the tendon, peroneal nerve dysesthesia, and impairment of the superior superficial peroneal retinaculum are complications described after open treatment of peroneal tendons [1, 9, 22, 27, 28, 34]. Peroneal tendoscopy is advantageous, as compared to the open surgical procedures, with respect to diminished complication rates and a functional aftertreatment [10, 12, 15, 18, 40, 42].

93.2 Anatomy

When considering peroneal tendoscopy, accurate knowledge of the anatomy of the peroneal tendons and the surrounding tissues is important. The peroneal muscles form the lateral compartment of the lower leg, also known as the peroneal compartment. Primary function of the tendons is eversion and abduction of the foot. In addition, they play an important role in the stability of the lateral ankle. The peroneus longus (PL) originates at the lateral condyle of the tibia, the lateral aspect of proximal fibular head, the intramuscular septa, and the adjacent fascia, while the peroneus brevis (PB) originates more distally on the fibular shaft and interosseous membrane. Approximately 3–4 cm proximal to the distal fibular tip, the PL becomes completely tendinous. The muscle fibers of the PB run more distal. The superficial peroneal nerve innervates both tendons, and blood is supplied by the peroneal artery and medial tarsal arteries through vincula [21, 29, 32].

Distal to the origin of the PB, the PL and the PB share a common tendon sheath with synovial fluid. At the tip of the distal fibula, the tendon sheath divides into two separate tendon sheaths [31]. There's a thin, vincula-like structure between the PL and PB that is dorsally attached to the dorsolateral aspect of the distal fibula. The distal fibers of the PB muscle belly transform to this membranous layer to end approximately at the tip of the distal fibula [40].

The PL and PB descend posterior to the distal fibular tip, passing through a fibro-osseous groove called the retromalleolar groove [20]. From the proximal insertion to the distal fibular tip, the PB is relatively flat and dorsomedially located in relation to the PL tendon. When the PB curls around the fibular tip, the tendon becomes rounder and crosses the PL. Both tendons are secured posteriorly to the distal fibula by the superior peroneal retinaculum (SPR), forming the lateral border of the superior peroneal tunnel [14]. Lateral, the SPR is attached to the posterior aspect of the distal fibula, extended to its tip. On the medial side, the retinaculum merged with the deep transverse fascia of the posterior compartment of the leg [2]. The medial part of the tunnel consists of two structures: an osseous lateral part, formed by the retromalleolar groove of the fibula, and a non-osseous medial part, formed by the distal part of the posterior intramuscular septum of the leg. The bottom of the tunnel, i.e., the floor of the peroneal tunnel, is formed by the deep crural fascia, in this part also known as the fibulotalocalcaneal ligament.

93.3 Patient History, Clinical Examination, and Diagnostics

History and clinical examination are key elements in diagnosing peroneal tendon pathologies. Due to relatively unknown nature of the symptoms, it can be challenging to differentiate between different posterolateral ankle pathologies [19]. Patients with acute peroneal tendon

pathologies typically report on a recent ankle inversion trauma mechanism. Chronic pathologies mostly result from a gross ankle inversion injury in the medical history or chronic lateral ankle ligament instability. Predisposing factors include rheumatoid arthritis, psoriatic arthritis, cavovarus hindfoot deformity, hyperparathyroidism, diabetic neuropathy, calcaneal fractures, fluoroquinolone use, and local steroid injections [3, 4, 25, 36, 37, 44]. Patients present with pain posterior or distal to the lateral malleolus. During physical examination recognizable tenderness over the peroneal tendons during palpation, crepitus, and swelling can be found at the posterolateral aspect of the fibula in almost all cases of peroneal pathology. Passive hindfoot inversion and ankle plantar flexion may exacerbate pain. In (partial) tears, pain on provocation of the peroneal tendons in eversion and on acute loosening of resistance during the provocation test is even more typical. In case of dislocation, the patient may present with lateral instability, giving way, and a popping or snapping sensation. Dislocation may be provoked during physical examination by active dorsiflexion and eversion [26].

Additional diagnostics may be required, since patient history and clinical examination alone are often not sufficient to pinpoint the exact diagnosis or to prove the clinical diagnosis. To rule out (additional) osseous pathologies like fractures, spurs, or calcifications, weight-bearing radiographs are advised in anteroposterior and lateral direction. In case of peroneal dislocation, a small avulsion fracture of the lateral malleolus or "fleck sign" may be visible on the anteroposterior radiograph (Fig. 93.1) [6]. MRI is the standard used method in evaluating the tendons, SPR, and retromalleolar groove [11]. Visible abnormalities include chevron-shaped/C-shaped tendon, clefts, defects, irregularity of the tendon contour, and increased signal intensity due to fluid in the tendon sheath (Fig. 93.2a–d) [23, 30]. However, abnormalities correlated with peroneal tendon pathologies like fluid within the tendon sheath can also be seen in asymptomatic patients [43]. Furthermore, the so-called magic angle effect may overestimate peroneal tendon disorders [24]. Ultrasound (US) potentially has some advantages over MRI, since it is more adequate in diagnosing dynamic injuries such as intrasheath subluxation and dislocation. However, this is dependent on the quality of the observer. Abnormalities visible on US include tendon thickening, peritendinous fluid within the tendon sheath, and ruptures. Dynamic US may visualize episodic peroneal subluxation and tears that are not visible on MRI. Peroneal tendoscopy is gaining popularity as a diagnostic method in peroneal tendon pathologies, since it is highly specific and sensitive and moreover provides easy transition to minimally invasive treatment [39]. The primary indication for peroneal tendoscopy is posterolateral pain due to tenosynovitis, subluxation or dislocation, partial tears, or postoperative adhesion [29, 39]. Since MRI can be inconclusive, peroneal tendoscopy should be performed when clinical suspicion for a peroneal disorder is strong, with or without positive MRI findings [17].

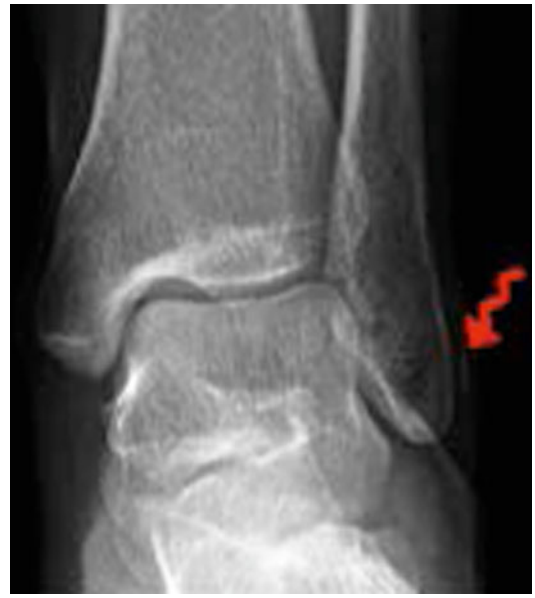

Fig. 93.1 Weight-bearing anterior to posterior radiograph with a small bony avulsion at the tip of the lateral malleolus (*arrow*), also known as the Fleck sign, suggestive for peroneal tendon instability

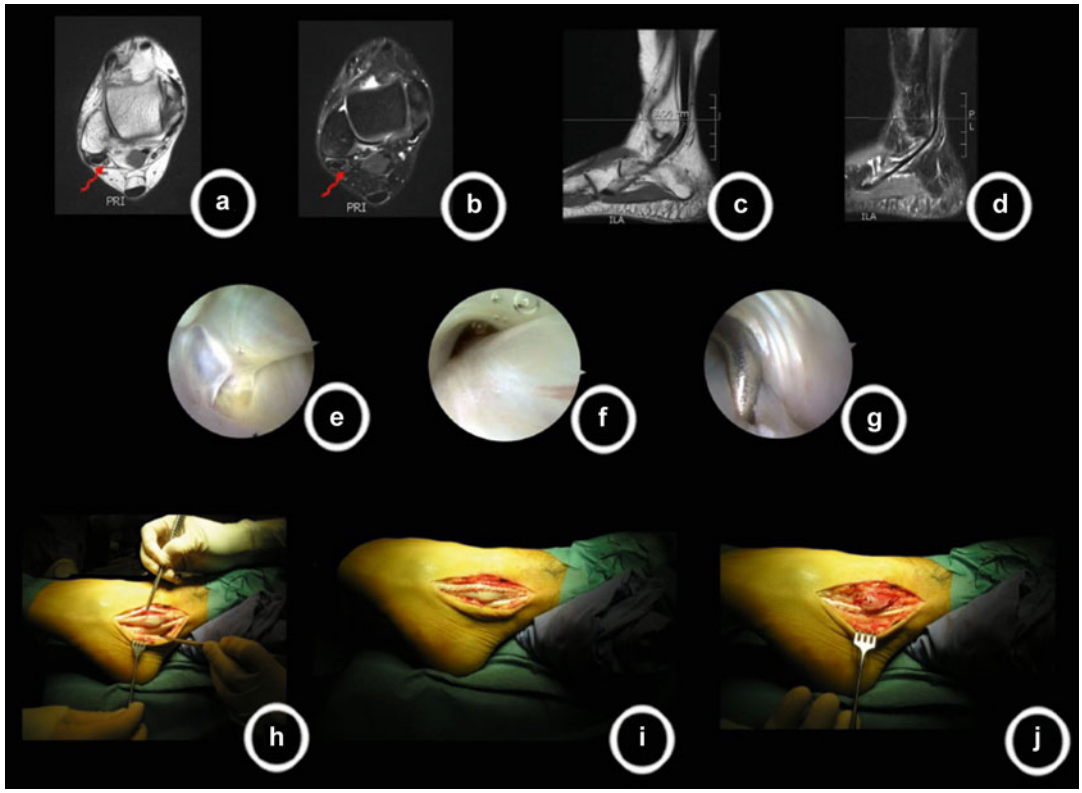

Fig. 93.2 A 25-year-old female patient with a symptomatic peroneus brevis tendon tear at the left side. (**a**) Axial T1-weighted magnetic resonance image (MRI) indicating a C-shaped peroneus brevis tendon and signaling change within the tendon sheath, suggestive for a tear; (**b**) axial T2-weighted MRI indicating a C-shaped peroneus brevis tendon, suggestive for a tear; (**c**) sagittal T1-weighted MRI indicating the location of the tear; (**d**) sagittal T2-weighted MRI indicating the location of the tear; (**e**) arthroscopic image from the most proximal proportion of the peroneal tendons; (**f**) arthroscopic image of the peroneus brevis tendon with mild tenosynovitis, indicating irritation of the tendon; (**g**) arthroscopic image indicating the tendon tear with the use of a probe. (**h**) Macroscopic image of the mini-open approach following the peroneal tendoscopy. The superior peroneal retinaculum is released, and both tendons have been released out of the retromalleolar groove. As proven with peroneal tendoscopy, the peroneus brevis tendon is torn over a substantial area; (**i**) macroscopic image after debridement of the peroneus brevis tendon followed by tubularization by a buried suture knot and running technique and (**j**) macroscopic image after repositioning both tendons in the retromalleolar fibular groove

93.4 Surgical Technique for Diagnosis and Treatment

Optimal portal access is achieved in lateral decubitus position, allowing access to the anterior and posterior aspect of the ankle when open techniques are required (Fig. 93.3a). Alternatively, patients can be placed with the foot in supine position and endorotation. When considering arthroscopic procedures in conjunction with tendoscopy, a semilateral position can be applied to facilitate access to the medial ankle. For free motion in the ankle during surgery, a support may be placed under the leg. Before anesthesia is administered, the patient is asked to actively evert the foot to visualize the location of the tendons. The course is drawn on the skin, and both locations of the portals are marked (Fig. 93.3b–d). Local, regional, epidural, or general anesthesia can be used for the surgery. A tourniquet is then inflated around the proximal thigh of the affected leg to optimize visualization.

First the distal portal is made, 2–3 cm distal to the posterior tip of the lateral malleolus. After an

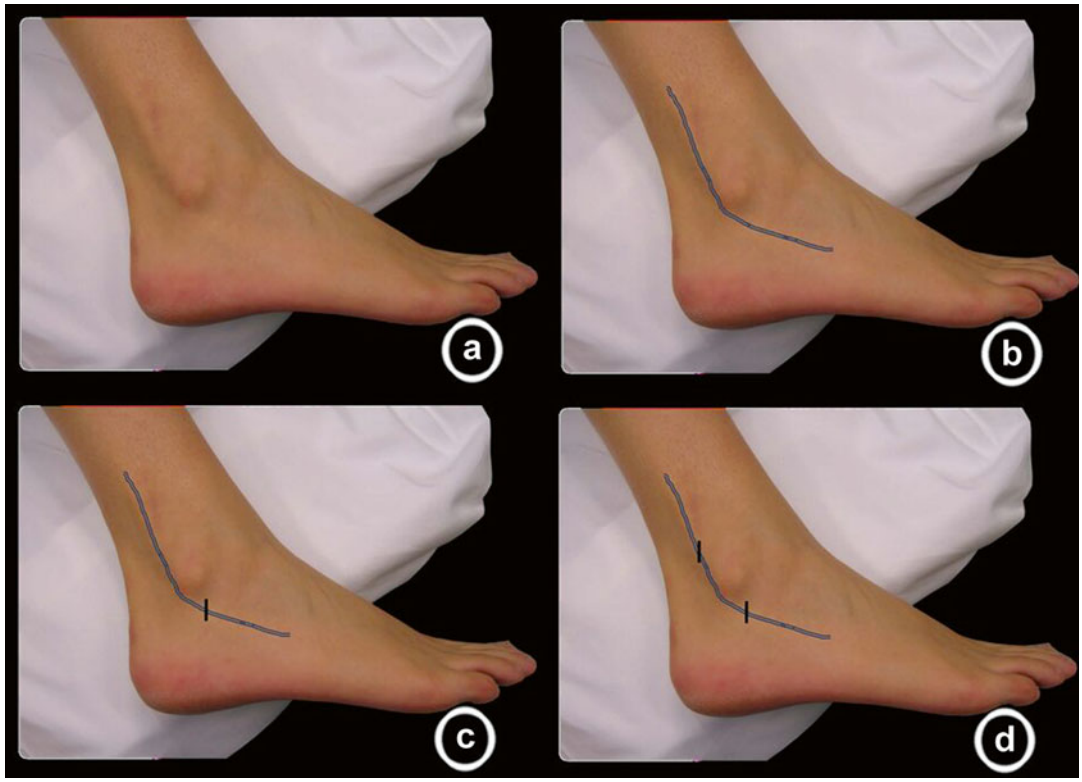

Fig. 93.3 Patient positioning and portal locations for peroneal tendoscopy of the right ankle. (**a**) Macroscopic image showing the position of the ankle in the lateral decubitus position; (**b**) marking the anatomical course of the peroneal tendons to create a better reference for the location of your portals; (**c**) position of the distal portal, 2–3 cm distal to the posterior tip of the lateral malleolus; (**d**) position of the proximal portal, 2–3 cm proximal to the posterior edge of the lateral malleolus tendon is tubularized using the buried suture knot and running technique (**h–j**)

incision is made through the skin only, the tendon sheath is penetrated with an arthroscopic shaft with a blunt trocar. A 2.7-mm arthroscope with an inclination angle of 30° is then introduced. A low-pressure, low-flow pump of 50–70 mmHg is recommended. Some surgeons prefer a 4-mm scope, affording increased flow with lower pressure [39]. However, it may be challenging to pass the larger diameter scope through the retinaculum [27]. Normal saline is used for tendoscopic fluid to maintain hemostasis.

Inspection of the tendons starts approximately 6 cm proximal to the posterior edge of the lateral malleolus (Fig. 93.2e). Here, a thin membrane splits the tendon compartment into two separate tendon chambers. More distally, the tendons lie in one compartment. A spinal needle is used to guide the second portal, approximately 2–3 cm proximal to the posterior edge of the lateral malleolus. By rotating the scope within the sheath, an overview of both tendons can be obtained and the course of the tendons can be inspected for suspected pathologies (Fig. 93.2f–g). When significant tenosynovitis is present, complete tenosynovectomy is recommended after which associated pathologies can be assessed, including tenosynovitis, tears, ruptures, dislocation, and stenosis [39].

In patients with recurrent dislocation or subluxation of the peroneal tendons, tendoscopic fibular groove deepening can be performed. Two Kirschner wires are placed to keep the peroneal tendons out of the way, decreasing the risk of iatrogenic damage. Using a 3.5-mm burr, a concavity can then be created in the retromalleolar fibular groove. The deepening should

cross from the most proximal end of the distal fibula to the tip of the lateral malleolus. The surface of the groove is smoothened and sharp edges are rounded, to prevent the tendons from lesions. When the SPR was stripped off, the surface can be tendoscopically roughened with the burr. Two of three suture anchors are then inserted to the fibular ridge and sutured to the SPR. When tears are found in one of both tendons, a mini-open approach is required. The tendon is brought into the incision, degenerative tissue is debrided, and the tendon is tubularized using the buried suture knot and running technique (Fig. 93.3h–j).

After finishing the procedure, the portal incisions are closed by sutures to prevent sinus formation. A compressive dressing is applied for 2 days, followed by full weight bearing as tolerated. Functional aftertreatment is recommended with active range of motion immediately after surgery. In case of retinaculum repair, it is favored to place patients in a lower-leg splint for 2 days followed by 12 days of a non-weight-bearing lower-leg cast. Hereafter, patients are either allowed weight bearing in a walker boot or in a lower-leg cast for an additional 4 weeks, followed by physical therapy to regain strength and range of motion.

93.5 Complications

Complication rates after peroneal tendoscopy are low. A rupture of the tendon sheath due to introduction of the surgical instruments is one of the most often reported complications, causing deteriorated visualization [17]. Other complications include iatrogenic tendon damage by surgical instrument introduction, suture irritation, and nerve injuries [16]. Increase of fluid pressure allows more working space and may thus prevent complications [17].

93.6 Pearls

Before creating the portals, it is important to identify the location of the peroneal tendons by asking the patient to actively evert the foot. Draw the course of the tendons on the ankle to create a clear reference for your portals.

Before anesthesia, repeat the physical examination to localize the maximal pain spot, and mark this on the skin in order to have an accurate intraoperative reference point.

Identify the posterior talofibular ligament and the calcaneofibular ligament before initiating the work on the posterior distal fibular surface during a groove deepening procedure to prevent iatrogenic damage.

93.7 Pitfalls

Introduction of the surgical instruments must be performed smoothly without any resistance to prevent iatrogenic tendon damage. Increase of fluid pressure during the tendoscopy allows for more working space, thereby preventing iatrogenic damage.

Don't include retinacular tissue during closure of the portals in order to prevent adhesions.

Conclusions

Tendoscopic procedures offer several advantages relative to open procedures. It allows visualization of the peroneal tendons from the myotendinous junction to the peroneal tubercle without damaging the soft tissue around the tendons and provides dynamical evaluation of the tendons. Moreover, peroneal tendoscopy is associated with less morbidity, smaller scars, less postoperative pain and complications, a functional aftertreatment, and good functional outcomes, as compared to open peroneal tendon surgery.

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94 Tendoscopy of the Achilles Tendon, Peroneal Tendon and Posterior Tibial Tendon

J.I. Wiegerinck and C.N. van Dijk

94.1 Introduction

Traditionally extra-articular problems of the ankle demanded open surgery. In general open surgery of the foot and ankle is associated with more complications compared to endoscopic surgery [1–3]. The percentage of complications reported with open surgery for posterior ankle impingement (removal of the os trigonum, scar tissue, hypertrophic posterior talar process or ossicle) varies between 15 % and 24 % [1–4]. Most frequently described complications are injury to the sural nerve or superficial peroneal nerve, infection, scarring and stiffness of the ankle joint [1–3]. The incidence of these complications has stimulated the development of endoscopic techniques [62]. Endoscopic surgery offers the advantages related to any minimally invasive procedure: fewer wound infections, less blood loss, rapid recovery, smaller wounds and less morbidity [5, 62]. Tendoscopy can be performed for the diagnosis and treatment of various pathologic conditions of the peroneal tendons, the posterior tibial tendon and the Achilles tendon [62]. Indications and surgical procedures are described.

J.I. Wiegerinck • C.N. van Dijk (✉)
Department of Orthopaedic Surgery,
Academic Medical Center, University of Amsterdam,
PO Box 22700, Amsterdam 1100 DE,
The Netherlands
e-mail: c.n.vandijk@amc.uva.nl

94.2 Tendoscopy of the Peroneal Tendons

94.2.1 Introduction

Pathology of the peroneal tendons is most often seen in combination with chronic lateral ankle instability. Peroneal pathology frequently causes chronic lateral ankle pain in runners and ballet dancers [6]. Posttraumatic lateral ankle pain is common, but peroneal tendon pathology is not always recognized as a cause thereof [7]. As the peroneal tendons are lateral ankle stabilizers, strain is put on these tendons in chronic ankle instability, resulting in hypertrophic tendinopathy, tenosynovitis, tendon (sub)luxation and eventually (partial) ruptures [8].

Peroneal tendon pathology accounts for the majority of symptoms at the posterolateral aspect of the ankle [9, 10]. The differential diagnosis consists of rheumatoid synovitis, calcifications or ossicles, pathology to the posterior talofibular ligament (PTFL) or disorders of the posterior compartment of the subtalar joint. In addition, posterior ankle impingement can present as posterolateral ankle pain. On clinical examination, there is recognizable tenderness over the tendons on palpation, often in combination with swelling and tendon dislocation. Due to the variety of pathologies, the diagnosis of peroneal tendon pathology can be difficult in a patient with lateral ankle pain. One should inquire about associated

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conditions of rheumatoid arthritis, psoriasis, diabetic neuropathy, hyperparathyroidism, calcaneal fracture, the use of fluoroquinolone and/or local steroid injections. These can all increase the prevalence of peroneal tendon dysfunction [11]. Additional investigations consisting of ultrasonography and/or MRI are helpful [12].

The primary indication for treatment is pain. Conservative management should be attempted first, consisting of activity modification, footwear changes and temporary immobilization. Also, lateral heel wedges can take the strain off the peroneal tendons which may relieve symptoms and allow healing. Failure of these conservative measures may be an indication for surgery. We therefore developed a safe and reliable endoscopic technique which we describe in details here [13, 14].

94.2.2 Surgical Technique

The peroneus brevis tendon is located dorsomedially to the peroneus longus tendon from its proximal aspect up to the fibular tip, where it is relatively flat. Distally to this lateral malleolus tip, the peroneus brevis tendon becomes rounder and crosses the peroneus longus tendon. The distal posterolateral part of the fibula forms a sliding channel for the two peroneal tendons. This malleolar groove is formed by a periosteal cushion of fibrocartilage that covers the bony groove. The tendons are held into position by the superior peroneal retinaculum [8, 15, 16].

The patient is placed in the lateral decubitus position, with the operative side up. Before anaesthesia is administered, the patient is asked to actively evert the affected foot. This enhances the palpation of the tendon; the portal location is marked. Surgery can be performed under local, regional, epidural or general anaesthesia. A support is placed under the affected leg to enable free movement of the ankle. After exsanguination a tourniquet (300 mmHg) is inflated around the thigh of the affected leg. The distal portal is made first, 2–2.5 cm distal to the posterior edge of the lateral malleolus. An incision is made through the skin, and the tendon sheath is penetrated with an arthroscopic shaft with a blunt trocar. Following this, a 2.7 mm 30° arthroscope is introduced (Fig. 94.1)

The inspection starts approximately 6 cm proximal from the posterior tip of the fibula, where a thin membrane splints the tendon compartment into two separate tendon chambers. More distally, the tendons lie in one compartment. A second portal is made 2–2.5 cm proximal to the posterior edge of the lateral malleolus under direct vision by placing a spinal needle, producing a portal directly over the tendons (Fig. 94.1). The distal portal provides a complete overview of both tendons. By rotating the arthroscope over and in between both tendons, the complete compartment can be inspected. When a total synovectomy of the tendon sheath is to be performed, it is advisable to create a third portal more distal or more proximal than the portals described previously. When a rupture of one of the tendons is seen (Fig. 94.2), endoscopic synovectomy is performed, and the rupture is repaired through a mini-open approach. In patients with recurrent dislocation of the peroneal tendon, endoscopic fibular groove deepening can be performed through this approach. Groove deepening is performed from within the tendon sheath with the risk of iatrogenic damage to the tendons. We therefore prefer an approach with the two-hindfoot portal technique [16, 62].

Portals are sutured, and a compressive dressing is applied. Full weight-bearing is allowed as tolerated, and active range of motion exercises are advised starting immediately after surgery [4, 16–18].

94.3 Tendoscopy of the Posterior Tibial Tendon

94.3.1 Introduction

Extra-articular posteromedial ankle pain is most often caused by disorders of the posterior tibial tendon. Inactivity of the posterior tibial tendon gives midtarsal instability and is the most common cause of adult-onset flatfoot deformity. There are two groups of patients: the younger one

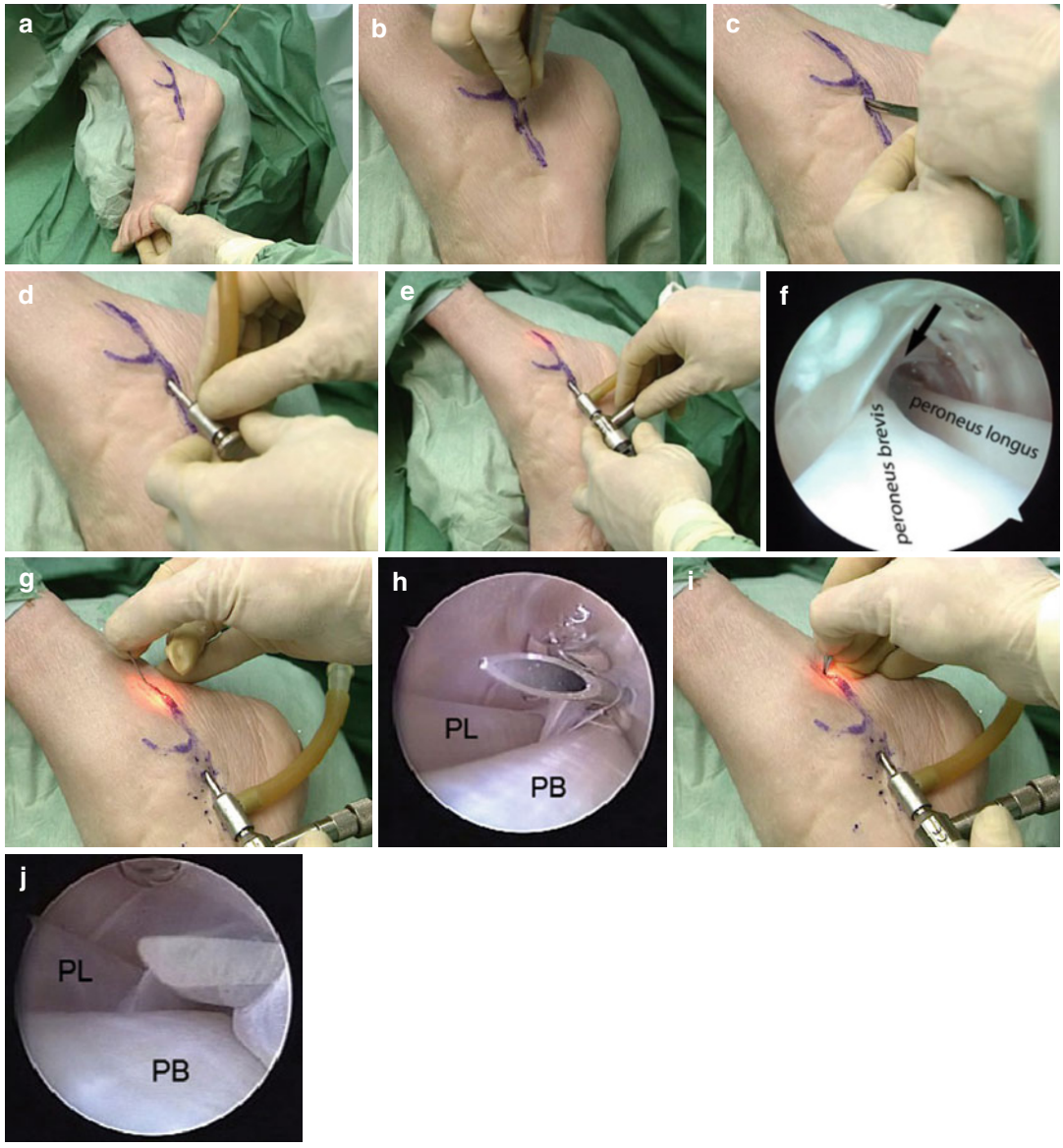

Fig. 94.1 Peroneal tendoscopy of the *left* ankle: (**a**) Marking the anatomy of the peroneal tendons. (**b**) Incision of the skin for preparation of the distal portal. (**c**) Blunt dissection of the peritendineum with mosquito clamp. (**d**) Introduction of arthroscopic shaft with a blunt trocar. (**e**) Introduction of 2.7 mm 30° arthroscope. (**f**) Arthroscopic view at introduction of the arthroscope looking from distal to proximal. An *arrow* indicates a thin membrane separating the two tendons proximally. (**g**) Placement of spinal needle under direct vision for preparation of the second portal. (**h**) Endoscopic view of needle looking from distal to proximal. (**i**) Incision for proximal portal. (**j**) Endoscopic view of the tip of the knife inside the tendon sheath (*PB* peroneus brevis, *PL* peroneus longus)

with dysfunction of the tendon, caused by some form of systemic inflammatory disease (e.g. rheumatoid arthritis), and an older group of patients whose tendon dysfunction is mostly caused by chronic overuse [19]. Posttraumatic adhesions cause irregularity of the posterior aspect of the tibia enhancing mechanic stress on the posterior tibial tendon. The vincula, connecting the posterior tibial tendon to its tendon sheath, can become symptomatic in these circumstances

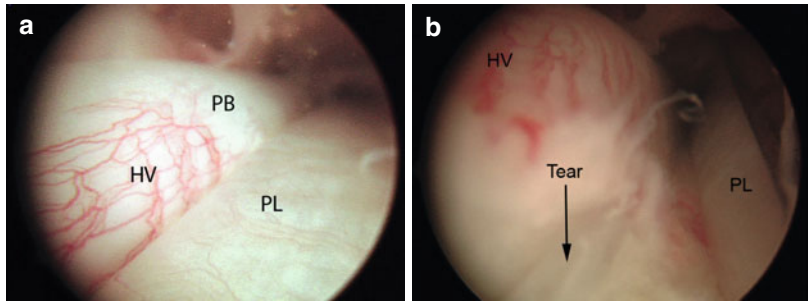

Fig. 94.2 Peroneal tendoscopy in a 38-year-old male patient with a longitudinal tear of the *left* peroneus brevis tendon. The arthroscope is introduced through the distal portal looking into a proximal direction. (**a**) Hypervascularization of peroneus brevis tendon as an expression of chronic irritation. (**b**) Endoscopic view of a longitudinal tear of the peroneus brevis tendon (*HV* hypervascularization, *PB* peroneus brevis tendon, *PL* peroneus longus tendon. The *arrow* indicates the tear)

[20, 21]. Vincular injury can cause thickening, shortening and scarring of the distal free edge. A painful local thickening can be palpated posterior and just proximal of the tip of the medial malleolus. Most chronic repetitive stresses onto the posterior tibial tendon result in a tenosynovitis. However, tenosynovitis is also a common extra-articular manifestation of rheumatoid arthritis, which may lead to a ruptured tendon [22].

Patients complain of persisting medial ankle pain, in addition to fatigue and aching on the plantar medial aspect of the ankle. Swelling, suggestive of tenosynovitis, is common. On clinical examination, valgus angulation of the hindfoot is frequently seen, with accompanying abduction of the forefoot, the "too-many-toes" sign [23].

The differential diagnosis consists foremost of intra-articular lesions: posteromedial impingement syndrome, subtalar pathology, loose bodies and/or osteochondral defects. Entrapment of the posterior tibial nerve in the tarsal canal is known as a tarsal tunnel syndrome. Clinical examination is sufficient to differentiate between these disorders. Although ultrasound imaging is known as a cost-effective and accurate to evaluate disorders of the tendon [24], magnetic resonance imaging (MRI) is the best method to evaluate a posterior tibial tendon pathology.

Conservative management is indicated primarily according to the RICE principle (rest, ice, compression and elevation), nonsteroidal anti-inflammatory drugs (NSAIDS) and immobilization. After failure of conservative management, surgery is indicated [25–28]. Endoscopic synovectomy offers the general advantages that are related to minimally invasive surgery [15, 16, 21].

94.3.2 Surgical Technique

The procedure can be performed on an outpatient basis under local, regional or general anaesthesia. Patients are placed supine. A tourniquet (300 mmHg) is placed around the upper leg. Prior to anaesthesia, the patient is asked to actively invert the foot, so that the posterior tibial tendon can be palpated, and the portals can be marked (Fig. 94.3a). Access to the tendon can be obtained anywhere along the course of it. We favour two portals directly over the tendon 2–3 cm distal and 2–3 cm proximal to the posterior edge of the medial malleolus. The distal portal is created: the incision is made through the skin, and the tendon sheath is penetrated by the arthroscopic shaft with a blunt trocar. A 2.7 mm 30° arthroscope is introduced, and the tendon sheath is filled with saline (Fig. 94.3b–f). Irrigation is performed using gravity flow.

The proximal portal is made under direct vision (Fig. 94.3). The complete tendon sheath can be inspected by rotating the arthroscope around the tendon.

Synovectomy can be performed with a complete overview of the tendon from the distal portal, over the insertion of the navicular bone to

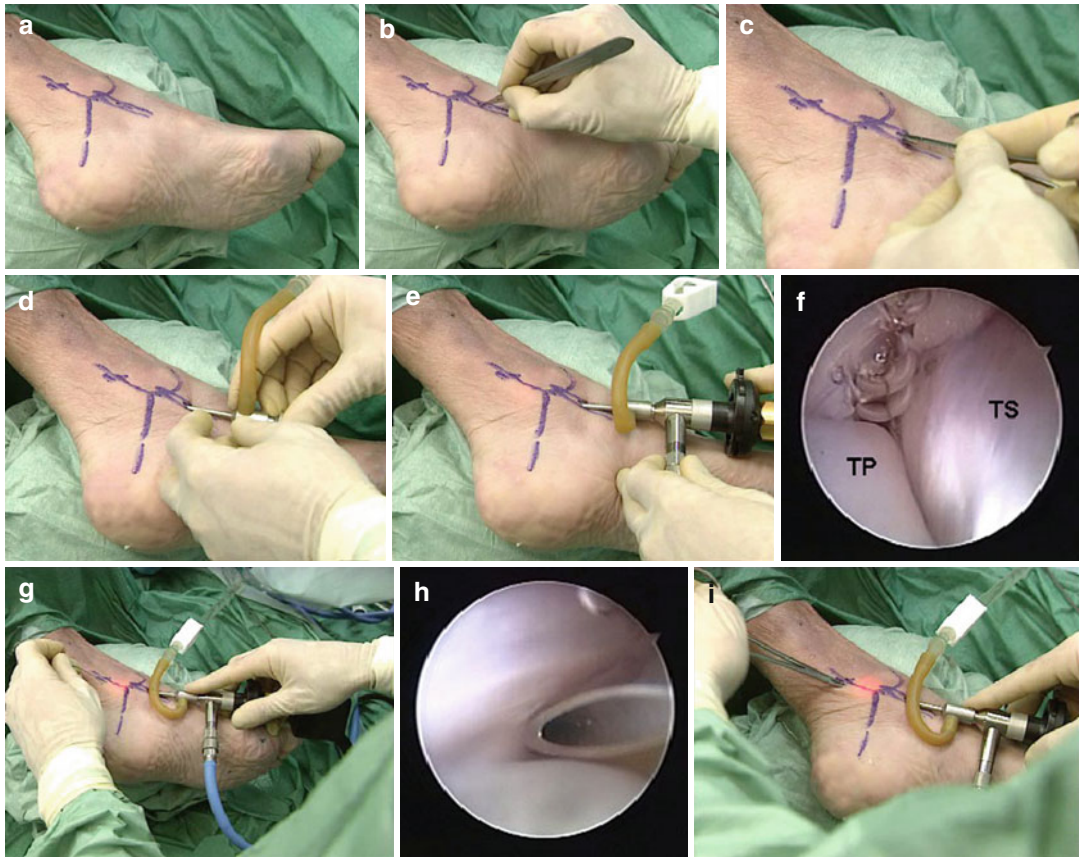

Fig. 94.3 (**a**) Marked anatomy of posterior tibial tendon of the *left* foot. (**b**) Skin incision for the distal portal. (**c**) Blunt dissection of the peritendineum with mosquito clamp. (**d**) Introduction of the arthroscopic shaft with a blunt trocar. (**e**) Introduction of a 2.7 mm 30° arthroscope. (**f**) Endoscopic view of the posterior tibial tendon at introduction of the arthroscope. (**g**) Placement of a spinal needle under direct vision to prepare a second proximal portal. (**h**) Endoscopic view of the needle looking from distal to proximal. (**i**) Blunt dissection of the proximal portal with mosquito clamp

approximately 6 cm above the tip of the medial malleolus. Special attention should be given when inspecting the tendon sheath, the posterior aspect of the medial malleolar surface and the posterior ankle joint capsule. If surgery is performed within the posterior tibial tendon sheath, the neurovascular bundle is not in danger. When a rupture of the posterior tibial tendon is seen (Fig. 94.4), endoscopic synovectomy is performed, and the rupture is repaired through a mini-open approach. Postoperative management consists of a pressure bandage and partial weight-bearing for 2–3 days. Active range of motion exercises are encouraged from the first day [19–21, 26, 29, 30].

94.4 Achilles Tendoscopy

94.4.1 Introduction

Non-insertional tendinopathy can be divided into three entities: tendinopathy, paratendinopathy and a combination of both [31, 32]. General symptoms include painful swelling, typically 4–6 cm proximal to the insertion, and stiffness after a period of rest. Achilles tendinopathy can present itself as diffuse thickening, with or without local degeneration and a partial tear. In paratendinopathy, there is local thickening of the paratenon. Clinically, a differentiation between tendinopathy and paratendinopathy

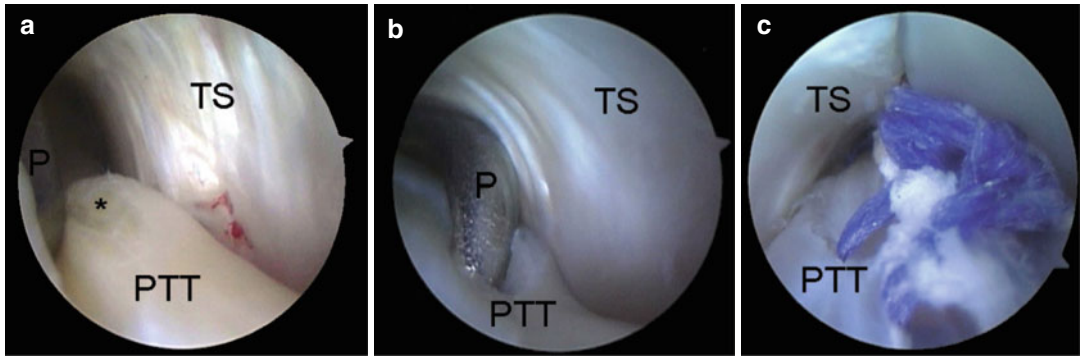

Fig. 94.4 Posterior tibial tendoscopy of the left foot in a 48-year-old female patient with pain over the posterior tibial tendon. The arthroscope is in the anterolateral portal looking proximally. (**a**) Superficial tear of the posterior tibial tendon (*asterisk*). (**b**) Rupture demonstrated with the arthroscopic probe. (**c**) Repair of the rupture through a mini-open repair (*P* probe, *PTT* posterior tibial tendon, *TS* tendon sheath)

can be made [33, 34]. The swelling does not move with dorsiflexion and plantar flexion of the ankle in paratendinopathy; in tendinopathy it does [33, 35, 36]. Paratendinopathy can be acute or chronic. Frequently the pain is more prominent on the medial side in patients with chronic tendinopathy [37]. This is possibly due to involvement of the plantaris tendon [35, 62]. The plantaris tendon is the distal part of a biarticular plantaris muscle. Simultaneous knee and ankle movements result in a different pull of the soleus and plantaris tendons at the level of the combined tendinopathy and paratendinopathy [38, 39]. In a healthy patient, the plantaris tendon can slide alongside the Achilles tendon. In case of chronic paratendinopathy, the plantaris tendon is attached to the Achilles tendon restricting separate movement and causing the medial pain [35]. Differential diagnoses are foremost insertional Achilles tendinopathy, retrocalcaneal bursitis and posterior ankle impingement with possible flexor hallucis longus pathology. MRI and ultrasound can be used to differentiate between these pathologies [40]. Treatment is started conservatively according to the RICE protocol. Shoe modifications and inlays are provided to relieve mechanical stress on the Achilles tendon. Physical therapy is focused on extensive eccentric exercises [41–45]. Shock wave treatment, a night splint and cast immobilization are alternative methods. Sclerosing injections in the Achilles tendon have initially shown promising results; however, a consensus regarding these injections has not been made [46–52]. If these conservative measures fail, surgery must be considered. The percentage of patients requiring surgery is around 25 % [33, 53, 54]. The described approach, based on the pathophysiology of the plantaris–Achilles tendon attachment, is an endoscopic release or resection of the plantaris tendon at the level of the nodule and removal of the local paratendinopathy tissue at the level of the painful nodule [55–59]. Apart from addressing the plantaris tendon, the procedure aims for denervation of the tendon at the level of the painful nodule [62].

94.4.2 Surgical Technique

The patient is in prone position with a tourniquet (300 mmHg) around the thigh of the affected leg and a bolster under the foot. The foot is placed right over the edge of the table (Fig. 94.5).

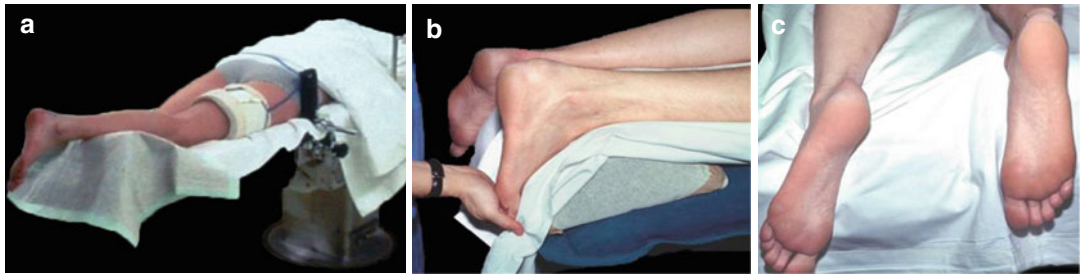

Fig. 94.5 Positioning of a patient for tendoscopy of the Achilles tendon. (**a**) The patient is placed prone. (**b**, **c**) The affected *right* leg is placed on a bolster and right over the end of the table. (**c**) The other foot is positioned so that the surgeon has sufficient working area

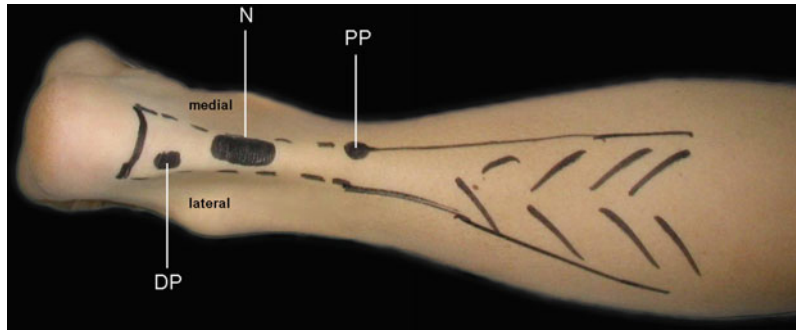

Fig. 94.6 Posterior aspect of the right foot and ankle. Anatomy and portals marked before surgery (*DP* distal portal, *N* nodule, *PP* proximal portal)

A 2.7 mm arthroscope and a pressurized bag or pump device is used to provide a proper flow of irrigation along with the 2.7 mm arthroscope. The distal portal is located on the lateral border of the Achilles tendon, 2–3 cm distal to the pathologic nodule. The proximal portal is located medial to the border of the Achilles tendon, 2–4 cm above the nodule (Fig. 94.6).

First, the distal portal is made: after the skin incision, the mosquito clamp is introduced, followed by the blunt 2.7 mm trocar in a craniomedial direction. With this blunt trocar, the paratenon is approached and is blindly released from the tendon by moving around it. Subsequently, the 2.7 mm 30° arthroscope is introduced. The arthroscope should be kept on the tendon to minimize the risk of iatrogenic damage. The proximal portal is made in the same manner as the distal portal. The plantaris tendon can be identified at the anteromedial border of the Achilles tendon (Fig. 94.7). Removal of the locally thickened paratenon and release of the plantaris tendon are the aims. Neovessels accompanied by small nerve fibres can be found in this area and are removed with a 2.7 mm bonecutter shaver. Changing portals can be helpful. At the end of the procedure, one must be able to move the arthroscope over the complete symptomatic area of the Achilles tendon. The portals are sutured. Aftercare consists of a compressive dressing for 2–3 days. Full weight-bearing is allowed as tolerated, patients are encouraged to actively perform range of motion exercises and elevate the foot in rest. [35, 60, 61].

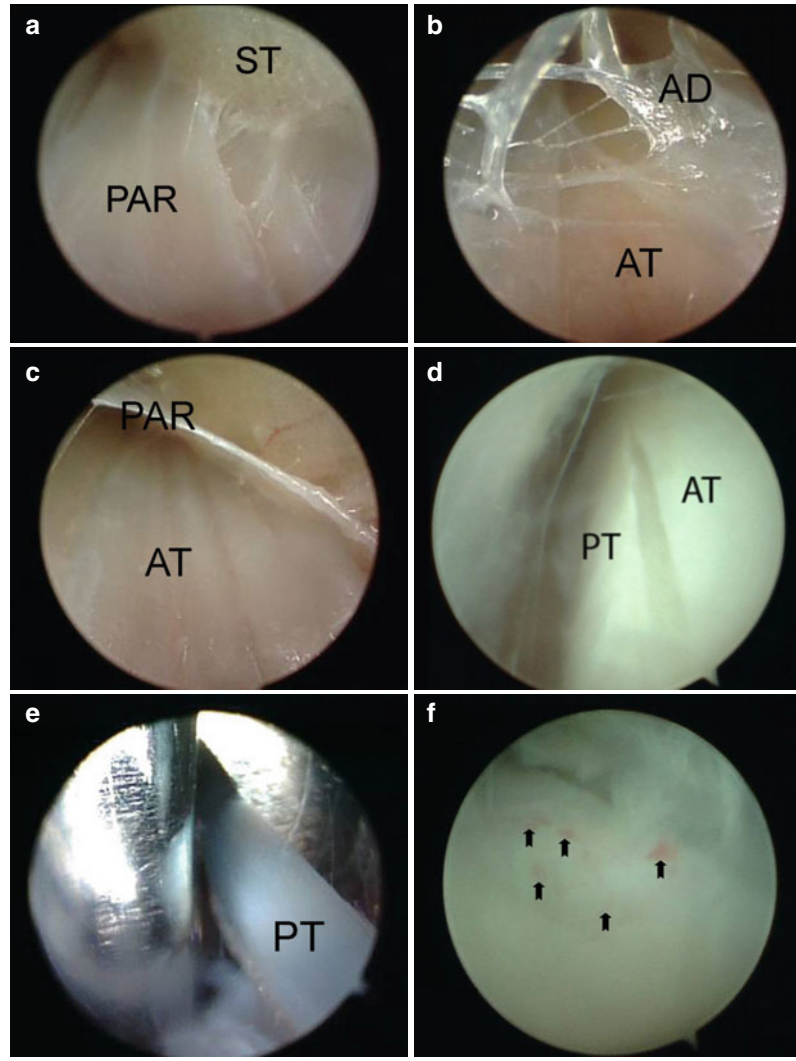

Fig. 94.7 Tendoscopy of the right Achilles tendon in a 52-year-old female patient with combined tendinopathy and paratendinopathy. The 2.7 mm arthroscope is introduced through the distal portal looking proximally. (**a**) Adhesions of the paratenon (*PAR*) to the subcutaneous tissue (*ST*) overlying the Achilles tendon. (**b**) Removal of adhesions (*AD*) of the paratenon to the Achilles tendon (*AT*), looking from distal to proximal. (**c**) Paratenon released from the Achilles tendon. (**d**) Plantaris tendon (*PT*) running medially to the Achilles tendon (*AT*). (**e**) Release of the plantaris tendon. (**f**) Neovascularization (*arrows*) before removal by bonecutter shaver

Conclusion

Tendoscopy of the foot and ankle has proven to be a safe and successful surgical technique. In comparison with open surgery, a low complication rate is seen and generally a high patient satisfaction. The main indications for surgical treatment are clinical and radiologic suspicion of rupture or partial rupture of the peroneal or posterior tibial tendons. The main indication for Achilles tendoscopy is chronic tendinopathy which is resistant to conservative treatment.

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Achilles Tendon Pathology

95

Robert Śmigielski and Urszula Zdanowicz

95.1 Preface

Although Achilles tendon is the strongest in the human body, it is one of the most frequently injured one [11, 15, 20].

There is no consensus on the best method for management of the Achilles tendon pathologies. Individual preferences, drawn from experience and study, determine whether treatment is operative or nonoperative.

95.2 Disorders of Achilles Tendon Insertion

95.2.1 Achilles Tendon Enthesis

Achilles tendon, as many other different tendons, approaches its distal attachment site obliquely, and during ankle plantar flexion, the tendon comes in contact with the bone (heel) (Fig. 95.1a, b), which puts stress dissipation at the enthesis itself [4]. The retrocalcaneal bursa allows for free movement between the tendon and the bone. The fat pad protrudes into the bursa during plantar flexion and is retracted during dorsiflexion. The Kager's fat pad has three distinct regions that are associated with all three borders of Kager's triangle: flexor hallucis longus part (which is responsible for moving the bursal wedge during plantar flexion), bursal part (which minimises pressure changes in the bursa) and Achilles part (which protects blood vessels that are entering the tendon) [25].

95.2.2 Insertional Achilles Tendinopathy

In 1928, Haglund described a single case of a clinical condition of painful hindfoot caused by an enlarged posterosuperior border of the os calcis and the wearing of rigid low-back shoes [8]. Haglund syndrome was defined as a complex of symptoms involving superolateral calcaneal prominence, retrocalcaneal bursitis and superficial Achilles tendon bursitis [26, 27]. However, one must distinguish Haglund syndrome with retrocalcaneal bursitis from Achilles tendinopathy. Unfortunately, these two pathologies may coexist, especially if insertional tendinopathy is considered (Fig. 95.2).

The confusion regarding terminology of distal Achilles tendon problems has a historical background. In the times when those conditions were first described, doctors were establishing their diagnosis almost solely based on clinical symptoms, and these may be very similar in different pathologies. The lack of adequate radiological examination and histopathological evaluation leaded to misuse, not fully understood, terms.

R. Śmigielski (✉) • U. Zdanowicz
Carolina Medical Center,
Pory 78, Warsaw 02-757, Poland
e-mail: robert.smigielski@carolina.pl

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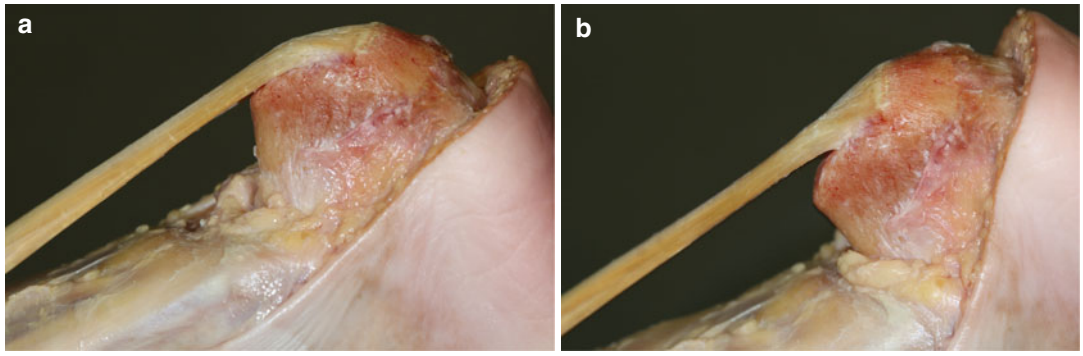

Fig. 95.1 (**a**, **b**) Cadaveric dissection of distal attachment of the Achilles tendon. Notice the way Achilles tendon approaches the calcaneus and gets in contact with the bone. This is the area where many Achilles tendon pathologies take place

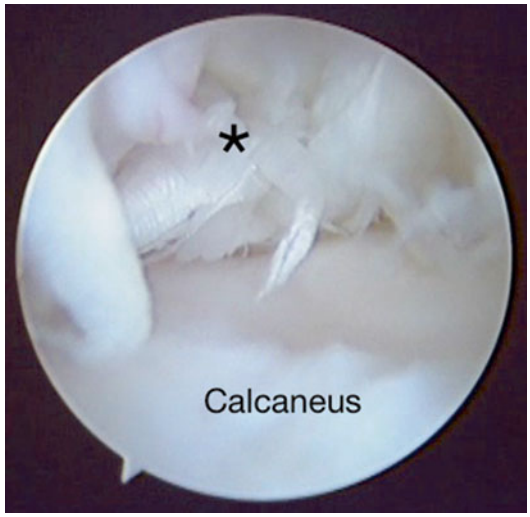

Fig. 95.2 Endoscopy of retrocalcaneal bursa. (*) Partial rupture of distal attachment of bursal side of the Achilles tendon

That is why Niek van Dijk et al. [27] proposed orderliness in the terminology and use of the following terms: insertional Achilles tendinopathy, retrocalcaneal bursitis and superficial calcaneal bursitis (see description in Table 95.1).

There are a variety of different procedures for treatment of retrocalcaneal bursitis and Haglund syndrome. Conservative treatment includes activity modification, avoiding rigid heel counters in shoes, NSAID, inlays, padding and/or physiotherapy. Some doctors also prefer local injections of steroidal drugs; however, there are a number of reports proving that it might be a risk factor of subsequent Achilles tendon rupture [2, 6, 22] (Fig. 95.3). Local steroid injections give rather quick pain relief in a short time, but rarely permanently solve the problem of underlying pathology. Nowadays for surgical treatment, endoscopic surgery (Fig. 95.4), first proposed by Niek van Dijk – as the one that offers the advantages of reduced morbidity and reduced postoperative pain and allows for early rehabilitation [7, 26] – should be the treatment of choice.

95.3 Achilles Tendinopathy

Terminology used to describe the painful condition of Achilles tendon is often confusing and most often does not reflect the underlying pathology. According to Khan et al. [13], the term "tendinopathy" might be defined as painful condition of the Achilles tendon, which is rather a general description of clinical symptoms than accurate and precise diagnosis.

95.3.1 Paratendinopathy

Paratendinopathy may be defined as local inflammation of the paratendon (Fig. 95.5a–c). It may be a separate pathology or an accompanying tendinopathy. Many believe that tendinopathy often starts with paratendinopathy. Clinical symptoms might not be different from tendinopathy or

Table 95.1 Terminology of distal Achilles tendon problems proposed by van Dijk et al. [27]

	Anatomic location	Symptoms	Clinical findings	Histopathology
Insertional Achilles tendinopathy	Distal insertion	Pain, stiffness, swelling	Painful tendon insertion in the mid-portion of the calcaneus, swelling, bony spur	Ossification within tendon insertion, tendon degeneration, micro-tears at the tendon attachment
Retrocalcaneal bursitis	Bursa between anteroinferior side of Achilles tendon and posterosuperior aspect of the calcaneus	Painful swelling superior to the calcaneus	Painful soft tissue swelling, medial and lateral to the Achilles tendon at the level of the posterosuperior calcaneus	Fibrocartilaginous bursal walls show degeneration and/or calcification, with hypertrophy of the synovial infoldings and accumulation of fluid in the bursa
Superficial calcaneal bursitis	Bursa located between calcaneal prominence or the Achilles tendon and the skin	Swelling of posterolateral calcaneus (often associated with rigid shoes)	Solid swelling (sometimes discoloration) often located at the posterolateral calcaneus	Inflamed bursa, lined by hypertrophic synovial tissue and fluid

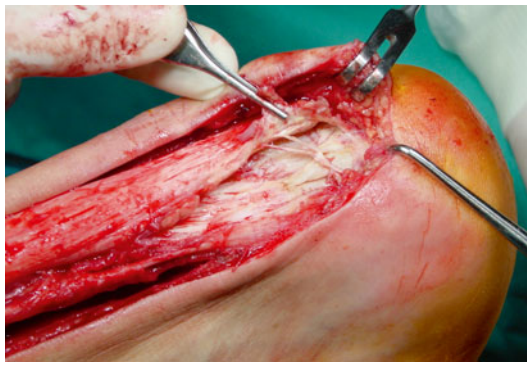

Fig. 95.3 A 28-year-old soccer player with a history of several local steroid injections presents with a sub-complete rupture of Achilles tendon distal insertion

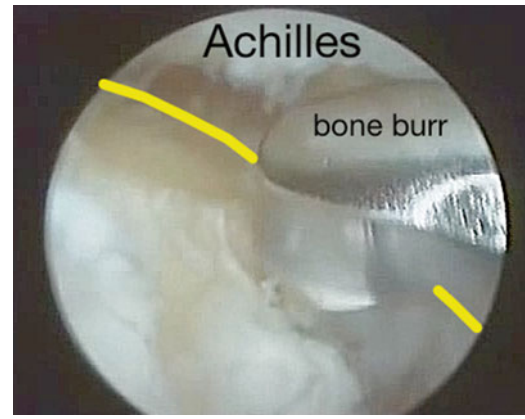

Fig. 95.4 Endoscopic calcaneoplasty

partial rupture, and therefore the need for radiologic evaluation occurs.

95.3.2 Architectonical Structure of the Achilles

In order to fully understand this pathology, one must understand the architectonical structure of the Achilles tendon. Sixty-five to 75 % of tendon consists of collagen (mostly type I) that is responsible for its mechanical strength. Two percent of tendon dry mass is elastin, responsible for recovery of the wavy configuration of the collagen fibres after stretch [5]. Type I collagen molecules have a unique ability to form microfibrils, as well as larger unit fibrils and fibres, that finally create the Achilles tendon (Fig. 95.6).

95.3.3 Metabolism of Tendon Cells

The level of oxygen consumption of a tendon is relatively low comparing to other tissues, like muscles or the liver. However, keeping in mind that the cell mass in tendon is only 1–3 % (while in the muscle almost 95 %) and calculating this ratio "per cell", not "per the dry mass of the tissue", this

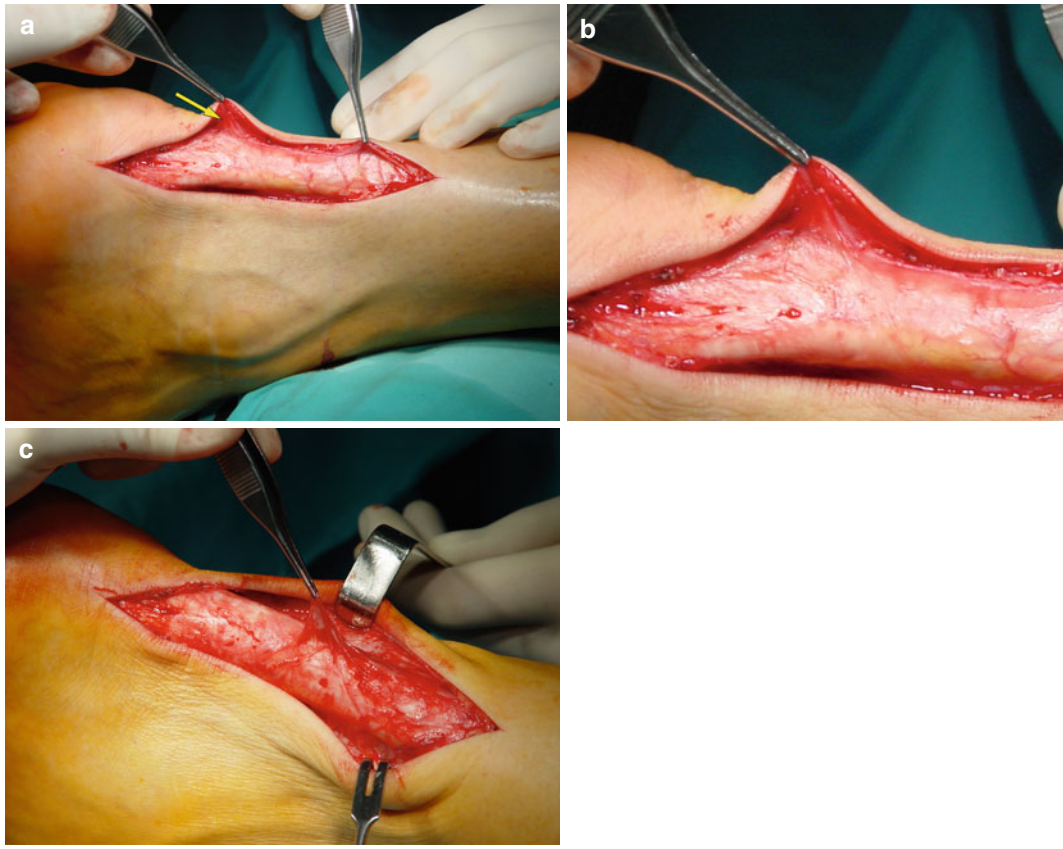

Fig. 95.5 (**a**) A 43-year-old female with chronic paratendonitis and tendinopathy, who did not respond to conservative treatment. Notice (marked with *yellow arrow*) adhesions between the paratendon, Achilles tendon and subcutaneous tissue. This may cause pain and crepitations. Some physiotherapist tries to break those adhesions with intensive manual therapy. (**b**) Same patient – zoom in on the adhesions between the paratendon and surrounding tissues. (**c**) Different patient, similar appearance: 38-year-old male, amateur runner with chronic paratendonitis

difference becomes much lower [17]. During the highest growth rate of a young tendon, all the three pathways of energy production (which means Krebs cycle, pentose phosphate shunt and anaerobic glycolysis) in the tendon are highly active. With increasing age, activity of Krebs cycle and the pentose phosphate shunt decreases, and production of energy changes to anaerobic [9, 12]. In neonate tendon collagen synthesis is high, but reduces drastically with age. Collagen turnover of adult tendon is low, comparable to ligamentous tissues. Metabolically most active collagen is the most newly synthesised [10]. This low metabolic rate of tendon, with well-developed anaerobic energy production, is essential if the tendon is to carry loads and remain in tension for periods of time without the risk of ischaemia and necrosis. However, the inevitable drawback of this low metabolic rate is also a slow recovery rate after activity and healing after injury [29].

95.3.4 Collagen Degeneration

A complete breakdown of collagen requires a number of enzymatic steps. The collagen enzymes make only one cut through each alpha chain, and this results in denaturation of the molecule [3, 23]. The denatured collagen is susceptible to degeneration with other proteolytic enzymes. Collagenases are produced by several tissues and cells, such as synovial cells, leucocytes and macrophages. Additionally, hormones and other substances may play, undefined yet, an

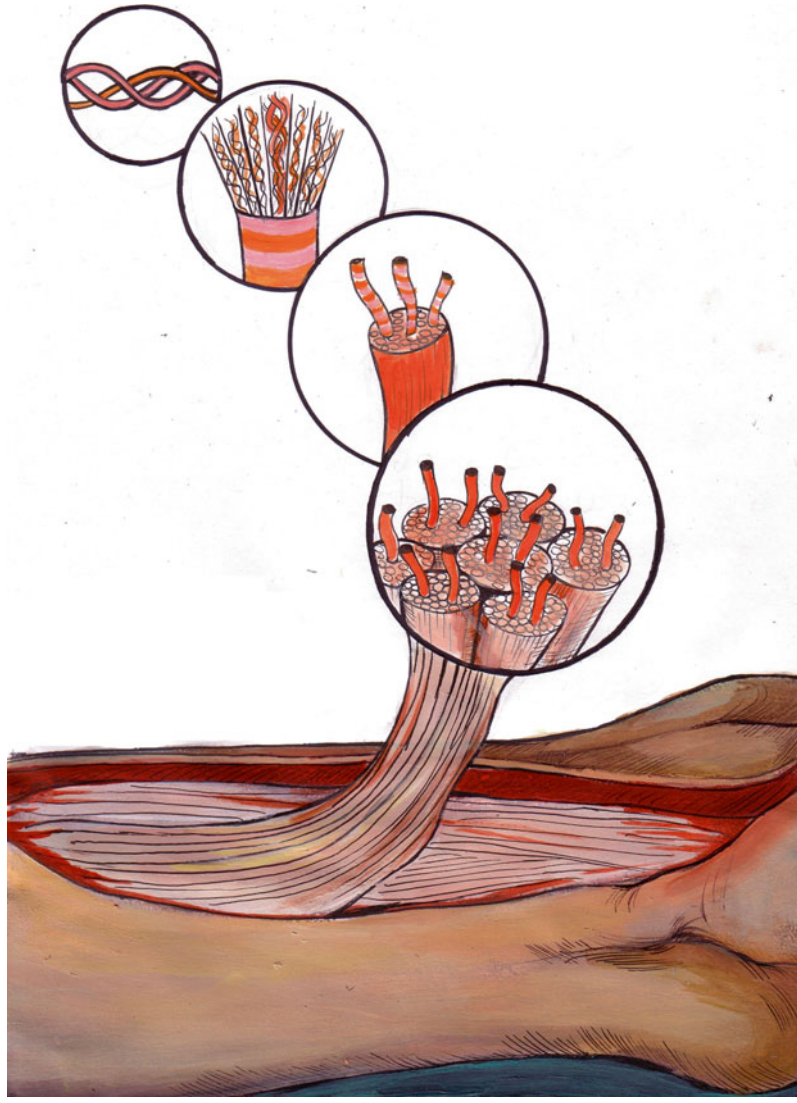

Fig. 95.6 Schematic drawing of Achilles tendon architectonical structure that consists of microfibrils forming bigger and bigger fibrils, fibres and finally Achilles tendon

operational role in the process of collagen degeneration [18].

95.3.5 Overuse Injury

An overuse injury is a long-standing orthopaedic problem and pain in the musculoskeletal system, which begins during exertion due to repetitive tissue micro-trauma. Repetitive micro-trauma results in microscopic injury. According to current knowledge, "overuse" in tendon injuries implies that the tendon has been strained repeatedly 4–8 % of its original length until it is unable to endure further tension, whereupon injury occurs [19]. In order to heal micro-injuries in otherwise poorly vascularised tendon tissue – neovascularisation is required. The majority of the blood supply to the Achilles tendon comes through the paratendon especially from its anterior surface [1].

VEGF is a growth factor, which stimulates endothelium cells and vessels to grow into the tendon, which is required for healing. But in normal tendon, there is no place for vessels; therefore,

VEGF needs to simulate also some extent of tendon degeneration to prepare this tissue, "making space for new vessels".

Area of neovascularisation within the Achilles tendon should be considered as an area with neovessels and accompanying nerves. And although those nerves are probably the direct cause of pain, nevertheless while treating those patients, one should not "kill" these new vessel formations, because it is a symptom and initial phase of healing.

Tendinopathy (Fig. 95.7) is a result of repetitive micro-trauma and failure of reparative process that may lead to symptomatic or asymptomatic micro-injuries and finally to partial or complete rupture (Fig. 95.8). Majority of complete Achilles tendon rupture patients previously had no symptoms of the Achilles tendon problems (but all of them present histopathologic changes within the tendon). Contrary it is rare that a symptomatic tendinopathy leads to complete rupture. This may be due either to the fact that symptomatic patients, because of pain, limit their activity and therefore stop overusing their tendons or maybe those with complete ruptures had much poorer tissue response and ability for healing.

Fig. 95.7 Schematic drawing picturing the idea of how a number of micro-injuries may cumulate and result in partial injury

95.3.6 Diagnosis and Treatment

In case of clinical symptoms of tendinopathy, the key is to determine the extent and the degree of tissue injury, because that would determine the choice of treatment. In some cases thickening (Fig. 95.9) or thinning might be observed. The severity of process is not proportional to the degree of pain. Therefore, at least one radiological examination, ultrasound and/or magnetic resonance, is required. Unfortunately, both, in inexperienced hands, might give false-positive and false-negative results. Be wise in choosing a good place and good radiologist, and trust your clinical examination.

With the extent of injury, the need to enhance the healing grows.

- With minimal structural changes, rehabilitation might be sufficient. Khan et al. [14] proposed mechanotherapy which turns movement into tissue healing. Immobilisation has not been proven as beneficial in those cases [28].
- With more advanced tendon changes, some healing stimulation incarnated as growth factor and/or stem cells injections, preferably under ultrasound control
- Partial injuries (Figs. 95.10 and 95.11) or failure of conservative treatment might require operative treatment.

95.4 Rupture of the Achilles Tendon

Partial rupture of Achilles was first described by Ljungqvist in 1967 [16]. It is believed that partial rupture results from asymmetric loading of

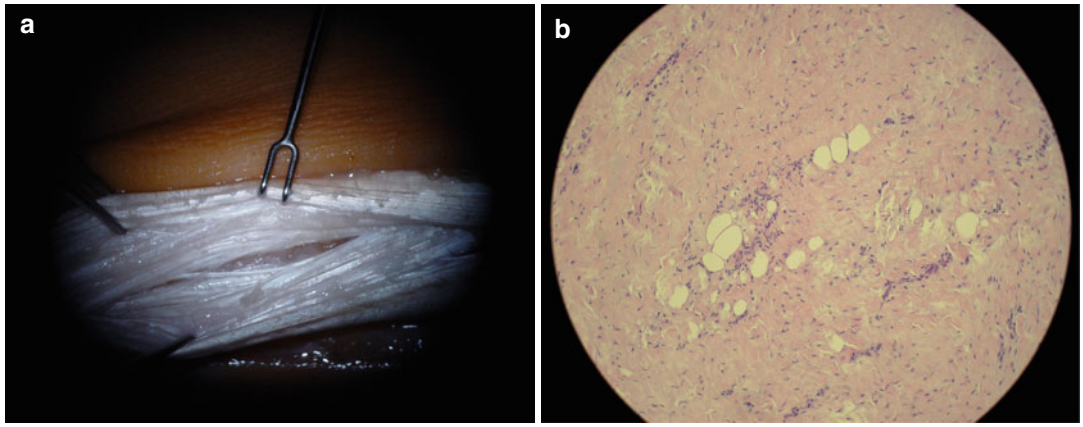

Fig. 95.8 Achilles tendinopathy. (**a**) Intraoperative picture (seen through operative microscope), notice shiny fibres are healthy ones, "frosted" ones – it is where tendinopathy occurs. (**b**) Histopathological view of Achilles tendinopathy: degeneration, old reparative process, disturbance of fibre arrangement

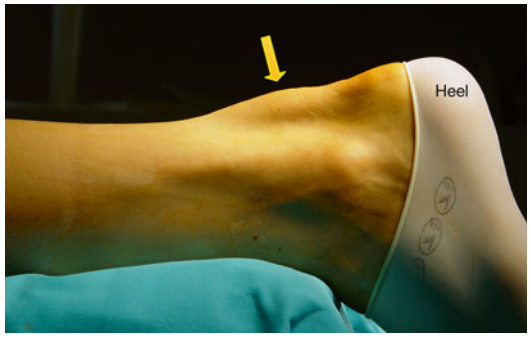

Fig. 95.9 A 36-year-old male with chronic, left Achilles tendinopathy. Notice thickening (marked with *yellow arrow*) of the tendon in typical area of Achilles waist

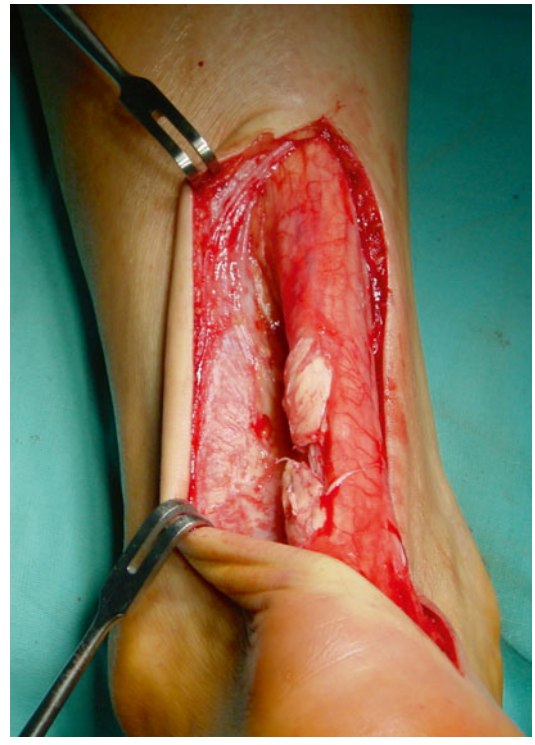

Fig. 95.10 A 27-year-old professional female boxer, with acute, partial rupture (marker with *arrow*) of fibres originating from medial head of the gastrocnemius muscle of left Achilles tendon (type: A-I-GM according to Śmigielski)

Achilles tendon. This asymmetrical loading is possible, because Achilles tendon is not a uniform structure, but consists of three separate bundles: one from medial, one from lateral head of the gastrocnemius muscle and one from soles muscle [20, 21, 24]. The injury occurs in the most loaded bundle. Śmigielski [20] proposed a new classification of partial Achilles tendon injuries, based on both histologic and anatomic appearance. In this classification first part states if this is an acute (A) or chronic (B) case. Second part describes how many Achilles tendon bundles are involved, and the last part describes which bundle is injured: S, fibres originating from soles muscle; GM, fibres from medial head of gastrocnemius muscle; and GL, lateral head of gastrocnemius muscle (e.g. B-I-GM means partial chronic injury of fibres originating from medial head of the gastrocnemius muscle).

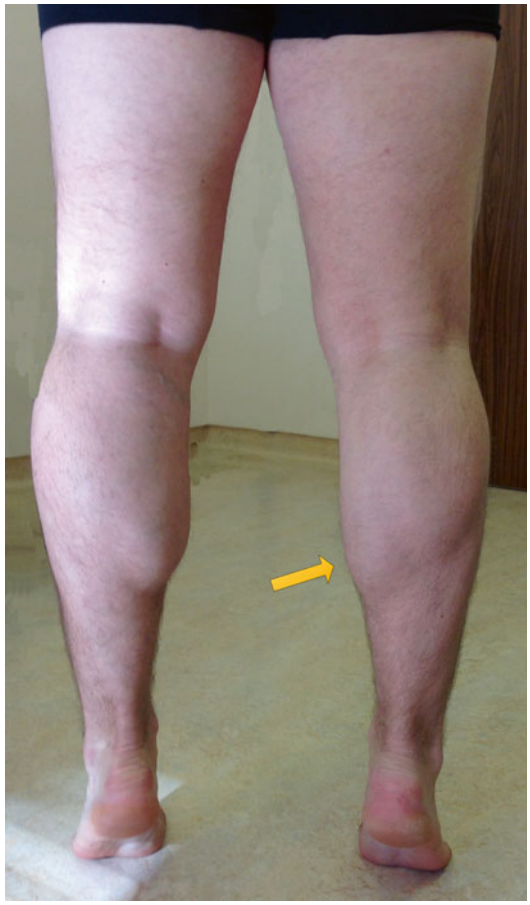

Fig. 95.11 Patient with chronic partial right Achilles tendon rupture. Notice atrophy (marked with *arrow*) of medial head of the gastrocnemius muscle – typical for chronic partial rupture of fibres from medial head of the gastrocnemius muscle. Type: B-I-GM, according to Śmigielski

The treatment of choice for partial ruptures of Achilles tendon is operative reconstruction [20, 21]. Exceptions are patient with general contraindications for operation, patient with rheumatoid diseases and patients with a low level of activity and low expectations, in terms of Achilles tendon function, like running or jumping [20].

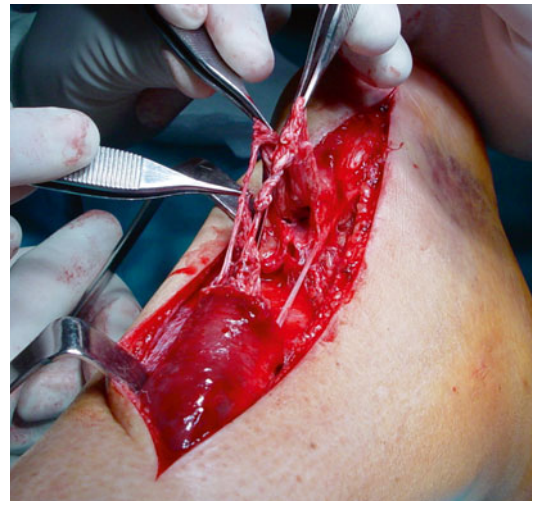

Fig. 95.12 Complete rupture of the Achilles tendon. Some elements of the three bundle structure are still visible

Also in complete ruptures of Achilles tendon, three-bundle structure of Achilles is clearly seen (Fig. 95.12). Those bundles/units depending on the side rotate as left- or right-handed screws – e.g. left Achilles tendon rotates (30–150°) against clockwise [20, 24] (Fig. 95.13a–c). This rotation has significance. It determines Achilles tendon function in terms of jumping and running, and therefore one should try to reconstruct those units and its rotation. On the other hand, in the area of the biggest torsion, there are the highest pressure forces and the poorest blood supply – this area is the most frequent injured one. Also in histopathologic evaluation, we observe much dense fibrocartilage there, for one side reinforcement to sustain those high pressure forces, but in the same time it means poor blood supply.

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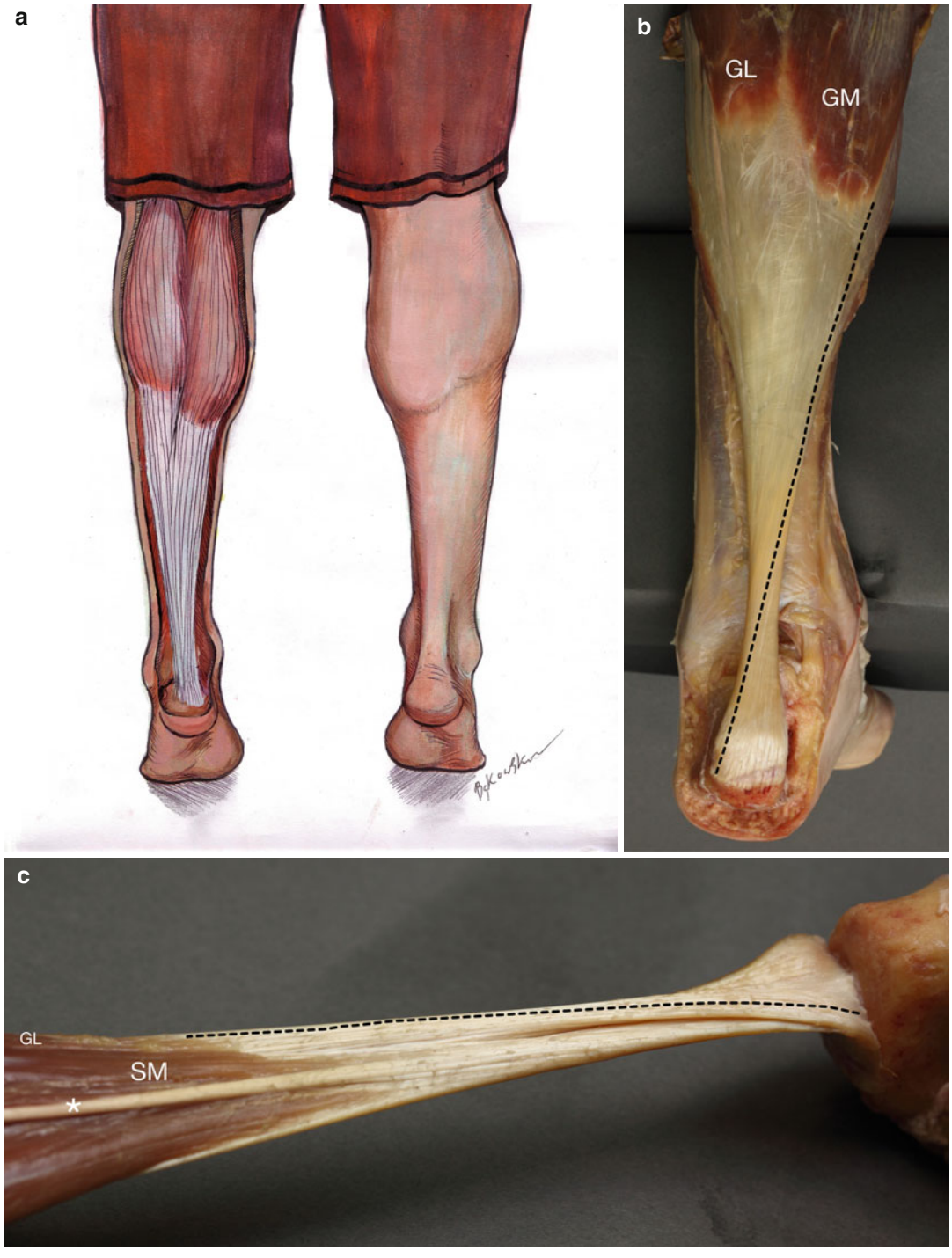

Fig. 95.13 (**a**) Schematic drawing of rotational anatomy of the Achilles tendon. (**b**) Anatomic dissection of the left Achilles tendon. GM – medial head of gastrocnemius muscle. GL – lateral head of gastrocnemius muscle. Notice the rotation of fibres of Achilles tendon and the way fibres originating from medial head of gastrocnemius muscle reaches the calcaneus on the lateral side (marked with *dashed line*). (**c**) Anatomic dissection. Ventral (anterior) part of Achilles tendon. *SM* soleus muscle. GL – lateral head of gastrocnemius muscle. (*) Plantaris tendon. Notice the way fibres from lateral head of the gastrocnemius muscle approaches calcaneus on the medial site (marked with *dashed line*). These are the fibres that get injured the first in cases of prominent posterosuperior edge of the calcaneus, because they are the closest to the bone

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Endoscopic Calcaneoplasty

96

R. Zwiers, J.I. Wiegerinck, and C.N. van Dijk

96.1 Introduction

Retrocalcaneal bursitis is an inflammation of the bursa located in the retrocalcaneal recess. This inflammation is caused by repetitive impingement of the retrocalcaneal bursa between the anterior side of the Achilles tendon and the posterosuperior protrusion of the calcaneus [1–3]. Patients present with posterior heel pain and tenderness. Frequently, there is a palpable calcaneal prominence. Typically, the pain occurs when patients start to walk after a period of rest. Dorsiflexion of the ankle can induce the pain due to decreasing the space between the prominence and the Achilles tendon. In case conservative treatment fails, endoscopic calcaneoplasty is a well-established treatment option [4]. This offers the advantages of minimally invasive surgical procedure compared with open surgical approaches, like low morbidity, short duration of surgery, improved scar healing, shorter rehabilitation time and a quicker resumption of sport [4–7].

96.2 Terminology

Overuse injuries of the Achilles tendon can be divided into insertional and non-insertional problems. Since there is no evidence available for inflammation in patients with "tendinitis", the term tendinosis has been proposed [1]. In 1998, Maffuli proposed to use the term tendinopathy, a clinical definition, characterized by a combination of pain, swelling and impaired performance of the tendon [2]. Pain located at the posterosuperior calcaneal prominence has been referred to as Haglund's syndrome [3]. Since then numerous "Haglund"-related pathologies have been described: Haglund's deformity, Haglund's disease and Haglund's triad. All describe pathology in the foot, most describe different pathologies and some, however, describe the same pathology. To limit confusion, a terminology based on the combination of anatomic location, symptoms, clinical findings and pathological changes was proposed [8]. Regarding insertional Achilles tendon disorders, insertional Achilles tendinopathy, superficial calcaneal bursitis and retrocalcaneal bursitis have to be distinguished.

Retrocalcaneal bursitis is defined as an inflammation of the bursa in the retrocalcaneal recess that results in a visible and painful soft tissue swelling, medial and lateral to the Achilles tendon at the level of the posterosuperior part of the calcaneus. Frequently, a posterosuperior calcaneal prominence can be identified on plain radiographs (Fig. 96.1). Histopathologically, the fibrocartilaginous bursal walls show degeneration and/or calcification, with hypertrophy of the synovial infoldings and accumulation of fluid in the bursa itself.

R. Zwiers (✉) • J.I. Wiegerinck • C.N. van Dijk
Milano, Italy
e-mail: R.zwiers@amc.uva.nl

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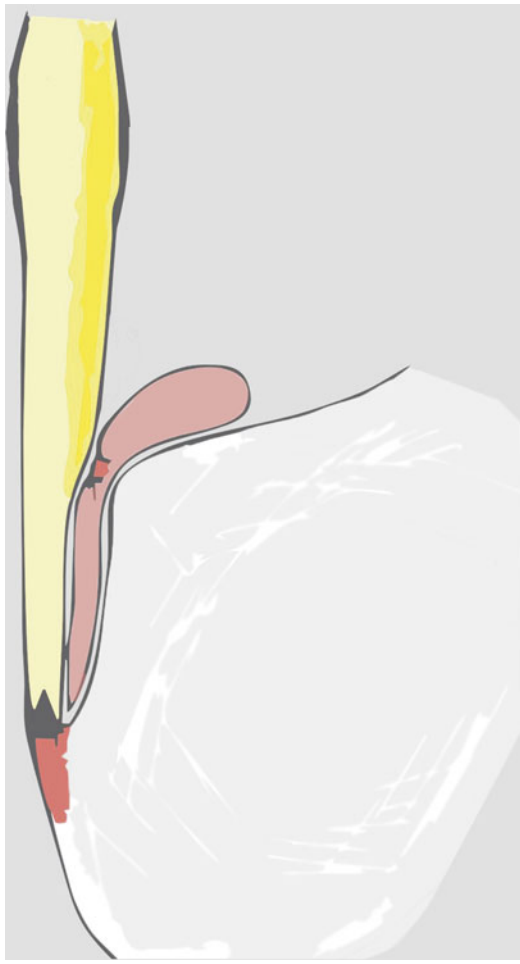

Fig. 96.1 Retrocalcaneal bursa located between the anterior side of the Achilles tendon and the posterosuperior aspect of the calcaneus

96.3 Aetiology

Retrocalcaneal bursitis is most often seen at the end of the second or the third decade, mainly in females, and is often bilateral. It is caused by repetitive compression of the retrocalcaneal bursa between the anterior aspect of the Achilles tendon and the posterosuperior aspect of the calcaneus.

96.4 Clinical Presentation

Patients with a retrocalcaneal bursitis typically describe the onset of pain when starting to walk after a period of rest. The distinction between a retrocalcaneal bursitis, insertional and mid-portion tendinopathy must be made by means of history taking and physical examination. In retrocalcaneal bursitis, physical examination shows swelling seen on both sides of the tendon at the level of the posterosuperior calcaneal prominence. Recognizable tenderness can be reproduced by palpation next to the lateral and medial border of the Achilles tendon at this level. Differentiation must be made with other pathologies. A patient with insertional tendinopathy presents with pain on palpation on the insertion of the Achilles tendon on the calcaneus. Mid-portion Achilles tendinopathy gives complaints more proximal. Superficial calcaneal bursitis is visible as a posterolateral swelling, with local pain on palpation.

96.5 Diagnostic Imaging

A conventional radiograph is the first step in diagnostic imaging. On the lateral standing radiograph, the pre-Achilles fat pad can be assessed [9]. Normally this fat pad, as seen on a weight-bearing lateral radiograph of the ankle, is triangular radiolucent with sharp, gently curving borders [10].

The retrocalcaneal bursa is situated in the posteroinferior corner of the pad. In bursitis, the bursa obliterates the normally sharply outlined radiolucent retrocalcaneal recess [9, 11]. In case of uncertainty, ultrasound or an MRI can confirm the diagnosis.

96.6 Treatment

Conservative treatment of retrocalcaneal bursitis consists of adaptation of the shoe, insoles, systemic use of nonsteroidal anti-inflammatory drugs, stretching and strengthening of the gastrocnemius-soleus complex, phonophoresis, adaptation of activities and physical therapy. In case of chronic retrocalcaneal bursitis, corticoid injections can be applied. When conservative treatment fails, surgery must be considered.

96.7 Surgical Technique

Surgery can be performed in an ambulatory setting under general or regional anaesthesia. The involved leg is marked preoperatively to avoid wrong side surgery. The patient is placed in the prone position. In the prone position, the feet are positioned just over the edge of the operating table, and a bolster is used to slightly elevate the involved leg. The anatomical structures are marked. These include both the medial and lateral border of the Achilles tendon and the calcaneus. After exsanguination, a tourniquet is inflated to 300 mmHg around the affected upper leg. The lateral portal is made, located lateral to the Achilles tendon at the level of the superior aspect of the calcaneus. The skin is incised using a small vertical incision. The location of the portal is 1.5–2 cm distal to the standard hindfoot portal as described by van Dijk [4]. Thereafter, the retrocalcaneal space is penetrated with a blunt trocar, and a 4.5 mm 30° arthroscopic shaft is introduced. Irrigation is achieved by gravity or pressured flow at 50 mmHg. To locate the medial portal, a spinal needle is introduced under direct vision (Fig. 96.2). This portal is made medial to the Achilles tendon, at the superior aspect of the calcaneus. After preparing the medial portal by a vertical stab incision, a 5.5 mm bonecutter shaver is introduced and visualized by the arthroscope. The bonecutter shaver is facing the bone throughout the process to prevent iatrogenic damage of the Achilles tendon (Fig. 96.3). Preoperatively impingement between the Achilles tendon and the calcaneus can be assessed by dorsiflexing the foot. Subsequently, the foot is brought into plantar flexion, and the posterosuperior calcaneal rim is removed. Both portals are used interchangeably for the arthroscope and the resector. It is important to remove sufficient bone at the posteromedial and lateral corner by changing portals intermittently (Fig. 96.4). The synovial resector is moved beyond the posterior edge onto the lateral and medial wall of the calcaneus to smoothen the edges. Full plantar flexion of the foot is necessary to visualize the Achilles tendon insertion and to create space between the Achilles tendon and the bone. 3.0 Ethilon sutures are used to close the incisions to prevent sinus formation. A 10 ml 0.5 % bupivacaine/morphine solution is injected at the incision site and surrounding skin. Finally, a sterile compressive dressing is applied.

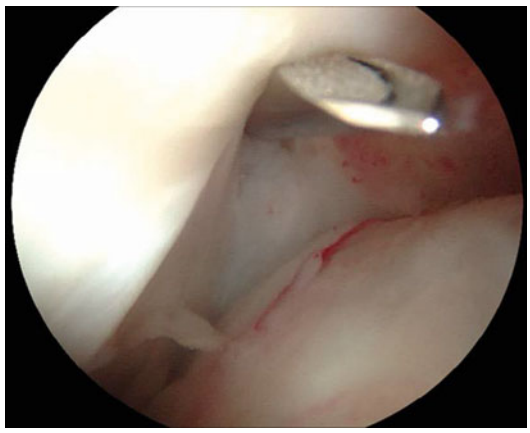

Fig. 96.2 A spinal needle is placed medial from the Achilles tendon to check the level. The portal should be exactly at the posterosuperior border of the calcaneal prominence as shown in the picture

96.8 Rehabilitation

Post-operative treatment is functional and weight bearing is allowed as tolerated; the patient is instructed to elevate the foot when not walking. Three days post-operatively, the bandage is removed. Active range of motion exercises are advised from day 1 for at least 10 min, three times a day. The patient may return to regular shoes as tolerated. After 2 weeks the sutures are removed. A conventional lateral radiograph can be made to ascertain if sufficient bone has been excised. Patients are directed to a physiotherapist if a limited range of motion remains.

96.9 Results

Hitherto four studies have been reported on this two-portal endoscopic technique, one study used an alternative technique using an additional portal. All studies reported favourable results. A recent systematic review of 15 studies also showed that endoscopic surgery is superior to an open approach. Endoscopic interventions show lower complication rates, higher patient

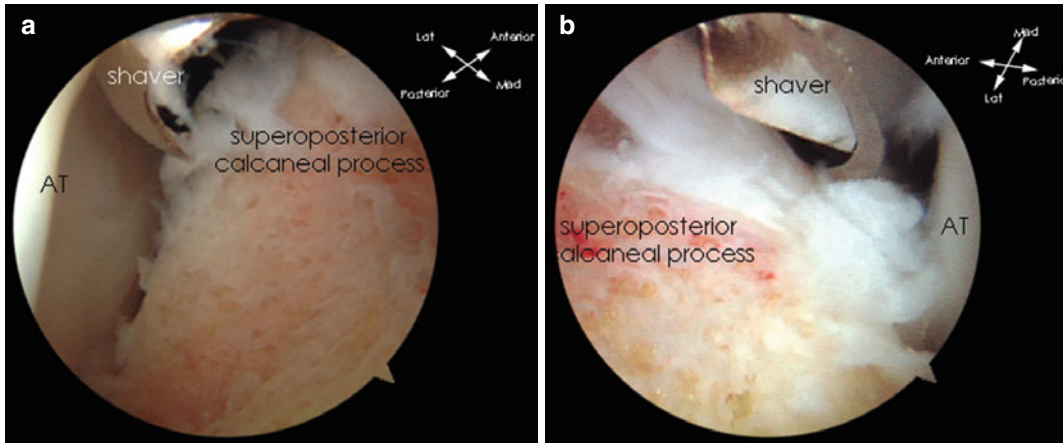

Fig. 96.3 Endoscopic calcaneoplasty. (**a**) Removal of the bone at the posteromedial border of the calcaneus with an arthroscope in the lateral portal. (**b**) Removal of the bone at the lateral border of the calcaneus after a change of portals

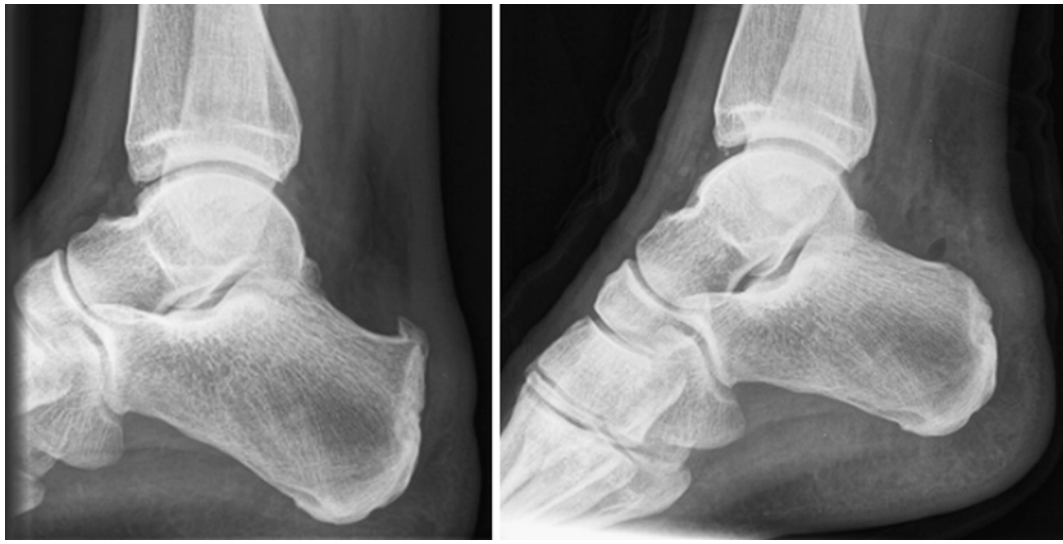

Fig. 96.4 Typical example of bony irritation with spur formation at the level of the posterosuperior border of the calcaneus and retrocalcaneal bursa. X-ray after successful endoscopic calcaneoplasty

satisfaction, shorter period of immobilization and non-weight bearing. Performing normal daily activity and resumption of sports is sooner achieved [12].

Scholten et al. published the results of 39 procedures of endoscopic calcaneoplasty in 36 patients. There were no surgical complications except from one patient who experienced an area of hypoesthesia over the heel pad. Postoperatively there were no infections, tenderness or problematic scars, and all patients were content with their small incisions. Except for two, all patients improved. The Ogilvie-Harris score was rated fair by 4 patients, 6 rated good and 24 had excellent results. Work and sport resumption was achieved at an average of 5 weeks (range, 10 days to 6 months) and 11 weeks (range, 6 weeks to 6 months), respectively [7].

Jerosch et al. reported on 164 patients, 81 males and 84 females, with age ranging between 16 and 67 years. According to the Ogilvie-Harris score, 71 patients had good results, and 84

patients had excellent results, while 5 patients showed fair results, and 4 patients had poor results. The post-operative radiographs showed sufficient resection of the calcaneal spur. Only minor post-operative complications were observed [6].

Leitze et al. published their series of 30 consecutive patients (33 procedures) treated by endoscopic decompression of the retrocalcaneal space. The AOFAS increased from 61.8 points preoperative to 87.5 post-operative. At an average of 22 months follow-up, 19 cases yielded an excellent outcome and 5 cases a good outcome. Both fair and poor outcomes were reported in three cases [13].

Ortmann and McBride described the results of 30 patients (32 ft) with retrocalcaneal bursitis treated with a similar two-portal endoscopic approach. Twenty-six heels had excellent results and three had good results. There was one patient with a poor outcome, requiring an open procedure with Achilles tendon augmentation. In one patient an acute Achilles tendon rupture occurred. After primary repair this patient returned to her preoperative activity level [14].

In a recent study by Wu et al., an adjustment on this endoscopic technique was introduced. Compared with the two-portal technique, an additional proximal posterolateral portal is used just lateral and 5 cm proximal to the insertion of the Achilles tendon. This portal is mainly used as viewing portal. Due to the larger distance to the prominence, this portal might provide a better view. Twenty-five heels were treated with this three-portal technique. Fourteen heels showed an excellent result, seven showed a good result and both fair and poor results were reported in after two procedures. According to the Ogilvie-Harris score, there were 15 excellent, 7 good, 1 fair and 2 poor results. No complications occurred.

Conclusion

Retrocalcaneal bursitis is an inflammation of the retrocalcaneal bursa between the anterior aspect of the Achilles tendon and the posterosuperior aspect of the calcaneus, resulting in posterior heel pain and tenderness at the level of the Achilles tendon insertion. Endoscopic calcaneoplasty is a well-established treatment option, with short recovery time, quick activity resumption and low complication rates.

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