Christophe Hulet
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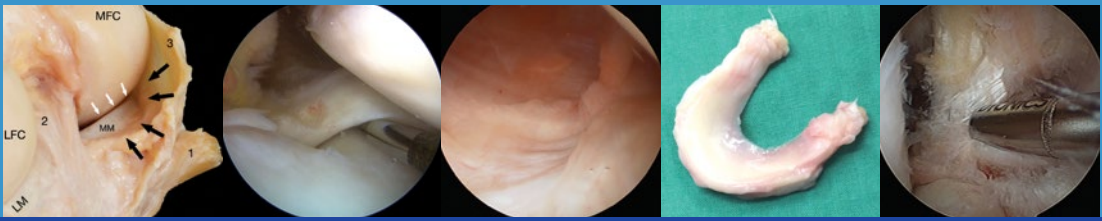
Editors



Surgery of the Meniscus

European Society of Sports Traumatology, Knee Surgery & Arthroscopy
ESSKA

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Springer

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ISBN 978-3-662-49186-7 ISBN 978-3-662-49188-1 (eBook)
DOI 10.1007/978-3-662-49188-1

Library of Congress Control Number: 2016934932

Springer Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer-Verlag GmbH Berlin Heidelberg is part of Springer Science+Business Media (www.springer.com)

Foreword

"Take it out, take it all out. Even if it is not torn, take it out"

Those were the slogan words by Smillie referring to meniscal injuries – and this is not even 100 years ago.

We have come a long way in trying to restore the anatomy and function of this weight-bearing cartilage body in the knee joint. Of course in Smillie's time, there was a clinical need to unlock the locked knee joint in order to restore limb function and allow for normal gait. In the young knee with good vital tissues and good and stable alignment, the remnant meniscus had a good chance to round off and function appropriately for years to come.

However, confronted even with minor additional injuries on ligaments or cartilage, the "organ", that is, the knee joint, was noted to start to fail rapidly leading to functional impairment and pain. Indeed, isolated ligament injuries having been addressed over the years with obvious success seem to behave less successfully when injury is associated with meniscal impairment or absence.

The biology and the mechanical integrity of this "organ" have to be preserved as best we can.

It is remarkable that this concept of meniscal preservation progresses over the years in our daily clinical practice.

However, the meniscectomy rate remains too high, even though robust scientific publications allow us to promote meniscal repair or abstention in traumatic meniscal injuries and abstention rather than meniscectomy in degenerative meniscal lesions.

There remains a major gap between "expert scientific publications" and daily clinical practice. Reasons enough: the myth of efficiency (I've always done that and it works!), the learning curve (but the suture is not more difficult than meniscectomy and has no higher morbidity), the societal push ("I have a meniscal injury" or "rehabilitation after repair takes too long") and finally the medical economics in practice (in many countries, return on meniscal repair is poor)

ESSKA has rightfully initiated sound efforts to further support this meniscal preservation.

Some years ago Philippe Beaufils and Rene Verdonk et al. published the first book ever on the meniscus covering it from its inception and foetal development through its close relationship with other anatomical bodies in the knee towards trauma and degeneration and describing the state of the art in repair and replacement.

Today ESSKA has taken over this setup with the best experts on the matter. Christophe Hulet has done a special job as editor in bringing together the scientific forces on all aspects that are important in saving the meniscus thus avoiding early biologic degeneration.

Taking the risk of failure in repairing the torn meniscus whenever possible (and well indicated) has become a state of mind of the prepared orthopaedic knee surgeon. Techniques are now available to make this job successful in many cases.

Taking the risk of failure in replacing the removed meniscus both partially as in its entirety may become the course of the future as new techniques and implants, improving on existing devices that may come up and support the protective effect on the weight-bearing cartilage as biology and mechanics may return to normal.

All individual authors are to be congratulated on a job extremely well done.

The drive to finalize this is to be found in the ESSKA Board and its scientific committees (Arthroscopy, Basic Science and Cartilage) creating the stamina needed to investigate again the subject of the meniscus and allowing common efforts to publish this piece of work. Let us hope that this book, carried by experts and a trusted scientific society, will contribute to pass the message along.

Pr. René Verdonk

Pr. Philippe Beaufils

Foreword Surgery Meniscus Book

We are very proud to introduce this new book on the meniscus, this anatomic structure which was too often insufficiently considered by past generations of surgeons. Rapid advances in arthroscopy and surgical technology have provided orthopaedic surgeons with the necessary tools allowing us to preserve the meniscus in many circumstances in our current daily practice. In that sense, the pioneering work of our predecessors has paved the way to a better patient care and hopefully prevention of later osteoarthritis in those patients where the meniscus has been repaired.

Bertrand Russell once said that in science the successors stand upon the shoulders of their predecessors. In that sense, we want to acknowledge 2 of these pioneers, e.g. Prof. René Verdonk from Ghent, Belgium, and Prof. Philippe Beaufils from Versailles, France, who initiated the work with their book *The meniscus*, edited back in 2010. Half a decade later, the ESSKA arthroscopy committee – under the vigorous leadership of Prof. Christophe Hulet from Caen, France – has provided an update of the knowledge gathered in the pioneering book.

When approving this project after the Amsterdam congress during the summer of 2014, the ESSKA Board recognized that sufficient new knowledge had been generated in the field of meniscus surgery to dare initiating yet another book on the meniscus. The careful reader will find an interesting European perspective on meniscus surgery with many new perspectives testifying the scientific dynamism in this field. In some fields, the European view was completed with additional international expertise.

In that sense we are proud to include this new book *Surgerey of the Meniscus* into the ESSKA book programme portfolio and would like to thank all the authors for their excellent contribution. We hope that the book will further help to improve the treatment of meniscus pathologies in Europe and beyond and that it may stimulate surgeons, other healthcare professionals and researchers to keep the field of meniscus medicine and research as vivid as it was over the last years.

Milano and Luxembourg, January 2016

Matteo Denti
ESSKA President

Romain Seil
ESSKA 1st Vice President

Matteo Denti
ESSKA President

Romain Seil
ESSKA 1st Vice President

Preface

Meniscus injuries are still one of the most frequent causes for orthopaedic surgery worldwide. Moreover, as Prof. René Verdonk from Ghent, Belgium, and Prof. Philippe Beaufils have stated, “nothing has changed so much in recent years in orthopaedics like the algorithm for treatment of meniscal injuries”. We have moved from the promotion of removal of the tissue (meniscectomy) to preservation (repair or even replacement).

The book from these two forerunners launched in 2010 has constituted an important landmark in defining new concepts and bringing attention to the fact that “preserving the meniscus is also preserving the future” of the joint.

This new book was born within the spirit of ESSKA in contributing to continuous progress and update in topics with high impact to clinicians, patients and society.

It was born from an initiative of the current Arthroscopy Committee with immediate support from Basic Science and Cartilage Committees.

It intends to provide a comprehensive and multidisciplinary approach on meniscus structure, pathology and treatment. In this we are proud and happy for having gathered so many top experts in different related topics.

This is a book dedicated to those interested in “surgery of the meniscus”. Despite the previous, it also includes the most recent hot topics on meniscus research as well as ongoing and future perspectives from uprising technologies.

We hope you can enjoy it and find it useful on your daily practice and as a support and guide for continuous research dedicated to meniscus injuries and their treatment.

The Chairmen of Arthroscopy, Basic Science and Cartilage Committees

Christophe Hulet

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Christophe Hulet, Goulven Rochcongar, Christine Tardieu, Julien Dunet, Etienne Salle de Chou, Valentin Chapus, and Andrei Korolev

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1.1 Introduction

Knee anatomy can be traced back more than 300 million years, to the pelvic appendages of the sarcopterygian lobe-finned fish [7]. Thorough knowledge of the gross anatomy and histology of the meniscus is a prerequisite to understanding its function. Furthermore, knowledge of meniscus-meniscal ligament complex phylogeny and ontogeny is necessary to correlate meniscal gross anatomy to meniscal function [4, 12, 14, 20]. The menisci are important primary stabilizers and weight transmitters in the knee. They primarily act to redistribute contact forces across the tibia femoral articulation. This is achieved through a

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_1

combination of the material, geometry, and attachments of the menisci. Kinematic studies of intact knees have revealed a combined rolling and gliding motion, with posterior displacement of the femorotibial contact point with increasing flexion. Both the medial and lateral menisci translate posteriorly on the tibial plateau during deep knee flexion. The posterior translation of the lateral meniscus (8.2 ± 3.2 mm) is greater than that of the medial one (3.3 ± 1.5 mm) [37]. This asymmetry of kinematics between the medial and lateral compartment, an established characteristic of human and many other extant mammalian knees [12, 14], results in an internal rotation of the tibia, relative to the femur with increasing flexion. Four bony characters are relevant to understanding the functional anatomy of the knee related to bipedalism: femoral shaft obliquity relative to the infra condylaire plane, architecture of the lateral femoral trochlea with lateral lip elevation, profile of lateral condyle of the knee, and form and shape of the epiphysis in the horizontal plane [12, 14, 21]. As described by Tardieu [31], three different human femorotibial characters are selected as derived hominid features and are relevant to modern bipedal striding gait. One of these characters for the soft tissues concerns the lateral meniscus and its double insertion on the tibial plateau. This chapter will explore and successively describe knee and meniscal phylogeny, meniscal ontogeny, and the particular case of discoid meniscus.

1.2 Knee and Meniscal Phylogeny

Most of the complex functional morphologic characteristics of the human knee are not unique to humans. Hominids share a common evolutionary history with all living tetrapods relative to the development of the complex morphologic asymmetries of the knee [9]. Tetrapods include all amphibians, reptiles, birds, and mammals. Indeed, bird knees share similar morphologic characteristics with human knees, including the presence of cruciate ligaments, asymmetric collateral ligaments, menisci, and a patella [11]. This commonality of design between human and avian knees reflects a shared genetic lineage of great antiquity, which implies the existence of a common ancestor that may have possessed many of these characteristics.

The tetrapod knee joint has been well investigated by Haines [10, 11], who in 1942 reported an impressive dissection study of numerous living tetrapods. Mossman and Sargeant [20] described the phylogenetic relationships of the major classes of tetrapods. They showed *Eryops* (from the Paleozoic period) to be a common ancestor to living reptiles, birds, and mammals. An *Eryops* knee is not so different from a *Crocodilus* knee. *Crocodile* menisci are both massive structures fitted between the surfaces of the femur and the tibia and are connected anteriorly by an intermeniscal ligament. They are attached to the inner capsular surface by their peripheral margins and by meniscofemoral and meniscotibial ligaments. *Varanus varius* (lizard) menisci are quite different. The lateral meniscus is a continuous mass, completely separating the femur from the tibia, while the medial meniscus is circular shaped and perforated in its center, through which the cruciate ligaments pass. The lateral meniscus is also attached to the fibula by a posterior meniscofemoral ligament. Anatomic features and knee movements are different in these two specimens, illustrating a correspondence between shape and function during evolution. In *Eryops*, the common ancestor of reptiles, birds, and mammals, over 320 million years, the knee joint has no patella. It is only in the last 70million years that the patella has grown in birds, reptiles, and some mammals. It is a late development compared to the development of the femoral condyles' cruciate ligaments [12, 38].

Starting with *Eryops*, the lineage that leads to mammals includes pelycosaurs such as *Dimetrodon* (sail-backed animal) [18]. During the Mesozoic era, 215 to 70 million years ago, the femurs of protomammals and dinosaurs rotated internally, causing the knee to become apex anterior, as in modern humans. It corresponds to a decisive change in the position of the limbs, relative to the vertebral column: the transition from transversal limbs to parasagittal limbs. By the beginning of the Cenozoic era, an osseous patella had developed independently in fossil lizards, birds, and mammals [25]. An inspection of the knee of the black bear reveals a classic mammalian knee very similar in morphologic features to a human knee [29].

In the primate lineage leading to humans (Fig. 1.1), the hominids evolved to bipedal stance approximately 3 to 4 million years ago (period of *Australopithecus afarensis*: Lucy), and by 1.3 million years ago, the modern patellofemoral joint was established with a longer lateral patellar facet and matching lateral femoral trochlea [33].

In mammals, the anatomy of the knee is fairly basic with two rigid balls, and they have very little contact with the tibial glenoid cavities. These are the ligaments and menisci that stabilize all with insert points together to avoid excessive movements. The shape of the patellofemoral joint is highly variable and depends on the mode of locomotion. Tardieu and Dupont [33] specify that these differences in anatomical shape depend on the type of movement among quadripedes.

In horses in the family of Onguligrades, the knee is placed in flexion and still never knows full extension. There is no continuity between the condyles and femoral trochlea. The horses sleep standing up, and shape of the lower limb is adapted to the race with guided and quick movements. In *Cercopithecus* a quadruped animal (horse) [12], there is no obliquity of the femoral diaphysis. The trochlea is symmetric with no depth; the lateral femoral condyle is circular. The distal epiphysis is not the same; the medial condyle is larger than the lateral condyle and different in length.

In apes and bears (Fig.1.2), Plantigrade family, there is no obliquity of the femoral diaphysis, and the knees are adducted. The trochlea is flat and there is only one facet for the patella. The lateral femoral condyle is circular, but the shape of the distal epiphysis is more rectangular (medial condyle larger than lateral condyle). The cruciate ligaments are very similar [29].

Three different human femorotibial characters were selected as derived hominid features rele-

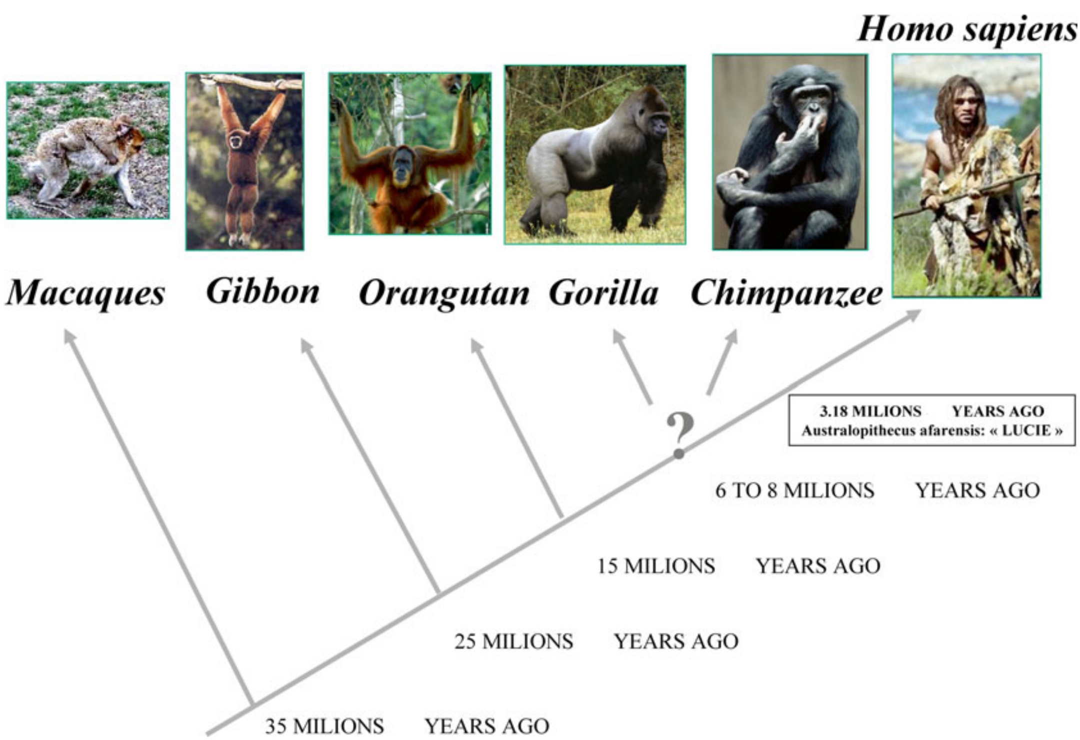

Fig. 1.1 The primate lineage leading to *Homo sapiens*

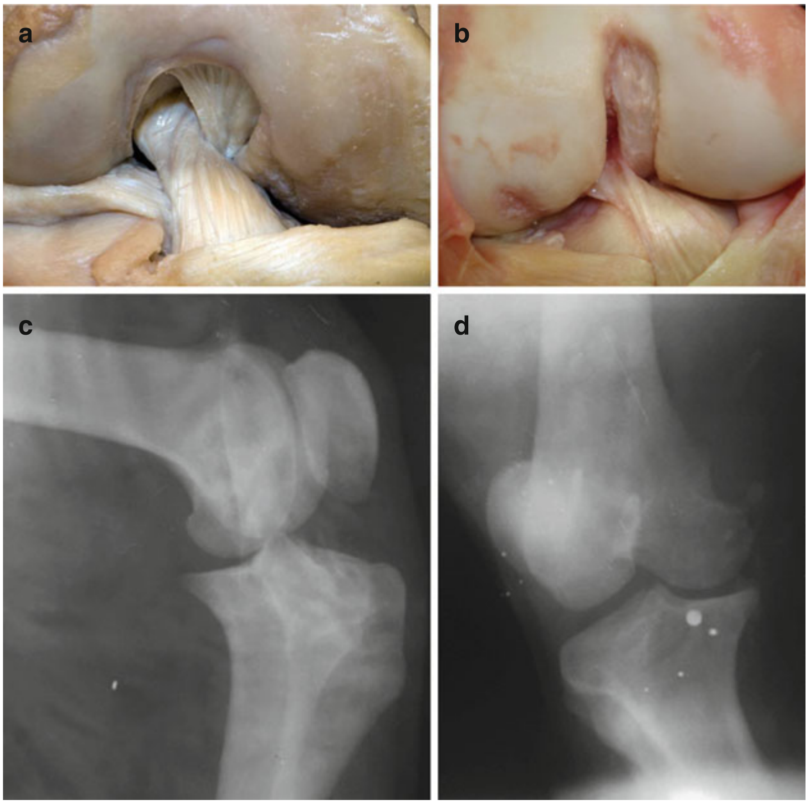

Fig. 1.2 Macroscopic view of gorilla (**a**) and bear knees (**b**). X-ray evaluation of the bear's knee (**c, d**)

vant to modern bipedal striding gait. The first feature is the bicondylar angle of the femur, contrasting with a chimpanzee femur, which is straight. The second feature relates to the shape of the femoropatellar groove: flat for the chimpanzee (rectangular) and grooved in humans (square) [12, 14, 21] (Fig. 1.3).

Finally, the third feature concerns the lateral meniscus and its double insertion on the tibial plateau (Fig. 1.4). In humans, the presence of a posterior tibial insertion of the lateral meniscus limits its mobility on the tibial plateau compared to the single insertion in chimpanzee (Fig. 1.5). The second posterior insertion aids in preventing extreme anterior gliding of the lateral meniscus during frequent extension [30]. The lateral meniscus is also pulled strongly anteriorly during medial rotation of the femur on the tibia. As in extension, the posterior attachment of the lateral meniscus limits this anterior movement [31]. This insertion, posterior to the external tibial spine, is a derived feature, unique among living mammals.

Also, in the human knee, the development of the meniscofemoral ligament to the cruciate ligament is critical to reinforce the posterior fixation of the lateral meniscus. Laterally, the meniscofemoral attachment of the lateral meniscus to the tibia and to the posterolateral corner provides better stability and fixation compared to the chimpanzee anatomy. Indeed, other nonhuman primates are unable to fully extend the knee joint in bipedal walking, while they are able to do so during quadrupedal gait.

Since terrestrial bipedalism of *Australopithecus afarensis* was likely associated with abilities of arboreal climbing and suspension, and was different from that of modern humans [28], Tardieu [31–33] investigated the transition from occasional bipedalism to permanent bipedalism. She observed that primate and other mammal knees contain a medial and a lateral fibrocartilaginous meniscus.

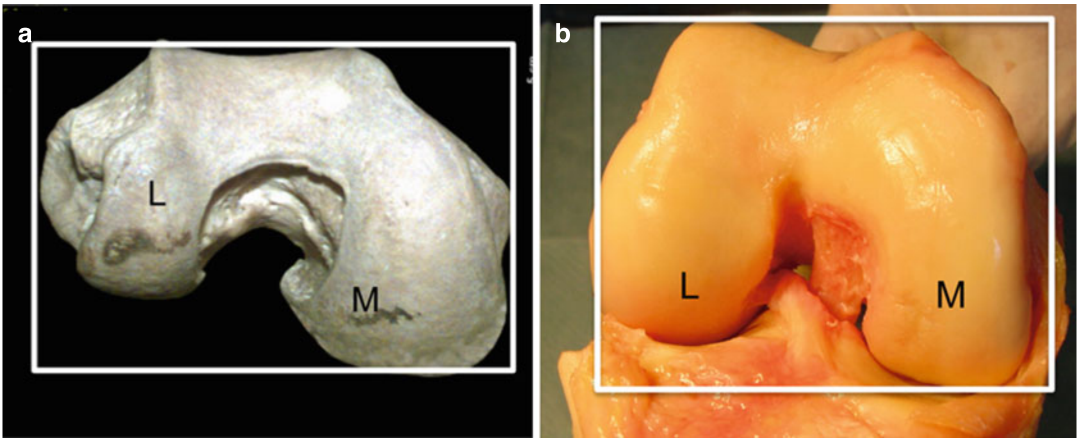

Fig. 1.3 Femoropatellar groove of gorilla (**a**) and human (**b**) knees. The shape is more rectangular in the gorilla example, and there is asymmetry in femoral condyles

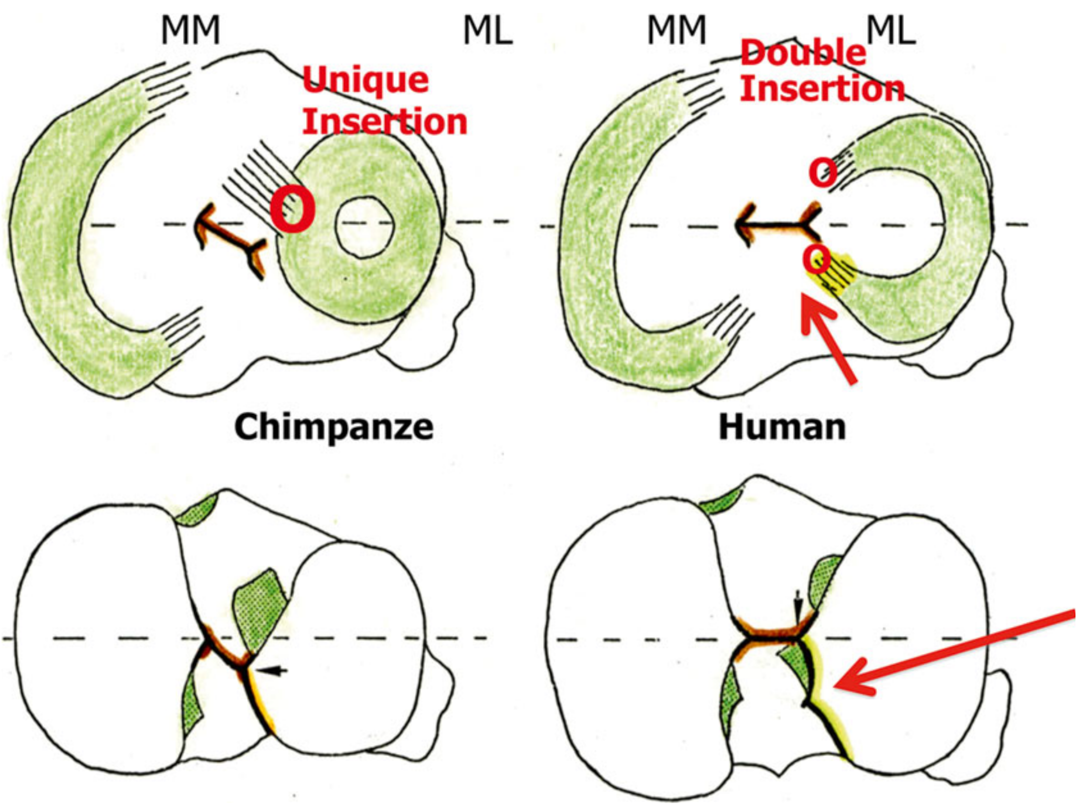

Fig. 1.4 Comparison between human lateral meniscal morphology with double insertion (*red arrow*) compared to the unique lateral meniscal insertion with greater mobility

The medial meniscus is very similar in all primates. It is crescent shaped with two tibial insertions, not so different from the *Homo sapiens*' meniscus. By contrast, the lateral meniscus is more variable in shape and in the pattern of tibial insertions. Dissections of different primates showed that the lateral meniscus displays three distinct morphologies in extant primates [24, 32, 34]. A crescent-

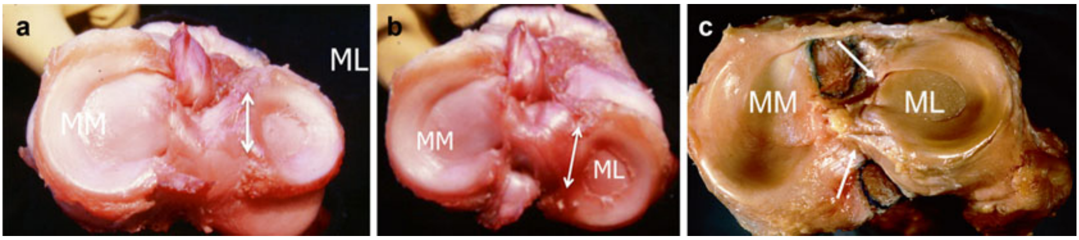

Fig. 1.5 The unique insertion of the lateral meniscus in chimpanzee with the emphasis on the anterior and posterior meniscal displacement (**a, b**). On the contrary, the lateral meniscus in human with its double insertion is far more stable, and there is less displacement (**c**)

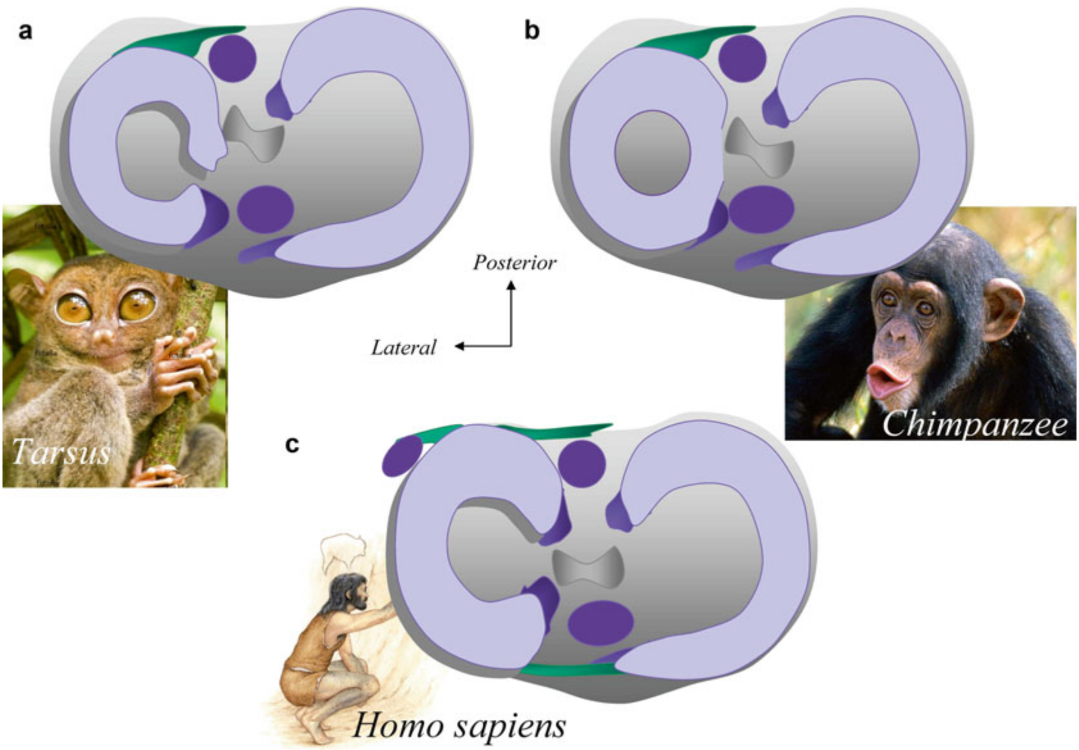

Fig. 1.6 The three distinct morphologies of menisci in extant primates: (**a**) crescent shape of the lateral meniscus with one anterior insertion, (**b**) ring shape of the lateral meniscus with one anterior insertion, and (**c**) crescent shape of the lateral meniscus with two insertions

shaped lateral meniscus with one tibial insertion, anterior to the lateral tibial spine, is present in Lemuriformes, *Tarsius*, platyrrhines, and *Pongo*. A ring-shaped meniscus with one insertion anterior to the lateral spine is found in all catarrhines, except *Pongo* and *Homo.* A crescent-shaped lateral meniscus with two tibial insertions, one anterior and one posterior to the lateral spine, is only found in *Homo sapiens* (Fig. 1.6).

The fossil record also provides evidence of a transition from the fossil record of a single to double insertion of the lateral meniscus in hominid tibias. While *Australopithecus afarensis* exhibits a single insertion, early *Homo* clearly exhibits a double insertion of the lateral meniscus on the tibia. This feature indicates a habitual practice of full extension movements of the knee joint during the stance and swing phases of bipedal walking [23].

Other features are associated with striding bipedal gait. Many differences exist between the lower limbs of *Homo sapiens* and other primates. Contrary to humans, other primates walk with a flexed knee.

As a result, the shape of the femoral epiphysis is different (Fig. 1.7). During the primate lineage leading to *Homo sapiens*, lower limb evolution showed a transition from an abducted knee to an adducted knee, which means that the femoral anatomic angle evolved to 7° of valgus [33]. Nonhuman medial femoral condyles were more spherical with a shallow trochlear groove and a smaller bicondylar angle. On the other hand, human femoral trochlea had a higher lateral lip, and the patella is different (see Fig. 1.7).

In the human knee, the medial compartment is very similar in terms of medial meniscus insertions and bony shape with concavity in both human and chimpanzee (Fig. 1.8).

In the chimpanzee, the convexity of the lateral tibial plateau is more pronounced compared to the human tibial knee (Fig. 1.9). Therefore, there is augmentation of osseous femorotibial contact with greater stability. The lateral meniscus is more stable with two insertions. All these changes generate better extension of the knee compatibility with bipedal walk, giving greater stability and less mobility of the lateral compartment.

All these modifications coincide with pelvic modification, especially with a decreasing interacetabular distance. According to Tardieu, modification

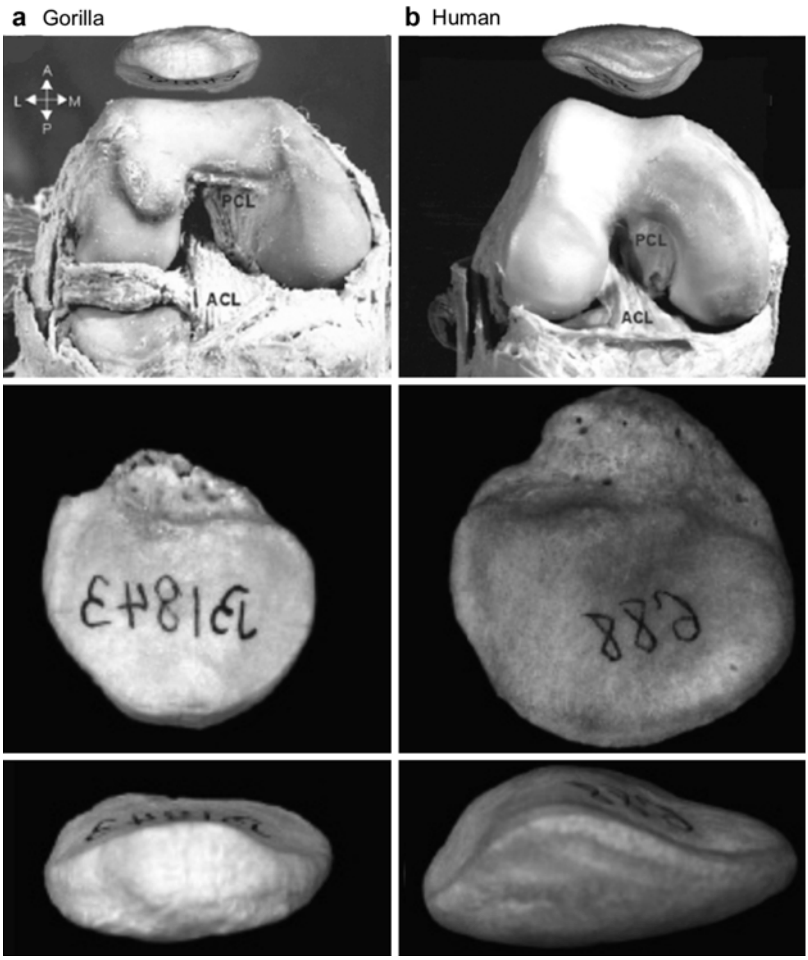

Fig. 1.7 Comparison between a gorilla knee (column **a**) and human knee (column **b**) in terms of shape of the trochlea and the patella

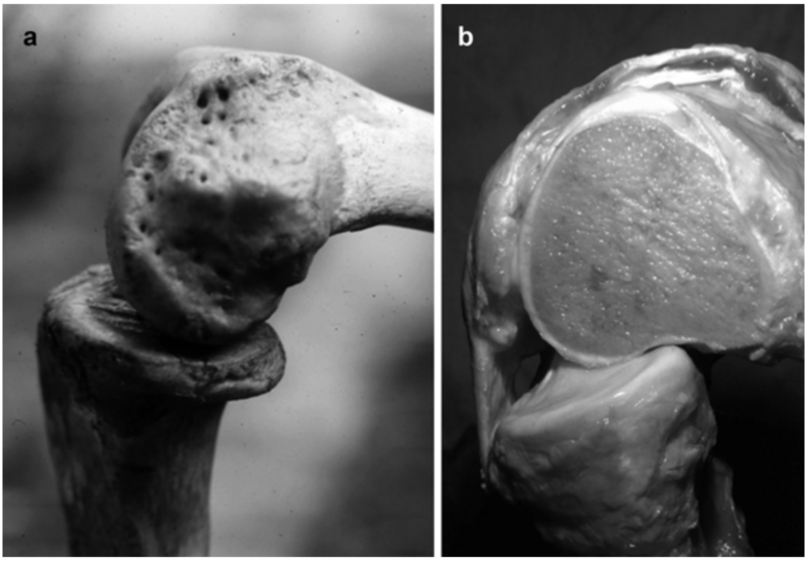

Fig. 1.8 Similarity of the medial compartment between a chimpanzee knee (**a**) and human knee (**b**) in terms of shape of tibial plateau

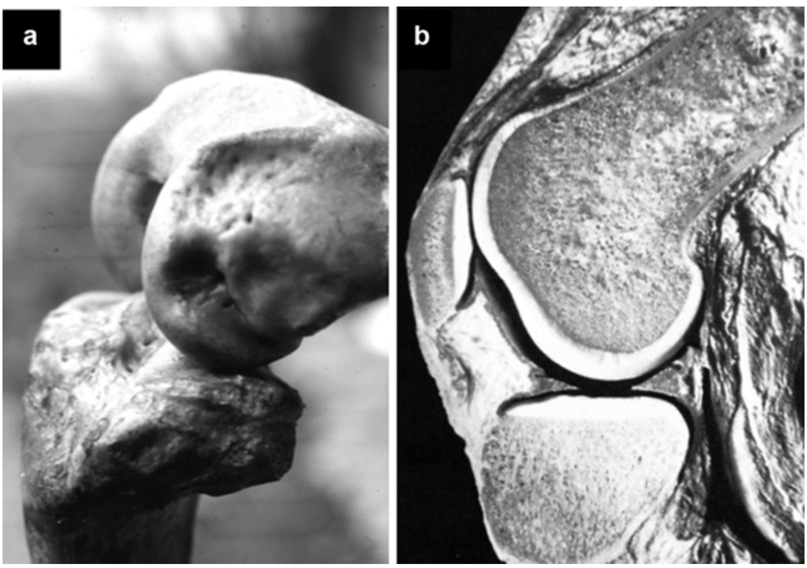

Fig. 1.9 Differences of the lateral compartment between a chimpanzee knee (**a**) and human knee (**b**) in terms of shape of the lateral tibial plateau

of the bicondylar angle is an epigenetic functional feature and has never been included in the genome for 3 million years [31]. The higher lateral lip of the femoral trochlea already present in the fetus today is genetically determined. Nevertheless, it has probably been firstly acquired epigenetically and then "genetically assimilated" [33].

1.3 Meniscal Ontogeny

Even if several longitudinal developmental studies of nonhuman vertebrate knees exist, literature data on developing menisci are scarce [6]. Gardner and O'Rahilly [8], McDermott [17], and others provided detailed descriptions of the prenatal development of the knee joint. However, they largely concentrated on the embryologic development (i.e., prior to three gestational months). Clark and Ogden [5] conducted a longitudinal fetal and postnatal development study of human menisci, correlating anatomy with histology. Their data analysis elucidated the changes that occur in the developing meniscus during growth.

The blastemal appendicular skeleton of the human embryo is initially formed as a continuous structure, with no spaces or joints separating the major anlagen from each other. However, as the mesenchymal model begins to chondrify, concomitant changes occur in the region of the presumptive joint to create the interzone [36]. This structure has three layers: two parallel chondrogenic layers and an intermediate, less dense layer. The interarticular structures (e.g., menisci and cruciate ligaments) appear as further condensations within this intermediate layer.

Clark and Odgen [5] reported a very early formation of the posterior insertion of the lateral meniscus *at 8 weeks of gestation*. This finding is consistent with the literature on the early formation of both menisci and their shape. The lower limb bud first appears at 4 weeks of gestation. By 6 weeks, chondrification of the femur, tibia, and fibula has commenced. At this time the knee joint is represented by a mass of blastemal cells. The meniscus is identifiable approximately 7.5 weeks after fertilization. The formation of the coordinated meniscoligamentous complex in the knee is well established in the 8-week embryo [8].

The meniscus assumes its characteristic gross shape during prenatal development. At no time does the lateral meniscus appear to have a discoid shape. Throughout growth the ratios of meniscal area to tibial plateau area and lateral meniscus area to medial meniscus area are fairly constant. At 8 weeks, the meniscus is highly cellular with a large nuclear/cytoplasmic ratio. Blood vessels are numerous and are most prominent along the capsular and meniscal attachment sites. However, vessels are identifiable throughout the substance of the fetal meniscus. At the French Arthroscopic Society meeting, we reported a meniscal fetal vascularization analysis using diaphanization [3] (Fig. 1.10). No abrupt change in development is noted at birth. The only major postnatal change is a progressively decreasing vascularity. The cellularity of the meniscus greatly decreases with an increase in collagen content [5]. This meniscal vascular

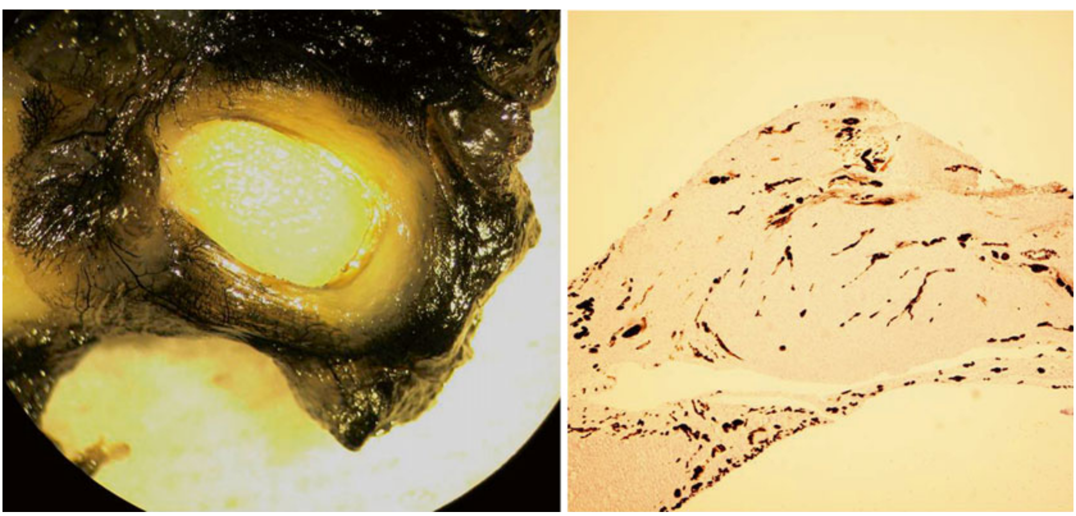

Fig. 1.10 Illustration of the medial meniscus vascularization of a human fetal meniscus (21 weeks old). The left picture shows that blood vessels are prominent along capsular and menisci attachment sites. The right picture shows the disposition of blood vessels into the anterior horn of the medial meniscus using immuno-microscopic analysis

mapping corresponds to the innervation mapping. In mature human menisci Assimakopoulos et al. [1] observed free nerve endings in the peripheral and the medial thirds of the meniscal body and three types of encapsulated mechanoreceptors in the anterior and posterior horns.

In fetal menisci, most of the collagen fibers are arranged in a circumferential fashion in the long axis of the meniscus. Radial fibers are mainly located on the surfaces of the meniscus, acting as tie rods resisting longitudinal splitting [4]. A few of the radial fibers change direction and run in a vertical fashion through the substance of the meniscus. These patterns undergo the most significant development as the child begins ambulation. Ingman et al. [13] studied the variation of proteins in the human knee meniscus with age and degeneration. They demonstrated that the ratio of collagenous to noncollagenous proteins decreased with age, resulting in a decrease of tensile strength. These changes were most marked between the neonatal and childhood meniscus. The biochemical and vascular environment of the young meniscus may be responsible for the low prevalence of meniscal injuries in children. Also, because of its vascularity and biochemical properties, the young meniscus may have greater reparative potential than the adolescent or adult meniscus. This particularity emphasizes the fact that especially in children every effort should be made to preserve peripherally detached menisci by careful reattachment.

1.4 The Particular Case of Discoid Meniscus

Discoid meniscus (Fig. 1.11) is a morphologic abnormality of the knee occurring almost exclusively on the lateral side [6]. Discoid lateral meniscus has been first described by Young [38] in 1889. The prevalence of discoid meniscus has been reported to range from 0 % to 20 % among patients undergoing arthroscopy.

The etiology of discoid meniscus is only partially explained. Smillie [27] reported 29 cases of congenital discoid meniscus in a series of 1,300 meniscectomies. He felt that the condition was simply a reflection of persistence of the normal fetal state of development from a cartilaginous disc. Kaplan [15, 16] studied human fetal material, stillborns, and premature and full-term infants and conclusively demonstrated that discoid meniscus was a definite pathologic entity that developed under specific conditions and was influenced by mechanical factors. According to Ross et al. [26], it is only at the very earliest phase of development during the embryonic period that the plate of undifferentiated mesenchyme, from which the cartilage develops, can be said to resemble a disc. In fact, Clark and Ogden's study [5] complements several embryologic studies showing that the meniscus does not normally assume a discoid configuration during its normal development.

Very often, in individuals with discoid lateral menisci, there is no attachment of the posterior

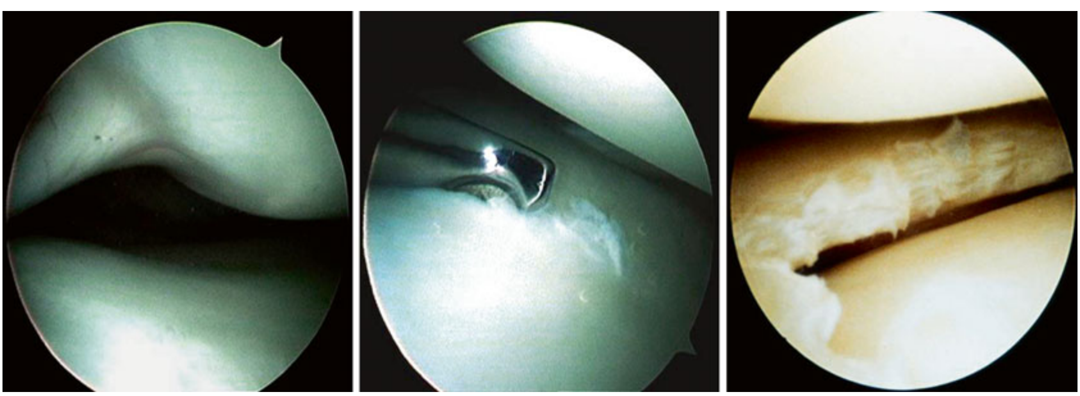

Fig. 1.11 Arthroscopic view of a complete discoid lateral meniscus, before and after meniscal saucerization

horn to the tibial plateau. Instead of this attachment a continuous Wrisberg ligament (meniscofemoral ligament) is present, which forms a link between the posterior horn of the meniscus and the medial condyle of the femur. This is similar to the normal arrangement observed in all mammals except humans. This absent insertion can be considered as a reversion of character. Therefore, the early appearance of the menisci with their definitive tibial insertions, even before articular cavities are present, supports the thesis that the factors responsible for their development are primarily genetic.

Multiple classification systems have been proposed; the most commonly used being that advanced by Watanabe et al. [35] in 1978. They described three major meniscal abnormalities: (1) complete, disc-shaped meniscus with a thin center covering the tibial plateau; (2) incomplete, semilunar-shaped meniscus with partial tibial plateau coverage; and (3) Wrisberg type, hypermobile meniscus resulting from deficient posterior tibial attachments. In 1998, Monllau et al. [19] identified a fourth type: the ring-shaped meniscus. A recent update by Beaufils et al. [2] focused on these four types and highlighted significant variability in lateral discoid meniscal morphology, attachment, and stability. Good et al. [9] proposed an interesting classification based on discoid meniscal instability as either anterior or posterior. Detachment of the anterior horn is likely a result of congenital deficiency. However, it is possible that such detachments are acquired as a result of excessive tensile stresses on the meniscal attachments. Pathologic examination of discoid meniscus specimens often shows intrinsic degenerative changes. It is unknown whether such changes are intrinsic to the meniscus (congenital) or acquired in response to abnormal meniscus kinematics, or both.

Conclusion

We have correlated the morphologic changes during phylogenesis and ontogenesis with the evolving meniscus physiology and function. During human ontogeny, the timing and mode of formation of the three derived human femorotibial characters have been shown to be very different. Correspondingly, during hominid evolution, different modes of selection of these features have been suggested. In hominid evolution with bipedal gait, the knee joint evolved from having a single insertion of the lateral meniscus on the tibia to a double one associated with bony changes of the knee joint (both trochlear groove and lateral compartment). This morphologic change occurred between Australopithecines and *Homo* by a "genetic modification," which took place at a very early stage of embryonic life. The early appearance of the menisci during human development supports the thesis that the factors responsible for their development are primarily genetic. During prenatal and postnatal life, the major change in menisci concerns their vascularization and composition.

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Anatomy and Vascularisation

2

Urszula Zdanowicz, Robert Śmigielski, Alejandro Espejo-Reina, Alejandro Espejo-Baena, and Henning Madry

Contents

2.1 Medial Meniscus

2.1.1 Overview

The human menisci consist of about 65–75 % of water, 22 % of collagen, 0.8 % of glycosaminoglycans and 0.12 % DNA [9]. Menisci contain an intricate network of collagen fibres, interposed with meniscal fibrochondrocytes, embedded in an extracellular matrix composed of proteoglycans and glycoproteins [10] (Fig.2.1). The principal collagen of the meniscal tissue is type I collagen. Its fibres are arranged in a circumferential orientation with interspersed radially oriented fibres. The proteoglycans retain water within the meniscal tissue, thus permitting its specific viscoelastic properties.

The medial meniscus has a semilunar shape and covers up to 50–60 % of the medial tibial plateau [4, 17] (Fig. 2.2).

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_2

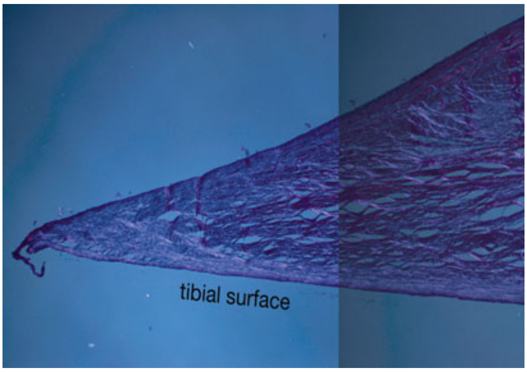

Fig. 2.1 Complex structure of human medial meniscus observed in the polarised light. Notice that the density of collagen fibres is much higher on the contact area of tibial surface

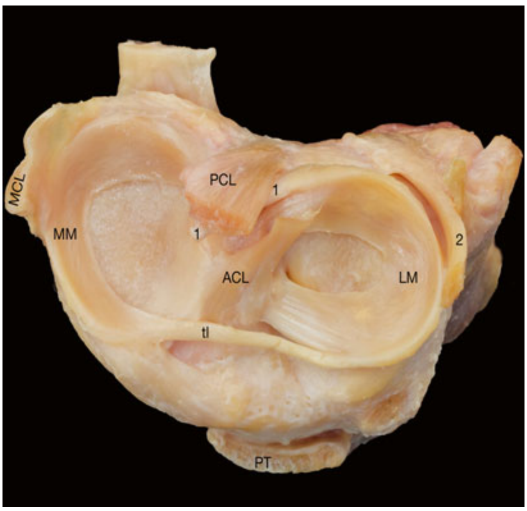

Fig. 2.2 Cadaveric specimen of the left knee joint. Femur is removed. *MM* medial meniscus, *LM* lateral meniscus, *PCL* posterior cruciate ligament, *ACL* anterior cruciate ligament, *PT* patellar tendon, *tl* transverse ligament, *MCL* medial collateral ligament. *1* – anterior menisco-femoral ligament (ligament of Humphry). *2* – popliteus tendon

Śmigielski et al. [17] proposed to divide medial meniscus into five anatomical zones (Fig. 2.3). Within each zone the structure and attachments of meniscus differ, and therefore different surgical techniques are required in order to achieve anatomical reconstruction.

2.1.2 Zone 1

Zone 1 consists of the anterior root of the medial meniscus. The centre of the anterior root of the

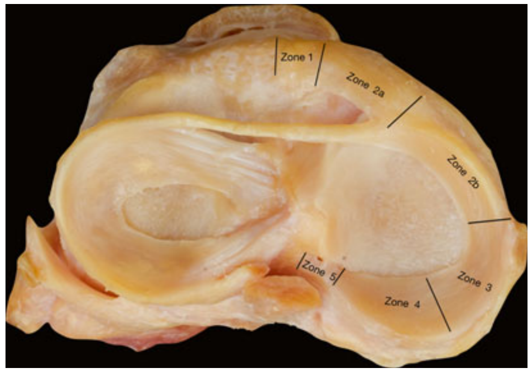

Fig. 2.3 Cadaveric specimen of the left knee joint. Femur is removed. Five anatomic zones (according to Śmigielski et al. [17]) are marked on the medial meniscus: zone 1 – anterior root, zone 2 – antero-medial part, zone 3 – at the level of medial collateral ligament, zone 4 – posterior part and zone 5 – posterior root

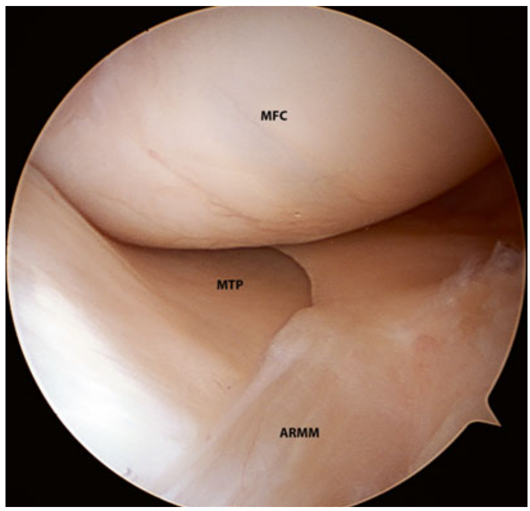

Fig. 2.4 Anterior root of the medial meniscus (ARMM) viewed from an anterolateral portal (right knee). *MFC* medial femoral condyle. *MTP* – medial tibial plateau

medial meniscus lies proximal to the superior aspect of the medial edge of the tibial tuberosity. In regard to arthroscopic landmarks, the anterior root of the medial meniscus is anterior to the apex of medial tibial eminence and anterolateral to the edge of the articular cartilage of the medial tibial condyle (Fig. 2.4) [12].

2.1.3 Zone 2

Zone 2 includes the antero-medial part of the medial meniscus. This zone may be divided

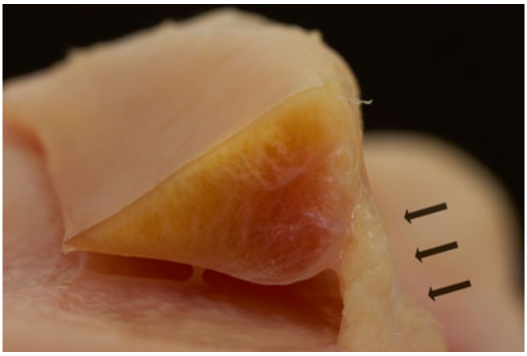

Fig. 2.5 Cadaveric specimen. Cross section of the medial meniscus at the zone 2b. Menisco-tibial (coronary) ligament is marked with *arrows*

further into two subzones: 2a (from anterior root attachment to transverse ligament) and 2b (from transverse ligament to anterior border of medial collateral ligament). A characteristic is that within this zone, the medial meniscus attaches to the bone only with menisco-tibial ligament (coronary ligament) (Fig. 2.5). Reconstructing this ligament should be taken into consideration in cases of meniscal suturing. The superior periphery of the medial meniscus in zone 2a has no attachments to surrounding tissues; however, in zone 2b the superior border of the medial meniscus is attached to the synovial tissue [12, 13, 16].

2.1.4 Zone 3

Zone 3 includes the part of medial meniscus at the level of medial collateral ligament (MCL). It is the only zone where the entire part of the meniscus is attached to the joint capsule. This attachment is identified in some studies as a deep layer of the MCL, or as a reinforcement of the joint capsule [17, 20] (Fig. 2.6).

2.1.5 Zone 4

Zone 4 is in essence the posterior horn of medial meniscus. In this zone, the superior edge of the medial meniscus does not attach to the joint capsule (Fig. 2.7). In contrast, the inferior part attaches to the tibia through the menisco-tibial ligament (coronary ligament). This ligament, together with the posterior joint capsule, forms the postero-medial femoral recess (Figs. 2.8 and 2.9) [6]. Zone 4 is a very special part of the medial meniscus. Not only is it one of the most frequently injured one but also very technically demanding for any type of suturing. Therefore, many surgeons would be satisfied suturing meniscus in this area to the posterior capsule. However, this could potentially have an influence on the mobility of the medial meniscus (especially with non-absorbable sutures), which subsequently might be responsible for poor long-term follow-up. For that very reason, a strictly anatomic medial meniscus (with reconstruction only of menisco-tibial attachment) may have to be considered [17].

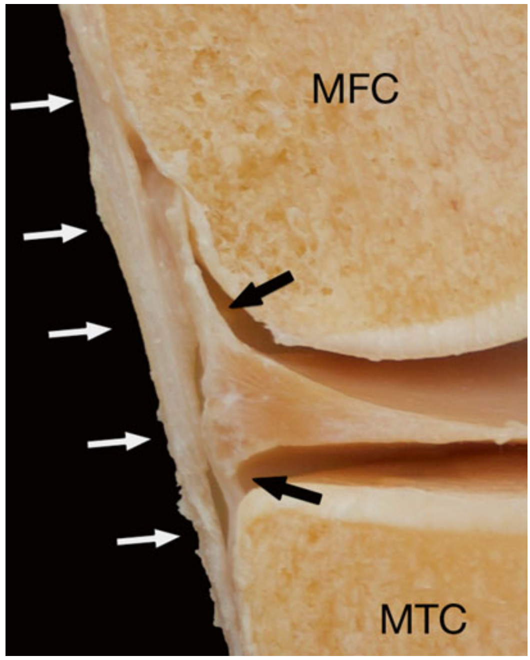

Fig. 2.6 Cadaveric specimen. Cross section of medial knee compartment in coronal plane at the level of medial collateral ligament (marked with white *arrows*), within zone 3. Note the way the medial meniscus attaches to surrounding tissues (marked with *black arrows*)

2.1.6 Zone 5

Zone 5 is the posterior root of medial meniscus. The insertion of the posterior root of the medial

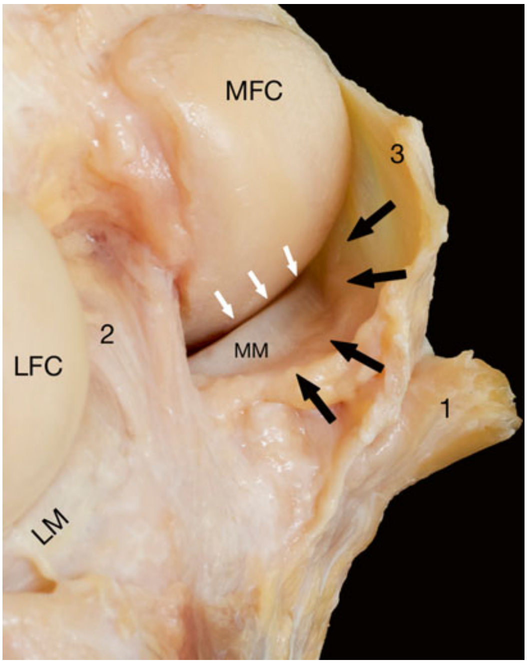

Fig. 2.7 Cadaveric specimen of the left knee joint. Posterior view. *MFC* medial femoral condyle, *LFC* lateral femoral condyle, *LM* lateral meniscus, *MM* medial meniscus. *1* – distal attachment of the tendon of the semimembranous muscle. *2* – posterior cruciate ligament. *3* – posterior capsule. Postero-medial femoral recess is marked with *black arrows*. Note the superior part of medial meniscus in zone 4 does not attach to the capsule (marked with *white arrows*). On the other hand, inferior part attaches to tibia with menisco-tibial ligament (also called coronary ligament)

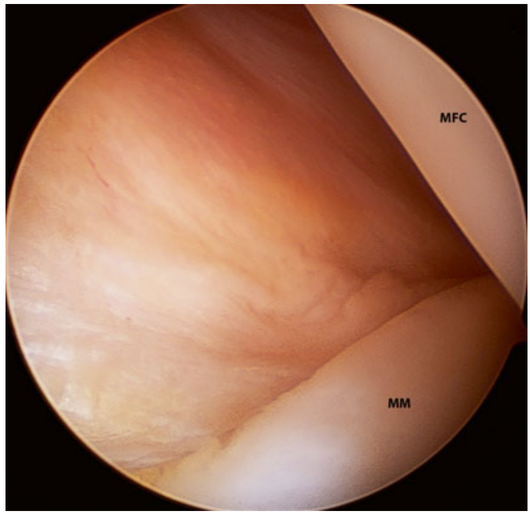

Fig. 2.8 Arthroscopic view. Postero-medial recess viewed from the intercondylar notch, through a transtendinous portal. No attachment to the joint capsule can be observed on the superior edge of the medial meniscus. *MFC* medial femoral condyle, *MM* medial meniscus

meniscus is located posterior and lateral from the medial apex of medial tibial spine (Fig. 2.10) [11].

2.2 Connections Between the Medial and the Lateral Meniscus

The medial and lateral menisci are connected with each other with four individual ligaments [22] (Figs. 2.1 and 2.11):

- Anterior intermeniscal ligament (transverse ligament) (present in 60–94 % of cases)
- Posterior intermeniscal ligament (1–4 %)
- Lateral oblique intermeniscal ligament (4 %)
- Medial oblique intermeniscal ligament (1 %)

2.3 Lateral Meniscus

The lateral meniscus has a more circular shape than the medial meniscus.

2.3.1 Anterior Root

The anterior root of lateral meniscus inserts deeply beneath the tibial attachment of the anterior cruciate ligament (ACL) (Fig. 2.10). The centre of the insertion site lies antero-medial to the apex of the lateral tibial eminence [12, 15]. That fact has a very important clinical relevance, because this part of lateral meniscus may be easily injured with some ACL reconstruction techniques.

2.3.2 Hiatus Popliteus

Evolutionary and developmental anatomy is the key to understand the complicated morphology of the posterior lateral corner structures and its relationship to the lateral meniscus. 360 million years ago in vertebrates as well as during human embryonic development, the fibula articulated

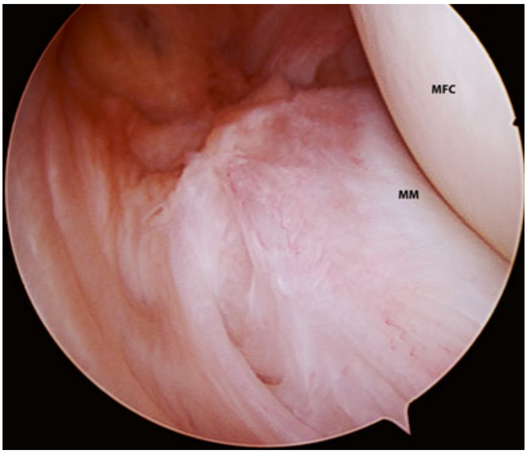

Fig. 2.9 Arthroscopic view. Postero-medial recess viewed from the postero-medial portal. No attachment to the sinovial membrane can be seen on the superior part of the medial meniscus. *MFC* medial femoral condyle. *MM* medial meniscus

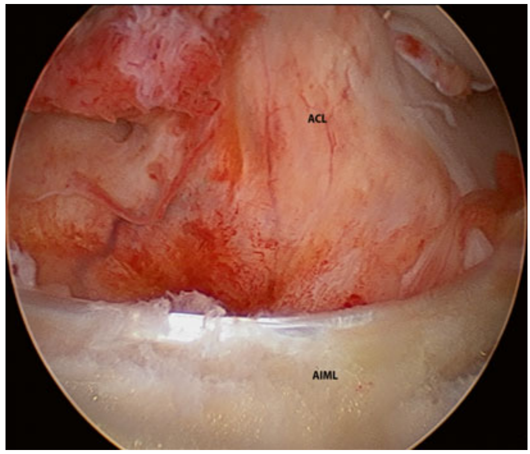

Fig. 2.11 Arthroscopic view. Anterior intermeniscal ligament (AIML) seen from a transtendinous portal (right knee). Note the relationship to the tibial insertion of the anterior cruciate ligament

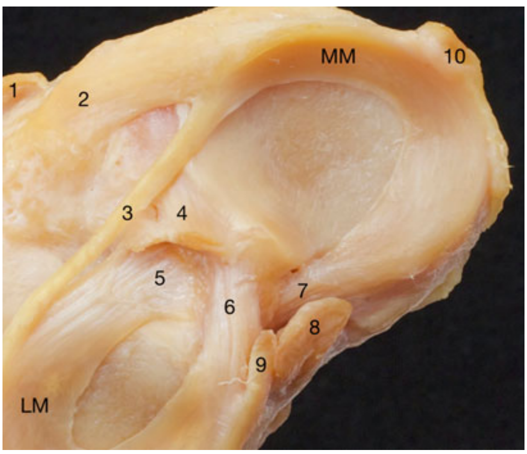

Fig. 2.10 Cadaveric specimen of the left knee joint. *MM* medial meniscus, *LM* lateral meniscus. *1* – patellar tendon. *2* – anterior root attachment of medial meniscus. *3* – transverse ligament. *4* – anterior cruciate ligament (notice how it covers the anterior root attachment of lateral meniscus). *5* – anterior root attachment of lateral meniscus. *6* – posterior root attachment of lateral meniscus. *7* – posterior root attachment of medial meniscus. *8* – posterior cruciate ligament. *9* – anterior menisco-femoral ligament (Humphry's ligament). *10* – medial collateral ligament

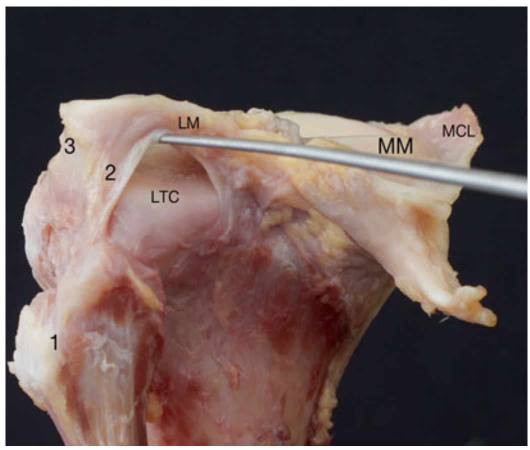

Fig. 2.12 Cadaveric specimen of the left knee joint. Posterolateral view. *LM* – lateral meniscus, *LTC* – lateral tibial condyle, *MM* medial meniscus, *MCL* medial collateral ligament. *1* – fibular head. *2* – menisco-fibular ligament. *3* – menisco-tibial ligament (coronary ligament)

with the femur. However, as the vertebrate knee evolved, the fibula and the attached lateral portion of the joint capsule moved distally, resulting in the popliteal hiatus and an intra-articular popliteus tendon. In early evolution – in the moment where the fibula still articulated with the femur – the popliteus tendon had its proximal attachment on the fibular head. In the course of the distal migration of the fibula, the popliteus tendon acquired a new femoral attachment whilst retaining its original fibular one [5].

The menisco-fibular ligament is a capsular ligament originating from the posterolateral part of the lateral meniscus, anterior to the popliteal muscle tendon [3] (Fig. 2.12). This relatively large, often underestimated ligament is believed to position the lateral meniscus and thus having a great impact on its biomechanics. Failure to reconstruct the menisco-fibular ligament might lead to secondary meniscal injures due to impaired biomechanics. Other stabilising structures are the popliteomeniscal fasciculis that connect the lateral meniscus to the popliteus tendon and joint capsule [18].

2.3.3 Menisco-femoral Ligaments

There are two menisco-femoral ligaments: the anterior menisco-femoral ligament (also known as Humphry ligament) and the posterior menisco-femoral ligament (Wrisberg ligament) [14]. Those ligaments are secondary restraints to posterior drawer. The menisco-femoral ligaments contribute in a reduction of the tibio-femoral contact pressure of the lateral meniscus [8, 19]. It is possible that chronic deficiency of those ligaments (after failure of its reconstruction during meniscal suturing or meniscal transplantation) may be responsible for reduced long-term results after those surgeries.

2.3.4 Posterior Root

The posterior root of the lateral meniscus is located anterior to the insertion of the posterior horn of the medial meniscus, medial to the articular margin of the lateral tibial plateau [7] (Fig. 2.13). According to You et al. [21], there are three different attachment patterns; in 76 % of cases, the posterior root of lateral meniscus shows two insertion sites: to the intertubercular area and with minor component to the posterior slope of the lateral tibial tubercule. In the remaining 24 %, the posterior root shows a solitary insertion site either to the intertubercular area or to the posterior slope of the lateral tubercle, respectively.

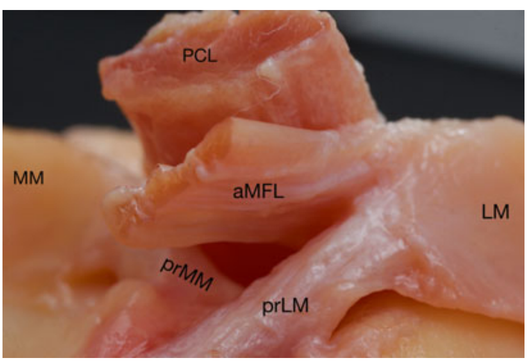

Fig. 2.13 Cadaveric specimen of the left knee joint. Close look at the posterior aspect of the knee, from the front. *MM* medial meniscus, *LM* lateral meniscus, *PCL* posterior cruciate ligament, *prMM* posterior root of medial meniscus, *prLM* posterior root of lateral meniscus, *aMFL* anterior menisco-femoral ligament

2.4 Vascularisation

The main vascular supply to the menisci is derived from branches of the superior and inferior geniculate arteries, which form a subsynovial and perimeniscal network of capillaries that infiltrate the periphery of the meniscus (Fig. 2.14). During embryological development, the human meniscus has blood vessels throughout its substance. During the postnatal period, the inner part of meniscus becomes avascular, which is believed to be caused by weight bearing and knee motion. Vascularisation is thus restricted to the peripheral parts of the menisci. Nerve fibres follow the blood vessels. The anterior and posterior horns of the menisci are the most richly innervated and vascularised [2].

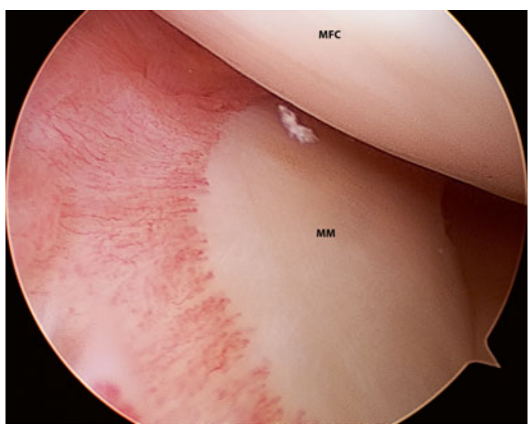

Fig. 2.14 The middle genicular artery supplies blood to the menisci via the synovial vascular network. Arthroscopic view of synovial vascular supply to the periphery of medial meniscus (*MM*). *MFC* medial femoral condyle

The central (inner) third of the meniscus is often termed the ‘white zone’, in contrast to the vascularised peripheral ‘red zone’. There is a direct relationship between the amount of blood vessels and the ability to heal [1]. However, further studies are needed to investigate how we may influence the healing by preserving (or restoring) the blood supply of the meniscus.

Acknowledgements The authors gratefully acknowledge Maciej Pronicki, MD, PhD, for providing histopathology examinations, Maciej Śmiarowski (maciej.Smiarowski@gmail.com) for taking photographs and Center for Medical Education (www.cemed.pl) for its help.

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Histology-Ultrastructure-Biology

3

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3.1 Introduction

The menisci are usually described as two wedge-shaped semilunar discs of fibrocartilaginous tissue (Fig. 3.1) which can play a decisive role in the homeostasis and function of the knee joint [31]. Despite the former, in the past they were described irrelevant structures with some possible minor function on joint nutrition and stabilization [43]. So, one must acknowledge that a lot has changed in recent years concerning the need to save "the meniscus" [49].

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_3

Briefly, the menisci are primarily constituted of interlacing networks of collagen fibers (predominantly type I collagen) interposed between cells and an extracellular matrix (ECM) of proteoglycans and glycoproteins (Fig. 3.2) [41]. Each meniscus is placed between the femoral condyles (lateral or medial) and its correspondent tibial *plateau*. It is acknowledged that the partial or total loss of this tissue determines deleterious consequences to the joint, particularly in the long term [16].

There has been a major overturn on the treatment approach for meniscus injuries: "from meniscectomy to preservation or substitution" [49] and the nearly universal arthroscopic surgical approach opposing to open surgery [16]. Since the decisive role of the menisci has been recognized regarding joint function, stability, and durability, there has been growing interest in the development of treatments aiming to preserve the menisci.

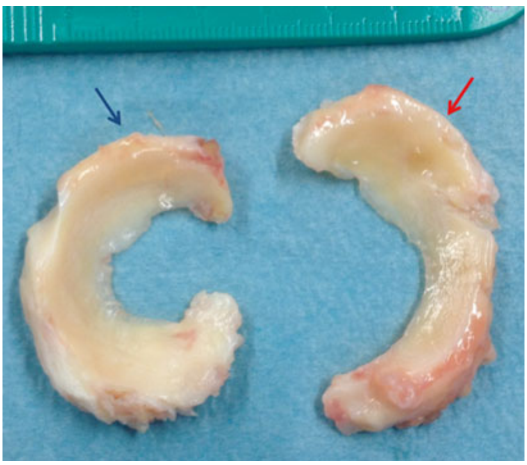

Fig. 3.1 The medial (*red arrow*) and the lateral (*blue arrow*) menisci

The biological characterization of this tissue has proven to be a challenge. However, it has definitely evolved considerably in the last few years. Different cellular populations have been described [48], while segmental variations have also been recognized concerning type of cells and density [12], ultrastructure, extracellular matrix, and biomechanical properties [38].

The basic science research around the meniscus is of paramount relevance once this will surely represent the fundamentals for the development of upcoming therapies. Anatomy, biology, and biomechanics are definitely not static disciplines. On the opposite, they represent the basis for the building the future and will assist in the development of surgery, tissue engineering, and regenerative medicine [40]. The herein presented work aims to summarize the most relevant basic science knowledge of this issue dedicated to the clinicians and researchers.

3.2 Overview of the Anatomy and Biomechanics

The biomechanical studies during the 1980s have described the role of menisci on load transfer and showed that total meniscectomy reduces the total contact area by a third to a half in the fully extended knee [27]. The comprehension of the biomechanical features of the joint is fundamental in interpreting the functional properties of the tissues [28, 44]. According to Walker et al., the lateral meniscus carries most of load transfer on lateral compartment while in the medial compartment the load transmission is more distributed

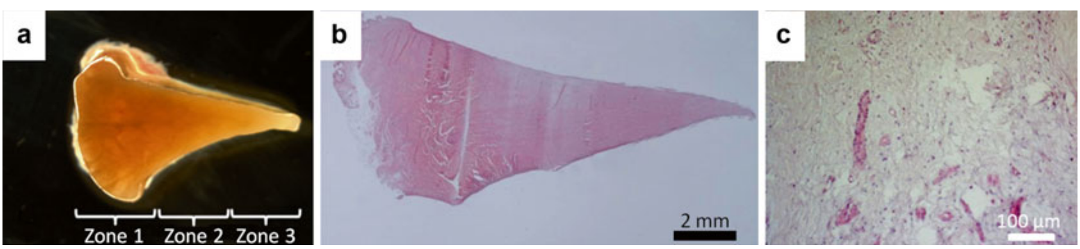

Fig. 3.2 A stereomicroscopy image of a portion of a human meniscus where the dense collagen fibers are visible (**a**) and the respective H&E-stained histological micrograph (**b**) and H&E-stained micrograph of meniscus are obtained in the vascular zone (zone 1) (2800 µm × 2100 µm) (**c**)

between the exposed cartilage surfaces and respective meniscus [51].

In vitro trials stated about 70 and 50 % of load transmission through the corresponding menisci in the lateral and medial compartment, respectively [6]. This knowledge stated the major importance of menisci in load transfer and brought attention to the possible consequences of meniscal excision. Such consequences will affect not only the joint surface but will also have influences on the subchondral bone and proximal tibia's trabecular bone and cortex [16, 17].

The menisci will follow, to some extent, the anteroposterior translation of the knee during joint motion once they are not firmly attached to the tibia. Due to its anatomical features (including stronger attachment to the medial collateral ligament), the medial meniscus is less mobile. In the stable knee, with preserved ligaments of the central *pivot*, the medial meniscus has a small role as secondary stabilizer contributing to oppose the anterior tibial displacement [31]. The anterior cruciate ligament (primary stabilizer) will stop anterior dislocation prior to significant contact of femoral condyle with the posterior horn of the medial meniscus and tibial plateau [29]. This phenomenon is increased in ACL-deficient knees and has been related to frequent patterns of meniscal injuries [4, 31]. The menisci also have the function to increase the congruency of the joint, particularly in the lateral femorotibial compartment. The lateral tibial plateau has a more convex morphology when compared to the medial compartment [29, 31]. For that reason, the lateral meniscus has a higher contribute to ensure joint congruency when compared to the medial.

The medial meniscus has been described to have the appearance of a "crescent" while the lateral meniscus has a more symmetric "C"-shaped form (Fig. 3.1). Moreover, there is a higher variability in medial meniscus insertion horns. Anterior and posterior insertion horns of the lateral meniscus are closer and are less variable in gross morphology [8, 52, 53]. These differences have implications for surgical approaches for meniscal repair or replacement.

The menisci also have a function to lower friction on articular structures during joint motion. Their biomechanical response to external forces is influenced by their macro-geometry and ultra-architecture (Fig. 3.3) and their anatomical attachment sites. The collagen bundles included in the more superficial layer of menisci have a random orientation that somewhat mimics hyaline cartilage [5].

The inner core of the meniscal tissue presents two different groups of collagen fibers, i.e., radial bundles (more frequent in the innermost mikuone-third) and circumferential bundles (in the outer two-thirds) [9]. It has been advocated that the inner third may play a major role in dealing with compression forces while the outer

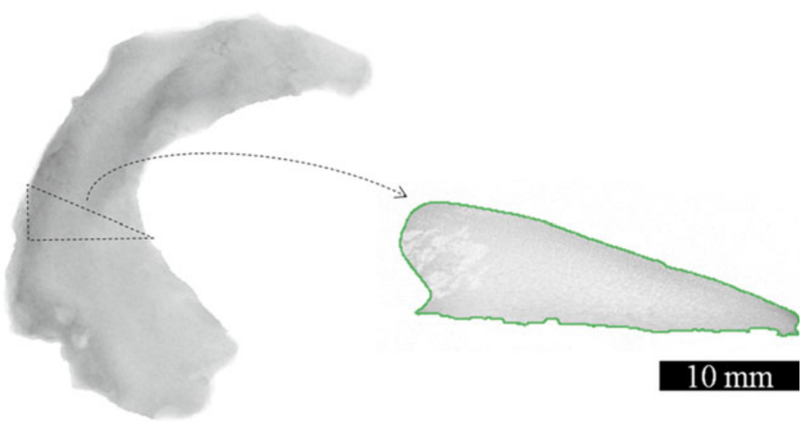

Fig. 3.3 An X-ray image of a fresh human medial meniscus acquired with a micro-CT equipment for subsequent segmental analysis of ultrastructure

two-thirds counteract radial tension forces. A third group is also described as the "tie fibers." These radially orientated collagen fibers might also be found within the bulk of the meniscal tissue, and their function is to counterattack longitudinal splitting forces of the circumferential collagen bundles [9]. Both anterior horns of the medial and lateral menisci are connected by the anterior intermeniscal (or transverse geniculate) ligament. This ligament is found in 60 % of the general population, and its practical role has not been yet clarified [26].

Two meniscofemoral ligaments [23] might connect the posterior horn of the lateral meniscus to the lateral side of the medial condyle of the femur: (i) The ligament of Humphrey (estimated prevalence of 74 %) runs anterior to the posterior cruciate ligament (PCL), and (ii) the ligament of Wrisberg (estimated prevalence of 69 %) runs posterior to the PCL.

The functional relevance of these two ligaments has been acknowledged once these contribute with 28 % of the total force resisting posterior drawer at 90° of flexion in the intact knee and 70.1 % in the PCL-deficient knee [22]. The anterolateral ligament also has a relation to the lateral meniscus as it passes distally. However, its implication in meniscus function or injuries remains unclear [50].

3.3 Ultrastructure, Cells, and Extracellular Matrix

The menisci have a high percentage of water content (72 %) by wet weight. The remaining 28 % is composed of organic matter, mostly extracellular matrix (ECM) and cells [30]. Most of the organic matter is composed of collagens (75 %), followed by glucosaminoglycans (GAGs) (17 %), DNA (2 %), adhesion glycoproteins (<1 %), and elastin (<1 %) [24, 30]. These proportions present variations according to age, injury, or pathological conditions [45].

Collagen is the key constituent of the meniscus. Several collagen types exist in different amounts depending on zones or segments [2, 14]. In zone 1 (red-red), collagen type I is predominant (80 % composition dry weight), while other collagens (types II, III, IV, VI, and XVIII) can also be found in minimal amounts (less than 1 %). In zone 3 (white-white) [2], collagen constitutes 70 % of the dry weight. In zone 3, 60 % is collagen type II and 40 % is collagen type I [14]. Besides collagen, another fibrillar component is elastin. Variable combinations of mature and immature elastin fibers have been found in very small quantities (<0.6 %) in the adult meniscus [20]. The clinical relevance of meniscal elastin is subject of ongoing research [30].

Another relevant part of ECM is the "proteoglycans." These molecules have a core protein, which is "ornamented" with glycosaminoglycans (GAGs). The main types of GAGs found in normal human meniscal tissue are chondoitin-6-sulfate (60 %), dermatan sulfate (20–30 %), chondroitin-4-sulfate (10–20 %), and keratin sulfate (15 %) [24].

Aggrecan is the most important "large proteoglycan" of the menisci, while biglycan and decorin represent the major "small proteoglycans" [42]. The function of proteoglycans is to permit the meniscus to absorb water. The capacity to confine water assists in the meniscus biomechanical function to resist compression [30]. The inner two-thirds of the menisci have a higher proportion of proteoglycans comparing to the outer one-third [42]. The ECM also includes adhesion glycoproteins, which are indispensable to link the components of ECM and cells. Fibronectin, thrombospondin, and collagen VI are the main adhesion glycoproteins within the human menisci [34].

Concerning ultrastructure, microcomputed tomography (micro-CT) analysis (Fig. 3.4) has shown that the mean porosity for lateral and medial meniscus is 55.5 ± 17.5 % and 64.7 ± 8.7 %, respectively [38]. Moreover, the mean interconnectivity is 26.3 ± 8.4 % and 31.7 ± 13.1 % for the lateral and medial meniscus. The mean wall thickness was defined as 143.4 (114.4–172.5) μm for the lateral and 139.2 (110.6–167.9) μm for the medial meniscus, while the mean pore size was 152.6 (113.2–192.1) μm for the lateral and 189.0 (164.3–213.8) μm for the medial meniscus [38].

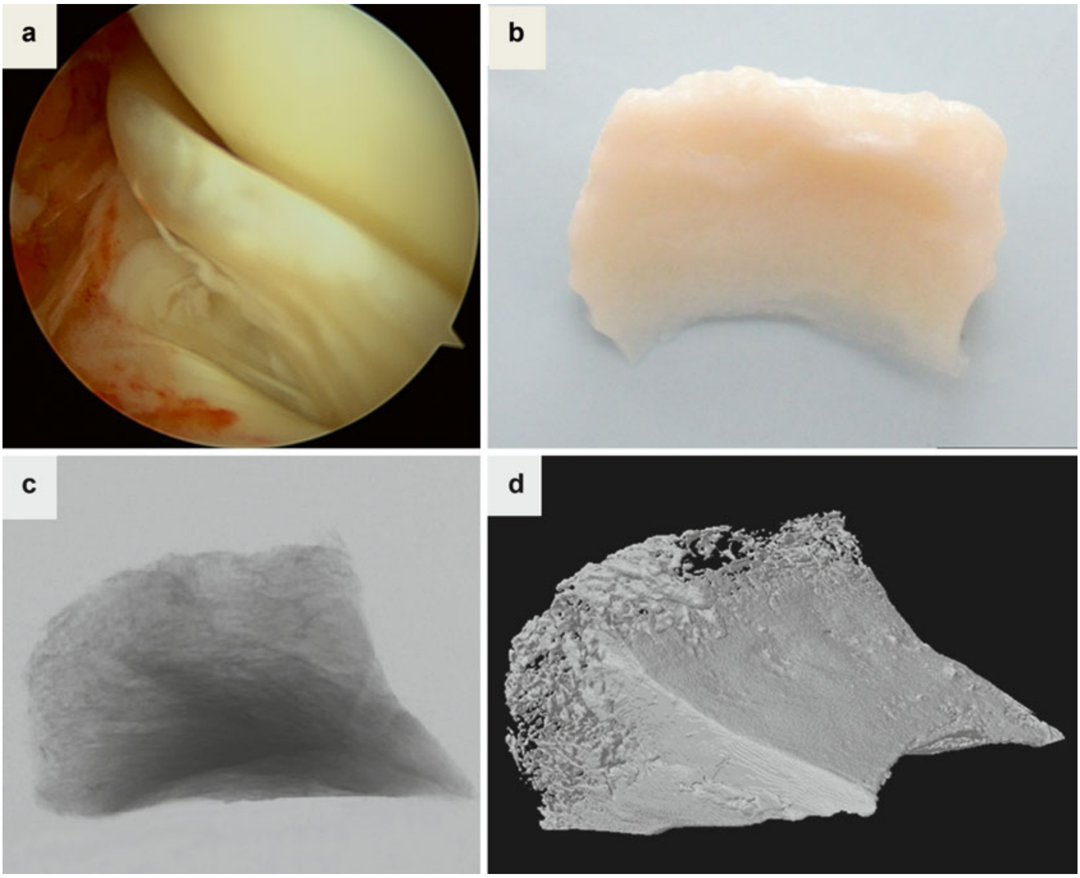

Fig. 3.4 Arthroscopic photographs of an irreparable bucket handle medial meniscus lesion (**a**), and respective meniscus debris harvested (**b**); an X-ray image of a portion of a freeze-dried medial meniscus acquired with a micro-CT equipment (**c**); 3D reconstructions of the micro-CT images of the meniscus portion (**d**)

There is still some controversy in the literature concerning meniscus cells classification with several designations being used (i.e., fibrocytes, fibroblasts, meniscus cells, fibrochondrocytes, and chondrocytes) [36]. Considering shape classification and territorial ECM, different types of cells have been described in the early 1980s: chondrocytes, fibroblasts, cells of intermediate form between fibroblasts and chondrocytes, mast cells, and degenerate and necrotic cells [19, 32]. More recently, four meniscal cell types have been reported [48]: (a) fibrochondrocytes, (b) fibroblast-like cells, (c) superficial zone cells, and (d) cells with intermediate morphology between fibrochondrocytes and fibroblast-like cells (Fig. 3.5). Fibrochondrocytes have a round or oval-shaped morphology [11]. They produce mainly type I collagen. Fibroblast-like cells have a flattened or fusiform shape with several thin and long cytoplasmic projections. These extensions serve to facilitate communication with other cells and the extracellular matrix. Fibroblast-like cells mainly synthesize collagen type II and are more frequently found in zone 1.

The cells of the superficial zone are fusiform in shape and lack cytoplasmic projections [48]. The ECM surrounding these cells has mainly type I collagen, with small percentages of glycoproteins and collagen types III and V [33]. The cells in the inner zones of the meniscus have rounded appearance and are surrounded by an ECM comprised mostly of type II collagen combined with a smaller but relevant amount of type I collagen. They also have higher concentrations

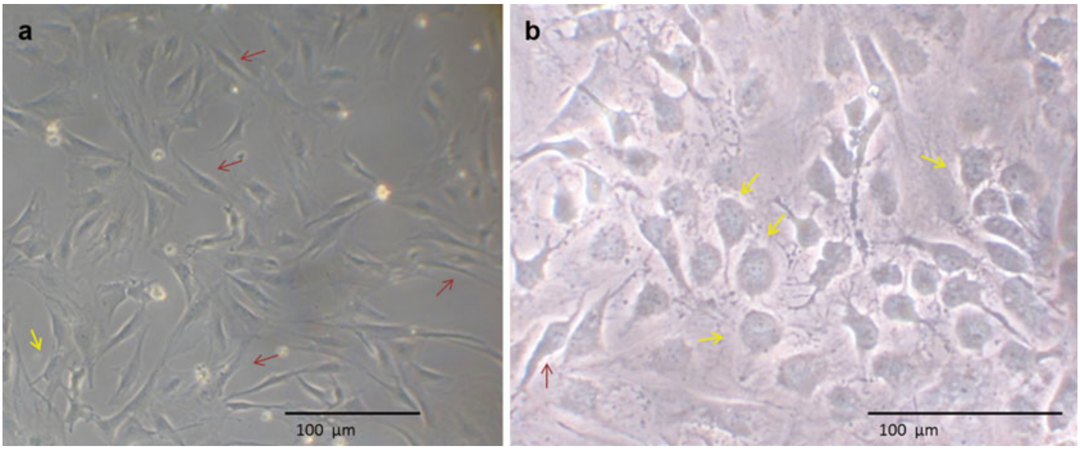

Fig. 3.5 Microscopy image of human meniscus cells in culture after isolation using an enzymatic digestion method (**a**, **b**). It is possible to observe meniscus cells depicting rounded (*yellow arrows*) and fusiform-like morphologies (*red arrows*)

of GAGs than cells in zone 1. This relative abundance of collagen type II and aggrecan in the inner zones of menisci is closer to the characteristics of hyaline articular cartilage. For this reason, such cells have been classified as fibrochondrocytes or chondrocyte-like cells [48] The third cell population described in the superficial zone of the meniscus cells presents an atypical morphology: They are flattened and fusiform and are absent of cell extensions. It has been proposed that these could be pluripotent cells with more regenerative capacities ([46].).

In brief, the cell-associated matrix (CAM) of one of the populations of meniscus cells is composed of high amounts of type I and II collagen and low amounts of aggrecan [48]. A second population synthesizes a CAM containing high amounts of type I collagen, low amounts of type II collagen, and high amounts of aggrecan. This population is known to be CD44+CD105+CD34-CD31- [48]. A third population, CD34+ (a stem cell marker), has also been described but has not been implicated in significant CAM production [48].

On fluorescence-activated cell sorting (FACS) analysis of human meniscus cells, it has been found over 97 % expression of CD44, CD73, CD90, and CD105 and a small expression of CD31 and CD34 (2.3 % ± 0.8 % and 3.2 % ± 1.0 %, respectively), while CD45 (marker for hematopoietic stem cells) was only identified in an even smaller percentage of cells (0.2 % ± 0.1 %). However, this small number of CD45+ hematopoietic cells might play a role in the chondrogenic differentiation of mesenchymal stem cells (MSCs) [1].

The vascularized zone of the meniscus (zone 1) contains more stem cells than the less vascularized zones, and such cells play a role in meniscal repair [37]. The cells from zone 1 seem to migrate quicker and exhibited lower adhesion strengths when compared to inner meniscus cells (zones 2 and 3) in experimental conditions [21].

Concerning viscoelastic behavior, the menisci present rubberlike features at high loading frequencies while at lower frequencies viscous dissipation occurs. Such properties are related with the ECM composition. Collagen plays a minor role in viscoelastic performance. However, GAG content has an important direct correlation and the water content has a reverse correlation with such features.

The regional variations in viscoelastic properties have been described [10]. It has also been demonstrated the regional and zonal variation in the glycosaminoglycan coverage, size, and cellular density in animal meniscal tissue [25].

More recently, a study in fresh human meniscus samples concluded that medial meniscus presents higher values of storage modulus (E')

and loss factor (tan δ) as compared to the lateral [38]. Moreover, the posterior and middle segments are significantly stiffer (higher *E*') as compared to the anterior. The anterior segments of either lateral or medial menisci have higher tan δ which implicates that they are more predisposed to dissipate mechanical energy [38].

There is also a significant difference in the zones and the segments of the human menisci concerning the 2D cellularity [38]. Regarding the zones, there is obviously a difference in the 2D cellularity between the vascular (higher density) and avascular zones [38]. The anterior segment of the meniscus has significantly higher damping properties than the other segments; on the other hand, the anterior segment has inferior 2D cellularity as compared to other segments [38].

More recently, in a study of human lateral meniscus 3D cellular density, the authors concluded that the 3D cellular densities of the vascular and avascular regions were quantified to be 27 199 and 12 820 cells/mm^3, respectively [12]. In this study, it was also described significantly higher cellularity on the anterior segments.

These recent studies have shown that the 2D and 3D analysis of the cellular density of the anterior segment is relatively higher than that of other segments [12, 38]. In this way, one might conclude that the higher damping properties of the anterior segments could be somewhat associated with the higher cellular density.

3.4 Vascularity and Innervation

The medial and lateral inferior and middle geniculate arteries are responsible for the vascularization of the human menisci. In the human adult, vessels supplying the body of the meniscus are limited to the periphery, with a variable penetration of 10–30 % for the medial meniscus and 10–25 % for the lateral meniscus. The anterior and posterior insertional horns are more richly irrigated by radial branches from a perimeniscal plexus which enter the meniscus at intervals [7]. There is an avascular area adjacent to the popliteus tendon [3]. Three classical zones according to vascularization continue to be used as references: red-red, red-white, and white-white. However, ISAKOS classification method is more accurate and in growing use (Fig. 3.6) [2].

The perimeniscal tissue is richly innervated. Concerning the innervation, most nerves are connected to vessels in their pathways. Smaller nerves and axons run in a radial way in tortuous patterns. Single axons course through the perimeniscal tissue. This way, rich innervation can be observed in the interstitial tissue of the peripheral zone of the meniscus and in the anterior and posterior horns. However, the inner meniscus core has no nerve fibers [7].

Studies of the vascular and nerve supply of the meniscus in humans have major clinical implications. It has been long established that meniscal vascularity is related to the healing capacity of meniscal tissue. However, some healing of meniscal tissue has been described in avascular portions of the meniscus [4]. In the human fetus, the vascular supply is much more

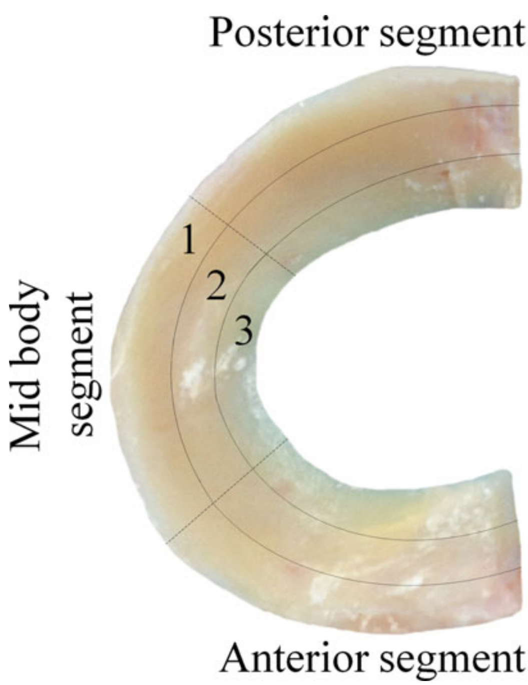

Fig. 3.6 Representation of lateral meniscus division for 3D cellularity assessment according to classification method encouraged by ISAKOS

extensive. The vascularization reaches the inner one-third. There is also a significant nerve supply that is similar in distribution to the vascular supply. These features are progressively lost during growth.

3.5 From Biology to Repair and Replacement

The progressive development of tissue engineering (TE) sciences envisions to change clinical medicine by means of combining life sciences and engineering principles with the goal of repairing or even improving the function of tissues [39, 40]. TE has its place in the domain of regenerative medicine [39, 40], which represents a broader perspective that also enrolls other fields of science including cellular and gene therapy [15]. The objective of TE is to regenerate the damaged tissues by using three main components (Fig. 3.7). The triad of tissue engineering comprises 1 scaffolds, 2 cells, and 3 growth factors, bioactive agents, and/or mechanical stimulation.

This field of knowledge demands deep comprehension of tissue biology, architecture, and ultrastructure of the tissue. Several tissue-engineered products, i.e., combining scaffolds and cells, are still under development but promising to improve current therapies and also to bring new options for future [39]. Acellular scaffolds [18, 35, 47, 54] have represented a significant step forward; however future perspectives might include a combination of scaffolds with cells and/or growth factors [39, 40] or even gene therapy [15].

The development of patient-specific cell-based meniscal implants is under development [13]. Such implants built on the basis of each patient's MRI might help to overcome the current

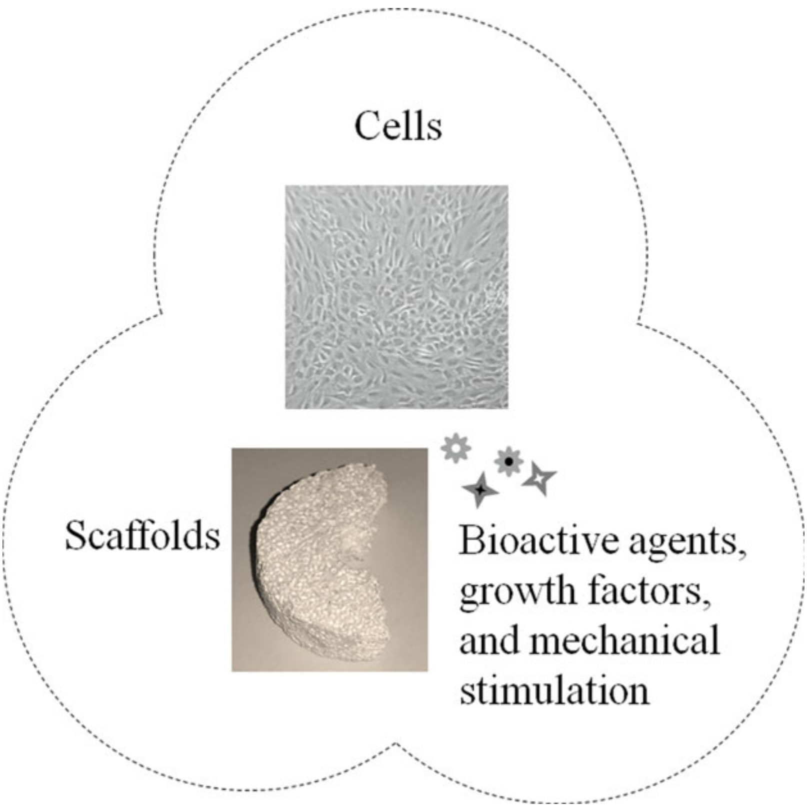

Fig. 3.7 The triad of tissue engineering comprises 1 scaffolds, 2 cells, and 3 growth factors, bioactive agents, and/or mechanical stimulation

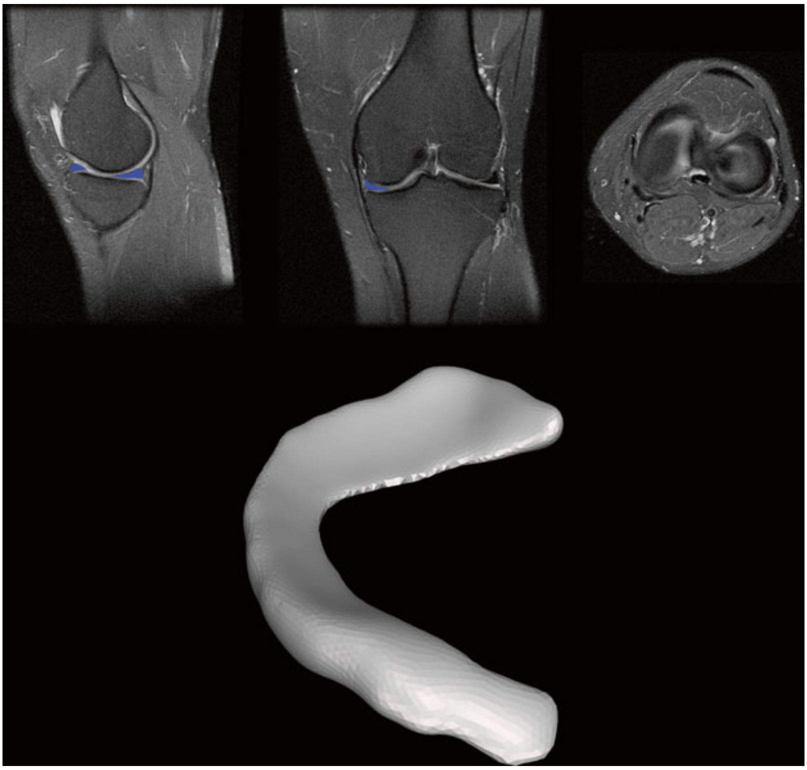

Fig. 3.8 Patient-specific meniscus implant based on silk fibroin and built upon three-dimensional MRI analysis of human meniscus

limitations of acellular scaffolds and allografts (Fig. 3.8). This might represent a viable option for partial and total meniscal replacement in a near future by mimicking architectural and biological features of native tissue.

However, only upon a deeper understanding of the native tissue biology, ultrastructure, and function, we might envision the complete success of these possibilities under development.

Conclusion

Progressive insights in meniscus structure, biology, and biomechanical properties are uprising. Such knowledge plays a determinant role in the development of biofunctional therapeutic options for full repair/regeneration of these structures known to be critical to the long-lasting physiological functioning of the knee joint. Biology is the launching pad for future effective treatment possibilities aiming to regenerate the menisci.

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Physiology: Biomechanics

4

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Contents

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4.1 Introduction

The menisci are two crescent-shaped fibrocartilagenous structures found in the medial and lateral compartments of the tibiofemoral joint of the knee. Once thought of as useless "remnant vestiges" [3], they are now well understood to play a critical role in knee joint stability and load distribution, protecting the smooth hyaline cartilage on both the distal femur and proximal tibia. These functional attributes are achieved via a combination of geometry, material properties, and ligamentous attachments of the menisci to the bones. They are also thought to play roles in knee joint lubrication and nutrient distribution [33] as well as proprioception [22]. With very poor self-healing capabilities and with injuries shown to speed up the progression of osteoarthritis, achieving effective repair or replacement of the menisci is an ongoing and important research aim.

4.2 Morphology

The lateral and medial menisci are both "c" shaped when viewed from above, although the medial meniscus is larger and more like a capital letter "C" (Fig. 4.1). They are wedge shaped in cross section when cut radially and are attached to the joint capsule via their peripheral rim and also to the tibia anteriorly and posteriorly by insertional ligaments. They partially cover the tibiofemoral joint surface (Fig. 4.2). In the sagittal

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_4

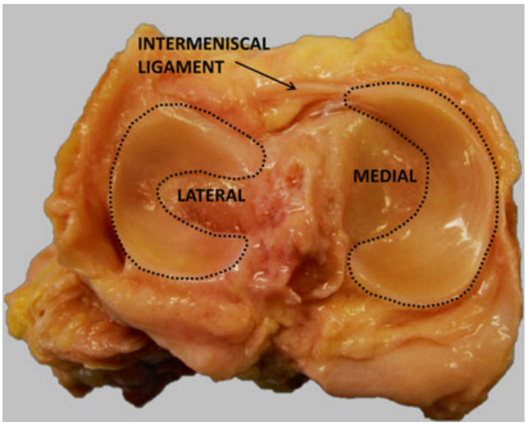

Fig. 4.1 A tibial plateau viewed from above. The donor was a 65-year-old female with moderate patellofemoral joint (PFJ) osteoarthritis (OA) and mild tibiofemoral joint (TFJ) OA

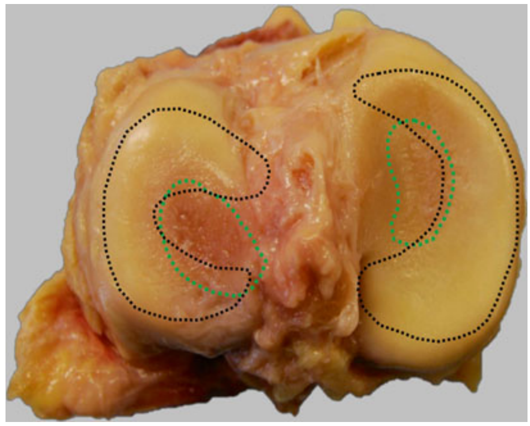

Fig. 4.2 The same tibial plateau as shown in Fig. 4.1, with the menisci removed. The outlines of where the menisci were shown, along with the areas of cartilage damage, where the menisci were not protecting the medial and lateral compartments (*dotted green lines*)

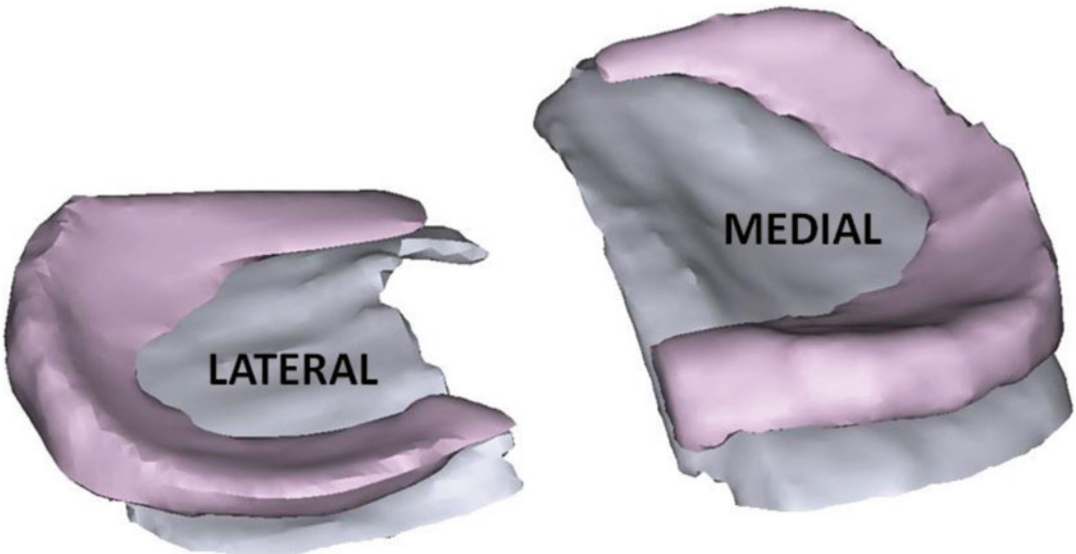

Fig. 4.3 3-dimensional reconstructions of the menisci (*pink*) and articular cartilage on the tibial plateau (*grey*), created from a magnetic resonance image. The convex lateral and concave medial compartments are clear

plane, the lateral compartment has a more convex tibial plateau than the concave medial compartment and the menisci conform to the tibial and femoral bony geometry (Figs. 4.3 and 4.4).

The various meniscal dimensions were measured as part of a study on meniscal allograft sizing [30]. Eighty-eight menisci (medial and lateral) were examined from 22 pairs of dissected cadaveric knees, and the dimensions described in Fig. 4.5 were determined using digital Vernier callipers. The results are given in Table 4.1. These results are of interest, as they demonstrate the wide variation in meniscal sizes that exists across different knees and are relevant because of the critical importance of accurate meniscal allograft and synthetic graft sizing [23, 41].

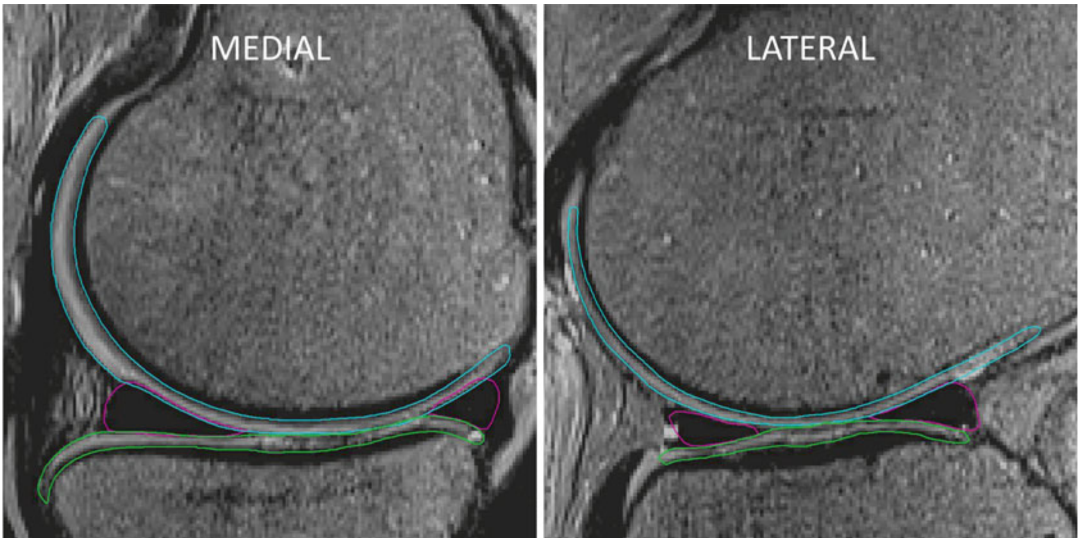

Fig. 4.4 Outlines of articular cartilage (*blue and green*) and menisci (*pink*), constructed using sagittal MRI slices and segmentation

Fig. 4.5 Left-sided menisci showing meniscus sizing notation. *MMC* medial meniscus circumference, *MMW* medial meniscal width, *MML* medial meniscal length, *LMC* lateral meniscus circumference, *LMW* lateral meniscal width, *LML* lateral meniscal length

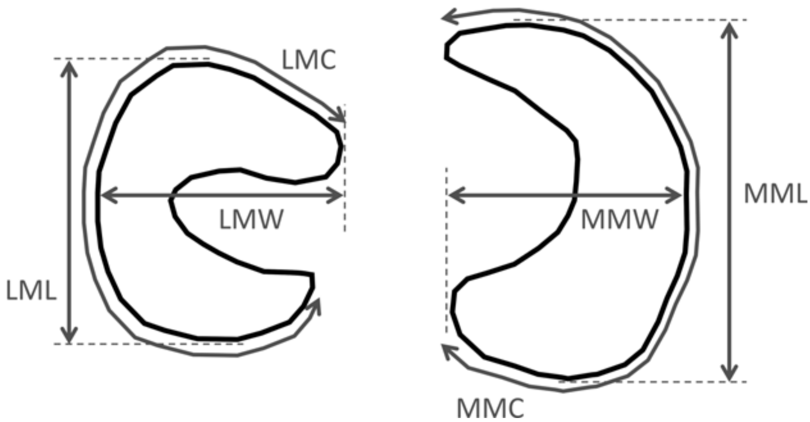

Table 4.1 Meniscal dimensions measured from 44 cadaver knees

	Mean ± SD (mm)	Smallest (mm)	Largest (mm)
Medial meniscus circumference (MMC)	99.0 ± 9.3	84.0	119.0
Medial meniscal width (MMW)	27.4 ± 2.5	23.3	32.7
Medial meniscal length (MML)	45.7 ± 5.0	30.1	56.1
Lateral meniscus circumference (LMC)	91.7 ± 9.6	78.0	112.0
Lateral meniscal width (LMW)	29.3 ± 3.0	24.0	36.3
Lateral meniscal length (LML)	35.7 ± 3.7	29.5	51.2

Data taken from McDermott et al. [30]

4.3 Material Properties of Meniscal Tissue

The microstructure (discussed in Chap. 3) of the meniscal tissue, as in all materials, principally defines the material properties and thus the mechanical behaviour of the tissue. The meniscal behaviour in both tension and compression is directly related to the predominantly circumferential orientation of the meniscal collagen fibres [4, 37, 38].

4.3.1 Tensile Material Properties

There are quite a few studies in the literature that have tested meniscal tissue in tension [13, 14, 26, 27, 45]. Because of the non-uniform nature of the shape of the menisci and their microstructure, uniformly shaped (rectangular or "dumbbell") specimens are harvested from whole menisci to be tested in tension. These samples are either taken in the radial or circumferential direction and can be cut either parallel or perpendicular to the bottom surface of the meniscus (Fig. 4.6). As well as this, the specimens are often classified by their location in the meniscus, in the horizontal plane: either anterior, central or posterior third (Fig. 4.6). It has been shown that circumferentially, the meniscus is about ten times stronger than it is radially (around 100 MPa compared to 10 MPa; Table 4.2), in keeping with the microstructure of the tissue, which may explain why the meniscus is more prone to circumferential tears, rather than radial ones. A corollary of the difference between radial and circumferential strength is that a radial tear is relatively uncommon and must break the collagen fibres, and so it defunctions the meniscus and is also hard to repair (due to sutures pulling out along the fibre direction and the tissue working at a high stress in the circumferential direction, across the radial tear). The opposite is true for circumferential tears, which occur easily because the tissue is weak when pulled apart radially, yet that also implies low stresses across the tear and hence it is relatively easy for sutures to hold it together. Lechner et al. [26] found that the cross-sectional area of their tensile testing specimens had an inverse effect on the tensile modulus, possibly a result of the thicker specimens having a greater water to collagen ratio than the thinner ones (Table 4.2). The results from these studies also suggest that the posterior third of the meniscus is less strong in tension in the circumferential direction, although there is no histological data explaining this difference.

4.3.2 Compressive Material Properties

There are three different types of compression tests that have been performed on the human meniscus: unconfined compression, confined compression, and indentation [8, 21, 32, 42, 44]. A combination of these test methods can give us knowledge about the non-linear and viscoelastic behaviour of the meniscus via the aggregate modulus (how stiff the material is under compression; H_A), the equilibrium modulus (how stiff the material is when fluid

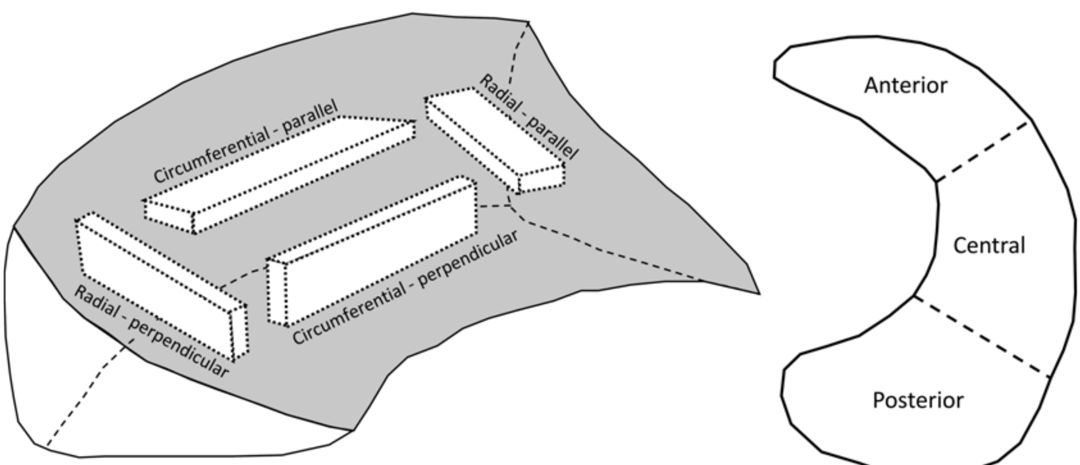

Fig. 4.6 Tensile testing specimens' harvesting locations

Table 4.2 Tensile properties of the human meniscus

Type of specimen	Study	Cross-sectional area of specimen (mm^2)	Tensile elastic modulus (MPa)			
			Anterior	Central	Posterior	Mean
Circumferential	Fithian et al. [14]	0.4	159	161	159	160
	Tissakht and Ahmed [45]	2.6–6.0	91	77	81	83
	Lechner et al. [26]	0.5	141	116	108	122
		1.5	105	94	61	86
		3.0	72	43	67	61
	Fischenich et al. [13]	1.0	170	–	105	138
Radial	Tissakht and Ahmed [45]	1.4–6.0	8	11	13	11

Table 4.3 Compressive properties of the human meniscus

Study	Test method	H_A (MPa)	k ($\times 10^{-15}$ m^4/Ns)	E_{eq} (MPa)
Joshi et al. [21]	Confined compression	0.23	1.99	
Sweigart et al. [44]	Indentation	0.12	1.78	
Seitz et al. [42]	Confined compression	0.06	4.24	
Chia and Hull [8]	Unconfined compression			0.08
Moyer et al. [32]	Indentation			1.59

flow has ceased; E_{eq}), the hydraulic permeability (how easily fluid flows through the tissue; k), and Poisson's ratio (the ratio of transverse to axial strain; ν). Values in the literature vary considerably (Table 4.3) which may be due to differing experimental methods and interpretation of data. Nevertheless, it is clear that the meniscus is considerable less stiff in compression than it is in tension (less than 1 MPa). This allows the cross section of the meniscus to conform to the condylar geometry when the knee is moving and may go some way to explain the loss of function and extrusion of the meniscus that can be observable in the older patient, particularly in the posterior medial meniscus in deep flexion, where it is squeezed against the rim of the tibial plateau, causing large deformation of the cross section of the meniscus.

4.4 Ligaments

Investigating the biomechanical function of the menisci is complex in nature, partly due to the many ligaments that are attached to them. There are 12 ligaments connected to the medial and lateral menisci and allograft transplantation should try and consider the functional contribution of these structures; there will most likely be functional limitations post-implantation because not all of the ligaments will be adequately replaced during surgery.

4.4.1 Meniscotibial Ligaments

There are two types of ligaments that connect the menisci to the tibia: the coronary ligaments and the tibial insertional ligaments.

The coronary ligaments resemble a "skirt" connecting the peripheral circumference of the menisci to the proximal tibia. These have not been investigated much in the literature and their exact function isn't clear. From their appearance it would be sensible to assume that they do have some kind of effect on meniscal movement and possibly also on knee stability.

The tibial insertional ligaments (or meniscotibial ligaments) connect the 4 horns of the menisci to the bone beneath the tibial plateau. These ligaments are extensions of the collagen fibres that run

Table 4.4 Maximum failure loads of the tibial insertional ligaments in cadaver knees

	Mean (*N*)	Range (*N*)	Number of roots tested
Anterolateral (AL)	673	250–1100	23
Anteromedial (AM)	532	200–824	24
Posterolateral (PL)	579	300–875	25
Posteromedial (PM)	596	388–850	19

Data taken from Kopf et al. [24] and Ellman et al. [11]

circumferentially through the bulk of the menisci. Data in the literature suggest that the pullout strength of these insertional ligaments is independent of location, though there is some variability between studies (Table 4.4). In studies that have examined the repair strength of various fixation methods used for meniscal root rupture, it has been concluded that none of the repair methods restore the pull-out strength of the insertions to the pre-injured state [12, 24], highlighting the importance of adequate fixation of allografts and implants.

4.4.2 Meniscofemoral Ligaments

There are two meniscofemoral ligaments: anterior (also known as the ligament of Humphry) and posterior (also known as the ligament of Wrisberg). Neither appear in all people, although the rate of incidence varies considerably in the literature [2, 17, 40]. If they are present, they act as a secondary restraint to posterior translation of the tibia up to 90° flexion and in deeper flexion, and they provide some resistance to external rotation [16].

4.4.3 The Deep Medial Collateral Ligament (dMCL)

As the dMCL passes from the tibia to the femur, it connects to the outer rim of the medial meniscus. It is thought to control the motion of the medial meniscus, although this has not been investigated in the literature. The ligament itself provides rotatory stability to the tibia as well as resisting valgus moments.

4.4.4 The Anterior Inter-meniscal Ligament

The anterior intermeniscal ligament (AIL; also called the transverse geniculate ligament or anterior transverse ligament) connects the medial and lateral menisci, via their anterior horns (Fig. 4.1). Its anatomy has been described [15, 34], but its exact function remains unclear. One anatomical study suggests that in a quarter of knees, the AIL acts as the primary connection between the medial meniscus and the tibial plateau, in the absence of an anterior medial horn or in cases where the horn is very fine [34]. This suggests that the AIL should not be compromised during surgical procedures, such as anterior cruciate ligament reconstruction.

4.5 Functional Biomechanics of the Menisci

4.5.1 Load Distribution

The force transmission role of the menisci is well established; during activities of daily living (ADLs), the knee joint is subject to axial compression, leading to contact stresses in the articular cartilage. The menisci help to make the contact between the femur and tibia more congruent, increasing the contact area of the tibiofemoral joint, thus reducing the contact stresses. The medial compartment is more congruent than the lateral one, because the medial side of the tibial plateau is more concave (Fig. 4.3). The lateral compartment is flatter and almost convex in some parts (Fig. 4.4). It has been shown that in meniscectomised knees, the contact area in that compartment goes down and the contact pressures therefore go up (Fig. 4.7), which is demonstrated by increased cartilage damage in meniscectomised knees (Fig. 4.8) and

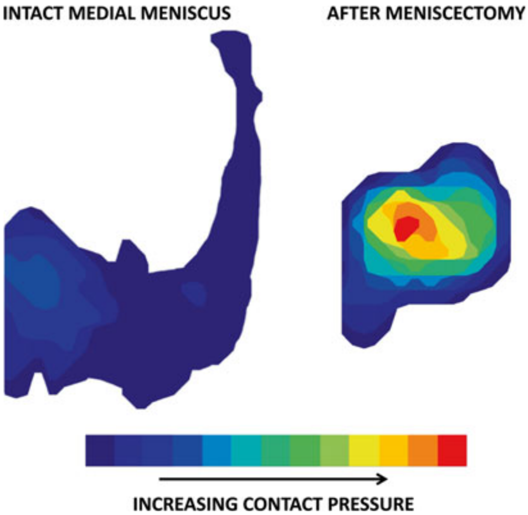

Fig. 4.7 A pressure map demonstrating the consequences of meniscectomy, using a Tekscan K-Scan 4000 pressure-sensitive film inserted underneath the medial meniscus in a human cadaver knee at 0° flexion with a 700 N axial compressive load

may partly explain the increased rate of incidence of osteoarthritis (OA) in people who have had partial or total meniscectomies [9].

Because the lateral meniscus covers a greater percentage of its compartment than its medial counterpart, combined with the fact that the lateral compartment is less congruent with its femoral condyle, it is implied that lateral meniscectomy would present a greater risk of OA development than medial. However, the clinical results are mixed, with some reporting worse outcomes with lateral meniscectomy [19, 20, 31] and others finding no difference between the two procedures [5, 28, 36]. In cadaveric experiments, contact areas and pressures change by similar amounts on the medial and lateral sides after simulated meniscal injuries (Fig. 4.9; [25, 35]). Although the lateral compartment is less congruent than the medial, the forces during gait are concentrated onto the medial aspect by the knee adduction moment which occurs during weight bearing.

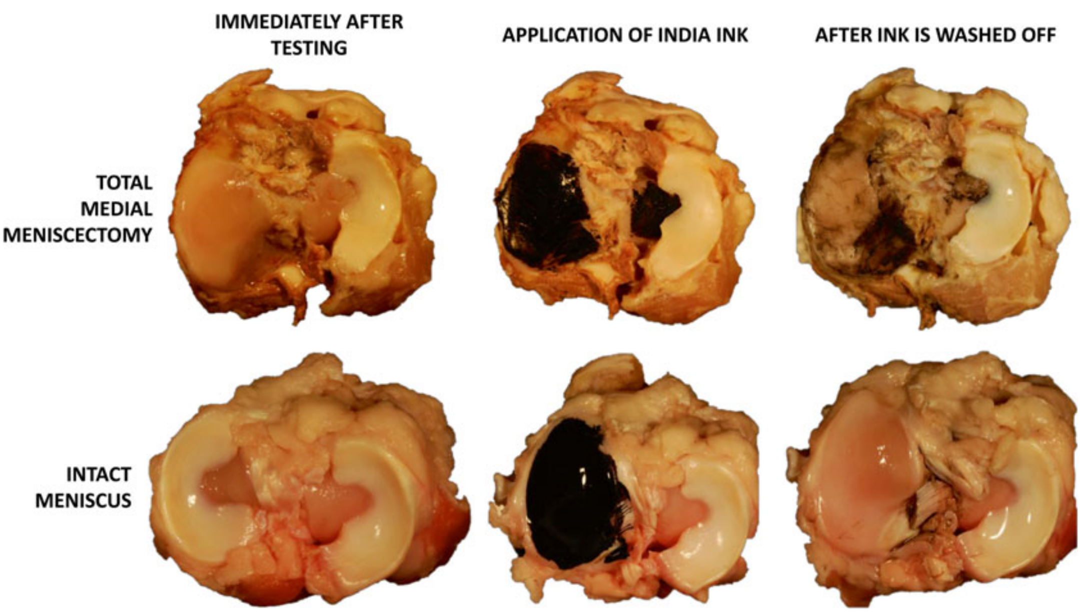

Fig. 4.8 Photographs demonstrating the consequences of meniscectomy, using an ovine stifle model. Joints were either left intact or had a total medial meniscectomy performed. They were then cycled 500,000 times in a bespoke flexion-extension rig, with a loaded stance phase. After testing, the joints were disarticulated and the medial compartment was coated with India ink. The ink was then washed off. The intact joint showed no damage while the meniscectomised joint showed significant cartilage damage, shown by the permanent staining by the ink [18]

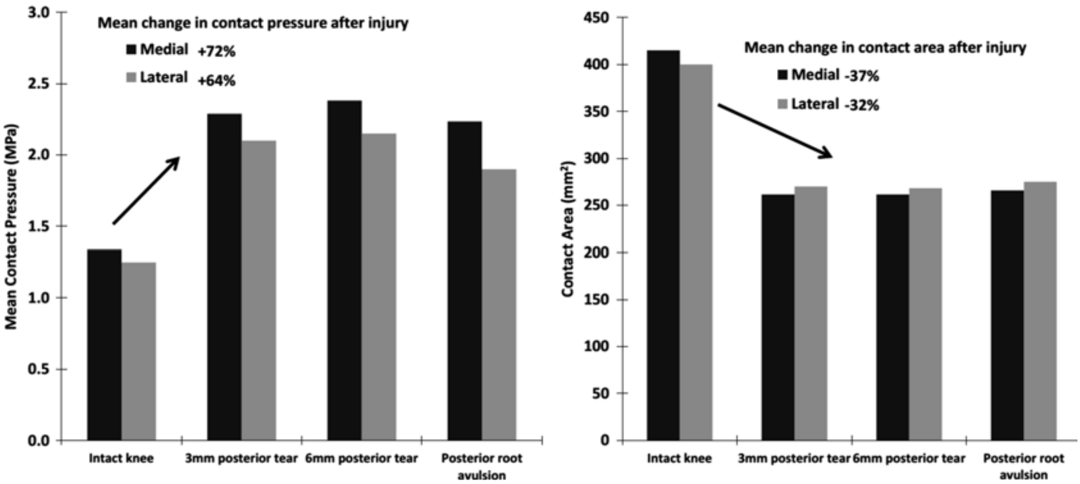

Fig. 4.9 Bar charts showing the consequences of differing amounts of meniscus injury on mean contact pressure (*left*) and contact area (*right*) for the medial and lateral compartments, pooled across flexion angles ranging from 0° to 90°. The data is taken from two separate journal articles (medial data taken from Padalecki et al. [35]; lateral data taken from LaPrade et al. [25]) but the work was done by the same research group

4.5.2 Stability

Because the menisci are attached to both the tibia and femur, they have a stabilising effect on the knee joint in certain degrees of freedom, at certain flexion angles. The medial meniscus in particular has been shown to be a secondary restraint to anterior translation of the tibia [1, 43] and the menisci also restrain tibial rotation and the pivot-shift mechanism [7, 39].

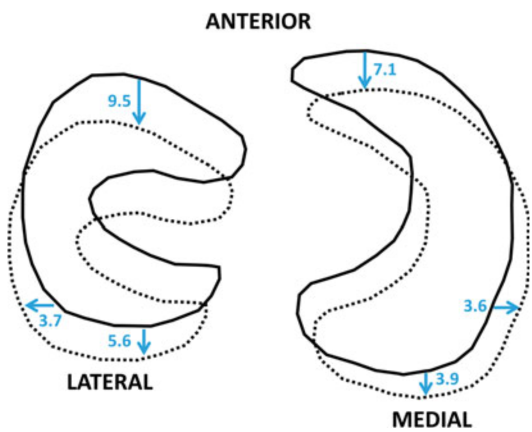

Fig. 4.10 A diagram showing the motion of the menisci during flexion measured in patients using dynamic MRI. Weight-bearing knee flexion from 0° to 90°. Both menisci move a similar amount peripherally but the lateral meniscus moves more posteriorly and the anterior horns move more than their posterior counterparts (data taken from Vedi et al. [46]. Diagram not to scale)

4.5.3 Meniscal Motion During Knee Flexion

The load-bearing role of the menisci is able to occur throughout the whole range of knee joint flexion (up to 160°) because the menisci are mainly attached to the tibia by insertional ligaments at their horns, which are mobile, allowing displacement in all directions. There have been several studies that have examined this movement in both cadaver and clinical settings, but only one has measured meniscal translation in vivo, under weight-bearing conditions, using open MRI.

Vedi et al. [46] described meniscal motion in the normal knee (Fig. 4.10). They observed that both menisci moved posteriorly as the knee flexed. The anterior horns were also noted to be more mobile than the posterior horns and the lateral meniscus was noted to be more mobile than the medial. The posterior horn of the medial meniscus was found to be the least mobile. The lateral meniscus was shown to be more mobile than the medial meniscus, partly due to the dMCL's attachment to the medial side but also because the concave medial tibial plateau, with secure attachment of the capsule to its rim, does not allow the posterior horn of the medial meniscus to displace off the joint posteriorly in deep flexion, whereas the convex posterior aspect of the lateral tibial plateau does allow this to occur to the lateral meniscus.

These observations may explain the increased frequency of medial meniscal tears compared to lateral meniscal tears, which happen twice as often [6]. They may also explain the observations of medial meniscal tears being located more frequently in the posterior horn of the meniscus [10].

Conclusion

The menisci of the knee and their associated ligaments in combination are a highly complex construct. Their function is inextricably linked to their structure and morphology and the interactions between the menisci, their ligaments and the proximal tibia and distal femur. The importance of the menisci is now well understood and meniscal preservation is practised routinely during surgery, if it is possible to do so and there are many different repair options available. However, structures such as the coronary, meniscofemoral and intermeniscal ligaments are often ignored during meniscal allograft procedures, and the tibial insertional ligaments are not adequately restored. Allografts have many contraindications for use and mixed results in long-term follow-up, but it has been shown to be possible to restore intact joint contact stresses at time zero in vitro [29]. There needs to be a better understanding of the relevance of the detailed anatomical features of the menisci in order to develop more accurate modelling of this tissue, in order to be able to manufacture or grow appropriate artificial scaffolds or tissue-engineered replacement tissue and to enhance the meniscal repair techniques.

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5 Physiopathology of the Meniscal Lesions

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Contents

5.1 Introduction

The menisci have a major role in the function of the knee joint [57].

Meniscal lesions continue to represent the second most common intra-articular injury of the knee and are the most frequent cause of orthopedic surgeries [33, 81]. In the United States, the mean annual incidence of meniscal lesions has been reported to range from 61 to 66 per 100,000 inhabitants [5, 51], and most of them

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_5

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continue to be treated by meniscectomy [33]. Among the injuries of athletes affecting the knee, most involve the anterior cruciate ligament (ACL) (20.34 %), followed by the medial (10.76 %) and lateral meniscus (3.66 %) [53].

Meniscal injuries are more frequent in men than women, with a male to female incidence ratio ranging between 2.5:1 and 4:1. The peak incidence occurs at 20–29 years of age for both sexes [5, 33, 54] and is more common in the right knee [5].

Despite meniscal lesions can occur in all age groups, patient's age has a major influence on the etiological and pathophysiological factors [9, 66, 81]. The proportions of meniscus constitution concerning water content, cells, extracellular matrix, collagen, and adhesion glycoproteins present variations according to age, injury, and pathological conditions [88].

Anatomic features, biological and biomechanical characteristics, and the type of external forces acting in different zones and segments during normal and abnormal motion are decisive in the mechanism of injury of these structures [9, 34, 54, 59, 91].

It has been recognized that the partial or total loss of meniscus brings negative consequences to the knee, principally at long term [27].

Great changes have been introduced in recent years concerning the clinical approach to meniscus injuries. The paradigm has changed "from meniscectomy to preservation or substitution" [93]. Arthroscopic techniques have also created a revolution in treatment, and the ongoing development of implants and tools has contributed to a major increase in options for treatment of several injuries of the menisci [9]. Understanding the mechanism of injury and the biological response of the tissue to aggression might assist in further development of effective treatment strategies [70–72].

The meniscus is a complex tissue, and segmental variations have been reported concerning cells, ultrastructure, extracellular matrix, and biomechanical properties [70]. Different cells can also play different roles in meniscus function and response to aggression (injury) [92].

This work describes the most relevant injury mechanisms of the menisci, correlated to its ultrastructure and anatomy.

5.2 Anatomy, Biology, and Biomechanics: Relevance on Meniscal Injuries

The menisci are C-shaped wedges of fibrocartilage located between the tibial plateau and femoral condyles. The menisci contain 70 % of type I collagen interposed with cells and an extracellular matrix (ECM) of proteoglycans and glycoproteins [73]. The collagen bundles are combined in different orientations to oppose compressive, radial, and shear stresses [73]. The collagen bundles include three different layers [10, 17], as follows:

1. One more superficial with random orientation of fibers, which somewhat can mimic hyaline cartilage
2. Radial bundles (more frequent in the innermost one-third)
3. Circumferential bundles (in the outer two-thirds)

It has been suggested that fibers in the inner third mainly oppose to compression forces, while the outer two-thirds counteract radial tension forces [17].

Another group of collagen fibers, the so-called tie fibers, is radially orientated and its function is to oppose longitudinal splitting forces of the circumferential collagen bundles [17].

The medial meniscus is larger, has a "semilunar" shape, and is attached more firmly than the more circular shaped lateral meniscus [73].

The anterior and posterior horns of both menisci are firmly attached to the tibial plateaus. Anteriorly, the transverse ligament connects both menisci.

The meniscofemoral ligaments thus help stabilize the posterior horn of the lateral meniscus to the femoral condyle [36]. The coronary ligaments connect it in a somewhat "loose" way to the peripheral meniscal rim to the tibia. The lateral meniscus has no attachment to the lateral collateral ligament (LCL) despite the close anatomic correlation.

The joint capsule is attached to the complete periphery of each meniscus but adheres more firmly to the medial meniscus [54]. The popliteal hiatus allows the popliteus tendon to pass through to its femoral attachment site and represents an interruption in the attachment of the joint capsule to the lateral meniscus. During knee flexion, contraction by the popliteus pulls the lateral meniscus in a posterior direction and this way prevents it to become entrapped within the joint space [75].

There is no direct muscular connection to the medial meniscus. The medial meniscus is capable to move a few millimeters, while the less stable lateral meniscus may shift more than 1 cm [57].

Different mobility patterns of both menisci are believed to influence different injury mechanisms [9]. On kinematic MRI evaluation, the menisci tended to move significantly to the posterior side when moving from extension to flexion [44]. The anteroposterior meniscal movement was higher for the anterior horn of the medial meniscus and inferior for the posterior horn of the medial meniscus [44].

Under compressive loads, the medial porcine meniscus and its attachments undergo significant displacement by up to 2.66 1.2 mm ($P<0.01$) under knee joint loads of 200 % body weight (BW) [28]. Moreover an increase of 0.9 mm in the distance between posterior and anterior horn ($P<0.001$) was observed [28]. The meniscus and its attachments presented an average radial stretch of 0.6 %, an average circumferential stretch of 0.9 %, and an average axial compression of 11.6 % at 200 % BW [28]. An in vivo study of meniscus movements using dynamic MRI has shown that on weight-bearing conditions, the anterior horn of the medial meniscus moves through a mean of 7.1 mm and the posterior horn through 3.9 mm, with 3.6 mm of mediolateral radial displacement [91]. The height of the anterior horn increases by 2.6 mm and that of the posterior horn by 2.0 mm [91]. The anterior horn of the lateral meniscus moves 9.5 mm and the posterior horn 5.6 mm, with 3.7 mm of radial displacement [91]. The height of the anterior horn increases by 4.0 mm and that of the posterior horn by 2.4 mm [91]. The most significant differences between weight-bearing and non-weight-bearing conditions were the movement and vertical height of the anterior horn of the lateral meniscus [91].

Knee flexion normally leads to posterior movement and shortening of the anterior-posterior diameter of the menisci, which can be related to the positioning and curvature of femoral condyles at the tibiofemoral contact point at knee flexion [41].

This biomechanical behavior must be considered when aiming to understand the response of meniscal tissue to external loads.

The role of menisci on load transfer has been described by several biomechanical studies [31, 49, 50]. Understanding the biomechanical behavior of the joint is fundamental to understand is pathophysiology [47, 84].

Concerning load transmission, 70 and 50 % of the load are transferred through the lateral and medial menisci in its corresponding compartments [15].

The lateral meniscus carries most of the load transfer on the lateral compartment, while in the medial compartment the load transmission is more evenly distributed between the cartilage surfaces and the medial meniscus [94].

During normal knee kinematics the menisci are exposed to compressive, radial tensile, and shear stresses [1, 35, 65].

This knowledge (Fig. 5.1) has obvious implications in meniscus injuries and on global joint consequences of these injuries [27].

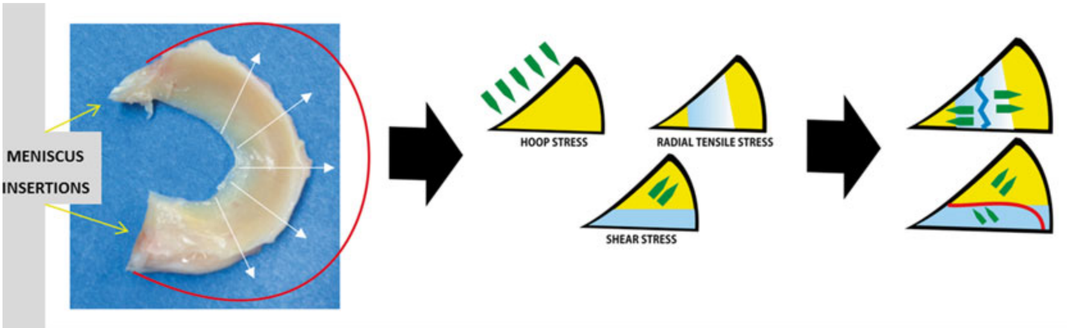

Fig. 5.1 Schematic representation of compressive (hoop), radial tensile, and shear stress forces (*green arrows*) implicated in pathophysiology of meniscus injuries

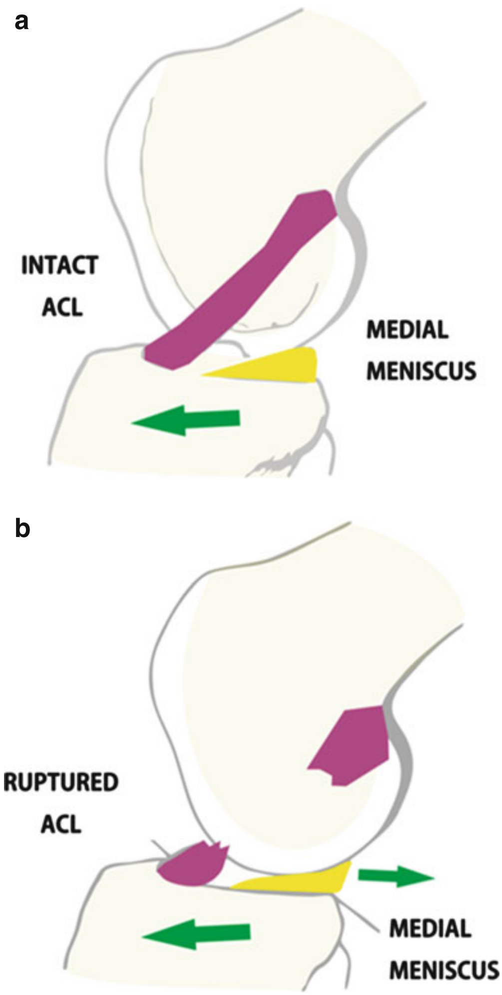

Fig. 5.2 Schematic representation of the primary role of ACL in impairing anterior tibial translation while the posterior medial meniscus horn acts as a secondary stabilizer (**a**); in the ACL-deficient knee the posterior horn of medial meniscus is frequently entrapped by the femoral condyle and tibial plateau during anterior tibial dislocation (**b**)

In the stable knee, with normal anterior cruciate ligament (ACL), the medial meniscus has a small function as secondary stabilizer when opposing to anterior tibial translation [57]. The ACL (primary stabilizer) impairs anterior dislocation prior to significant contact of the femoral condyle with the posterior horn of the medial meniscus (Fig. 5.2) [50]. However, in ACL-deficient knees this mechanism has been related to frequent patterns of meniscal injuries, including acute longitudinal and horizontal tears [9, 57].

The competence of collateral ligaments is also relevant once the absence of collateral ligaments increases the loads in cruciate ligaments and contact stresses transmitted through cartilage layers and menisci. Higher risk for injury consequently subsides, especially when varus-valgus forces are accompanied by other modes of loading as well [12].

The knee is a relatively incongruent joint (Fig. 5.3), thus producing quite different patterns of load transfer as compared to the ankle, being the latter a good example of a congruent joint of the inferior limb [90]. The menisci have an important role in increasing joint congruency. However, the lateral meniscus has a higher contribution in ensuring joint congruency when compared to the medial. Both these facts must be kept in mind when aiming to understand the physiopathology of meniscal injuries [61].

The meniscus has been divided for description and research purposes according to zones and segments [3].

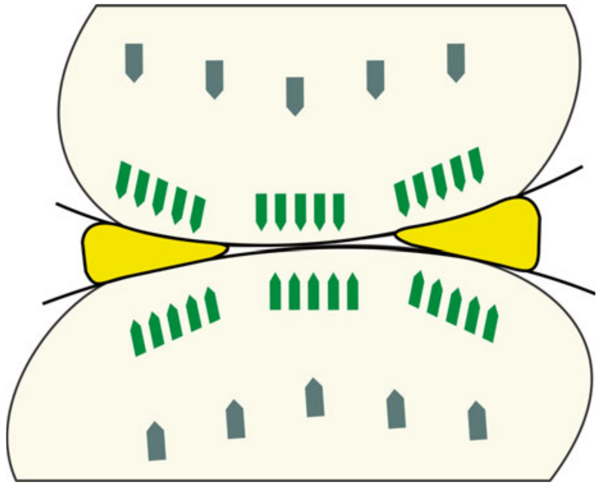

Fig. 5.3 Schematic representation of compressive load transmission (*gray arrows*) on an incongruent joint (e.g., the knee) and the important role of the meniscus in load transmission (*green arrows*)

The more vascularized zone 1 has higher quantity of stem cells than the less vascularized zones 2 and 3, and such cells might play a role in meniscal repair [67]. Meniscal vascularization is related to the healing capacity of meniscal tissue including recovery from repetitive loading. However, some healing of meniscal tissue has been described in avascular portions of the meniscus [9]. Anterior and posterior insertional horns are more richly irrigated [16].

Regional variations in viscoelastic properties [18] and regional and zonal variation in glycosaminoglycan coverage, size, and cellular density have also been reported in animal meniscal tissue [43].

For the first time, a recent study about regional variations in fresh human meniscus tissue concluded that medial meniscus presents higher stiffness (storage modulus – E') and loss factor (tan δ) as compared to the lateral [70]. Moreover, anterior segments present significantly lower stiffness (lower E') as compared to mid-body and posterior segments. Anterior segments of either lateral or medial menisci have higher tan δ, which suggests that they are more predisposed to dissipate mechanical energy [70]. Besides the fact that anterior segments have higher damping properties, they also have inferior cellularity as compared to other segments [19, 70]. The exact implication of such fact on injury and repair mechanism is subject to ongoing research.

Despite the material properties, stresses in the meniscus are also sensitive to the geometry of structures (meniscus width and radius of curvature of the femoral surface of the meniscus) [61, 62].

Biomechanics has implications in injury mechanism but it also can influence repair. It has been shown that joint loading through physical therapy may be beneficial in promoting healing of meniscal lesions under inflammatory conditions [60].

5.3 Traumatic Meniscus Injuries in Younger Population

Menisci can be traumatically injured during sports practice or high-energy trauma [78]. Meniscal tears might also occur in combination with fractures around the knee [78]. Clinical presentation of acute tears includes pain and/or swelling of the knee joint. Unstable, displaced tears might lead to mechanical symptoms such as clicking, catching, or locking of the knee joint [74].

Meniscal tears are more common in young and active individuals, particularly when enrolled in level 1 contact sports that comprise frequent pivoting, such as soccer, rugby, or American football [74]. However, such type of injuries can occur after apparently innocuous activities such as walking or squatting [6].

The most frequent traumatic mechanism is a twisting movement at the knee while the leg is bent (Fig. 5.4). Torsional loading or a high

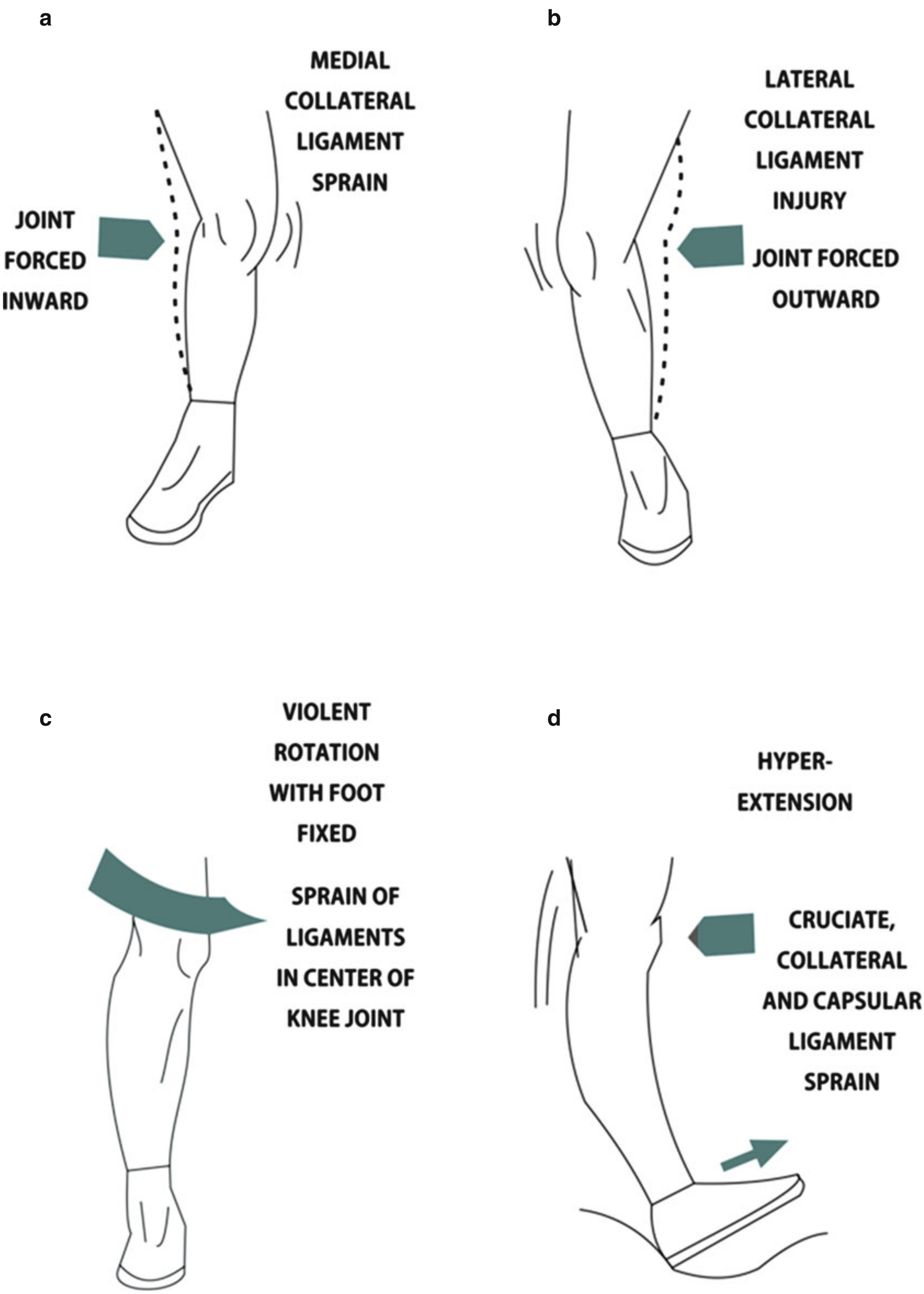

Fig. 5.4 Schematic representation of common injury mechanisms of ligaments, cartilage, and meniscus of the knee joint. (**a**) joint forced inward (often associated to medial colateral ligament injury); (**b**) joint forced outward (often associated to lateral colateral ligament injury); (**c**) violent knee rotation with the foot fixed (central pivot and menisci); (**d**) Hyperextension (multiple intra and extra articular injuries)

compressive force between femoral and tibial articular heads (axial loading) can cause meniscus damage at a different extent [30]. Valgus impact with external rotation of the tibia might also cause a triad of injuries involving meniscal damage with associated medial collateral and ACL tears [20, 83]. Another typical movement is a sudden transition from knee's hyperflexion to full extension, catching the meniscus trapped between the femur and tibia [30].

As aforementioned the lateral meniscus has a higher articular surface and is therefore more involved in absorption and load transmission. It is also more mobile and thus less susceptible to fracture as compared to the medial meniscus [55].

The patient's main complaints are usually knee pain and swelling. These are worse when the knee bears higher loads (e.g., when running). Another typical patient's complaint is joint locking, with patients referring that they are unable to straighten the leg completely. This can be accompanied by a sense of "clicking." Some patients also refer an impression of giving away [30].

The patients can often remember a specific trauma, activity, or movement during which the meniscus injury occurred. Diagnosis must be primarily based on clinical examination; however, MRI evaluation is often useful [80].

Meniscus tears (Fig. 5.5) can be classified in various ways: by anatomic location, by proximity to blood supply, etc. They can be referred as incomplete, complete, stable, or unstable [69]. Various tear patterns and configurations have been described [13, 40] (Table 5.1).

The functional importance of these classifications, however, is to ultimately help surgeons determine whether a meniscus is repairable or not.

More recently, the ISAKOS classification of meniscal tears has been developed for pooling of data from international clinical trials designed to evaluate the outcomes of treatment. The method has shown sufficient interobserver reliability [3].

Several risk factors have been implicated in the etiology of either degenerative or acute meniscal tears, with some of these factors being potentially modifiable [85].

There is moderate evidence that weight bearing during trauma is an important risk factor for acute meniscal tears [29]. Sports activity appears

Table 5.1 Type of meniscal tears

Type of lesion	Comment
Longitudinal lesion	Most frequent meniscal injuries Represent 29 % of all medial lesions and 33 % of all lateral lesions [69]
Bucket-handle lesion	More common in the medial meniscus A complete longitudinal lesion can progress to become a bucket-handle lesion
Oblique tears (or flap)	More frequent in the region between the mid-body and posterior segments of the meniscus
Complex lesions	Usually a consequence of repeated knee trauma
Radial lesions	More often originate from the free border to the meniscal periphery
Horizontal tears	Usually are degenerative lesions

Pellacci et al. [69]

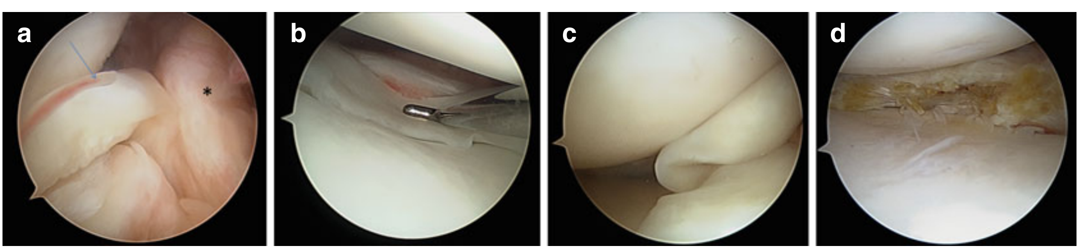

Fig. 5.5 Arthroscopic images of: lateral meniscus bucket-handle tear (*blue arrow*) with the ACL visible (*) (**a**), medial meniscus longitudinal peripheral tear (**b**), medial meniscus flap/parrot-beak tear (**c**), and degenerative, complex medial meniscus tear (**d**)

to be a relevant risk factor in such lesions [6, 7, 85]. Certain types of sports, described as contact sports, have been correlated with increased risk for meniscus tears. American football, basketball, soccer, baseball, and skiing in particular are the most frequently involved in meniscal lesions, accounting for more than 1/3 of all cases [54]. However, despite its low-contact profile, swimming has also been identified as risk factor for acute tears [7]. There is some evidence that running might also be considered as a risk factor [85]. Global joint laxity is another risk factor for meniscal tears [5]. These persons with higher risk should be included in pre-participation prevention programs [6].

Delayed ACL repair for more than 12 months after the ACL injury determines an overall *odds ratio* of 3.50 for medial meniscal tears when compared to early ACL repair [85]. Conversely, minimal to no evidence was found for the period of time comprised between ACL injury and reconstruction surgery as a risk factor for lateral meniscus tears [85]. These findings should be understood considering the above-mentioned different roles of medial and lateral menisci within knee joint [57]. Moreover, a delay in surgical treatment is also associated with a higher incidence of medial meniscal tears in pediatric and adolescent populations [63]. Increased age and body mass index are independently associated with a higher rate of medial meniscus tears [21].

Symptomatic horizontal meniscal tears (Fig. 5.6) in young patients are a rare entity and often correlate with severe meniscus injuries. It has been mostly considered as an overuse syndrome [76].

Complete radial tears (Fig. 5.7) significantly diminish the capacity to maintain hoop tension in the meniscus. However, the residual meniscus might continue to provide some load transmission and distribution functions across the joint [11]. Repair techniques for complete radial meniscal tears are focus of intense development and research [56].

Meniscal root tears (MRTs) can either be traumatic or degenerative (Fig. 5.8). Traumatic MRTs are often combined with ACL tear, particularly on the lateral meniscus [9]. The disruption of collagen fibers, which provide hoop strength, eventually results in diminished biomechanical properties leading to meniscal extrusion [68]. In high-energy trauma causing acute tibial plateau fractures, depression of the joint line is a potential predictor of specific meniscal (and ligamentous) injuries [86].

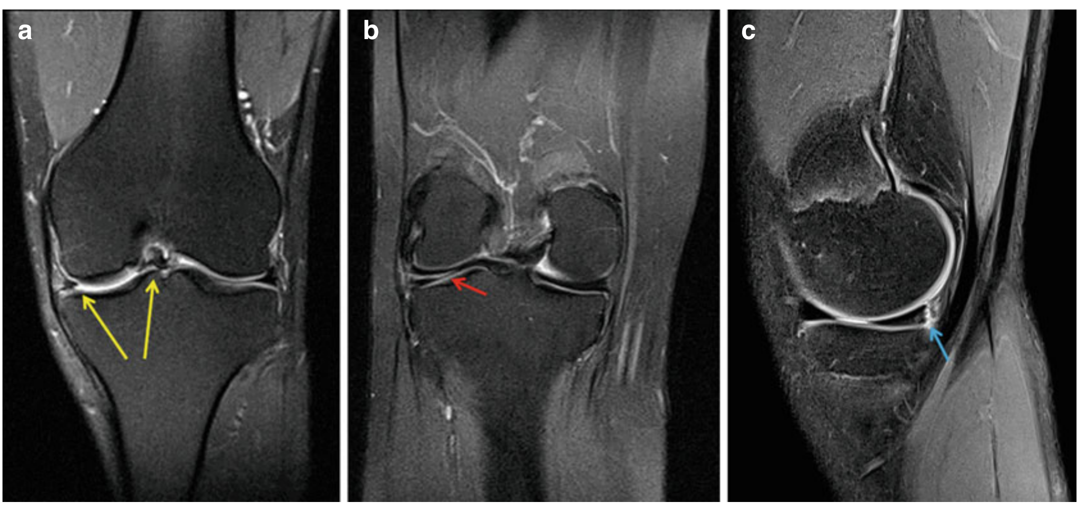

Fig. 5.6 MRI T2 images of: medial meniscus bucket-handle tear (*yellow arrows*) (**a**), lateral meniscus horizontal cleavage tear (*red arrow*) (**b**), and medial meniscus complete longitudinal peripheral tear (*blue arrow*) (**c**)

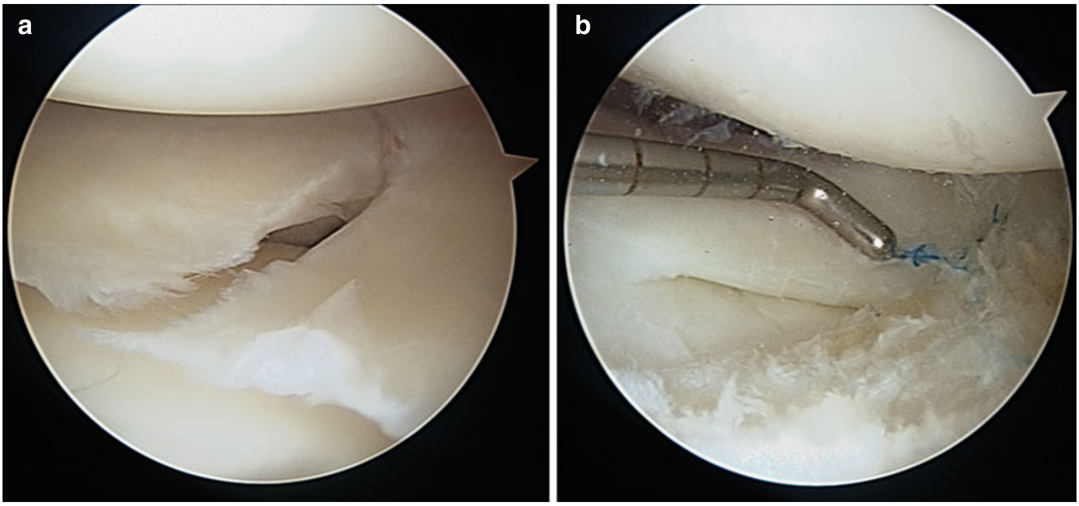

Fig. 5.7 Complete radial tear of the lateral meniscus (**a**) and postoperative look after suture of the same radial tear combined with limited excision of tissue in the most avascular zone (**b**)

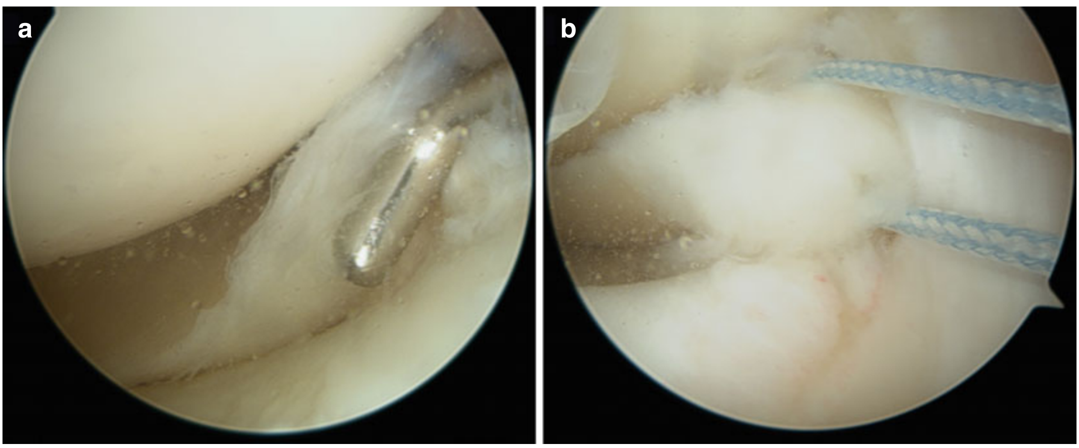

Fig. 5.8 Medial meniscus posterior root tear (**a**) and intraoperative look of sutures passed through the posterior root for subsequent reinsertion within a bone tunnel (**b**)

5.4 Degenerative Meniscus Tears in Older Population

Meniscal lesions can occur very frequently in middle-aged and elderly patients [23]. Typical configurations of these tears are horizontal cleavages and/or flap/oblique tears involving the medial meniscal body and or injuries of the posterior horn (Fig. 5.5d). Most meniscal tears exist in persons without knee symptoms. Hence, meniscal tears are an extremely common incidental finding on magnetic resonance imaging of the knee [23]. Most tears encountered in patients within this age group usually result from long-term degenerative changes. Such meniscal lesions might be implicated in joint swelling, joint line pain, and/or mechanical blocking [8, 23]. Among patients with clinical and radiographic findings of osteoarthritis, the reported prevalence of meniscal lesions is comprised between 68 and 90 % [26, 45]. This high correlation causes severe limitations for diagnostic and proper course of action. Only if the main pathology in a symptomatic knee is properly identified, one can choose the most effective treatment. It is highly unlikely that the treatment of meniscal tears with partial meniscectomy is effective in the reduction of symptoms caused by global joint osteoarthritis [9].

Meniscus repair in older people has been providing less promising outcome compared to younger age groups [8].

One fact supporting such unfavorable outcome is the degenerative etiology surrounding meniscal tears in such older patients, considering the previously referred changes in meniscus properties as well as the declining vascularization of the aging meniscus [9, 54].

The currently preferred surgical treatment for the majority of surgeons for treating symptomatic meniscus tears in older patients is meniscectomy, either partial or total, depending on the degree of meniscal damage [23].

Other risk factors associated with development of degenerative lesions besides self-reported knee injury include the malalignment of the knee (the more loaded compartment) and the presence of signs of hand osteoarthritis [22]. This screening method of x-ray screening might be useful to identify systemic or potentially a common environmental factor [22]. Occupational load also plays a role in the development of symptomatic meniscal tears [79].

When a meniscus is damaged, the degenerative processes leading to knee osteoarthritis dramatically increase, probably due to loss of meniscal function in load distribution and shock absorption. In elderly patients the presence of meniscal injury may often be considered as a sign of incipient osteoarthritis [22–25].

The prevalence of meniscal tears increases with aging, ranging from 16 % in the knees in 50–59-year-old women to over 50 % in the knees of men aged 70–90 years [23]. Moreover, among elderly patients, it has been reported about 10 % of cases with partial destruction or complete absence of normal meniscal tissue [23]. This shall not be classified as meniscal tear, but is a finding typically associated with radiographic evidence of osteoarthritis [23].

However, among elderly patients, most of meniscal tears do not cause knee symptoms as over 60 % of tears were seen in knees of subjects without knee pain, aching, or stiffness [23]. Hence, a meniscal tear is a common incidental finding when performing MR imaging of the knee in this population. However, having such meniscal damage on MRI has been associated with an almost sixfold increased odds ratio for development of radiographic knee osteoarthritis over 30 months [24].

Another key issue besides its morphologic integrity is the meniscus position within the knee joint once varying degrees of meniscal extrusion have been implicated after degenerative meniscus tears [48]. Meniscal extrusion of the meniscal body is more frequent in the osteoarthritic knee [32, 42, 87]. Moreover, meniscal extrusion lowers the coverage of the tibial surface and has been reported to be an important risk factor for cartilage loss [25, 38, 82] and joint space narrowing seen on conventional tibiofemoral radiographs [37, 39].

In brief, injury mechanisms of degenerative meniscus tears are usually multifactorial. Assessment of joint alignment, aging changes in the meniscus tissue proper, and osteoarthritic joint environment must be considered besides any possible traumatic event.

5.5 Meniscal Tears in Children

Meniscal lesions in children have different features when compared to adult patients. In children, most cases (>71 %) correspond to isolated meniscal lesions [4, 52, 77].

The most frequent mechanism of meniscal injury in children is sports-related twisting of the knee. One possible predisposing factor for a small percentage of cases is the presence of a discoid meniscus [46]. Diagnosis is based on medical history of the patient and clinical examination. If a meniscal tear is suspected, complementary imaging methods of diagnosis are often required. However, MRI has lower sensitivity and specificity for diagnosing meniscal lesions in children compared to adults [58, 89].

There is less knowledge available in literature concerning treatment of meniscal injuries in children compared to adults. However, most studies reported that the overall success rate for meniscal repair in children appears to be at least similar to that observed in adults, especially for cases of isolated tears [2, 14, 64].

Take-Home Message

There are important differences in the medial and lateral meniscus concerning biology, anatomy, and biomechanics, which have a decisive role in different types of tears and epidemiologic features for both. Moreover, there are regional and segmental variations within each meniscus with implications in their function and subsequently in their injury and repair mechanisms. The menisci must oppose to compressive, tensile, and shear forces.

Several traumatic events with different combinations of forces have been enrolled in etiology of different types of meniscal tears.

Despite the previous, other factors such as age, joint alignment, body mass index, level of activity, and age also play a role on the pathophysiology of meniscus tears.

The degenerative meniscus tears in older populations result from a multifactorial and complex combination of events and are usually difficult to separate from the global environment of a globally arthritic joint in many of the older patients. In addition, most degenerative tears that are found on MRI studies within these elder populations are asymptomatic.

This must be taken into account when preparing the treatment of such patients.

Meniscus injuries are rare in children and are mostly related to sports trauma, and in a small percentage of cases, a discoid meniscus might be implicated.

Growing insights from basic science studies promise to bring new insights for some difficult questions in the near future concerning this topic of physiopathology of meniscus injuries.

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6 Meniscus Basic Science: Synthesis

Helder Pereira

Basic Science can only be understood as the group of sciences dedicated to study the fundamentals or the pillars of any topic. This multidisciplinary approach dedicated to the meniscus tissue has been noticeably developed in recent years.

We have new means to evaluate tissue, to understand their function, and to predict their reaction to injury as well as to treatments and a new world of innovative perspectives for future.

However, we all agree on the relevance of understanding phylogenesis and ontogenesis, vascularization, anatomy, biomechanics, ultrastructure, and pathophysiology all correlated to function of the meniscus.

Herein we can understand the implication of phylogenesis and ontogenesis on meniscus physiology and function from a "species evolution" perspective. Such knowledge is connected to the differences found on hominid evolution leading to the bipedal gait of humans. This reinforces a close connection between anatomy and function and is wonderfully illustrated in the first chapter.

The second chapter is focused on presenting an astonishing pictorial perspective of meniscus anatomy focused on practical issues with interest for surgeons. Understanding anatomy is critical to develop and improve surgical techniques and their outcome.

The global mechanical properties of meniscus and surrounding tissues are described in detail. The various meniscal ligaments and their functions are elucidated: what purpose do they serve and how do they achieve that.

The menisci are nonuniform and heterogeneous structures with segmental variations according to its biology and function. Segmental and zonal variations have been described concerning biomechanical features and cellularity distribution. These new concepts promise to play an important role on tissue engineering and regenerative medicine approaches to meniscus injuries.

Pathophysiology of meniscus injuries comprises combination of compressive, tensile, and shear forces. Besides the characteristics of the tissue itself, several other factors are enrolled in the etiology of meniscus tears. These include the external load/traumatic event in a given moment,

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_6

the joint alignment, age, body mass index, or patient's activity level. On the other hand, degenerative tears are usually multifactorial and not always easy to separate from the environment of a globally osteoarthritic joint.

Progressive insights in meniscus "Basic Science" are uprising. Such knowledge plays a determinant role in the development of further biological and surgical therapies in respect for joint homeostasis.

Biology is the launching pad for future effective treatment possibilities aiming to meniscus regeneration.

Hélder Pereira

Part II

Classification Meniscal Lesions

Traumatic Meniscal Lesions

7

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7.1 Introduction: Traumatic Versus Degenerative Meniscal Tears

Traumatic meniscus tear (TMT) can be defined as a tear that happens as a consequence of a knee injury which is capable to tear the meniscus. The patient can often remember a specific trauma, activity, or movement during which the meniscus tear occurred. TMTs might occur during sports activities or high-energy trauma. In the former, TMT can be combined with fractures around the knee [32]. TMTs are frequent injuries affecting young and active individuals, particularly those who are involved in contact level 1 sports mainly those involving frequent pivoting, such as soccer, rugby, or American football [26]. However, swimming has also been identified as risk factor for acute tears despite its low-contact profile and running has minimal evidence also as a risk factor [4, 5]. The meniscus can also be injured during low-energy activities such as walking or squatting [4]. Overall, sports seems to be a relevant risk factor for acute meniscal tears [4, 35]. The traumatic mechanism is frequently a twisting movement at the knee with some degree of flexion. Valgus impact with external rotation of the tibia can also cause a triad of injuries involving meniscal damage associated with medial collateral and anterior cruciate ligament disruption [10, 33]. Generally, considering all meniscal lesions, in different sports, the medial meniscus is affected in 24 % of cases, while the lateral meniscus is implicated in around 8 %, and 20–30 % of meniscal lesions are associated with other ligament injuries [16].

Acute tears can lead to immediate/fast developing pain and/or swelling of the knee joint. These injuries might originate displaced tears which more often cause mechanical symptoms such as clicking, catching, or locking of the joint [26]. When the central part in a bucket-handle tear is dislocated into the intercondylar notch, then mechanical locking symptoms are produced [36].

Several classification methods have been proposed over the years and will be further discussed within this chapter [2]. Vertical or longitudinal tears and bucket-handle and radial tears (Fig. 7.1) usually belong to the traumatic group [25]. Flap tears are another type of meniscal tear which frequently arises after a traumatic event. Opposing to the previous, horizontal tears are frequently not traumatic and have a degenerative nature instead (even in younger patients) [34].

There is moderate evidence that weight bearing during trauma is an important risk factor for meniscal tears [4].

Generic joint laxity is a risk factor for meniscal tears, which despite not being modifiable might be subject to pre-participation prevention programs [4]. ACL injuries are another very important concomitant and/or etiologic factor to consider [35].

Considering severe trauma implicated in acute tibial plateau fractures, joint line depression is a potential predictor of specific meniscal (and ligamentous) injuries [32].

In contrast to the previously exposed, degenerative characteristics of meniscus lesions include slower progression of symptoms, cavitations, multiple tear patterns, softened meniscal tissue, fibrillation, or other degenerative changes [2].

7.2 Classification of the Meniscal Tears

Several systems for classification of meniscal tears have been proposed over time (Fig. 7.1) considering several aspects: by anatomic location, by proximity to blood supply, etc. Various tear patterns and configurations have been described [6, 8]. These include the following.

7.2.1 Radial Tears

These are often related to trauma and can be complete or incomplete. They appear vertically oriented extending from the inner edge of the meniscus toward its periphery. Radial tears are in general defined as unstable [37]. They were generally considered as non-repairable because the circumferential hoop fibers are disrupted

Fig. 7.1 Schematic representation of frequent types of meniscal tears

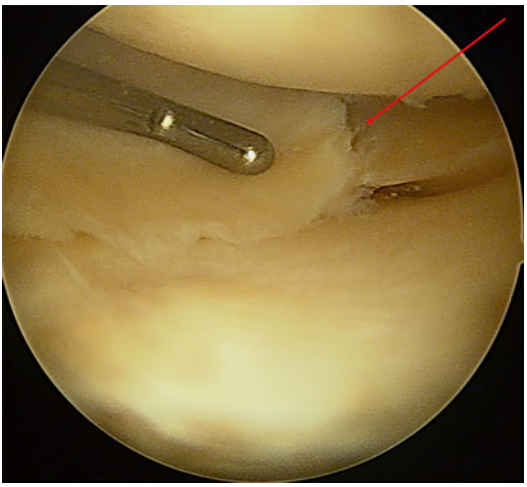

Fig. 7.2 Radial tear (*red arrow*) of the medial meniscus

and the majority of the tear is avascular (Fig. 7.2). 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 [20]. The major objective is to achieve a primary stable meniscal repair. This is considered crucial in order to provide a chance for meniscal healing [20]. The combination of sutures enhanced by fibrin clot has allowed positive results for treatment of radial tears [31].

7.2.2 Flap or Parrot-Beak Tears

Usually they are radial tears with a circumferential extension creating a flap of meniscal tissue (Fig. 7.3).

7.2.3 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 most of the time ideal tears for repair (Fig. 7.4). In terms of partial or very short meniscus tears, a stable tear is defined as a tear that is not displaceable with the probe.

7.2.4 Bucket-Handle Tears

When the inner fragment of a longitudinal tear displaces over into the intercondylar notch, it is commonly referred as a bucket-handle tear (Fig. 7.5). Whenever possible, these lesions should be reduced and repaired once they represent a big part of the meniscal tissue.

7.2.5 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 occur in older people (Fig. 7.6). 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. Open meniscal repair of complex horizontal tears 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 [29].

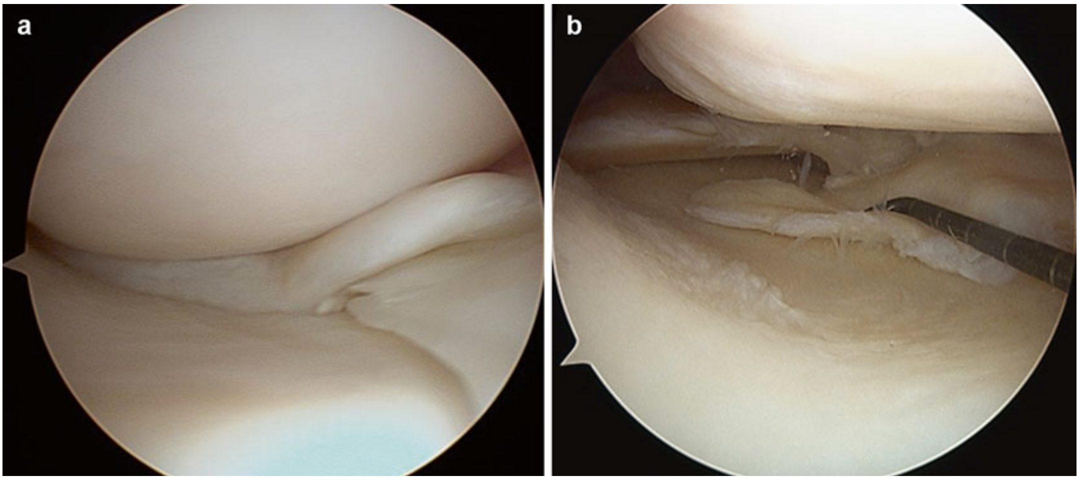

Fig. 7.3 Flap tear of the medial meniscus (**a**); the hook probe is used to explore the tear (**b**)

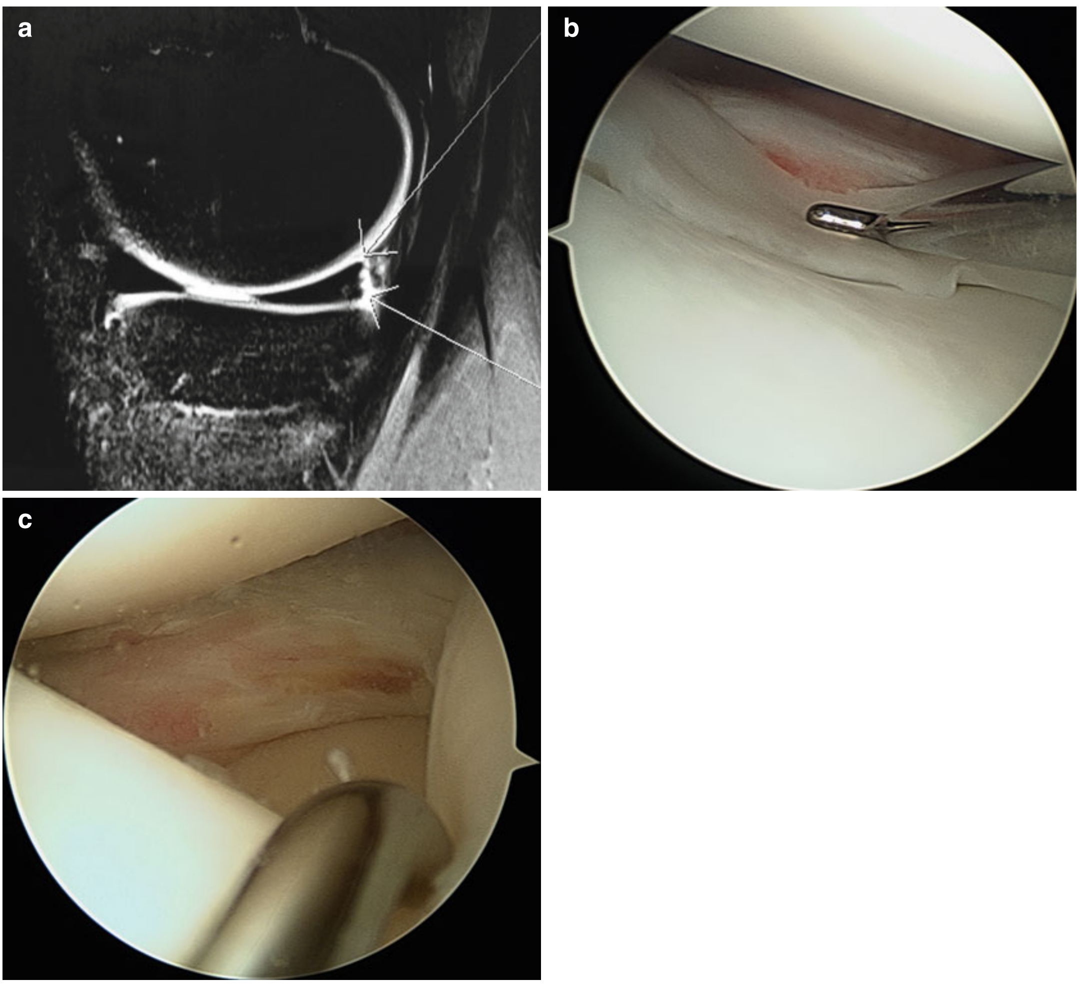

Fig. 7.4 Peripheral, longitudinal tear of the lateral meniscus view on MRI (**a** – *white arrows*); arthroscopic view using the probe to assess stability (**b**, **c**)

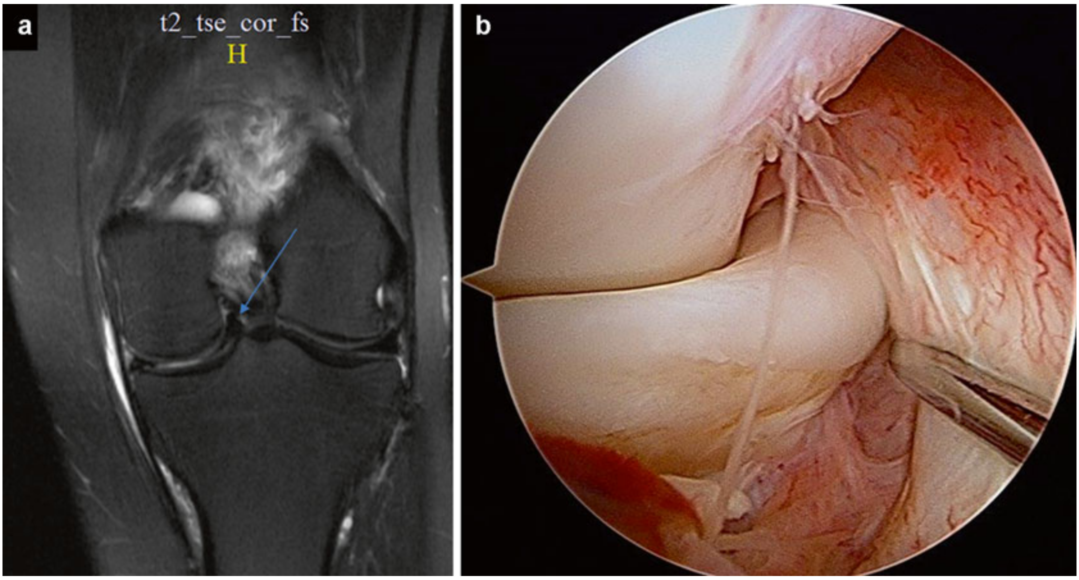

Fig. 7.5 Bucket-handle tear of the medial meniscus on MRI (**a**); arthroscopic view of bucket-handle tear of the lateral meniscus (**b**)

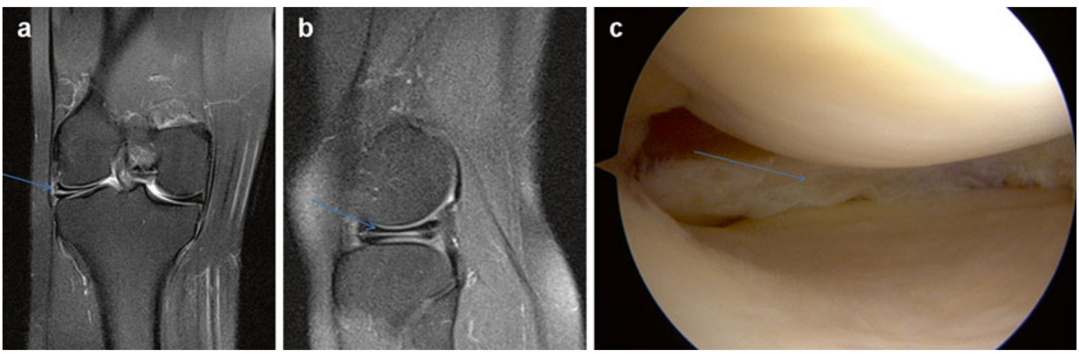

Fig. 7.6 Horizontal degenerative cleavage tears (*blue arrows*) of the medial meniscus on MRI frontal (**a**) and lateral (**b**) views. (**c**) Arthroscopic view of horizontal tear (*blue arrow*)

7.2.6 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 (Fig. 7.7). 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.

7.2.7 Meniscal Root Lesions (MRTs)

This type of meniscal tears has been recently described and is receiving growing attention [7]. 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 (Fig. 7.8). They have been ignored for a long time, and some authors now defend that they should be systematically assessed dur-

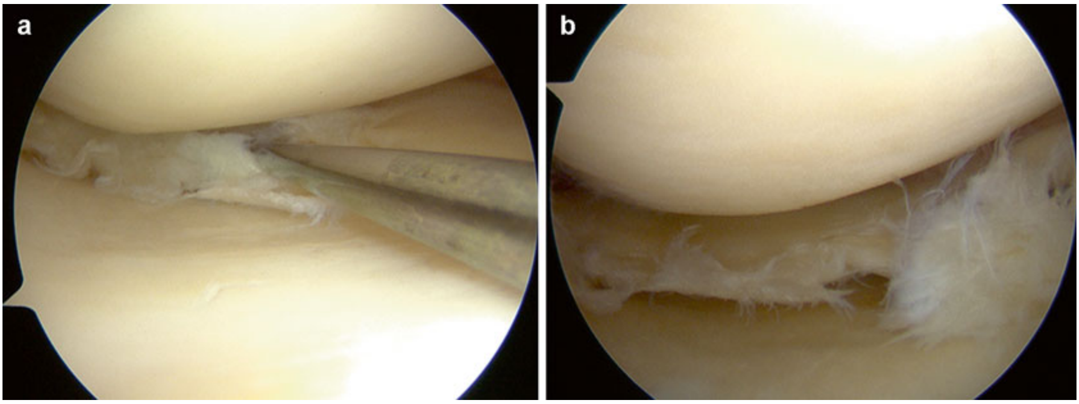

Fig. 7.7 Complex (**a**) and degenerative (**b**) of the medial meniscus

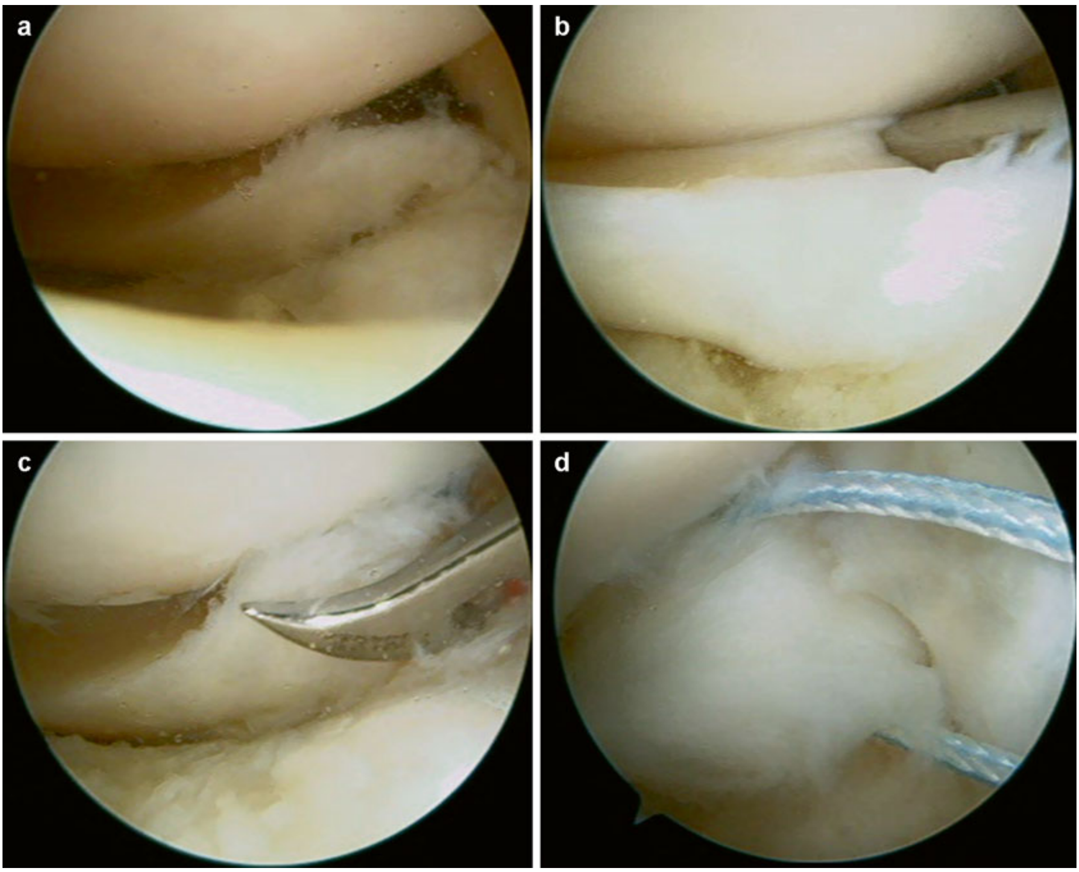

Fig. 7.8 Arthroscopic view of root tear of the lateral meniscus (**a**). The hook probe is used to assess instability and explore the injury site (**b**). Repair is possible by using suture passer and fixation within a tibial tunnel (**c**, **d**)

ing an ACL reconstruction [7]. They can be treated by tibial re-fixation, using a transtibial tunnel [1].

In MRTs, the disruption of collagen fibers which warrant hoop strength resistance will finally result in extrusion of the menisci and loss of their biomechanical properties. Clinical diagnosis is difficult, but magnetic resonance imaging usually allows identifying the lesion. For definition, MRTs are located in the vascularized zone of the meniscus. Thus, management is preferentially arthroscopic repair either with arthroscopic transosseous sutures or suture anchors [23]. No significant differences between the two methods have been demonstrated so far [23]. Biomechanical and clinical studies demonstrate that surgical repair of acute, traumatic meniscal root injuries fully restores the biomechanical features of the menisci, leading to pain relief and functional improvement.

The functional meaning and relevance of any classification system is ultimately to determine the most adequate course of treatment.

The possibility to repair a meniscal injury is multifactorial [6]; thus several factors must be considered including:

- Age/strength
- Activity level
- Tear pattern
- Chronicity of the tear
- Associated injuries (anterior cruciate ligament injury)
- Healing potential/vascularization

7.3 International Classification of Meniscal Tears

ESSKA 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 outcomes assessment [18]. 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. The ISAKOS classification of meniscal tears provides sufficient interobserver reliability for pooling of data from international clinical trials designed to evaluate the outcomes of treatment for meniscal tears [2].

7.3.1 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 surfaces of the meniscus [11, 19].

7.3.2 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 [3, 9, 13]:

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.

7.3.3 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 [9].

(b) The posterior-anterior classification might follow the indications provided by ISAKOS classification [2]. 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 [13].

The observed agreement and the statistical analysis were higher for the anterior/posterior classification than the anterior, middle, and posterior classification. Despite that, the consensus reached by the committee opted for the historic standard anterior, middle, and posterior classification for descriptive purposes because certain tears reside in specific zones [2].

7.3.4 Tear Pattern and Treatment

It has been stated that meniscus repair, if possible, provides better clinical and biomechanical results compared to meniscectomy [15, 17, 24]. However, meniscal repairs still have higher reoperation rates compared to meniscectomies [24].

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 [30]. Nevertheless, partially or incompletely healed menisci are often asymptomatic at least in the short term [27, 29].

There has been a tremendous development of suture techniques based on improved basic science knowledge. As a representative example of the former, a recent technique of suturing in an oblique direction considering the collagen fibrils of the meniscus has shown superior fixation than the standard double horizontal suture technique [20].

According to literature, the failure rate after arthroscopic meniscal repair ranges from 5 to 43.5 % (mean, 15 %) [27]. 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 [27]. Taking these facts into account, one can conclude that there are few detrimental effects when suturing a meniscal lesion initially considered as "repairable." Despite the known risk for failure, the possible benefits must be weighted opposing to the known long-term consequences of meniscectomy [15].

Arthroscopic meniscal repair provides long-term protective effects, even if the initial healing is incomplete [30]. Methods of repair can use all-inside (Fig. 7.9), inside-out, or outside-in techniques alone or in combination (Fig. 7.10). Rasping or augmentation with fibrin clot may assist in increasing the healing rate.

Meniscectomy can always be considered for irreparable complex acute tears, but it is currently considered as a "last option" given the awareness of the deleterious long-term consequences [15]. Moreover, the amount of resected tissue is directly implicated in the consequences of meniscectomy [14]. In some cases, it can be combined to partially resect part of the meniscus but still suture the remaining repairable part [1].

Patients must receive informed consent and, according to realistic expectations, they should take part in the choice of final treatment.

7.4 Traumatic Meniscal Lesion in ACL-Deficient Knee

In cases with meniscus tears combined with ACL injury, every effort should be made to avoid subsequent meniscectomy. Meniscectomy in the ACL-deficient knee is known to compromise functional performance, joint stability, and cartilage, whether it is associated with ACL reconstruction or not [15]. Meniscal repair and even "leave the meniscus alone" are considered to be the best options whenever possible. Several different scenarios should be considered.

7.4.1 Symptomatic Anterior Laxity of the Knee (Functional Instability) in a High-Demand Sports-Active Person

In such patients, ACL reconstruction is strongly indicated. In this situation the meniscal lesion is diagnosed before or during the ACL surgery and should be treated simultaneously. Meniscal preservations are indicated if possible. The

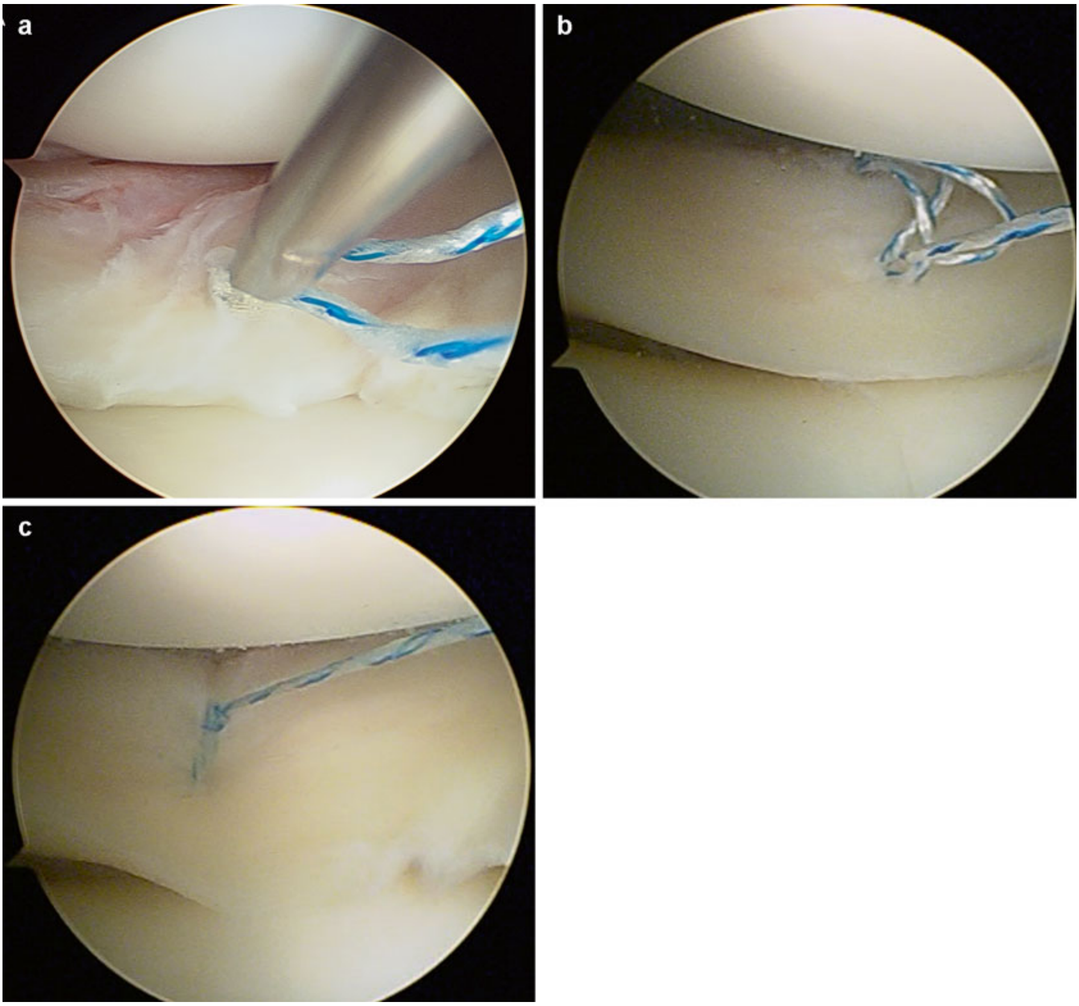

Fig. 7.9 All inside meniscal repair (**a**) deployment of the first anchor (**b**) second anchor has been deployed (**c**) self-locking knot is pushed down to tension the repair

postoperative rehabilitation protocol for ACL surgery is not significantly changed by meniscal repair or leave the meniscus alone strategies.

7.4.2 Anterior Laxity of the Knee Associated with Minor Symptoms in an Active Individual in Low-Demand Sports Activities

In this case the indications for ACL reconstruction are still somewhat debatable. The diagnosis of a concomitant repairable meniscal lesion represents 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. A simple meniscectomy without ACL reconstruction should only be considered in the case of a symptomatic meniscal lesion in a sedentary middle-aged patient who does not present functional instability.

7.4.3 Meniscal Repair or Leave the Meniscal Tear Alone Without Treatment

A commonly shared opinion is that unstable or symptomatic meniscal tears should be surgically repaired at the time of ACL reconstruction,

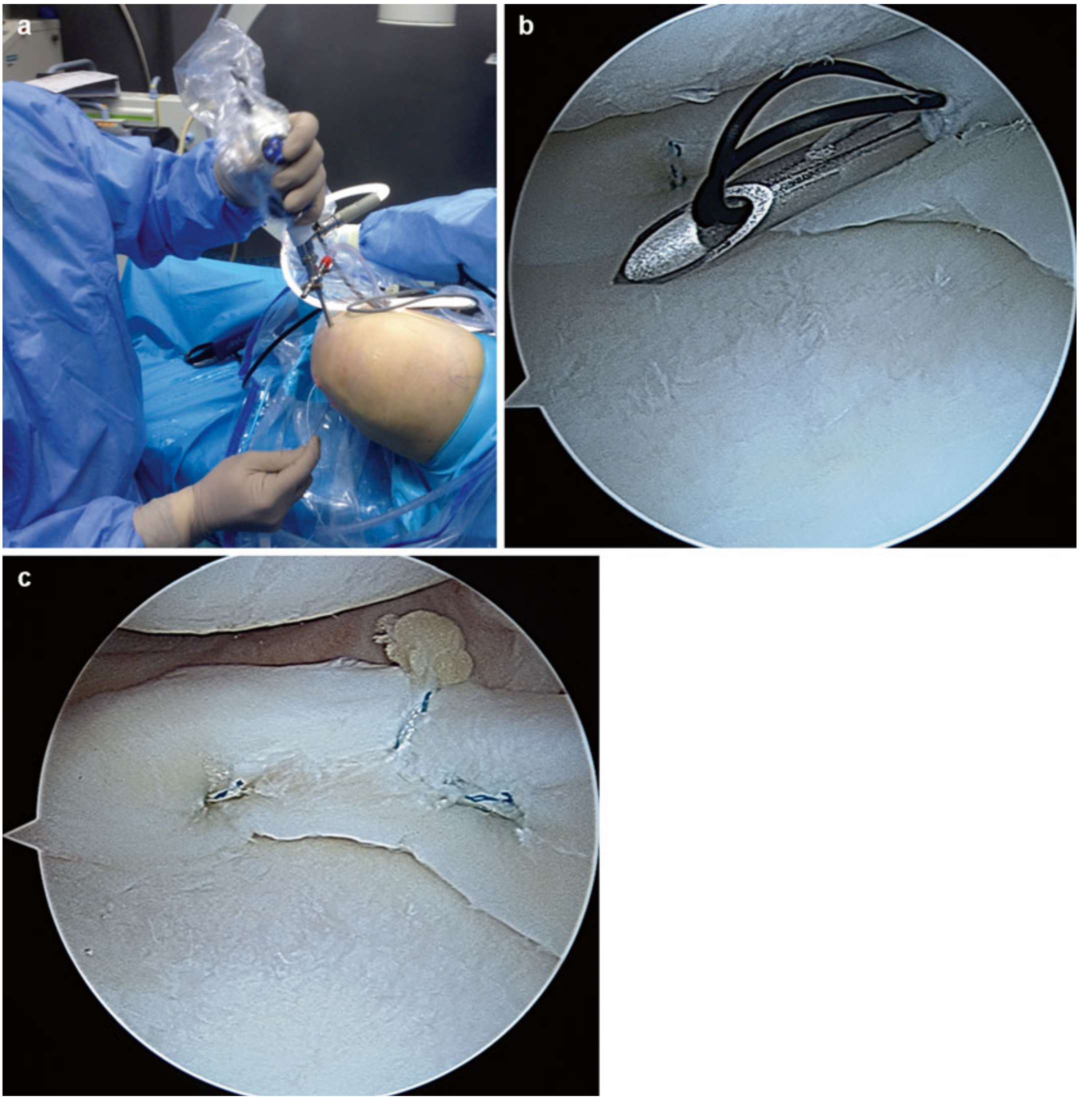

Fig. 7.10 Outside-in meniscal suture technique (**a**, **b**) used to enhance previous all-inside sutures (**c**)

while stable asymptomatic tears can be left untreated (consciously neglected). Nevertheless, the concept of meniscal lesion instability is still controversial, and the problem of establishing proper criteria (e.g., size of lesion and abnormal mobility of the meniscus) remains unsolved. At most, 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 [28]. On the other hand, for the lateral meniscus with small stable lesions, "leave the meniscus alone" can be the preferred approach given the low risk of subsequent meniscectomy [5].

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 compared to less than 12 months after ACL injury [35]. 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 [35].

These findings are somewhat in line with the recognized different roles of medial and lateral menisci within the knee joint. The role of the medial meniscus as secondary restrictor of anterior tibial displacement and the relatively higher mobility of lateral meniscus are of major relevance [21]. Moreover, a delay in surgical treatment has also been associated with a higher incidence of medial meniscal tears in pediatric and adolescent populations [22]. Pediatric patients treated >150 days after injury for ACL tears have a higher rate of medial meniscus lesions than those treated ≤150 days after injury [12].

Take-Home Message

Classification of meniscus tears is very important for the assessment of the tear; 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. Traumatic meniscal injuries present a wide spectrum of presentation and several types of lesions are possible. Understanding the injury mechanism, the ultrastructure of the tissue, and global joint kinematics is of paramount relevance for the development of prevention strategies. 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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Degenerative Meniscus Lesions, Cartilage Degeneration, and Osteoarthritis of the Knee

8

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Contents

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8.1 Etiology and Pathogenesis of Degenerative Meniscus Lesions

In contrast to traumatic meniscus tears, degenerative meniscus lesions have a slower, more complex, and still poorly understood pathogenesis as compared to traumatic meniscal tears. Increasing evidence, however, supports the concept that degenerative lesions occur in meniscus tissue with already ongoing degenerative change [31, 55, 57, 78]. The typical morphological configurations of these tears are horizontal cleavages and/or flap tears with horizontal component most commonly involving medial meniscus body and/or the posterior horn [18, 61].

The only longitudinal (natural history) study with repeat MR imaging capturing the development of meniscal tears in middle-aged persons reported only 1 of 43 incident meniscal tears was associated with an acute knee trauma [46]. Instead it was a slowly (over several years) developing process likely involving progressive mucoid degeneration and weakening of the meniscus ultrastructure (Fig. 8.1).

The presence of intrameniscal signal of linear character on MR images reported to represent mucoid degeneration can thus be considered a risk factor for a degenerative meniscal lesion [31, 46, 78]. It is also plausible that a degenerative meniscal lesion can in some individuals be elicited by minor knee trauma or chronic high repetitive knee loading (sheer stress to the menisci) in

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_8

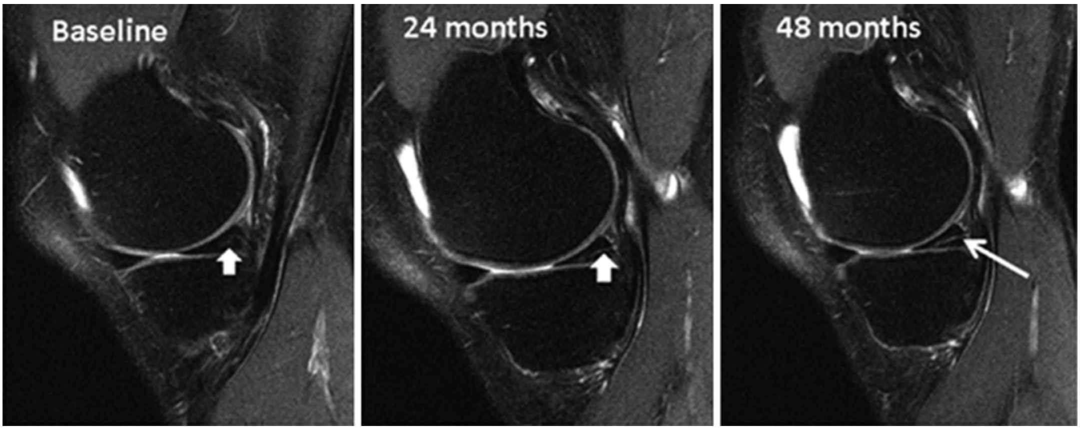

Fig. 8.1 The development of intrameniscal signal into a horizontal cleavage lesion in the posterior horn of a medial meniscus over the period of 4 years captured on repeat 3-Tesla knee MRI

susceptible individuals [16]. Knee malalignment, obesity, and occupational kneeling could result in such unfavorable chronic overloading. Overloading, coupled with degenerative meniscal matrix changes possibly related to early-stage osteoarthritis, could thus lead to meniscal fatigue, rupture, and extrusion [17, 58, 68]. Much uncertainty about the degeneration itself remains in the former. It is likely though often a part of, or a consequence of, early-stage knee osteoarthritis in the typically middle-aged patient or a consequence of aging. The continued osteoarthritic disease process is then often the pathological response of joint tissues to abnormal biomechanical stress in these individuals with partial loss of meniscal function [16].

8.2 The Definition of a Degenerative Meniscal Lesion at Arthroscopy or Magnetic Resonance Imaging

Although there are no strict or widely accepted morphological criteria to distinguish a degenerative meniscal lesion from a traumatic meniscal tear, the former has some typical characteristics. For example, a degenerative meniscal lesion can (typically for research purposes) be classified on the basis of the morphological appearance on knee MR images.

Increased meniscal signal should be indicative of a meniscal tear (traumatic as well as degenerative) when it communicates with the inferior, superior, or free edge of the meniscal surface (or more than one of those) on at least two consecutive images (or, for a radial tear, if it is visible on both the coronal and sagittal images) [14, 15, 19, 25]. Meniscal tears can crudely be categorized as follows: *(I)* horizontal, defined as a tear parallel to the tibial plateau separating the meniscus into upper and lower parts; *(II)* oblique (parrot beak), defined as a tear oblique to the circumferentially oriented collagen fibers; *(III)* longitudinal, defined as a vertical tear perpendicular to the tibial plateau and parallel to the orientation of the circumferential fibers; *(IV)* radial, defined as a vertical tear that began in the central free margin and was perpendicular both to the tibial plateau and to the circumferential fiber orientation; *(V)* complex, defined as multiple tears in more than one configuration; and *(VI)* root tear, defined as a tear in the posterior or anterior central meniscal attachment [54]. The absence of meniscal tissue on MR images or at arthroscopy owing to complete maceration, destruction, or prior surgical resection can be classified as *(VII)* meniscal destruction, but this should *not* to be considered a meniscal tear per se. The most typical degenerative lesions are the horizontal cleavage lesion, the flap tear, or complex tear which may involve a flap typically located in the posterior horn [18, 19]. It is likely that radial meniscal tears may also have some degenerative origin although its pathogenesis is more speculative in lack of firm evidence. It is important to note that a radial tear or root tear extending all the way to the capsule has severe consequences for meniscal function as it transsects all the way through the circumferentially oriented collagen fibers. This is the main orientation of the fibers and thus critical to generate the hoop tension to prevent meniscus extrusion (radial displacement).

8.3 The Prevalence of Degenerative Meniscal Lesions

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 knees of men aged 70–90 years (Fig. 8.2) [18]. In addition, some 10 % of right knees in the Framingham study had partial destruction/maceration, i.e., absence of normal meniscal tissue (of all without prior knee surgery). This is not classified as meniscal tear but as meniscal destruction that is a finding typically associated with other structural changes/evidence of osteoarthritis and likely a part of meniscal osteoarthritic degradation leading to maceration and its destruction. A prevalence of meniscal tear of over 90 % has been reported in knees of patients *with* symptomatic knee osteoarthritis [5, 22, 42, 49].

These epidemiologic studies are important in a couple of aspects: First, they demonstrate the remarkably high prevalence of meniscal lesions in the general population – so high it may even be considered part of normal aging. Second, 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 [18]. 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. Thus, consequently degenerative meniscal lesions may often be *misinterpreted* to be the

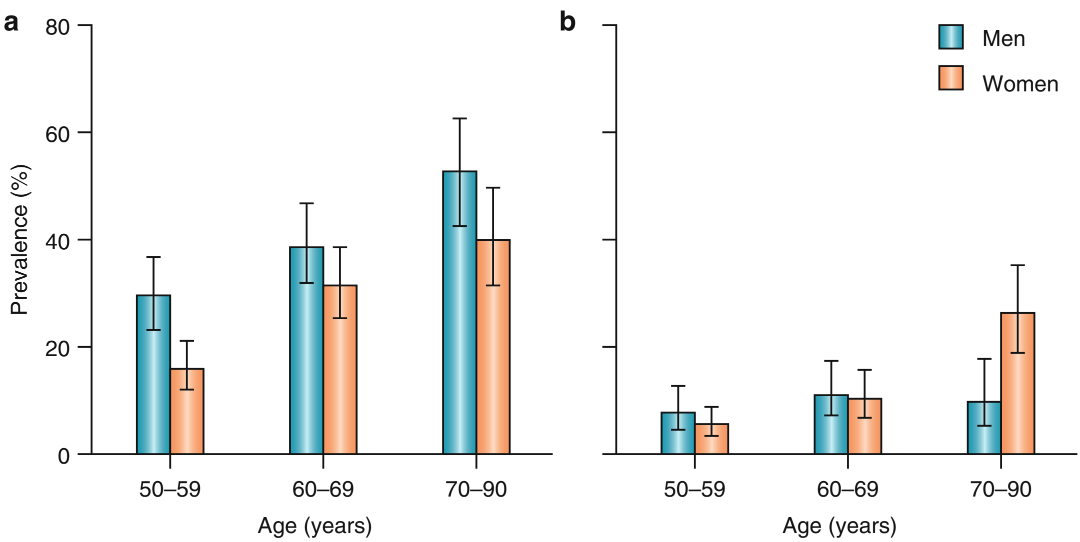

Fig. 8.2 The prevalence of meniscal tears and destruction in a randomly recruited population-based sample. (**a**) Meniscal tear and (**b**) meniscus destruction (not classified as a tear) in the right knee of men ($n=426$) and women ($n=565$) aged 50–90 from Framingham, Massachusetts, USA. Diagnosis was based on MRI. Participants were not selected on the basis of knee or other joint problems. Error bars show the 95 % CI (Reprinted with permission from *New Engl J Med*)

cause of knee pain or knee joint discomfort as they are one pathology typically found on knee MR images or at arthroscopy incidentally.

8.4 Degenerative Meniscal Lesions and Knee Symptoms

Already in 1974, Noble and Hamblen insightfully reported from a series of necropsy studies that "*The horizontal cleavage lesion probably exists much more commonly than symptoms arising from it. Therefore, other factors must be involved in the production of symptoms*" [57]. The association between degenerative meniscal lesions and knee joint symptoms is challenging to disentangle – this is true in knees with clear evidence of radiographic osteoarthritis as well as in knees with *no* or *little* other evidence of osteoarthritis [5, 18, 56].

In the Framingham study, the majority, 61 % of persons aged 50–90 years, with a meniscal lesion (study population screened with knee MRI) did not report any knee pain, aching, or stiffness. Virtually all of the tears identified on MR images were horizontal cleavages, complex, and/or even large oblique/flap tears, i.e., typical degenerative lesions. No distinction with respect to symptoms was noted whether the tear was classified as large or involving the peripheral one third or a flap. Importantly, just because in the remaining 39 % of the study subjects with a meniscal lesion reported some pain, aching, or stiffness in their knee does not necessarily imply the meniscal lesion is the *direct* cause. Most of these community-based persons with knee symptoms also had radiographic evidence of osteoarthritis and other features that may explain symptoms such as the presence of subchondral bone marrow lesions [18, 24]. Also, Zanetti and coworkers reported the presence of meniscal lesions on MR images in the contralateral *asymptomatic* knee in 63 % of patients (mean age 42 years, range 18–73) scheduled for arthroscopy due to meniscal tear.

A parameniscal cyst may occasionally develop and is virtually always associated with degenerative horizontal cleavage lesion (Fig. 8.3) [9, 13].

Fig. 8.3 Knee MR image showing large horizontal cleavage lesion of the posterior horn of the medial meniscus and a parameniscal cyst (high signal intensity) on the medial side

These cysts likely develop due to leakage of synovial fluid and may be associated with joint line discomfort [86].

A meniscal tear can be unstable [8]. However, importantly the hallmark of an unstable tear is the *bucket-handle* tear of typical traumatic origin, i.e., a *longitudinal* tear where the central torn part may dislocate into the central area of the knee and cause catching symptoms or locking of the knee. However, the evidence for such derangement and resulting symptoms is more uncertain and speculative for the typical degenerative meniscal lesion. "Milder" mechanical symptoms, i.e., no true locking, in the degenerative knee are often more unspecific than in the acute knee trauma patient. In the degenerate knee, the symptoms are often substantially fluctuating – they come and go. In the patient with the degenerate knee, such symptoms may be instead related to osteoarthritis such as uneven cartilage surfaces, synovitis, and/or bone marrow lesions. Further, there is little plausible rationale that the most typical degenerative meniscal lesion, i.e., a horizontal cleavage without a flap, would dislocate to cause true locking or catching symptoms [8].

Given the broad general belief regarding the validity of preoperative mechanical symptoms as an indication for knee arthroscopy in patients with a degenerative meniscus lesion [11, 23, 39, 44, 45, 62, 64, 65, 80, 87], there is limited evidence supporting such policy. Matsusue and Thomson [51] reported that 55 % of patients 65 years of age or older with preoperative symptoms of locking or catching reported the presence of these symptoms approximately 8 years after partial meniscectomy. Similarly, McBride et al. [52] reported alleviation of symptoms of locking in only 17 % (1/6) of patients undergoing arthroscopic partial meniscectomy for a degenerative meniscus tear over a 35-month follow-up. In the Finnish FIDELITY trial, the resection of a torn meniscus tissue provided no added benefit to a placebo-meniscectomy procedure in relieving patient-reported sensations of knee catching or occasional locking. However, in patients with a *traumatic* meniscus tear, the success rate of arthroscopic partial meniscectomy in curing mechanical symptoms is reported to range from 76 % [52] to 100 % [37]. Still, in lack of further evidence, in the patient with the degenerate knee, who truly has episodes of locking and/or an extension deficit, a torn unstable meniscus must naturally be considered as one plausible cause to these symptoms.

Although a cross-sectional study indicated meniscal extrusion – a feature often co-occurring with a degenerative meniscal lesion – to be more frequent in painful knees than the contralateral non-painful knee of similar radiographic osteoarthritis stage, it is still largely unknown if meniscal extrusion may be directly associated with pain due to, for example, stretching/irritation of the synovial capsule [84].

Importantly, health-care professionals seeing patients with knee pain need to be aware of the fact that a meniscal lesion may be asymptomatic per se in a patient with knee pain. Just because there is a degenerative meniscal lesion, visible on knee MR images or at arthroscopy, it does not necessarily imply that the torn meniscal tissue is actually painful, so that surgical resection will resolve the patient's pain or aid the patient in the long term [29, 41, 53, 74]. Catching sensations may be due to other issues in the knee such as cartilage defects or simply sudden painful sensations misinterpreted as "mechanical" in nature.

There is very limited evidence of the accuracy of clinical tests to reliably identify unstable degenerative meniscus lesions. A common and fundamental flaw in the study of clinical tests for meniscus tears is the often underlying assumption that all meniscus tears identified are the source of symptoms. Most studies evaluating, e.g., McMurray's or Apley's test typically include patients with knee trauma, mixed study samples, or cross-sectional designs [30, 67, 72, 77]. Further challenges are the unspecific nature of clicking and popping sensations as well as the many other features/processes that may be involved in the production of joint line tenderness and pain in the degenerate knee [24, 79, 88]. Therefore, the true answer to the clinical utility of meniscal tests in the degenerate knee can only be determined by its integration into examiner-blinded sham meniscus surgery-controlled randomized clinical trials similar to the FIDELITY trial by Sihvonen et al. [76].

In summary, there is mounting evidence that the link between the actual degenerative meniscal lesion and symptoms often is spurious, i.e., the meniscus gets inadequately blamed to be the cause when it is other processes that are directly involved in the patient's symptoms [5, 22, 57, 76]. For example, the pain may be a result of compromised meniscal function of a torn and extruded meniscus leading to increased stress on joint cartilage and subchondral bone, which may result in subchondral bone marrow lesions [21]. Bone marrow lesions have been found to be highly associated with knee pain and fluctuations in knee pain [24, 88]. Parameniscal cysts may cause joint line symptoms. Meniscus tears are also reported to be associated with synovitis which may be a source of pain [66]. Recently, increased vascular penetration and nerve growth have also been reported of the menisci obtained from osteoarthritic knees [1]. Importantly, degenerative meniscal lesions are so common in the general population that it should *not* be regarded as a "diagnosis." It should probably be considered one (of many) structural feature indicative of a knee with, or at high risk of, degenerative joint disease, i.e., early osteoarthritis of the knee.

8.5 The Consequences in the Knee by a Degenerative Meniscal Lesion

The biomechanical effect of *loss* of meniscal function by *meniscal resection* is well documented in multiple biomechanical studies already by the late 1970s [26, 47, 69, 70, 73, 83]. However, a *torn* meniscus may also lead to loss of meniscus function depending on the location and extent of tear. This applies to a degenerative meniscal lesion as well as traumatic meniscal tear. In observational studies, persons with a degenerative meniscal lesion have been reported to be at highly increased risk of developing radiographic tibiofemoral osteoarthritis [20]. This is probably due to the potential partial loss of meniscal function, primarily in load distribution. However, it could also be related to an already ongoing osteoarthritic disease process within the knee joint, where the degenerative meniscal lesion is one of the first morphological features of the disease. Cartilage loss has predominantly been reported to occur in the vicinity of where the degenerative meniscal lesion is located, suggesting a close cause and effect relationship between the meniscal lesions and structural progression of osteoarthritis [10].

Another critical aspect of the meniscus in addition to its morphological integrity is its positioning within the knee joint. Degenerative meniscus lesions, for example, are often accompanied by varying degrees of meniscal extrusion, i.e., radial displacement of the meniscus outside the joint margin [40, 48]. Several investigators have reported of more frequent meniscal extrusion of the meniscal body in the osteoarthritic knee [27, 40, 81]. Meniscal extrusion and low coverage of the tibial surface of the meniscus have been reported to be a potent risk factor for cartilage loss [35, 71]. Further, meniscal body extrusion is a strong risk factor for the development of bone marrow lesions [21]. Extensive meniscal extrusion or maceration is also reported to be a contributing factor to joint space narrowing seen on conventional tibiofemoral radiographs, i.e., it may not all be explained by loss of joint cartilage [6, 7, 34, 36]. However, there are also studies suggesting that tibiofemoral joint space doesn't necessarily change immediately, at least after partial meniscectomy, and the preservation of an intact peripheral rim may be important [2, 63].

8.6 Knee Osteoarthritis

According to the most recent Global Burden of Disease Study, knee and hip osteoarthritis is the 11th highest contributor to global disability [12]. This means major challenges for health care as well as society in general. Of the conditions included in the study, osteoarthritis in the knees and hips combined was one of the most prevalent diseases.

The prevalence of knee osteoarthritis is expected to rapidly increase in our steadily aging and increasingly obese population. Based on Swedish data, there is going to be an *additional* 46 000 health care-seeking knee osteoarthritis patients per 1 million adults aged 45+ by the year 2032 (+36 %) compared to what we already have today (Fig. 8.4) [82]. This increase is much larger than the population prognosis (only +18 %) which

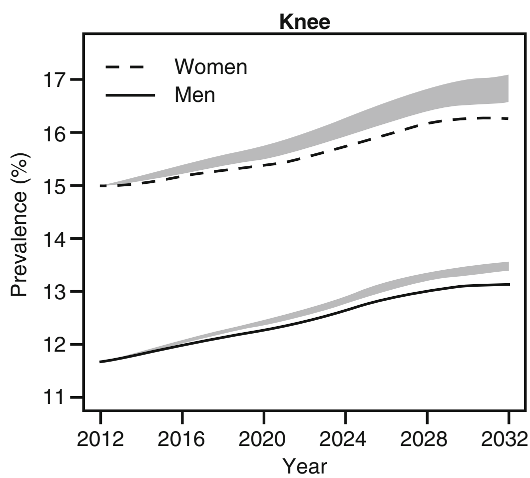

Fig. 8.4 Year 2032 prognosis of knee osteoarthritis prevalence in the population aged 45 years or older leading to consultation. Results obtained by cross-linkage of Swedish health-care data with the population register, the population prognosis (size and age structure = *black*) from Statistics Sweden, and the effects of increased body mass index (*gray*)

is an effect of our increasingly obese and aging European population, both strong factors associated with osteoarthritis. Hence, there is a future "knee osteoarthritis epidemic" to be expected.

Debut of symptoms of knee osteoarthritis often occurs at middle age and typically affects participation in both occupational and leisure activities and hence quality of life [32]. Besides causing pain, reduced function, and disability, people with knee osteoarthritis may also be affected by comorbid conditions such as depression and cardiovascular disease due to inactivity and increased weight [38]. Available treatments for knee OA are only symptomatic, i.e., there is no curative treatment in a biological sense. Further, only 10–20 % of patients with knee osteoarthritis will ever receive a total joint replacement hence reach the end stage of the disease [59]. This means that the knee osteoarthritis management in health care needs to be individually tailored for very long periods of the patient's adult life.

Knee osteoarthritis is a clinical diagnosis. The diagnosis can typically be made on the basis of the duration and character of the knee joint symptoms, patient history including the presence of strong risk factors for osteoarthritis (age, obesity, heredity, prior knee injuries, and/or surgeries), and findings from clinical examination. In the orthopedic setting, weight-bearing semi-flexed knee radiographs (such as the Lyon Schuss view) are recommended to be included in the workup of the middle-aged or older patient with knee pain, but it is typically not needed in general practice. Importantly, knee radiography does *not* necessarily capture early stages of osteoarthritis, even if performed with semi-flexed knee and weight bearing according to protocol.

8.7 The Association Between Degenerative Meniscus Lesions and Osteoarthritis

Even if knee osteoarthritis is the result of multiple risk factors such as genes, obesity, joint injury, and/or unfavorable occupational load and has a complex pathogenesis, the disease is often driven by increased biomechanical loading in susceptible individuals and the pathological response of joint tissues to this abnormal biomechanical stress [21]. 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 loss [4, 35], bone alterations including trabecular bone changes [43, 60, 85], increased bone mineral density [50], development of subchondral bone marrow lesions, and increasing malalignment – the vicious cycle of knee osteoarthritis is in motion (Fig. 8.5).

In support, risk factors reported to be associated with development of degenerative meniscal lesions are malalignment of the knee (the more loaded compartment) and the presence of signs of hand osteoarthritis suggesting systemic or potentially a common environmental factor [17]. Further, in cross-sectional studies floor layers have been found to have a higher prevalence of lesions than graphic designers suggesting occupational load may contribute although limited causal inference can be drawn due to the cross-sectional nature of the data [68]. Knee malalignment, obesity, and occupational hazards might result in chronic overloading, which, in combination with degenerative meniscal matrix changes (possibly related to early-stage osteoarthritis), could lead to meniscal fatigue, rupture, and extrusion [17, 58, 68]. This chain of events could also be triggered by a knee trauma where meniscus function is lost in a previously healthy knee. The biomechanical effect of loss of meniscal function is well documented [26, 47, 69, 70, 73, 83].

8.8 Imaging Assessment of the Degenerate (Osteoarthritis) Knee: Role of Knee Radiographs

To define sensitivity and specificity of knee radiography to detect osteoarthritis (typically joint space narrowing and osteophytes) in a clinical setting is challenging due to our current inability

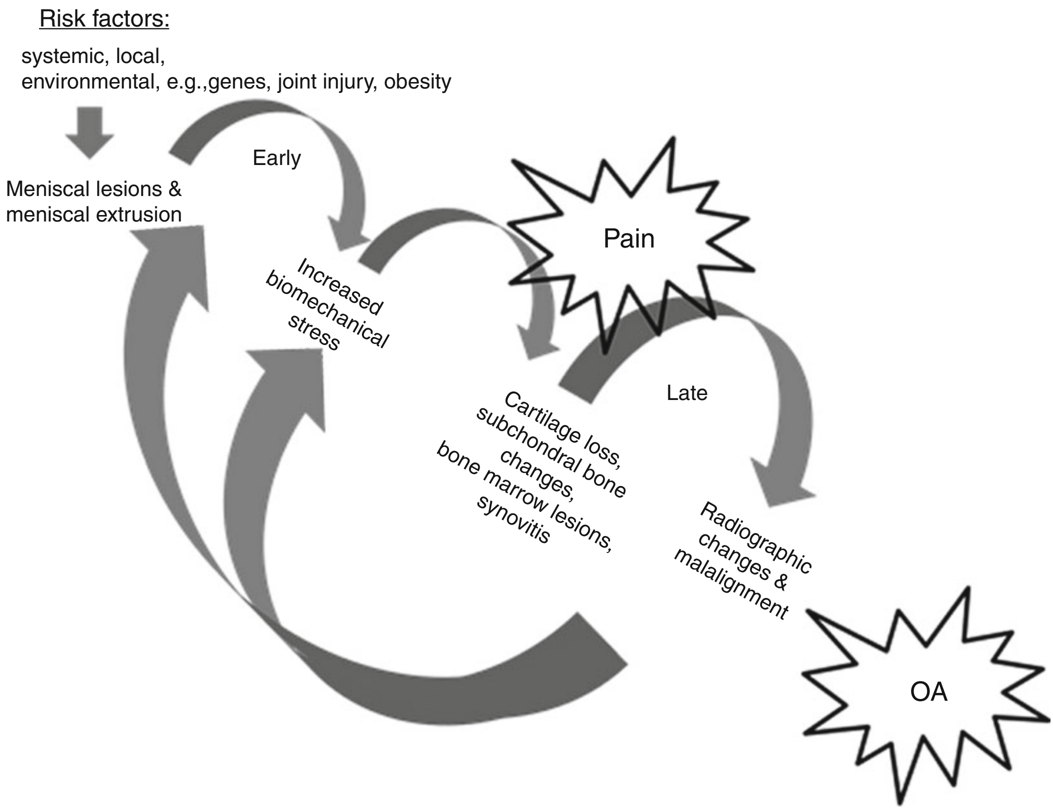

Fig. 8.5 Meniscal pathway to knee osteoarthritis (OA)

to be able to accurately define the "threshold" of when to "call out" the degenerate knee as having osteoarthritis. This is mainly due to the slow progressive nature osteoarthritis, the involvement of multiple structural features/processes, and the poor correlation between structural pathology and the often fluctuating nature of patient-reported symptoms [3]. However, as general rule of thumb, the sensitivity with radiography is considered to be moderate, while the specificity is considered to be high. This means that with knee radiography, (1) radiography *captures* a fair amount of all patients with knee osteoarthritis, but far from all of those with the true disease (in particular early knee osteoarthritis), and (2) knee radiography is *unlikely* to produce false-positive structural findings of osteoarthritis.

As mentioned, the most typical features of osteoarthritis on radiography include osteophytes and joint space narrowing, which support the *clinical* diagnosis of osteoarthritis. It is important, however, to remember that the association between radiographic severity of osteoarthritis and knee joint symptoms is quite low [3] (Fig. 8.6). A normal semi-flexed weight-bearing knee radiograph should *not* rule out the clinical diagnosis of early-stage (pre-radiographic) osteoarthritis. In general practice, knee radiography is typically *not* needed in the workup of the middle-aged or older patient with nontraumatic onset of knee joint symptoms.

8.9 Imaging Assessment for the Degenerate Knee and Osteoarthritis: Role of Magnetic Resonance Imaging

MRI captures an incredible amount of tissue changes, but today there is very limited knowledge of how to differ normal aging

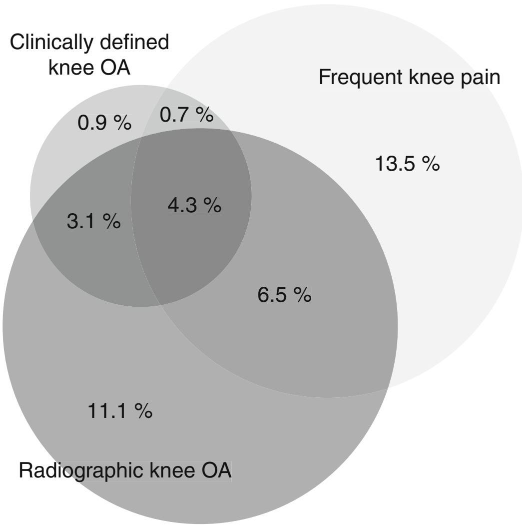

Fig. 8.6 The discordance between radiographic evidence of osteoarthritis (OA) and knee joint symptoms. Figure shows the prevalence and overlap of frequent knee pain and radiographically defined knee OA in an adult population 56–84 years of age

processes from, e.g., osteoarthritic processes [28]. Importantly, in the clinical setting knee MRI is rarely indicated in the workup of the middle-aged or older patient with knee pain. It should primarily be used conservatively to save resources but also to avoid the risk of incidental findings, i.e., findings with no or very little clinical relevance that generates unnecessary concern or treatments. Such incidental findings on MR images are to be considered a rule rather than an exception in the middle-aged or older patient [18, 28]. Thus, the treatment decision (e.g., surgery or no surgery) should be made on the patient's history, patient's symptoms, and findings from clinical examination. Knee MRI may be indicated (after knee radiographs) in selected cases with treatment-refractory symptoms or in the presence of "warning flags" or symptoms indicating more rare disease that needs to be ruled out, e.g., osteonecrosis.

In research, however, knee MRI is a useful tool to gain new knowledge of the etiology and progression of knee osteoarthritis which is a disease involving the whole joint including the menisci. There are also *suggested* criteria to define knee osteoarthritis on MR images for *research* purposes [33]. According to the report, a definition of tibiofemoral osteoarthritis on MR images would be the presence of *both* "group A" features or *one* "group A" feature and *two or more* "group B" features.

Group A features after exclusion of joint trauma within the last 6 months (by history) and exclusion of inflammatory arthritis (by radiographs, history, and laboratory parameters) are:

(i) Definite osteophyte formation
(ii) Full-thickness cartilage loss

Group B features are:

(i) Subchondral bone marrow lesion or cyst not associated with meniscal or ligamentous attachments
(ii) Meniscal subluxation, maceration, or degenerative (horizontal) tear
(iii) Partial-thickness cartilage loss (where full-thickness loss is not present)
(iv) Bone attrition

Definition of patellofemoral osteoarthritis requires all of the following involving the patella and/or anterior femur:

(i) A definite osteophyte
(ii) Partial- or full-thickness cartilage loss

In the clinical setting, knee MRI is rarely indicated for the degenerative knee. As a degenerative meniscal lesion is poorly associated with symptoms, a "diagnosis" of degenerative meniscal tear should be avoided. Instead it should be considered a feature indicative of early-stage knee osteoarthritis, and the patient be treated accordingly.

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Hidden Lesions and Root Tears

9

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Contents

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-662-49188-1_9) contains supplementary material, which is available to authorized users.

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9.1 Arthroscopic All-Inside Suture Repair of Medial Meniscus Lesion in Anterior Cruciate Ligament-Deficient Knees

9.1.1 Introduction

Up to two thirds of patients with anterior cruciate ligament (ACL) rupture have combined medial meniscus posterior horn (MMPH) tears [20, 22, 33, 42]. Repairing this torn meniscus anatomically allows the reconstructed ACL knee to be more stable than those with a meniscectomy [1, 4, 31]. However, many surgeons overlook this combined tear because of its concealing location and benign-looking appearance from the anterior portals [41]. Previous studies have shown that magnetic resonance imaging (MRI) has a sensitivity of only 69–89 % for detecting meniscal tears in patients with acute or chronic ACL tears [10, 38, 39]. The development of all-inside meniscus repair devices has been a turning point in the advance of arthroscopic technique due to simplicity of implant insertion and the reduction in surgery time [23, 27, 28]. Although these

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_9

devices are easy to use, there have been several complications reported with their use. The all-inside suture for peripheral longitudinal tear of MMPH using a posteromedial (PM) portal is a very efficient and safe technique that provides anatomic coaptation of the torn meniscal fragment, an easy placement of vertically oriented suture, and a strong fixation while minimizing the risk of neurovascular or chondral injuries. We previously reported an arthroscopic modified all-inside suture technique of Morgan using 2 PM portals for repair of MMPH tears [2]. However, recently we began performing arthroscopic all-inside suture for MMPH tear through a single PM portal [4, 6]. Our suturing technique allows greater freedom in suture hook maneuvering by creating a single posterior portal without using a cannula. This technique allows excellent visualization of the posterior compartment, anatomic coaptation of the torn meniscus, and strong knot tying while avoiding inadvertent injury to the remnant meniscus and articular cartilage.

9.1.2 Classification

We propose a classification for medial meniscocapsular tears. Type A is ramp lesion behind the meniscotibial ligament with low mobility at probing. Type B is a partial superior lesion in front of the meniscotibial ligament with low mobility at probing. Type C is a partial inferior lesion (hidden lesion) with high mobility at probing. Type D is a complete lesion with very high mobility at probing. Type E is double tear (Fig. 9.1).

9.1.3 Surgical Technique

The indication for this repair technique is both longitudinal tears being within 5 mm of the peripheral rim and greater than 1 cm in size at the posterior horn of both menisci. Placement of arthroscopic all-inside vertical suture using a suture hook appears to be safe and effective, and a high rate of meniscal healing can be expected in patients with tears located in MMPH.

The standard anterolateral and anteromedial portals are used for comprehensive examination with a 30° arthroscope and a probe. If an MMPH tear is suspected from the preoperative MRI or during arthroscopic examination, or if ACL ligament was torn concomitantly, the posterior compartment is approached by passing the 30° arthroscope from the anterolateral portal through the intercondylar notch between the medial femoral condyle and the posterior cruciate ligament (PCL). This is first facilitated by placing the anterior portals close to the margins of the patellar tendon. Afterward, a standard PM portal is created under direct arthroscopic visualization. This makes instruments, such as the suture hook, easier to move and manipulate. Using a probe, the posterior compartment is examined thoroughly (Fig. 9.2). Switching the scope to the PM portal, the posterior horn is reexamined. After establishing a suture plan, a 70° arthroscope is reinserted to the anterolateral portal and placed through the intercondylar notch to view the posterior compartment.

While viewing from the anterolateral portal through the intercondylar notch using a 70° arthroscope, a shaver or rasp is introduced through the PM portal without a cannula for debridement of both sides of the tear (Fig. 9.3). A 45° curved suture hook (Linvatec, Largo, FL) loaded with a polydioxanone synthetic (PDS) No. 0 (Ethicon, Somerville, NJ) is inserted through the standard PM portal. A suture hook loaded with PDS No. 0 is introduced to the PM portal, and then a suture passage is made starting from the inner tear penetrating the most central fragment from inferior to superior. During this procedure, care must be taken not to damage the cartilage of the femoral condyle, as the sharp tip of the hook passes close to the condyle during this procedure. Both ends of PDS No. 0 are taken out with a suture retriever through the PM portal. The superior end of the suture is marked with a straight hemostat, and the inferior suture end is left alone. A suture hook loaded with MAXON 2-0 (Syneture™, Norwalk, Connecticut, USA) is then inserted through the PM portal and used to penetrate the peripheral rim at the capsular side from the

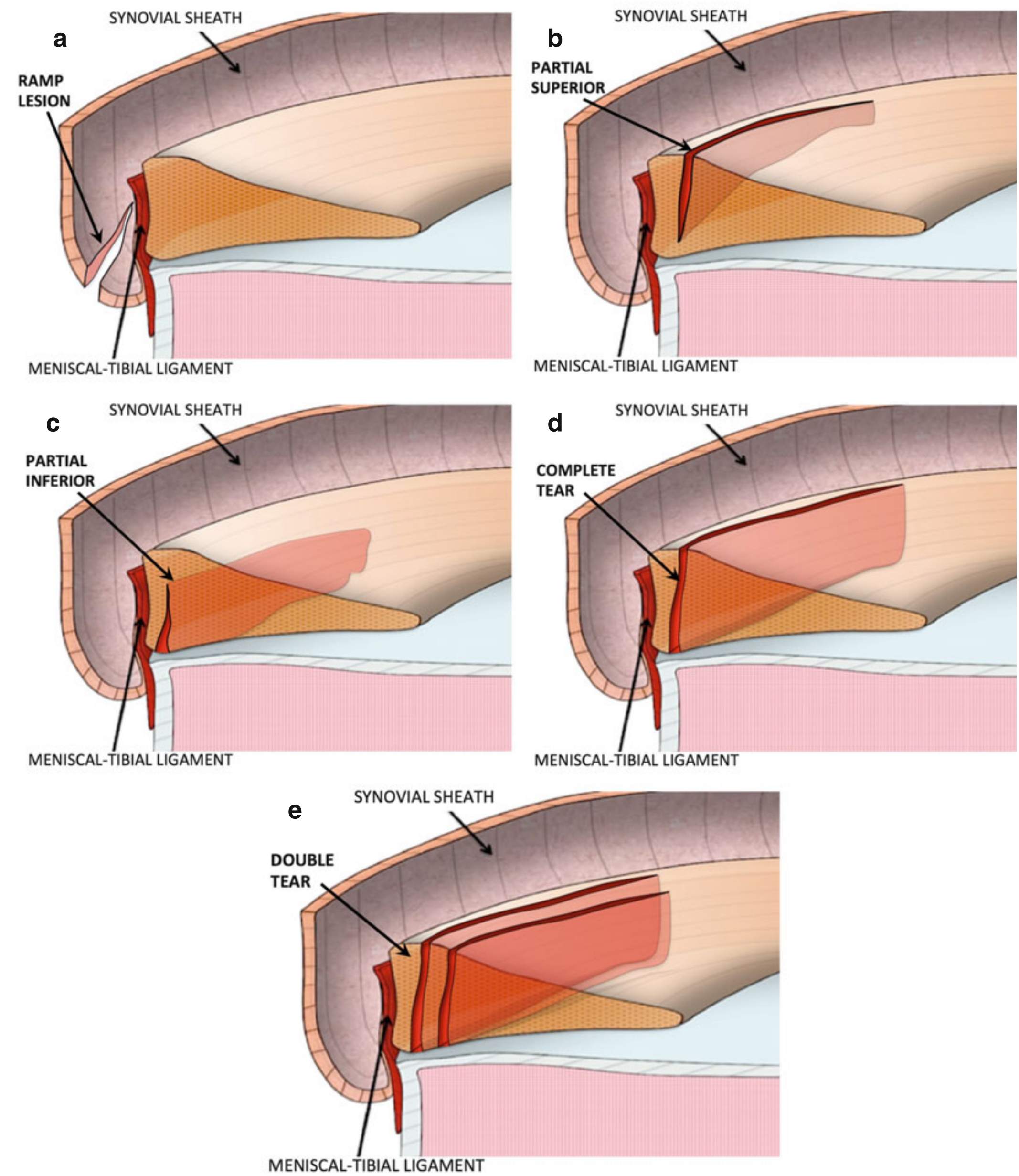

Fig. 9.1 Classification proposition for medial menisco-capsular tears. (**a**) Type 1: ramp lesions. Very peripherally located in the synovial sheath. Mobility at probing is very low. (**b**) Type 2: partial superior lesions. It is stable and can be diagnosed only by trans-notch approach. Mobility at probing is low. (**c**) Type 3: partial inferior or hidden lesions. It is not visible with the trans-notch approach, but it may be suspected in case of mobility at probing, which is high. (**d**) Type 4: complete tear in the red-red zone. Mobility at probing is very high. (**e**) Type 5: double tear

superior to inferior surface in the same manner. After both ends of MAXON are taken out of the PM portal with suture retriever, the superior end of the suture is marked with a straight hemostat. The inferior sides of the PDS and MAXON are held together and retrieved out of the PM portal using the suture retriever at the same time to avoid soft tissue interposition between both limbs. The inferior side end of MAXON 2-0 is then tied with the inferior side

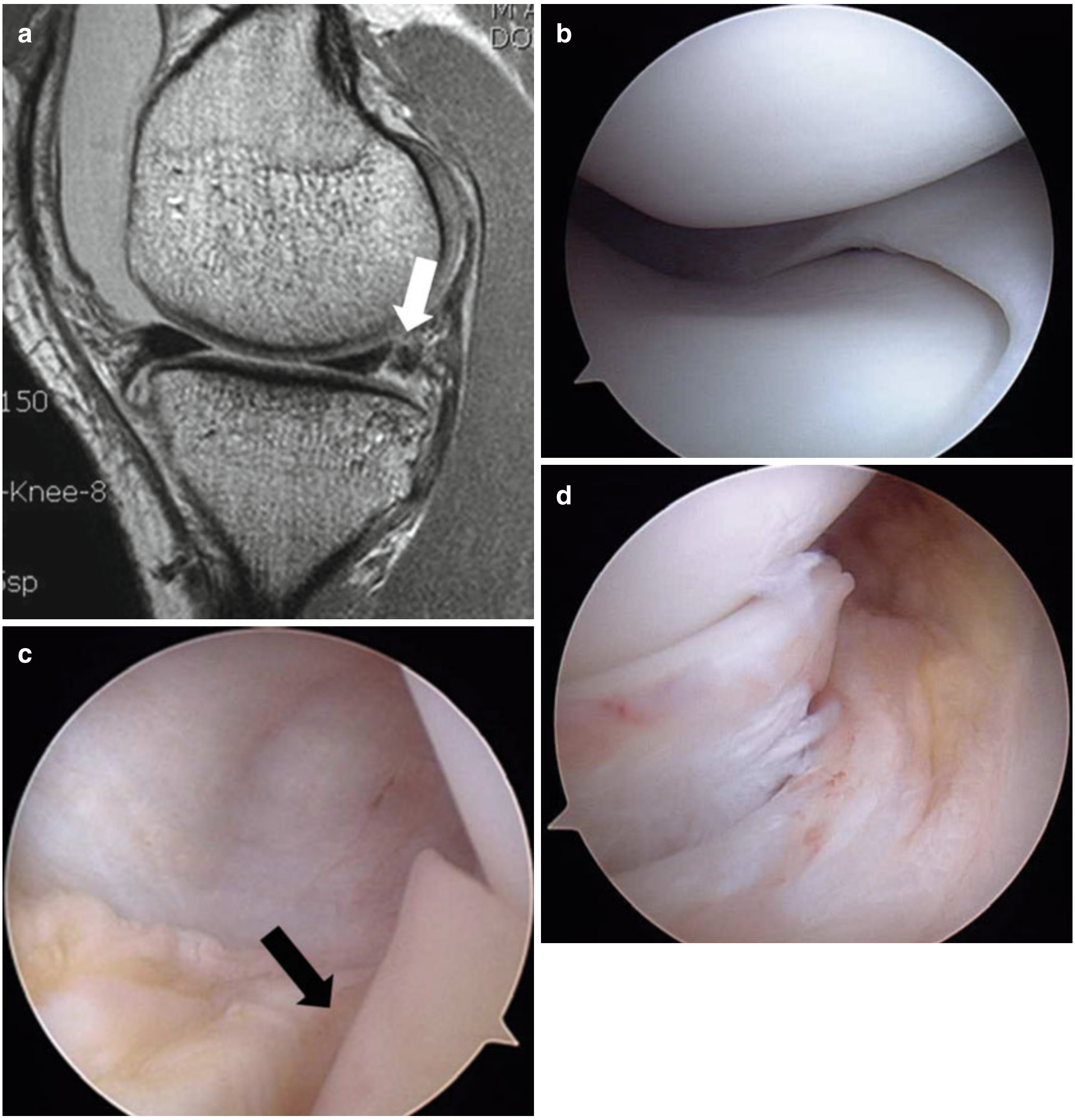

Fig. 9.2 (**a**) The sagittal MRI finding shows longitudinal tear of posterior horn of medial meniscus (*arrow*). (**b**) The peripheral tear of posterior horn cannot be seen from anterior portal. (**c**) The longitudinal tear of posterior horn (*arrow*) is seen from a 30° arthroscope is inserted from the anterolateral portal to the posteromedial compartment. (**d**) The posteromedial portal verifies the lesion definitely

of the end of PDS, and the hemostat holding the superior end of MAXON is then pulled. The PDS is subsequently passed through both sides of the meniscal tear as the MAXON is changed for the PDS No.0 from the tibial to the femoral surface. Both ends of PDS are held together and retrieved at the same time through the PM portal using a suture retriever. An SMC (Samsung Medical Center) knot [24] is tied and slid through the cannula with a knot pusher, with additional securing half-hitch sutures. Additional two or three half-hitch knots with alternating posts on reverse throws are made, and the reduction is carefully inspected arthroscopically. For good coaptation and stable fixation of the torn meniscus, we advise placing 3–4 sutures with a 4–5 mm interval. If the tear is extended to the mid-body, our modified inside-out technique or meniscal fixators are used in combination with all-inside

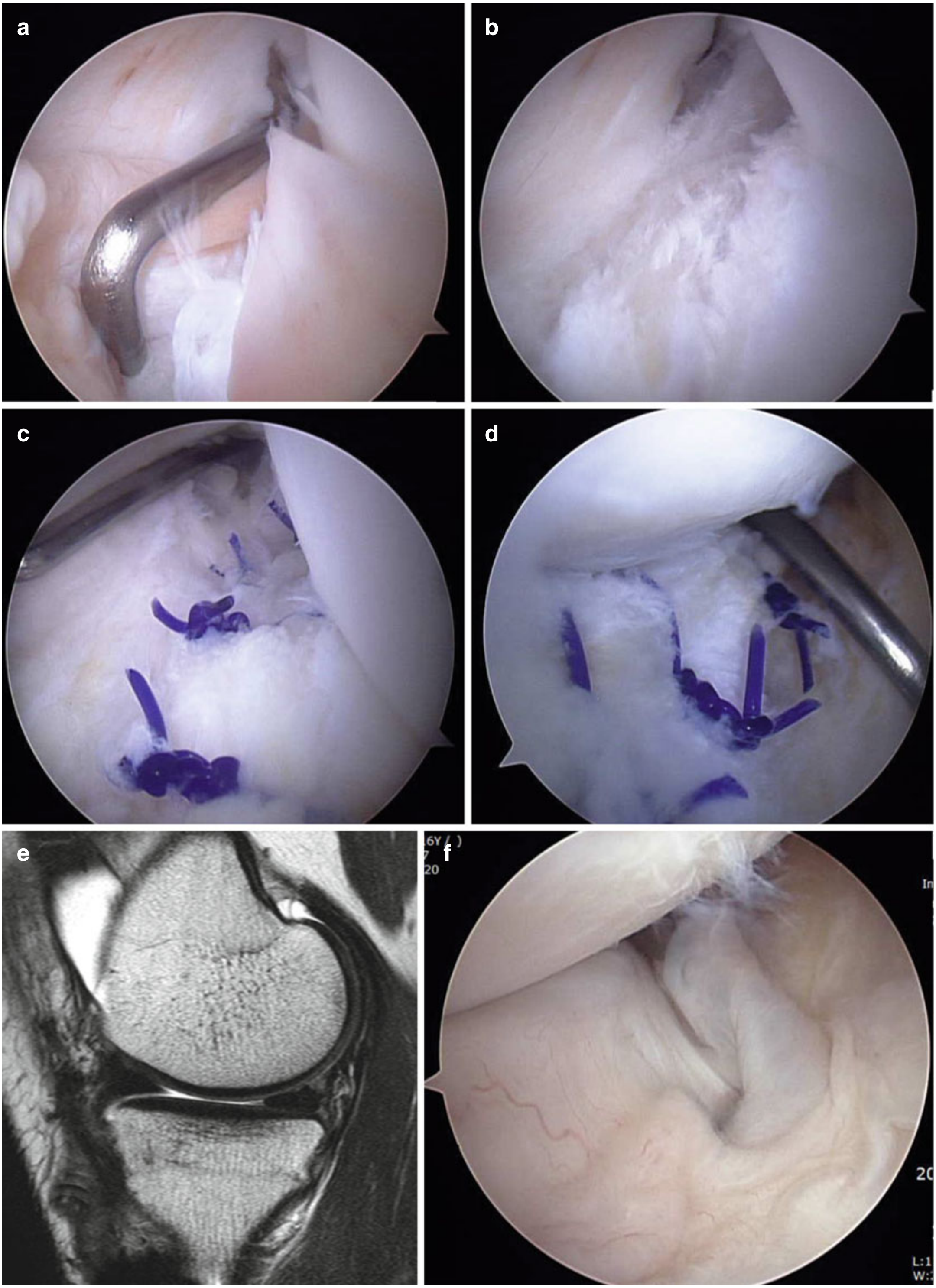

Fig. 9.3 (**a**) The tear pattern is clearly seen after changing to a 70° arthroscope inserted from the anterolateral portal. (**b**) Both tear sides of the tear is debrided by a shaver inserted from the posteromedial portal. (**c**) The 70° arthroscope, inserted from anterolateral portal to the posteromedial compartment, shows four vertical sutures at longitudinal tear of posterior horn of medial meniscus. (**d**) The 30° arthroscope inserted from posteromedial portal shows same findings. (**e**) Complete healing is shown on the MRI at 7 months postoperatively and (**f**) second-look arthroscopy at 1 year 11 months postoperatively

suturing. If the patient has ACL insufficiency, ACL reconstruction is performed after the meniscal repair.

9.1.4 Authors' Clinical Outcomes

We evaluated 140 patients who underwent MMPH repair using either a modified all-inside or inside-out technique with concomitant ACL reconstruction and were performed by a second-look arthroscopy at a mean of 37.7 months postoperatively [5]. Among 140 patients, 118 (84.3 %) showed complete healing, 17 (12.1 %) had incomplete healing, and 5 (3.6 %) failed to heal. The clinical success rate was 96.4 % (135/140) because patients in the incomplete group showed no clinical symptoms associated with meniscal tears.

9.2 Arthroscopic All-Inside Repair for Lateral Meniscus Root Tear in Patients Undergoing Concomitant Anterior Cruciate Ligament Reconstruction

9.2.1 Introduction

A lateral meniscus posterior horn (LMPH) root tear can occur in conjunction with an ACL ruptures and may be associated with the extrusion of the lateral meniscus [9]. An LMPH root tear is defined as a tear that occurs less than 1 cm from the posterior insertion [19]. It was reported that lateral meniscus tears, including posterior horn tears, stable radial flap tears, and peripheral or posterior third tears that do not extend further than 1 cm in front of the popliteus tendon, can be treated successfully with abrasion and trephination or by being left in situ [37, 40].

The LMPH is inserted in both the bone and meniscofemoral ligament (MFL) [35]. Double attachments of the root are observed in the posterior horn of the lateral meniscus, with the anterior portion attached to the tibial intercondylar eminence and the posterior portion to the femoral medial condyle through the meniscofemoral ligaments [8, 26, 36]. Therefore the possibility exists that displaced posterior lateral meniscus root tears may be overlooked as a posterior-based flap tear even if the bony attachment has been completely transected [3, 5]. The confusion between a complete radial tear and a flap tear of the posterior root likely occurs because of a residual meniscofemoral attachment [43]. In this situation partial meniscectomy of the torn portion of the meniscus may lead to poor clinical results because of the failure of the hoop strain mechanism [11, 14, 16, 17]. This chapter is to document the classification of the LMPH root tear according to our experiences and describe an LMPH root repair technique using a modified all-inside suture technique.

9.2.2 Classification of the LMPH Root Tear

All incomplete radial tears or longitudinal tears around the posterior horn not in the root area within 1 cm from the bony insertion were excluded. Accordingly, the arthroscopic findings were categorized into four types by both the radial and longitudinal tear components which extend to the attachment of the MFL: (1) radial tear with oblique flap, (2) longitudinal cleavage between the bony insertion and MFL insertion, (3) acute T type, and (4) chronic inner loss type (Fig. 9.4). Four types required similar arthroscopic repair techniques except for longitudinal cleavage and the T-shape tear which need the repair of longitudinal component using additional PL portal. In the chronic inner loss type, we think that it is necessary to repair the remaining meniscus to the flap of bony insertion for preventing the extrusion of the meniscus.

9.2.3 Surgical Technique

A diagnostic arthroscopic examination of the knee is performed using the standard AL and AM portals. While viewing with arthroscopy through the AM portal, the tear site is evaluated with probe inserted through the AL portal with the

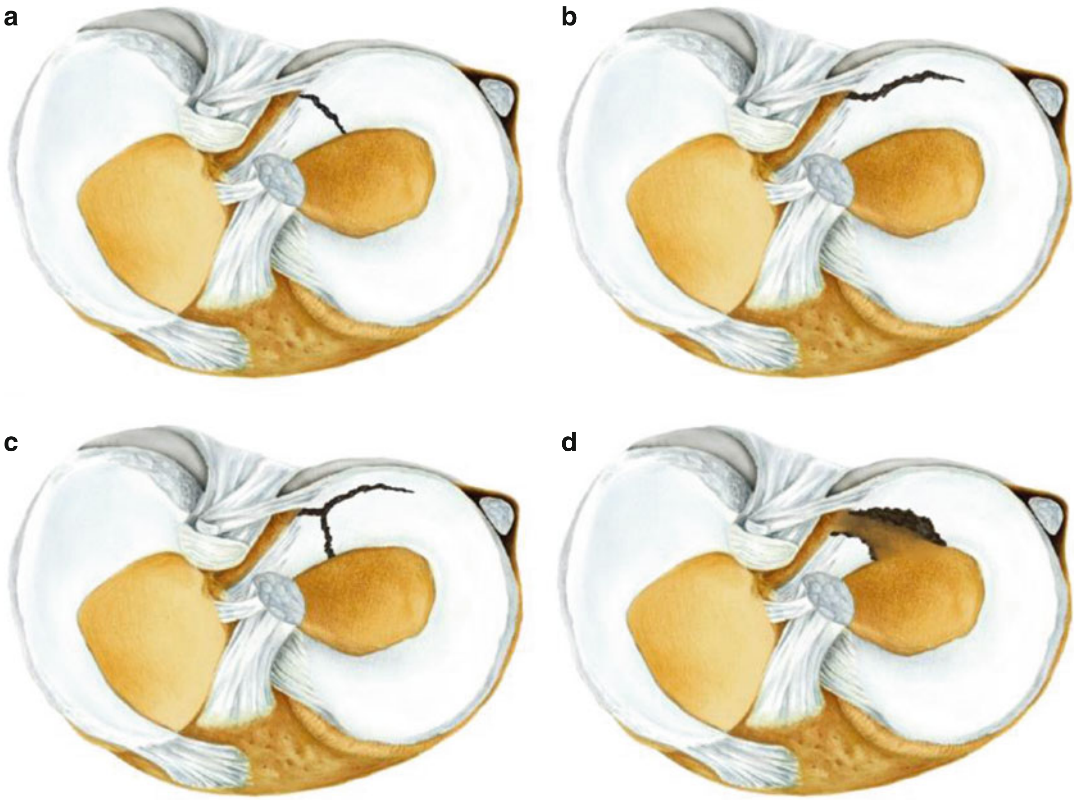

Fig. 9.4 Classification for the root tear of the lateral meniscus posterior horn. (**a**) Radial tear with oblique flap. (**b**) Longitudinal cleavage between the bony insertion and meniscofemoral ligament insertion. (**c**) Acute T-type. (**d**) Chronic inner loss type

knee in a Fig. 9.4 position. Gentle debridement is performed at the tear site using a motorized shaver. A vertical suture can be inserted in top-to-bottom fashion or vice versa, according to which approach is more feasible. A straight suture hook loaded with PDS No. 0 is introduced through the AL portal and then penetrates at 3–5 mm lateral to the torn edge of the LMPH from a superior to inferior direction. Both ends of PDS No. 0 are taken out with suture retriever through the AL portal. The superior end of the suture is marked with a straight hemostat, and the inferior suture end is left alone. The suture hook loaded with MAXON 2-0 is inserted through the AL portal and used to penetrate the posterior tibial attachment of the LM in the same manner (Fig. 9.5). The bottom sides of the PDS and MAXON are held together and retrieved out of the AL portal using the suture retriever at the same time to avoid soft tissue interposition between both ends. As before, the bottom end of MAXON 2-0 is tied with the bottom end of the PDS. The hemostat holding the superior end of MAXON is then pulled bringing the PDS suture across the tear from the tibial to femoral surface. Both ends of PDS are retrieved through the AL portal and tied using an SMC sliding knot. One or two sutures are placed according to the tear length and approximation.

9.2.4 Authors' Clinical Outcomes

From 2003 to 2007, 27 (7 %) of a consecutive series of 388 anterior cruciate ligament reconstructions had a concomitant LMPH root tear. Of the patients, 25 (92.6 %) were followed up for more than 1 year. There was no postoperative effusion, joint-line tenderness, or positive McMurray provocation testing observed at

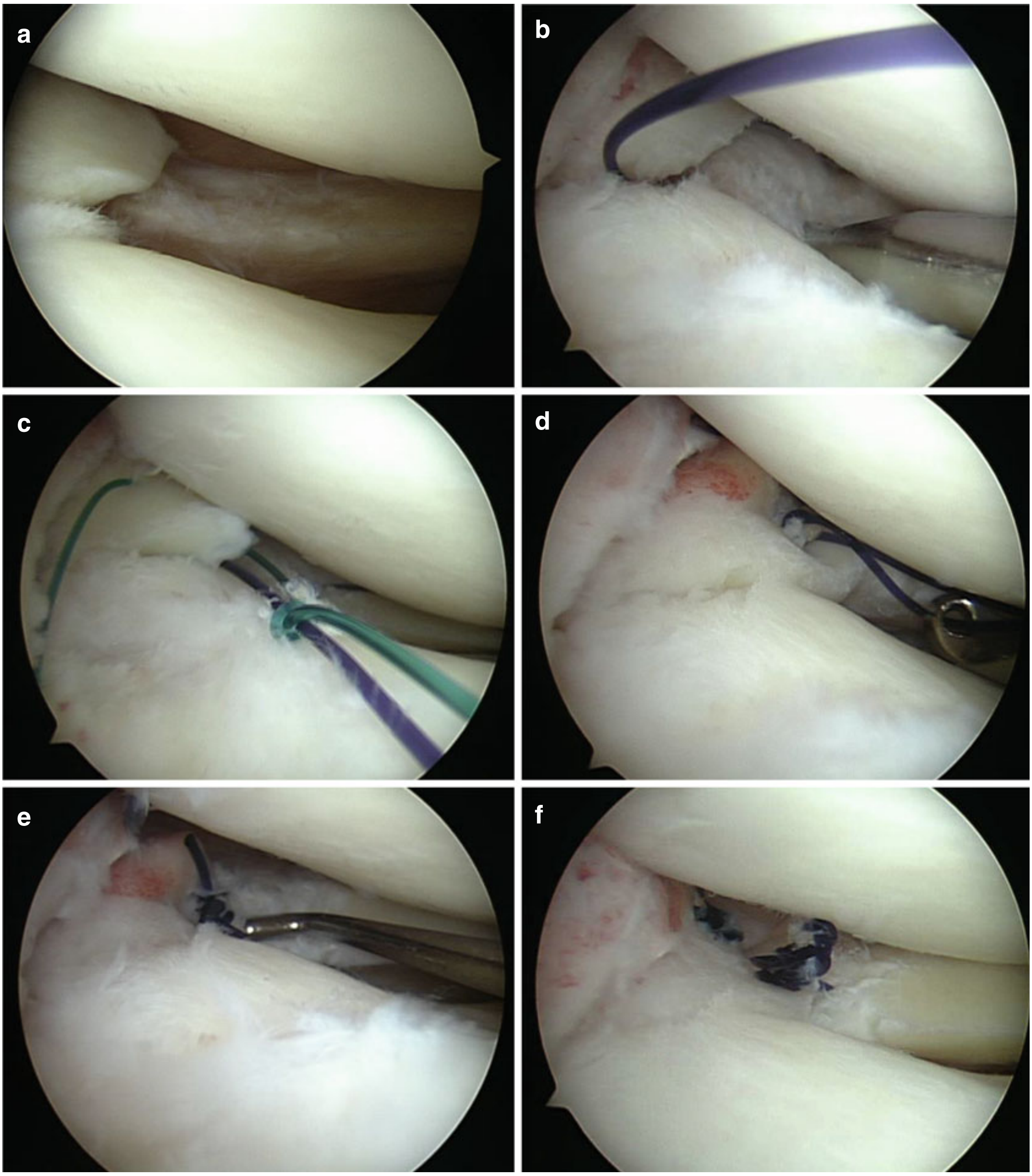

Fig. 9.5 (**a**) The arthroscope shows the radial tear in the root of the lateral meniscus posterior horn. (**b**) The suture hook loaded with PDS is inserted through the lateral side from the superior to inferior surface. (**c**) The bottom side end of MAXON is tied with the bottom side of end of PDS and the hemostat holding superior end of the MAXON is pulled. (**d**) The PDS is subsequently passed through both sides of the meniscal tear as the MAXON is changed for the PDS. (**e**) The sliding knot is used for knot tying. (**f**) The arthroscope shows two vertical sutures at radial tear of posterior horn of lateral meniscus

the last follow-up. In comparison between preoperative and follow-up MRI, sagittal extrusion improved significantly although no statistically significant improvement was observed in the coronal plane.

Posterior lateral meniscus root tears were classified based on arthroscopic findings: type I, oblique flap; type II, T shape; type III, longitudinal cleavage; or type IV, chronic inner loss. A type I tear was found in 7 patients, type II in 4, type III in 4, and type IV in 10. After repair of posterior lateral meniscus root tears, MRI showed that the displaced lateral meniscus was reduced, mainly in the sagittal plane.

9.3 Arthroscopic Meniscus Root Re-fixation Technique Using a Modified Mason-Allen Stitch

9.3.1 Introduction

A complete MMPH root tear results in the failure of the hoop strain mechanism and a loss of the ability to resist extrusion under axial loading, which results in a biomechanical equivalent to a total meniscectomy [7, 32, 34]. The MMPH root tears are mainly the result of degenerative meniscal disease in middle-aged women occurred at bony insertion sites without meniscal stump [21, 25]. Therefore the most commonly used technique for root tears is arthroscopic transtibial pull-out suture [13, 15, 18, 29, 30]. A biomechanical study evaluated the biomechanical properties of 4 different suture techniques for MMPH root tears and found that the modified Mason-Allen technique provided the best biomechanical properties [12]. Lee et al. [30] demonstrated that the modified Mason-Allen stitch was associated with improved healing, better restoration of meniscal extrusion, and slower progression of cartilage degeneration. This chapter is to describe a posterior root repair technique using a modified Mason-Allen stitch with two strands consisting of a simple horizontal and a simple vertical stitch. It will provide superior binding of the torn end of the posterior medial meniscus.

9.3.2 Surgical Technique

Another critical issue for successful repair of root tear is strict patient selection. Symptomatic MMPH root tears with minimal arthritis are indicated for repair with pull-out suture technique. However, MMPH tears associated with varus alignment of more than 5° and diffuse grade 3 or 4 chondral lesions should be considered when performing valgus-producing high tibial osteotomy.

Routine diagnostic examination is performed using the standard anterolateral (AL) and anteromedial (AM) portal. Careful probing is performed to evaluate root tears with meniscal degeneration and access the possibility of reduction to the root of MMPH. A standard PM portal is created under direct arthroscopic visualization. Switching the scope to the PM portal, the root tear of the posterior horn is reexamined. After confirming the root of MMPH, a bony bed at the insertion site is prepared with curette. The tip of ACL guide is introduced to the AL portal and placed to the root of MMPH. Two guide pins are inserted from the anterolateral proximal tibia to the insertion site (Fig. 9.6).

While viewing from the AL portal, a shaver or rasp is introduced through the AM portal for debridement of the end of the tear. A straight suture hook (Linvatec, Largo, FL) loaded with a PDS No. 0 is inserted through the AM portal. The detached portion of the MMPH is penetrated by the sharp tip of the suture hook at 3–5 mm medial to the torn edge in a vertical direction from the femoral side to the tibial side. Then, PDS No. 0 was advanced through the suture hook, and the tibial side of the PDS is taken out through the anteromedial portal using a suture retriever. The superior end of the suture was marked with curved mosquito forceps for tying with the other suture in the next step. The other strand was placed anterior to the first suture in the same manner through the same portal. As a next step, the superior ends of the two simple sutures were tied outside of the portal, and the inferior end of the first suture is then pulled. Using the shuttle relay method, the first suture is exchanged with the second suture. Finally, the horizontal loop is completed (Fig. 9.7). Once again, a suture hook loaded with MAXON is passed through the anteromedial portal. A simple vertical stitch was made that overlaid and crossed the center of the horizontal suture, and both ends of the suture are taken out through the anteromedial portal. This resulting cruciate-shaped stitch is similar to the modified Mason-Allen technique. By pulling the

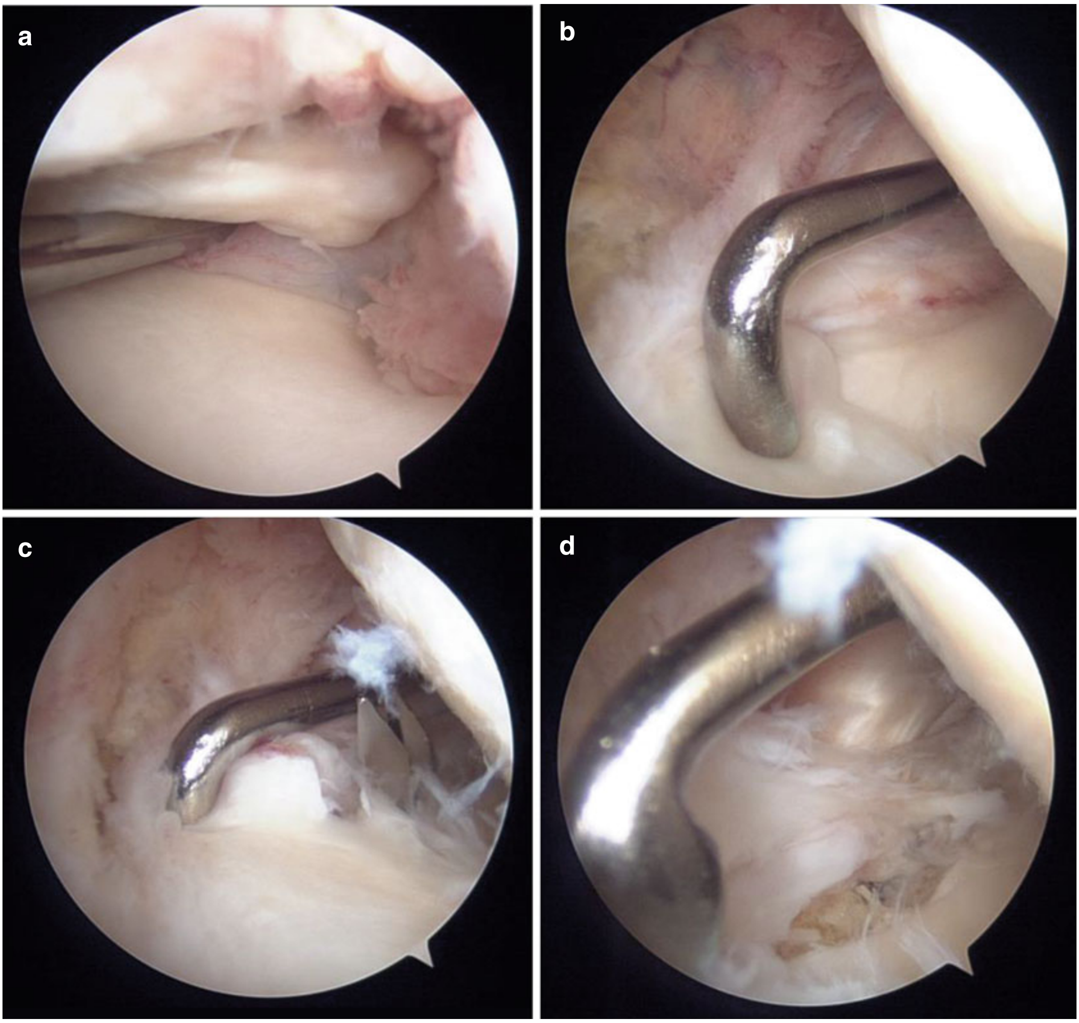

Fig. 9.6 (**a**) The 30° arthroscope inserted from anterolateral portal shows the radial tear in the root of the medial meniscus posterior horn. (**b**) The 30° arthroscope inserted from posteromedial portal shows the tear of medial meniscus around the root area. (**c**) The double transosseous tibial tunnel is drilled by placing the anterior cruciate ligament drill guide. (**d**) The cartilage is removed by a curved curette at just anterior of the insertion point of posterior cruciate ligament

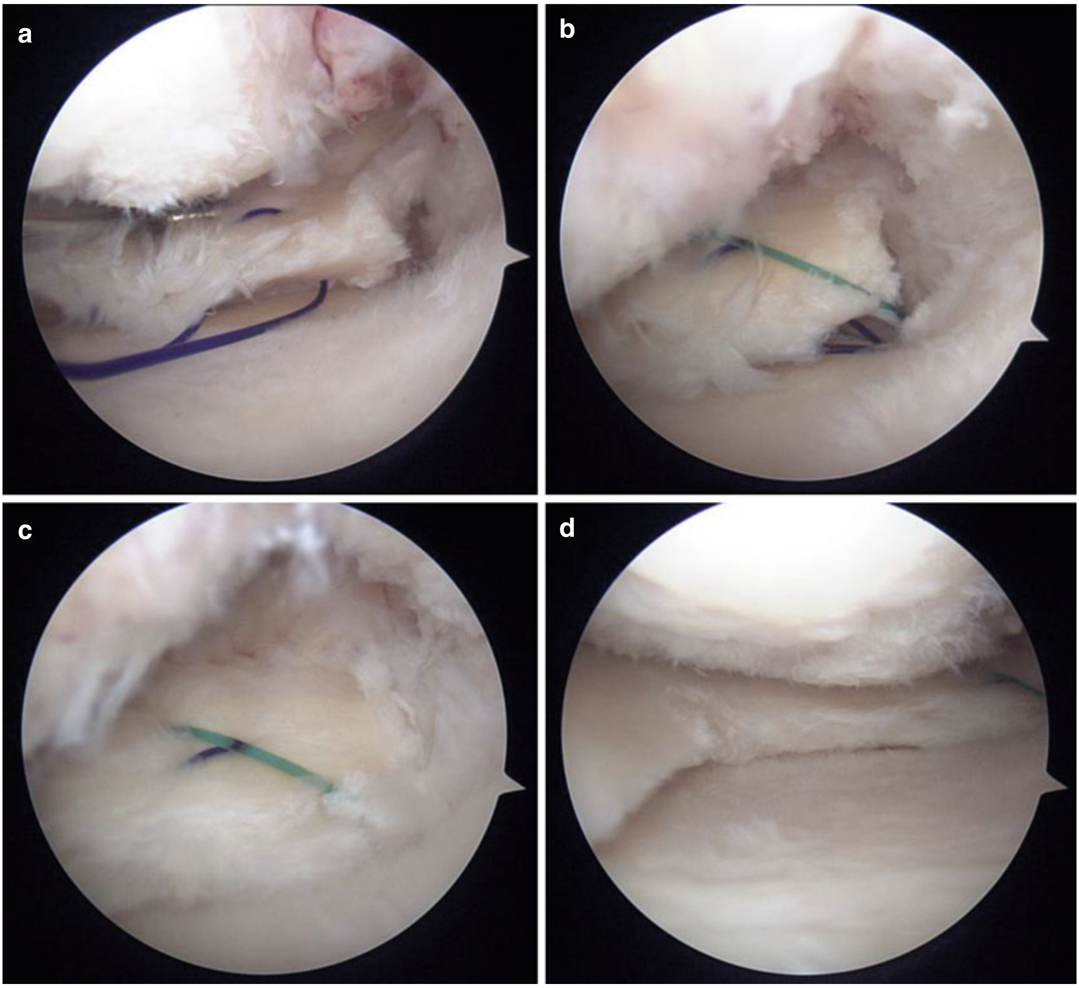

Fig. 9.7 (**a**) The 30° arthroscope inserted from the anterolateral portal shows two PDS sutures of the substance of the posterior horn of medial meniscus and was brought out through the anteromedial portal. (**b**) A cruciate-shaped stitch is made, and the ends of the sutures were pulled through the tibial tunnel. (**c**) The torn root is pulled toward the insertion site through the tibial tunnel. (**d**) The detached posterior horn is reduced and tied under adequate tension

ends of the sutures under adequate tension through the tibial tunnel, the suture ends are tied at the anteromedial tibial cortex. A final arthroscopic evaluation is performed to confirm reattachment of the torn posterior root and tension of the entire medial meniscus.

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Meniscal Lesions in Children: Classification, Discoid Meniscus, Traumatic Lesions

10

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10.1 Introduction

The incidence of meniscal lesions in children and adolescents is not really known but is actually increasing due to more intensive and earlier sports activities [8, 9, 43] and the improvement of diagnostic tools such as MRI [8]. In adults, lesions are either traumatic with a stable or unstable knee, or they are degenerative by progressive wear of the knee. In children, the approach is different depending on the presence or not of constitutional meniscal abnormalities. Thus, anatomy of the meniscus separates two groups:

- A group with "normal meniscus": the meniscus has a classical aspect with normal roots and normal peripheral attachments. Similarly to adults, there are traumatic lesions in this group with stable or unstable knee. Morphological classifications of the lesions have no specificity in children compared to adults.
- A group with "meniscal abnormality": there is an abnormality of the meniscus. Tears and lesions will develop more easily, earlier, with special characteristics, and no real associated trauma. It mainly concerns the discoid meniscal pathology and the group of hypermobile meniscus. A better understanding in the onset and development of the lesions in case of malformative meniscus allowed to change classifications in this group. They don't aim at only describing different forms of discoid meniscus,

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_10

but they especially analyze the lesion and help to plan a surgery which will be adapted to the principle of meniscal economy.

10.2 Tears and Normal Meniscus

10.2.1 Generalities

Tears of the normal meniscus occur in 80–90 % of cases following a sports injury [43]. It can also sometimes occur after a simple trauma, without any sports activities, similarly to adults.

There are several ways of classifying the meniscal tears in this group, considering several factors: vascularization of the meniscus, place and direction of the tear, and stability of the knee.

10.2.2 Description of the Tears

10.2.2.1 According to the Vascularization of the Meniscus

In adults, the vascularization of the meniscus is a crucial factor in order to decide the surgical indication of suturing and to hope for healing. It is essentially limited to the peripheral third, with a meniscal vascular segmentation in three zones: red-red, red-white, and white-white described by Arnoczky and Warren [7].

In children, the vascularization of the meniscus changes with growth [11]. It is complete in the fetus but rapidly after birth, the central meniscal third becomes avascular. The vascularization of the middle third decreases progressively during childhood. At about the age of 12 years, the meniscus is vascularized similarly to adults. This classification is then insufficient in children to decide when suturing the meniscus. With a higher potential for healing, indications of sutures in children are thus much wider, even when the lesion has reached the inner edge of the meniscus [39, 47].

10.2.2.2 According to the Type of Tear

In young people, types of tears are the same as in adults. There is no specific classification for children. We can mention the classification of O'Connor [41] (Fig. 10.1) and the classification of Trillat [45] described initially for the medial

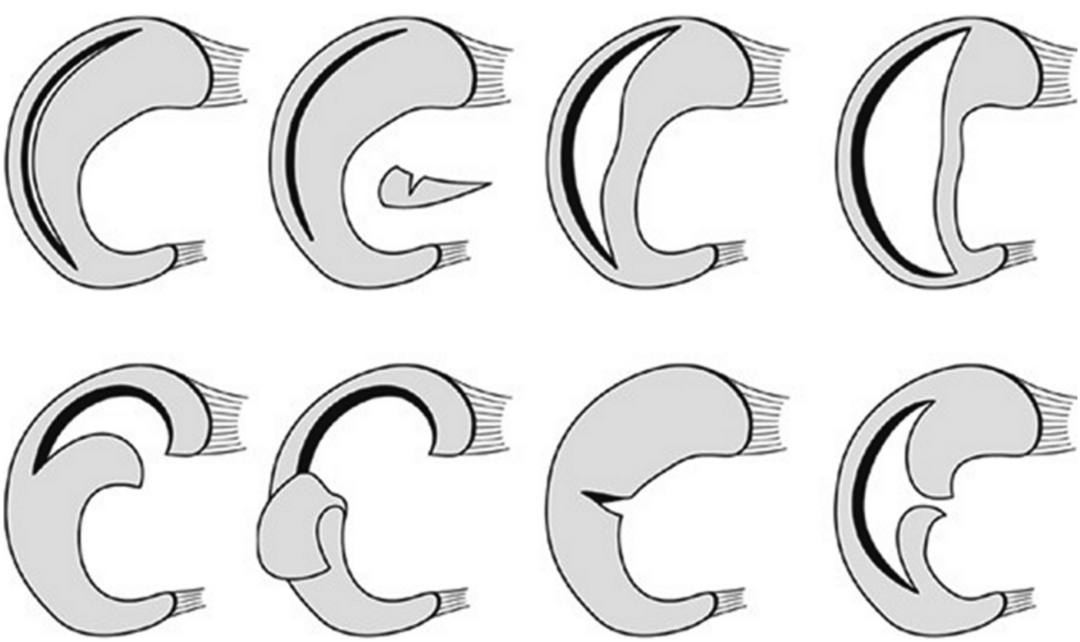

Fig. 10.1 Classification of O'Connor (Reproduced from O'Connor's text book of arthroscopic surgery. Lippincott, Philadelphia 1992 [41])

meniscus and then secondarily applied to the traumatic tears of the lateral meniscus (Fig. 10.2) [20].

Types of tears are classified according to their direction, which is relative to the plane of the meniscus, and the longitudinal direction of the collagen fibers: the lesions appear either in a vertical or horizontal plane:

- Horizontal tears are parallel to the articular surface and correspond to a delamination of the meniscus. They occur mostly in the middle segment of the lateral meniscus. They are rare, often associated with discoid meniscus. They can allow the development of cysts in children when they reach the outer edge of the meniscus. Thus, a meniscal cyst in children and adolescents does not have the same origin as in

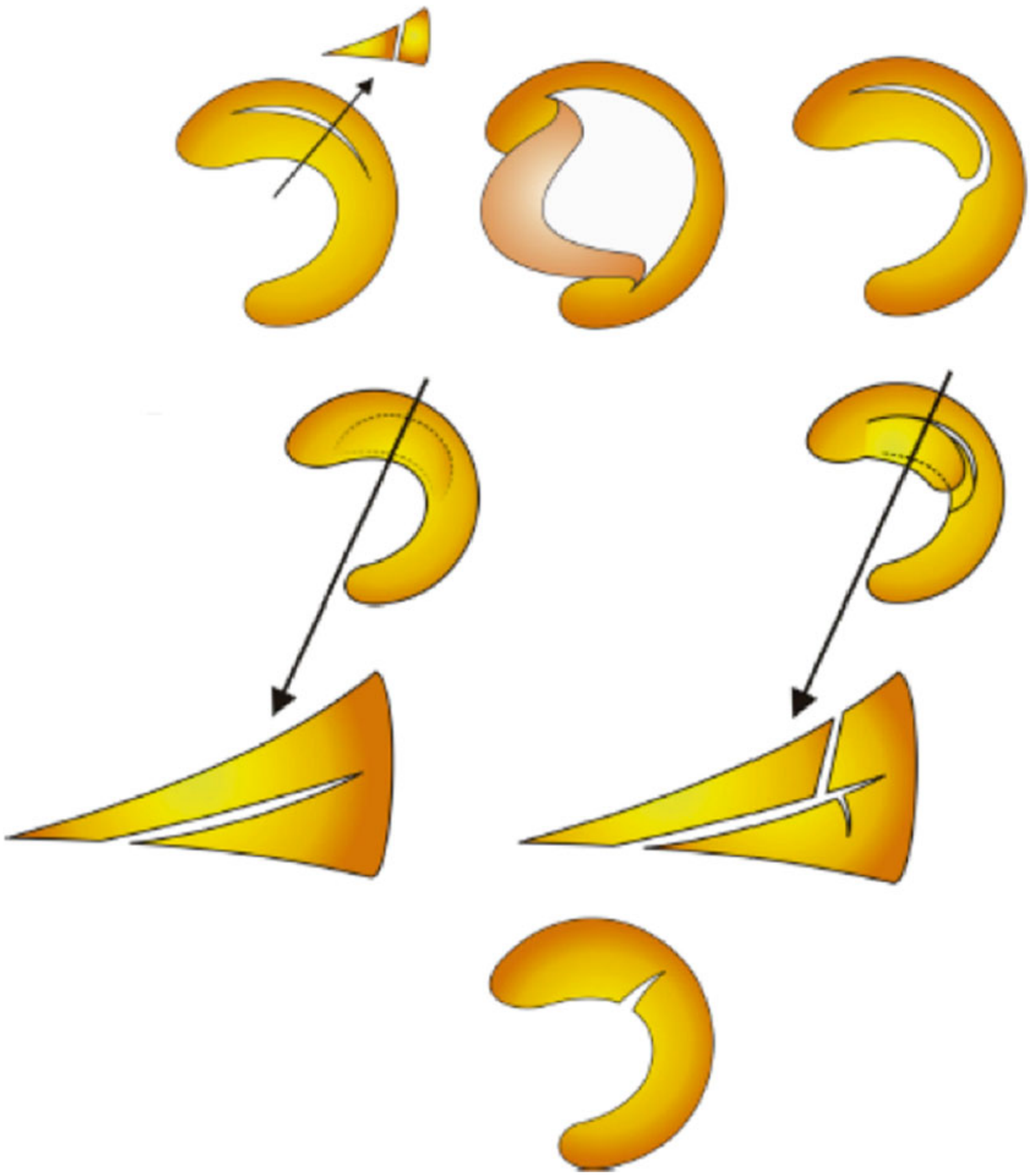

Fig. 10.2 Modified classification of Trillat (Pictures of Burdin P, reproduced from Hulet et al. [20])

adults in whom it is mainly associated with degenerative lesions of the lateral meniscus [21]. In children, it is associated with a horizontal lesion at the junction of the anterior third and middle third of the meniscus [8, 26] sometimes without any trauma. The meniscus can be normal or with a discoid aspect (Fig. 10.3). The cyst is usually next to the joint line, just in front of the lateral collateral ligament and is easily palpable when the knee is flexed.

- Vertical tears appear either longitudinally or transversely with respect to the meniscus. They are divided into three categories:
  – Vertical longitudinal tears

  This is the most frequent lesion, occurring in up to 70 % of cases according to Terzidis et al. [44], whether with a stable or unstable knee. It is mainly located in the peripheral third of the posterior segment and can extend forwardly to form a longitudinal bucket-handle lesion. Its potential for healing is very good at over 85 % [27, 44]. It is a meniscal flap if it reaches the inner edge of the meniscus.

  – Radial tears

  This lesion is rare, rather situated on the middle or posterior segment of the meniscus. There is a break in the continuity of longitudinal collagen fibers. A radial tear may lie at the horn of the meniscus, especially at the posterior horn of the medial meniscus, and form a tear or an avulsion of the meniscal root (MMPRA, medial meniscus posterior root avulsion). A ligament injury is often associated to it [13]. Biomechanically, it is a serious lesion because it is a source of secondary meniscal extrusion synonymous with “ghost meniscus” [40]. Four cases have been reported in children [17, 28, 42]. It can then be not a tear of the meniscal horn, but a real bone avulsion or fracture of the tibial insertion of the meniscal horn just as an avulsion of the ACL insertion. This is explained in children with a less resistance of epiphyseal bone structures compared to meniscal and ligamentous structures.

  – Oblique tears

  These lesions have neither any particularity in children nor any specificity in their care.

– The combination of several lesional components constitutes complex tears [29, 36].

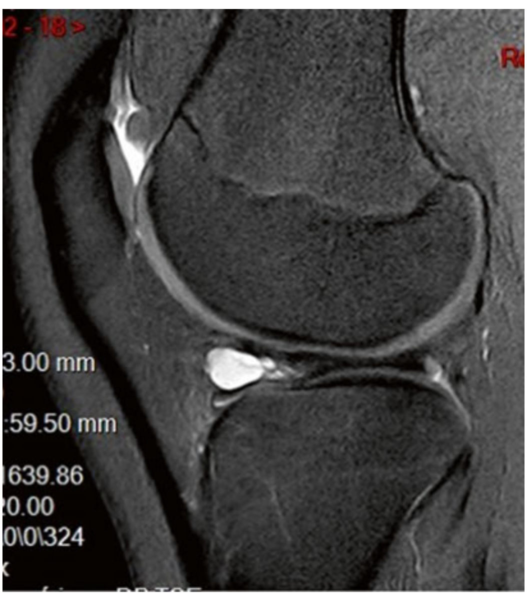

Fig. 10.3 MRI sagittal view of a knee. Meniscal cyst of the anterior horn of a discoid lateral meniscus

The healing potential of these radial, longitudinal, or complex lesions is less good (between 18 and 65 %) [25] but still better than in adults [27]. Thus, according to some authors, all lesions can be repaired in children regardless of the type provided the lesion is reducible and the suture is stable [24, 37].

10.2.2.3 According to the Stability of the Knee

Traumatic meniscal lesions on normal meniscus are either isolated or associated with lesions of the ACL or PCL.

The incidence of meniscal lesions with a stable knee is uncertain [1]. It is rare in children before the age of 10 years [18]. Terzidis et al., about 378 meniscal tears diagnosed on a stable knee in young patients, described a lesion of the medial meniscus in 70 % of cases [44]. Lesions are mainly vertical (78 %), posterior, and located at the meniscal wall (75 %).

The association of meniscal lesion with ACL rupture is classic. For Stanitski et al., 45 % of children and adolescents with hemarthrosis have a meniscal tear of which three fourth have a lesion of the ACL [43]. The meniscal tear can occur at the same time as that of the ACL tear. Thus, up to 70 % of ACL tears in children are associated with a meniscal lesion [16, 31, 38]. It mainly concerns the posterior segment of the lateral meniscus as a vertical tear at the red-white area [38]. The meniscal lesion may also be secondary to a chronic knee laxity and then concerns the posterior part of the medial meniscus [19, 30].

Thus, the underlying stability of the knee is a key element in the treatment of a meniscal lesion. As in adults, an isolated meniscal suture on an unstable knee is not recommended.

10.3 Meniscal Tears and Morphological Meniscal Anomaly

10.3.1 Discoid Meniscus

The discoid meniscus is a meniscal abnormality whose origin remains unknown. The prevalence is estimated between 0.4 and 16.6 %, being more frequent in the Asian population [4, 6]. The anomaly mainly concerns the lateral meniscus; only a few cases have been reported for the medial meniscus. The disease is bilateral in 5–20 % of cases [5, 22]. The classification of Watanabe (Fig. 10.4) described the discoid meniscus in 3 morphological forms: type I "block-shaped stable and complete meniscus," type II "block-shaped stable and partial meniscus," and type III "unstable meniscus, the Wrisberg ligament type" which results from a lack of the posterior tibial insertion [48].

A fourth variant is "the ring-shaped meniscus" described by Monllau et al. in 1998 [32].

It is now clear that this discoid abnormality exposed patients to meniscal injuries [11, 12, 34, 35] due to a larger volume and a greater thickness of tissue. The patient becomes symptomatic (pain, snap, deficit of extension, locked knee). It can be classical lesions such as above, including horizontal tears [8] or complex lesions. More specifically, meniscal lesions of discoid meniscus are mainly represented by disinsertions of anterior and/or posterior segments at the wall. The Watanabe classification doesn't account for these lesions and therefore remains insufficient to determine the treatment and the type of suture to consider.

Several authors introduced the notion of peripheral meniscal instability of discoid meniscus [15, 23]. In 2008, Ahn et al. proposed in that way 2 very practical classifications: one based on the MRI [3] and the other based on the morphological arthroscopic aspect [2]. These classifications allow both to explain some symptoms such as meniscal "clunk" and to plan management

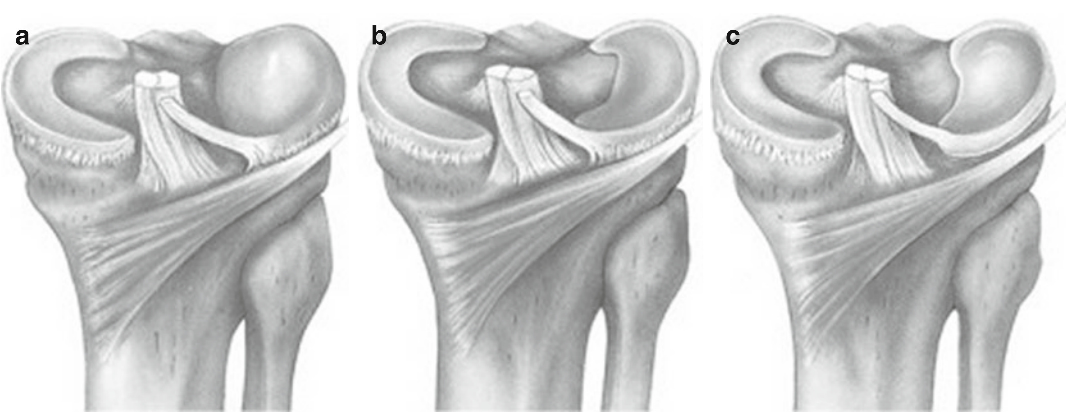

Fig. 10.4 The Watanabe classification of discoid lateral meniscus. (**a**) Type I, block-shaped stable, complete meniscus. (**b**) Type II, block-shaped stable, partial meniscus. (**c**) Type III, unstable meniscus, with stability arising only from the ligament of Wrisberg. (Reproduced from Andrish [49])

of the lesion by saucerization and repair by respecting the principle of the meniscal economy.

The MRI Ahn classification (Figs. 10.5, 10.6, 10.7, and 10.8) proposed 4 types based on the meniscal displacement secondary to a peripheral vertical tear:

- Anterocentral shift type, when the meniscus is dislocated forward (Fig. 10.5).
- Posterocentral shift type, when it is dislocated backward (Fig. 10.6).
- Central shift type, when it is dislocated in the notch (Fig. 10.7).
- No shift type, when there is no meniscal displacement (Fig. 10.8). It's important to note that MRI can find other lesions such as horizontal intrameniscal tears that will be visible only after the arthroscopic saucerization has been performed (Figs. 10.9, 10.10, 10.11, and 10.12).

Fig. 10.5 MRI Ahn classification anterocentral shift type (coronal plane)

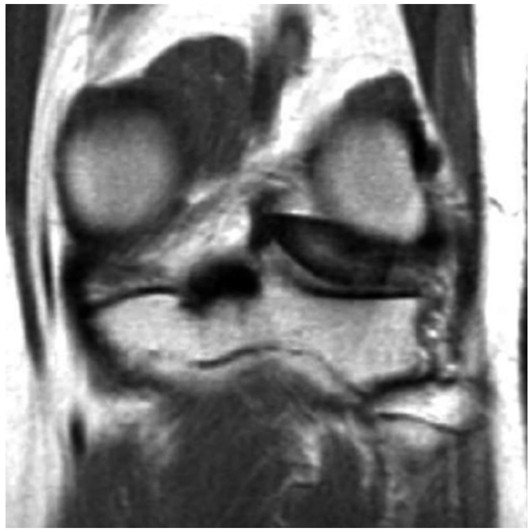

Fig. 10.7 MRI Ahn classification posterocentral shift type (coronal plane)

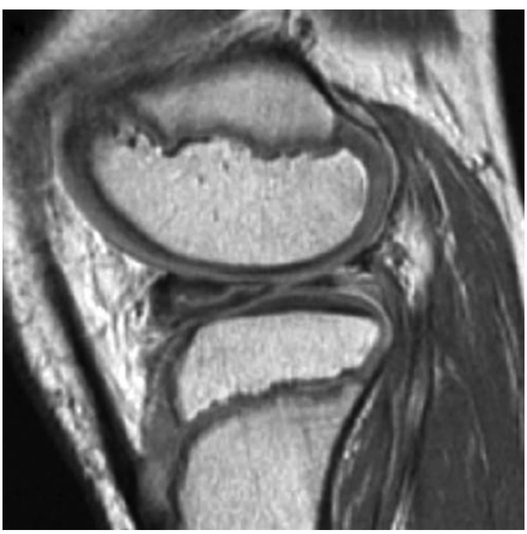

Fig. 10.6 MRI Ahn classification anterocentral shift type (sagittal plane)

Fig. 10.8 MRI Ahn classification posterocentral shift type (sagittal plane)

Fig. 10.9 MRI Ahn classification central shift type (coronal plane)

Fig. 10.10 MRI Ahn classification central shift type (sagittal plane)

Fig. 10.11 MRI Ahn classification no shift type (coronal plane)

Fig. 10.12 MRI Ahn classification no shift type (sagittal plane)

The arthroscopic Ahn classification (Figs. 10.13, 10.14, and 10.15) described three types by both rim stability and site of tear: meniscocapsular junction anterior horn type (MC-A), meniscocapsular junction posterior horn type (MC-P), and posterolateral corner loss type (PLC). Thus, for Ahn et al., the lesion seems to start at the level of the popliteal hiatus and then spreads either forward (MC-A type, the most common) or backward (MC-P type). In his study, Ahn et al. [2] noted a strong correlation between the MRI and the arthroscopic classification: MRI lesions such as posterocentral shift type correspond to the meniscocapsular junction anterior horn type (7/7 cases). MRI lesions such as anterocentral shift type correspond to the posterolateral corner loss type (3/3 cases). No shift-type lesions amount to the MC-P type in arthroscopy (6/7

Fig. 10.13 Arthroscopic Ahn classification meniscocapsular junction anterior horn type (MC-A)

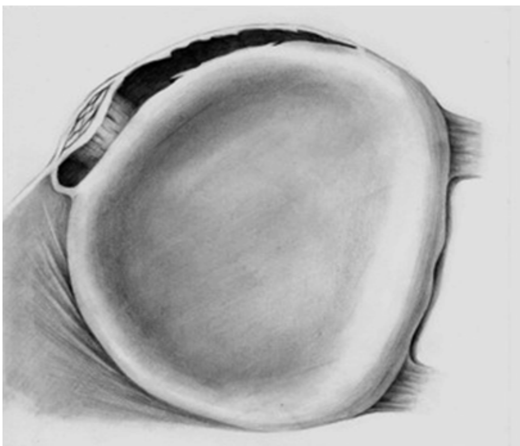

Fig. 10.14 Arthroscopic Ahn classification meniscocapsular junction posterior horn type (MC-P)

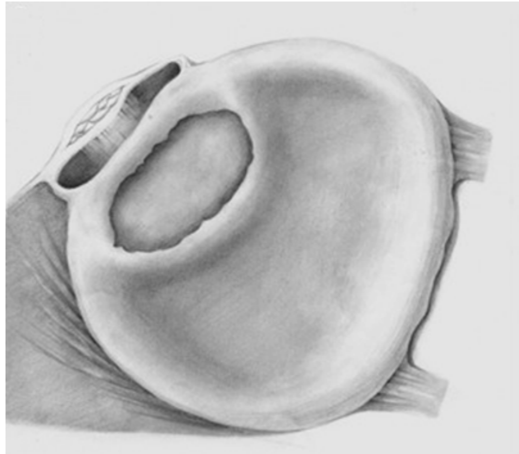

Fig. 10.15 Arthroscopic Ahn classification posterolateral corner loss type (PLC)

Fig. 10.16 Lateral hypermobile meniscus: MRI sagittal view with hyperintensity behind the posterior segment of the lateral meniscus

cases) and lesions such as central shift type are mainly represented by PLC loss type (9/11 cases).

10.3.2 Lateral Hypermobile Meniscus

It is a rare anomaly mostly seen in children and adolescents; only a few cases are described in adults [10, 14]. Patients have locking in mid-flexion and the lateral meniscus is concerned (Figs. 10.16, 10.17, 10.18, and 10.19). There is a normal morphology of the meniscus with hypermobility of the posterior meniscal segment ahead of the femoral condyle. The pathogenesis is not clear. Some authors think it is the Wrisberg variant type of discoid meniscus [15, 33] but with a normal meniscal shape, without discoid appearance. Then it would be a failure of the posterior menisco-synovial insertion. Other authors link this anomaly to a trauma [14]. MRI may appear normal and can be sensitized if performed with the knee flexed. CT arthrography may also highlight the injury more easily. Treatment involves suturing the meniscus [46].

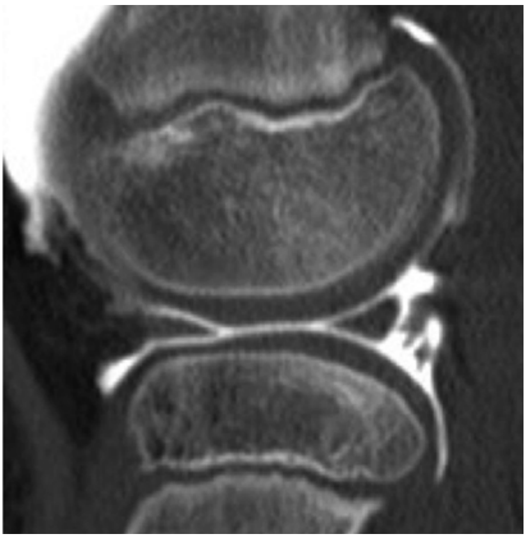

Fig. 10.17 Lateral hypermobile meniscus: CT arthrography sagittal view

Fig. 10.18 Lateral hypermobile meniscus: Arthroscopic view of the lateral meniscus with a normal aspect

Fig. 10.19 Lateral hypermobile meniscus: Arthroscopic view showing the hypermobility with a dislocation in front of the femoral condyle with the probe

Conclusion

Meniscal injuries in children are either post-traumatic and usually occurring on a normal meniscus or not traumatic and occurring on a meniscus with an abnormality.

Lesions on normal meniscus in children and adolescents do not have specificities with respect to the adult except a better healing potential in younger patients justifying an expansion of indications for meniscal sutures.

Lesions on meniscus with abnormality are mainly represented by vertical longitudinal tear at the meniscal wall whose starting point seems to be the popliteal hiatus. Recent classifications of Ahn objectify these lesions and enable surgical planning combining suture and meniscoplasty to ensure an absence of recurrence and to save the meniscus.

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Discoid Meniscus: Histology

11

Kecojević Vaso

Content

Discoid meniscus is an abnormality of the morphology of the meniscus, in which meniscus has the appearance of flat disk instead of the usual semilunar shape. It is thickened than normal one and covers the whole area of the tibial plateau. It is occasionally symptomatic, most often occurs in the lateral compartment than in the medial, and is often seen in childhood and in the adolescent. Young [1] first described it in 1889. The incidence of discoid meniscus differs for lateral and medial and ranges from 0.4 to 17 % for lateral compared from 0.06 to 0.3 % for medial discoid meniscus [2]. Smillie [3] reported 6 % discoid menisci out of 3000 meniscectomies, and Nathan and Cole found only 2.5 % discoid menisci in their study [4] from 1219 surgically removed menisci. There is a difference, too, comparing worldwide population. In Asian countries, the incidence is higher (16.6 % in a Japanese population [5, 6], 10.9 % in a Korean population [7], 5.8 % in an Indian population [8]) than in white population (1.8 % in a Greek population [9]). There are occasional reports of familial series [10]. Interesting are reports of associated anatomical abnormalities of fibula (high fibular head, fibular muscular defects [11]), lateral femoral condyle (hypoplasia, osteochondritis dissecans [12, 13]), and tibia (hypoplasia of the lateral tibial spine, cupping of the lateral tibial plateau [4, 14]).

The origin of the discoid shape of the lateral meniscus is not clearly determined. At the 8-week fetus, menisci are clearly defined structures [15, 16]. From 9 to 14th week, menisci

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_11

have normal relationship with other structures of the knee like in adult [16, 17]. Smillie stated that the discoid shape is remnant of the normal fetal stage of the meniscal development [18]. On the other hand, Kaplan demonstrated that the discoid meniscus is pathological condition generated by mechanical influence [19, 20]. Ross noted that only in the earliest phase of the embryo undifferentiated mesenchymal cells from which the meniscus will develop look like disk [21]. Clark and Ogden measured the area of the tibial plateau that is covered by menisci. They found out that the growth of both menisci is uniform. They found out that the lateral meniscus covered from 80 up to 93 % of the lateral tibial plateau and concluded that mild to moderate instability, followed by absence of the meniscofemoral attachment, could produce the fulfilling and closure of the central area that is usually surrounded by the lateral meniscus [22]. Le Minor proposed that the lateral discoid meniscus is an atavistic abnormality [23]. He also noted that there is no embryological study on human fetus that shown initial discoid stage of lateral meniscus [23]. A lot of authors considered that discoid meniscus has congenital origin [22, 24–27]. Kale et al., in the paper from 2006, stated that the primordial shape of the meniscus is discoid and it is transformed to other shapes [28]. They excluded degenerative changes in neonatal period and assume that final form of the adult menisci is guided by developmental changes. There are limited data in the literature regarding histology of the discoid lateral meniscus. Since now, only two studies were performed. In 2007, Atay et al. published the first ultrastructural study of the lateral discoid meniscus [29]. They stated that there is a disorganization and decreasing in number of the circumferential collagen fibers in the discoid lateral meniscus. Lower collagen concentration is similar to degenerated menisci, and disorganization of the collagen fibers decreases the stress capacity, which in common may led to increasing vulnerability and tear incidence. Authors found out that limitations of the study are that biopsy samples were used from torn menisci, they were not performed topographic analysis and scoring of the collagen fibers network, and radially oriented collagen fibers were not evaluated.

Papadopoulos et al. [30] published the first histological study of discoid meniscus.

Study results indicate that the collagen matrix of the complete discoid lateral menisci significantly differs from that in their normal counterparts regarding the circular collagen fiber network. Many issues with regard to the discoid variation of knee meniscus remain unknown or incompletely studied. No theory can explain the mechanism of discoid malformation in all cases. Regardless of the pathogenesis of the discoid meniscus dysmorphy, many arthroscopic and imaging studies have shown high vulnerability of the discoid menisci to tear and cystic degeneration [31–34]. It has been suggested that the predisposition of discoid menisci for tear is attributable to increased volume of meniscus and altered biomechanical behavior. However, a high tear rate has been described even in normally configured discoid meniscus remnants after arthroscopic central partial meniscectomy [6, 33, 35]. Because the relation between the arrangement of collagen fibrils and biomechanical features of meniscus is well known, any disorganization of the matrix collagen network may be an important factor predisposing patients to tears. In the normal meniscus, a highly organized collagen matrix is well documented [36, 37]. Four collagen fiber networks have been described. Along the surfaces of the meniscus, radially arranged collagen fibers are located, resisting shear loads. The inner circumferential collagen fiber network represents the main portion of the meniscus tissue and dissipates the hoop stresses on the meniscus structure during weight bearing. Two accessory networks consisting of superficial fine fibrils and oblique connective fibers anchoring the circumferential ones have been described as well. The role of an intact collagen network as a scaffold to hold the glycosaminoglycans necessary for normal meniscus function is of great importance. Histomorphologic mapping of the discoid meniscus matrix still remains unknown. In Papadopoulos study, complete-type lateral discoid menisci were involved. Arthroscopic diagnosis of incomplete type is often established based on subjective criteria, and the Wrisberg variant constitutes a very rare lesion with discrete pathogenesis, and, usually, the normal meniscus configuration is preserved [38]. Therefore, these discoid meniscus types were excluded from the study. By use of the technique of arthroscopic partial meniscectomy in one piece, full-thickness large meniscus specimens rather than partial-thickness biopsy specimens were obtained, and a topographic investigation of the collagen matrix was possible. Despite the discrepancy in the mean patient age between study groups, the finding of disorganization of the circular collagen fiber network in the discoid meniscus group even in comparison to older, degenerated menisci emphasizes the structural difference between discoid and normal menisci. The weakness of this study relates to the inability to perform histomorphologic examination of the entire discoid meniscus tissue because the study material was collected arthroscopically and partial meniscectomy–saucerization represents the treatment of choice in these patients. Thus, the location of the tissue analyzed in the study group did not correspond precisely to the location of the tissue in the control group, but it was not possible to obtain correlative specimen tissue from discoid menisci without harm to the patient. However, the study results are indicative of significant differences in the matrix collagen between discoid and normal menisci and can give the basis for further histologic and biomechanical studies to address the issue of the high vulnerability of the discoid menisci to tear.

Findings of discontinuity and inhomogeneity of the circumferential collagen network in the discoid meniscus in comparison to normal meniscus indicate that the discoid lesion represents a structural lesion rather than a morphologic variant.

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Classification of Meniscal Lesions: Synthesis

12

João Espregueira-Mendes

Classification of meniscal lesions is a very important and not fully achieved goal.

Finding the most effective classification method enables transmission of information among clinicians and aims to correlate with prognostic and algorithms for treatment.

ESSKA and ISAKOS Knee Committee created a Meniscal Documentation Subcommittee in 2006 with the objective of developing a reliable, international meniscal evaluation and documentation system to facilitate outcome assessment.

The meniscus tears have been classified by morphology, reparability, symptomatology, and by the type of injury.

Understanding the injury mechanism of both traumatic and degenerative meniscal tears, the ultrastructure of the tissue and global joint kinematics is also crucial for the development of prevention strategies.

Traumatic meniscal injuries present a wide spectrum of presentation and several types of lesions are possible. The ACL-deficient knee presents a different topic demanding specific care. Several advances in the field of diagnosis and surgical treatment have recently aroused.

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Degenerative meniscus lesions are usually not a result of acute knee trauma. They typically involve a horizontal cleavage and are the result of slowly developing changes of mucoid degeneration and sheer stresses to the meniscus. Such lesions are very common in persons with and without knee joint symptoms. In essence, degenerative meniscus lesions should be clearly distinguished from traumatic meniscal tears due to their different etiology, high prevalence, and strong association with degenerative joint disease.

Currently, most authors favor repair over meniscectomy even in some types of injuries previously considered as irreparable.

A new hot topic, receiving a great deal of attention in recent times, is the so-called hidden lesions and root tears.

It has been recognized that up to two third of patients with anterior cruciate ligament rupture have combined medial meniscus posterior horn tears. Moreover, some authors state that repairing this torn meniscus anatomically allows the reconstructed ACL knee to be more stable than those with a meniscectomy.

However, the finding of such injuries requires suspicion from the surgeons or systematic evaluation once its concealing location makes them difficult to identify from the anterior portals. Magnetic resonance imaging has some limitations for detecting meniscal tears in patients with acute or chronic ACL tears.

However, recent technical improvements have warranted efficiency and reliability in the

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_12

treatment of several of these lesions. The all-inside suture of peripheral longitudinal tears of medial meniscus posterior horns using a posteromedial portal has shown to be an efficient and safe technique, while minimizing the risk of neurovascular or chondral injuries.

A lateral meniscus posterior horn (LMPH) root tear can also occur combined with ACL ruptures and may be associated with the extrusion of the lateral meniscus. An LMPH root tear is defined as a tear that occurs less than 1 cm from the posterior insertion. These injuries have received a different approach once they also have a different prognosis comparing to medial posterior horn lesions.

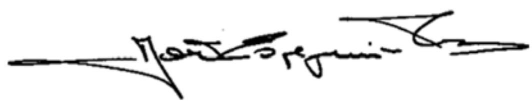
Classifications of meniscal lesions in children are interesting from several points of view: diagnostic, prognostic, and therapeutic. Although classifications similar to those dedicated to adults can be used, the presence or absence of an abnormality of the meniscus is the main parameter.

Meniscal injuries in children are either post-traumatic (usually occurring on a normal meniscus), or not traumatic, and occurring on a meniscus with an abnormality including discoid meniscus.

Lesions on normal meniscus in children and adolescents do not have specificities with respect to the adult except a better healing potential in younger patients justifying an expansion of indications for meniscal sutures.

Lesions on meniscus with abnormalities are mainly represented by discoid meniscus in its different forms and vertical longitudinal tear at the meniscal wall (whose starting point seems to be the popliteal hiatus). Recent classifications of the former have been proposed in order to facilitate a surgical planning combining suture and meniscoplasty to preserve as much as possible the meniscus.

In summary, there are novel types of injuries and new classifications of meniscal injuries to consider aiming to find the most efficient correlation between diagnosis and treatment.



João Espregueira Mendes

Part III

Preoperative Clinical Examination and Imaging

Clinical Examination, Standard X-Rays

13

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13.1 Introduction

Meniscus injuries are the most common type of intra-articular knee injury, involving about 60–70 per 100,000 inhabitants per year [14, 20].

Although a definitive diagnosis is only possible during arthroscopic examination [8], and the surgical indication passes almost always through a magnetic resonance imaging, the suspicion of a meniscal lesion comes first and foremost from the clinical examination.

Hereinafter, the clinical examination of the knee and the validity of meniscal tests will be presented, as well as the utility of standard X-rays to provide surgical indication for a meniscal lesion.

13.2 Clinical Examination

13.2.1 Anamnesis

The purpose of the examination is to make a correct anatomic diagnosis [28].

Meniscal injuries typically occur by applying specific forces while the knee joint is in certain positions, and this may dictate what anatomic structures are at risk of injury. Hence, it is important to obtain an accurate medical history, by asking the patient to describe the knee position and direction of forces at the time of injury, even if most patients do not report a real trauma, but rather an acute pain that occurred after a twist to the knee under load or a knee flexion.

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For example, a flexion-intrarotation movement can produce a longitudinal tear of the substance of the meniscus. If the tear extends anteriorly beyond the MCL, thus creating a bucket-handle tear, then the unstable meniscus fragment can cause the knee to lock in a flexed position. The lateral meniscus, being more mobile, is less likely to lock when torn.

Older patients are more likely to have degenerative meniscal tears with fewer mechanical symptoms and an insidious onset.

13.2.2 General Clinical Examination of the Knee

The knees should be inspected for asymmetry that may indicate swelling, which can be confirmed by palpation and ballottement of the patella, which is not a specific finding in knees with meniscal injury.

A meniscal lesion can also affect the range of motion of the knee, in terms of deficit in extension or in flexion, thus suggesting an anterior or posterior tear, respectively.

13.2.3 Tests Commonly Used to Assess Meniscal Lesions

Several tests have been described in the literature to detect meniscus lesions [22]. The most commonly used and analyzed ones are described along with their specific statistic values as reported in the literature in Table 13.1, where a statistical analysis was performed to find the overall sensitivity and specificity derived from the available studies. The tests can be divided into palpation tests (joint line tenderness, McMurray's) and rotation tests (Apley's, Thessaly's, Steinmann I, Ege's, Childress's, Payr's, Bohler's).

13.2.3.1 Joint Line Tenderness

The patient lies supine on the bed with the knee and hip bent. The examiner holds the knee with one hand while pressing on the joint line with his thumb. In a positive test, the patient will feel pain along the joint line (Fig. 13.1).

Level of evidence: sensitivity 64.1 % (64.0–64.2 %), specificity 65.4 % (65.3–65.5 %), positive predictive value 74.5 % (74.4–74.6 %), and negative predictive value 53.6 % (53.5–53.7 %)

13.2.3.2 McMurray's Test

The patient lies supine on the bed with the knee and hip bent. Keeping the heel as close to the hip as possible, the examiner holds the knee joint with one hand by placing his index finger and thumb along the joint line and then uses the other hand to hold and twist the foot in external rotation or internal rotation. The patient will feel pain and Possibly hear a noise from the knee joint held by the examiner if the test is positive (Fig. 13.2).

Level of evidence: sensitivity 55.2 % (53.0–57.5 %), specificity 82.7 % (80.4–85.0 %), positive predictive value 85.1 % (83.1–87.1 %), and negative predictive value 50.8 % (48.4–53.1 %)

13.2.3.3 Apley's Test

The patient lies prone on the bed with the affected knee bent to a 90° angle. The examiner holds the patient's thigh close to the bed with one hand while using the other hand to hold and twist the patient's foot in external and internal rotation and applies a compressive force on menisci. If the patient feels pain, meniscal pathology is assumed to be present (Fig. 13.3).

Level of evidence: sensitivity 37.4 % (34.1–40.8 %), specificity 87.5 % (84.4–90.0 %), positive predictive value 81.2 % (76.8–84.9 %), and negative predictive value 49.1 % (46.0–52.2 %)

13.2.3.4 Thessaly's Test

The patient stands flatfooted on the floor with arms outstretched and the examiner holds the patient's outstretched hands. The patient then rotates his or her knee and body, internally and externally, three times, keeping the knee in slight flexion (20°). Patients with suspected meniscal tears experience medial or lateral joint-line discomfort and may have a sense of locking or catching (Fig. 13.4).

Level of evidence: sensitivity 68.8 % (65.4–72.0 %), specificity 84.1 % (79.7–87.7 %), positive predictive value 90.5 % (87.8–92.7 %), and negative predictive value 54.9 % (50.6–59.2 %)

Table 13.1 Specific statistic values of the most common meniscal tests as reported in the literature and combined literature values to show their sensitivity and specificity

Analyzed test	Author, year	Evidence level	N° patient	Study population	Reference standard	Acute/chronic	Sensitivity (%)	Specificity (%)
Join line tenderness	Abdon (1990) [1]	4	145	Consecutive patients with suspected meniscal lesion	Arthroscopy	Chronic	50	84
	Akseki (2004) [2]	4	150	Consecutive patients with knee pain	Arthroscopy	Chronic	78	62
	Barry (1983) [4]	4	44	Nonconsecutive patients with meniscal pathology	Arthroscopy, arthrotomy	Chronic	76	43
	Boeree (1991) [5]	4	203	Consecutive patients with knee injury	MRI	Acute and chronic	46	78
	Eren (2003) [9]	3	104	Consecutive patients with suspected meniscal lesion	Arthroscopy	Chronic	90	82
	Fowler (1989) [11]	1	160	Consecutive patients with knee pain	Arthroscopy	Chronic	85	29
	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	95	5
	Karachalios (2005) [16]	1	410	Consecutive patients with knee injury	Arthroscopy	Chronic	48	89
	Konan (2009) [17]	4	109	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	79	92
	Kurosaka (1999) [18]	4	160	Consecutive patients with suspected meniscal lesion	Arthroscopy	Chronic	55	67
	Noble (1980) [21]	4	200	Nonconsecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	79	11
	Pookarnjanamorakot (2004) [23]	4	100	Consecutive patients with ACL insufficiency	Arthroscopy	Acute and chronic	27	96
	Shelbourne, 1995 [27]	4	173	Consecutive patients with ACL rupture	Arthroscopy, arthrotomy	Acute	48	62
	Steinbrück, 1988 [29]	4	300	Consecutive patients with ligament or meniscal lesion	Arthroscopy	Acute and chronic	63	67
	Wadey, 2007 [31]	1	71	Consecutive patients with knee pathology	Arthroscopy	Acute and chronic	85	31
	Cumulative values (Lower C.I. to upper C.I.)						64.1 % (64.0–64.2 %)	65.4 % (65.3–65.5 %)

(continued)

Table 13.1 (continued)

Analyzed test	Author, year	Evidence level	N° patient	Study population	Reference standard	Acute/chronic	Sensitivity (%)	Specificity (%)
McMurray's test	Akseki (2004) [2]	4	150	Consecutive patients with knee pain	Arthroscopy	Chronic	60	79
	Anderson (1986) [3]	4	100	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	69	86
	Barry (1983) [4]	4	44	Nonconsecutive patients with meniscal pathology	Arthroscopy, arthrotomy	Chronic	56	100
	Boeree (1991) [5]	4	203	Consecutive patients with knee injury	MRI	Acute and chronic	27	89
	Corea (1994) [7]	4	93	Consecutive patients with suspected meniscal lesion	Arthroscopy, arthrotomy	Acute and chronic	59	94
	Evans (1993) [10]	1	104	Consecutive patients with knee pain	Arthroscopy	Chronic	16	98
	Fowler (1989) [11]	1	160	Consecutive patients with knee pain	Arthroscopy	Chronic	29	95
	Goossens (2015) [12]	2	593	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	70	45
	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	66	62
	Jerosch (2004) [15]	1	64	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	74	11
	Karachalios (2005) [16]	1	410	Consecutive patients with knee injury	Arthroscopy	Chronic	81	90
	Konan (2009) [17]	4	109	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	43	90
	Kurosaka (1999) [18]	4	160	Consecutive patients with suspected meniscal lesion	Arthroscopy	Chronic	37	77
	Noble (1980) [21]	4	200	Nonconsecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	63	57
	Pookarnjanamorakot, 2004 [23]	4	100	Consecutive patients with ACL insufficiency	Arthroscopy	Acute and chronic	28	92
	Steinbrück, 1988 [29]	4	300	Consecutive patients with ligament or meniscal lesion	Arthroscopy	Acute and chronic	25	92
	Cumulative values (Lower C.I. to upper C.I.)						55.2 % (53.0–57.5 %)	82.7 % (80.4–85.0 %)

Apley's test	Anderson (1986) [3]	4	100	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	69	86
	Fowler (1989) [11]	1	160	Consecutive patients with knee pain	Arthroscopy	Chronic	16	80
	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	58	80
	Jerosch (2004) [15]	1	64	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	70	33
	Karachalios (2005) [16]	1	410	Consecutive patients with knee injury	Arthroscopy	Chronic	41	90
	Kurosaka (1999) [18]	4	160	Consecutive patients with suspected meniscal lesion	Arthroscopy	Chronic	13	90
	Pookarnjanamorakot (2004) [23]	4	100	Consecutive patients with ACL insufficiency	Arthroscopy	Acute and chronic	16	100
	Steinbrück (1988) [29]	4	300	Consecutive patients with ligament or meniscal lesion	Arthroscopy	Acute and chronic	35	91
	Cumulative values (Lower C.I. to upper C.I.)						37.4 % (34.1–40.8 %)	87.5 % (84.4–90.0 %)
Thessaly's test	Goossens (2015) [12]	2	593	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	64	53
	Karachalios (2005) [22] [16]	1	410	Consecutive patients with knee injury	Arthroscopy	Chronic	91	97
	Konan (2009) [17]	4	109	Consecutive patients with suspected meniscal lesion	Arthroscopy	Acute and chronic	53	88
	Cumulative values (Lower C.I. to upper C.I.)						68.8 % (65.4–72.0 %)	84.1 % (79.7–87.7 %)
Steinmann I test	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	63	62
	Pookarnjanamorakot (2004) [23]	4	100	Consecutive patients with ACL insufficiency	Arthroscopy	Acute and chronic	29	100
	Cumulative values (Lower C.I. to upper C.I.)						38.4 % (29.5–48.1 %)	88.5 % (82.8–92.6 %)

(continued)

Table 13.1 (continued)

Analyzed test	Author, year	Evidence level	N° patient	Study population	Reference standard	Acute/chronic	Sensitivity (%)	Specificity (%)
Ege's test	Akseki et al. (2004) [2]	4	150	Consecutive patients with knee pain	Arthroscopy	Chronic	66	86
	Cumulative values (Lower C.I. to upper C.I.)						66.1 % (77.7–89.8 %)	86.0 % (65.3–96.6 %)
Childress' sign (Squat test)	Pookarnjanamorakot (2004) [23]	4	100	Consecutive patients with ACL insufficiency	Arthroscopy	Acute and chronic	68	60
	Cumulative values (Lower C.I. to upper C.I.)						67.9 % (56.5–77.6 %)	59.9 % (34.0–79.0 %)
Payr's test	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	60	79
	Cumulative values (Lower C.I. to upper C.I.)						59.5 % (39.0–77.0 %)	79.1 % (68.7–86.8 %)
Bohler's test	Grifka (1994) [13]	4	113	Consecutive patients with meniscal lesion	Arthroscopy	Chronic	41	80
	Cumulative values (Lower C.I. to upper C.I.)						41.4 % (25.1–60.7 %)	79.5 % (68.6–87.1 %)

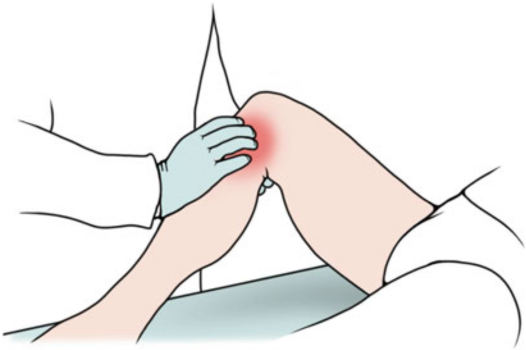

Fig. 13.1 Joint line tenderness

13.2.3.5 Steinmann I Test

While the knee is flexed over the examination table, the examiner forcefully and quickly rotates the tibia internally and externally. Pain in the lateral compartment with forced internal rotation indicates a lateral meniscus lesion. Medial compartment pain during forced external rotation indicates a lesion of the medial meniscus (Fig. 13.5).

Level of evidence: sensitivity 38.4 % (29.5–48.1 %), specificity 88.5 % (82.8–92.6 %), positive predictive value 67.2 % (54.2–78.1 %), and negative predictive value 70.1 % (63.7–75.9 %)

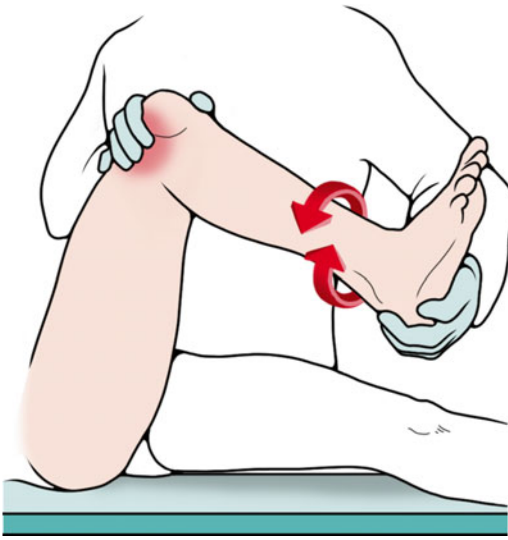

Fig. 13.2 McMurray's test

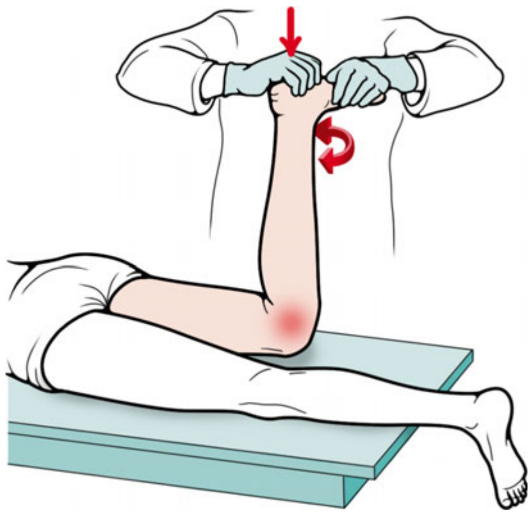

Fig. 13.3 Apley's test

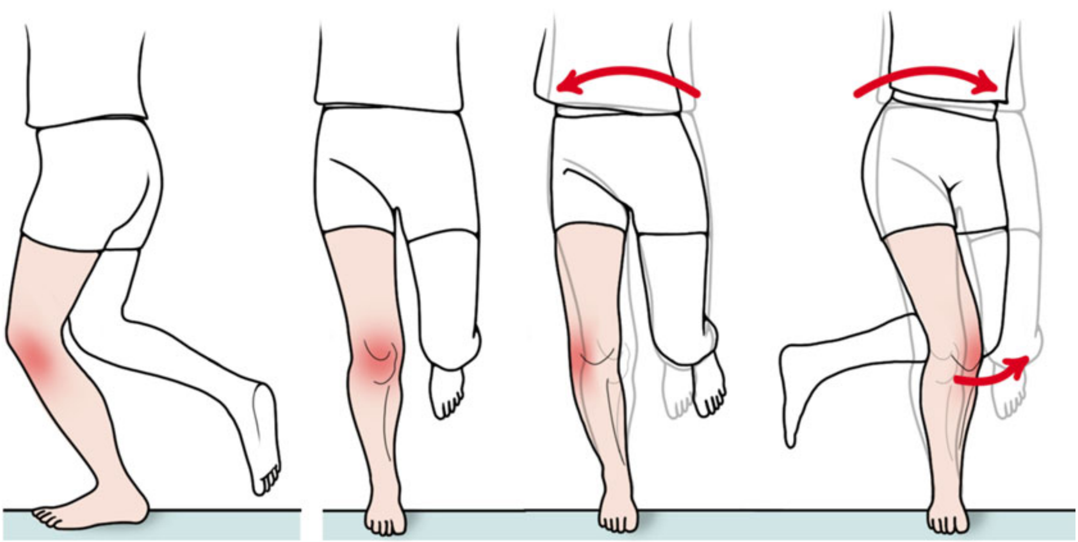

Fig. 13.4 Thessaly's test

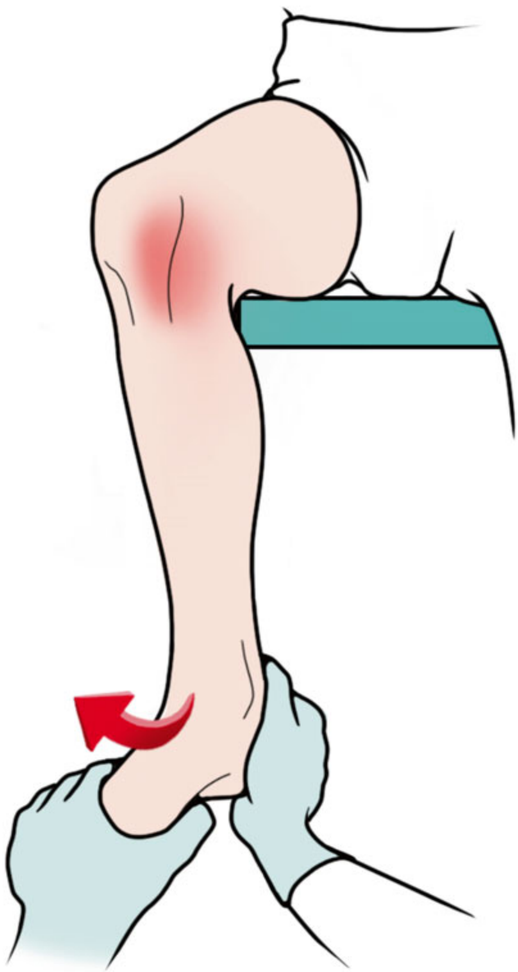

Fig. 13.5 Steinmann I test

13.2.3.6 Ege's Test

The test is performed with the patient in a standing position. The knees are in extension and the feet are held 30–40 cm away from each other at the beginning of the test. To detect a medial meniscal tear, the patient squats with both lower legs in maximum external rotation and then stands up slowly. For lateral meniscal tears, both lower extremities are held in maximum internal rotation while the patient squats and stands up. The test is positive when pain and/or a click is felt by the patient (sometimes audible to the physician) at the related site of the joint line (Fig. 13.6).

Level of evidence: sensitivity 66.1 % (77.7–89.8 %), specificity 86.0 % (65.3–96.6 %), positive predictive value 96.6 % (89.5–99.1 %), and negative predictive value 31.7 % (20.9–44.8 %)

13.2.3.7 Childress' Sign (Squat Test)

The patient squats and walks like a duck. If the test is positive, the patient will feel pain and cannot squat all the way down and will feel a snap or click from the knee joint (Fig. 13.7).

Level of evidence: sensitivity 67.9 % (56.5–77.6 %), specificity 59.9 % (34.0–79.0 %), positive predictive value 87.3 % (76.0–94.0 %), and negative predictive value 29.8 % (16.4–47.2 %)

13.2.3.8 Payr's Test

With knees flexed over 90° and legs crossed, a downward force on the knee leads to pain in the medial knee compartment due to compression. A positive test is associated with a lesion of the medial posterior horn (Fig. 13.8).

Level of evidence: sensitivity 59.5 % (39.0–77.0 %), specificity 79.1 % (68.7–86.8 %), positive predictive value 47.1 % (30.2–64.6 %), and negative predictive value 86.1 % (76.0–92.5 %)

13.2.3.9 Bohler's Test

In Bohler's test a varus stress and a valgus stress are applied to the knee: pain is elicited by compression of the meniscal tear (Fig. 13.9).

Level of evidence: sensitivity 41.4 % (25.1–60.7 %), specificity 79.5 % (68.6–87.1 %), positive predictive value 43.3 % (26.0–62.3 %), and negative predictive value 78.3 % (76.6–86.3 %)

13.2.3.10 Combination of Different Tests

Overall, poor sensitivity and specificity have been found for meniscus tests, with very variable results among the reports in the literature. However, more satisfactory results can be obtained by combining different tests [6, 12, 17, 19].

Thus, no test should be preferred over the others, but several tests should be used together to improve the clinical detectability of a meniscal lesion.

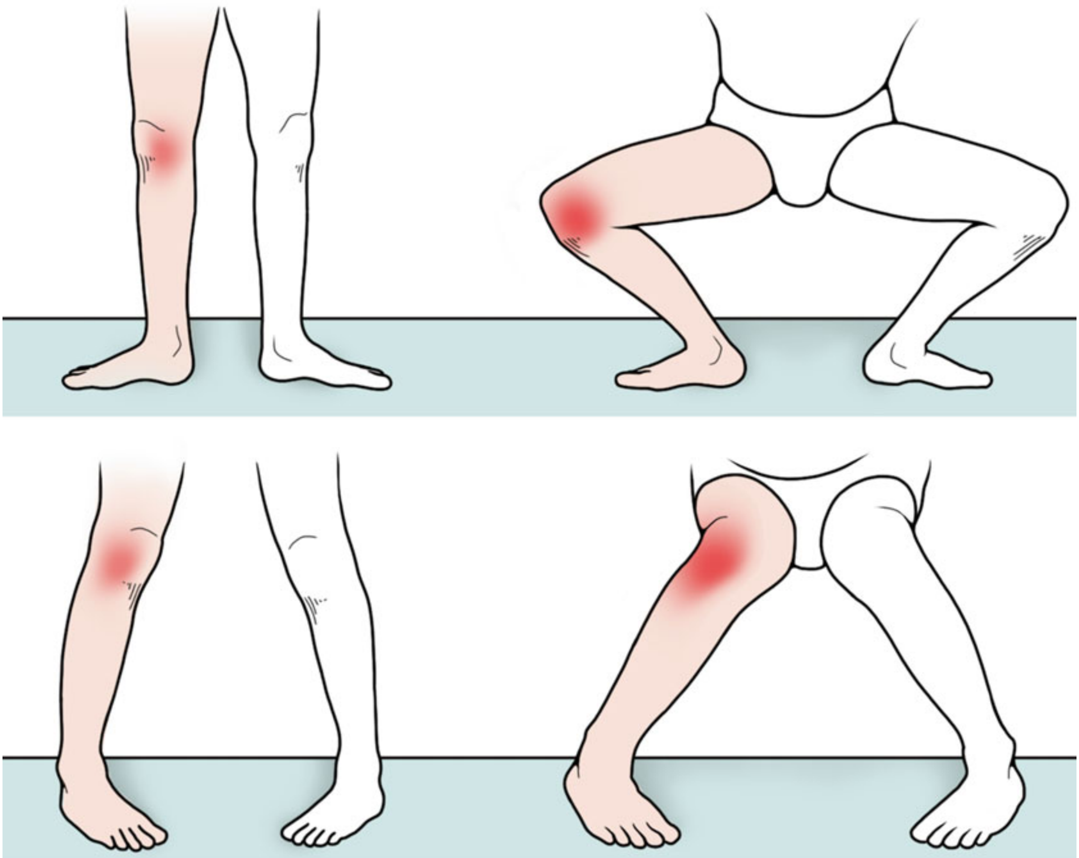

Fig. 13.6 Ege's test

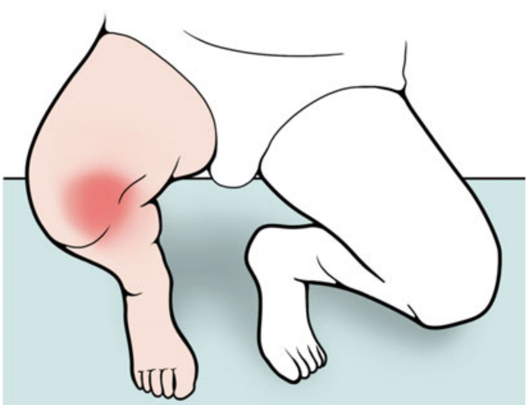

Fig. 13.7 Childress' sign (squat test)

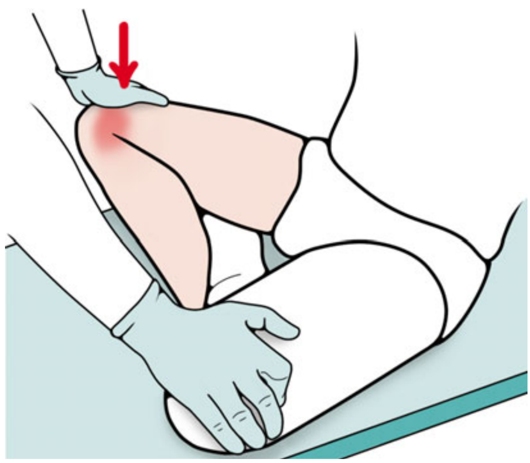

Fig. 13.8 Payr's test

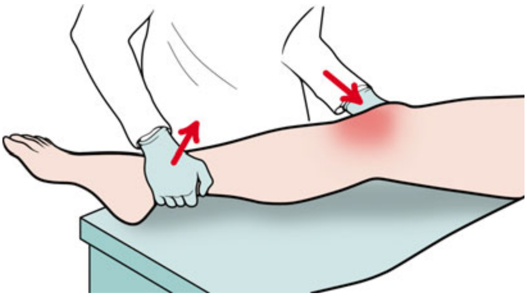

Fig. 13.9 Bohler's test

13.3 Standard X-Rays

Although the meniscus is not normally visualized in conventional radiography, standard X-rays of the knee are able to provide useful information in case of meniscal pathology. Different details have to be investigated depending on the suspected etiology of the meniscal lesion and the age of the patients.

In case of a suspected traumatic meniscal tear in a young patient, standard X-rays should be investigated to exclude fractures related to the traumatic event. Anteroposterior and lateral views of the injured knee are recommended.

In a patient older than 40 years with nontraumatic knee pain, indication for treatment may change, depending on whether a degenerative meniscal tear is found in an osteoarthritic knee or whether an isolated meniscal tear is detected. Thus, X-rays are taken to assess the presence of any degenerative articular changes, like osteophytes and joint space narrowing. Osteophytes are detectable in bilateral weight-bearing anteroposterior and lateral views, and their appearance generally precedes joint space narrowing, which requires further projections in addition to the standard ones. Weight-bearing X-rays have to be taken bilaterally, in order to evaluate the height of the joint space of the weight-bearing area and compare it to the contralateral side.

Since the most frequently involved zones of articular cartilage overuse are the contact areas of knees positioned in between 30° and 60° of flexion, and since conventional extension weight-bearing anterior radiographs may miss slight joint space narrowing [30], an anteroposterior view in flexion should be added: the Schuss view is a weight-bearing posteroanterior radiograph of the knee at 30° of flexion [25]; the Rosenberg view is taken at 45° of flexion and also allows to detect earlier degenerative changes [26]. No superiority of one above the other has been demonstrated in the literature.

Narrowing of the cartilage space ≥2 mm is strongly correlated with grade 3 or 4 cartilage degeneration [26]; moreover narrowing of the joint space is not influenced by meniscectomies, and thus it can be considered pathognomonic of osteoarthritis [24].

Acknowledgments The authors would like to thank Maria Pia Cumani from Scuola di Disegno Anatomico, Rizzoli Orthopaedic Institute, Bologna, Italy, and Elettra Pignotti and Keith Smith from the Task Force of Rizzoli Orthopaedic Institute, Bologna, Italy.

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Preoperative MR Imaging of the Meniscus

14

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Contents

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14.1 Introduction

Since its inception into clinical practice in the 1980s, magnetic resonance (MR) imaging has become the best imaging gold standard for evaluating meniscal pathologies. MR shows a high accuracy (74–79 %), sensitivity (73–84 %) and specificity (75–81 %) in detecting meniscal tears [6, 16, 20–22].

Before MR, arthroscopy has been possessed to be the optimal diagnostic tool for internal derangements of the knee joint. However, arthroscopy is an invasive procedure and is nowadays preferably performed for treatment purposes. Advances in MR technique, such as dedicated high-channel knee coils and increasing magnetic field strength, make high-resolution images possible in an appropriate scan time. The role of MR imaging has expanded to a critical decision-making tool providing information that may not only alter the surgical technique but also provide information that would obviate surgery.

14.2 Imaging Technique

Sagittal, coronal and axial intermediate-weighted turbo-spin-echo (TSE) fat-saturated (FS) sequences have been recommended for the evaluation of meniscal lesions. Additional three-dimensional thin-sliced (<1 mm) isotropic sequences allow multiplanar reformations of the menisci. T1-weighted images in coronal or sagittal

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_14

orientation complete a standard knee protocol. The field of view should be adjusted to the knee joint with slice thickness of 3 mm for TSE sequences. High resolution is maintained with 3 tesla MR scanners and the use of a dedicated knee coil [4, 5, 9, 15, 17, 19, 25, 32].

14.3 Meniscal Tears

The meniscus is composed of fibrocartilage with low signal intensities (SI) in all sequences. MR criteria for a meniscal tear include linearly increased SI unequivocally contacting the inferior or superior articular surface [9, 15, 34]. High SI penetrating the free edge of the meniscus may as well represent a tear. If these criteria are present on at least two consecutive images, sensitivity and specificity for the detection of a meniscal tear increase [6, 7, 9]. In contrast, menisci with only one abnormal MR image were considerably less likely to be found torn at arthroscopy [7].

Intrasubstance SI should not be mistaken as a tear as this most likely represents mucoid degeneration [15, 21]. In children and adolescents, linear high SI not penetrating the articular surface of the meniscus reveals residual meniscal vessels, which are mainly present in the posterior horn [15, 21, 31].

14.4 Imaging Pitfalls

A profound knowledge of normal MR anatomy and its variants is crucial. These should not be misinterpreted as meniscal tears.

Linear high SI at the attachment of the intermeniscal transverse ligament of the anterior meniscal horns is frequently seen and should not be mistaken as a tear [10, 15]. Anterior (Humphrey) and posterior (Wrisberg) meniscofemoral ligaments are considered as third part of the posterior cruciate ligament, but are inconsistently seen [23]. On sagittal and coronal slices, the meniscofemoral ligaments may be misinterpreted as meniscal flap tears. The oblique meniscomeniscal ligament attaches at the anterior horn of the meniscus to the posterior horn of the contralateral meniscus, coursing through the intercondylar notch between the cruciate ligaments [27]. The linear shape of a synovial recess bearing the popliteus tendon, which is close to the posterolateral meniscus, may be misdiagnosed as a tear [10, 15]. A wavy pattern of the inner zone of the body of the meniscus at sagittal images is called a "meniscal flounce" [32] (Fig. 14.1). This represents a buckling of the meniscus in slight flexion and may disappear when the knee is fully extended. A small fluid-filled bursa may be detectable in over 90 % of cadaveric knees between the medial collateral ligament and the posterior horn of the medial meniscus [33]. Therefore, differentiation between this bursa and a meniscocapsular separation may be difficult.

The discoid meniscus is a frequent anatomic variant of the knee, in which the meniscus is thickened and disc shaped, covering a greater

Fig. 14.1 Meniscal flounce (*arrow*) is an anatomic variant of the inner portion of the meniscal body and may diminish in full extension

area of the tibial plateau than the normal semilunar meniscus. According to the classification described by Watanabe, the discoid menisci can be divided into three types: complete, incomplete and Wrisberg variant [2, 28]. The most employed criterion for the detection of discoid menisci is the presence of three or more completely body segments on sequential sagittal images or a meniscal body on coronal images greater than 15 mm sometimes extending into the intercondylar notch [14, 24, 28, 30].

A lateral discoid meniscus is more common than a medial one. It has a prevalence of 1.2–16.6 % and 0.03–0.6 %, respectively [2, 24, 28].

14.5 Classification of Meniscal Tears

Meniscal tears can be classified regarding the orientation of the meniscus (longitudinal, radial or parrot-beak tear) or the spatial plane (horizontal or vertical tear). Special types of meniscal tears include bucket handle, flipped meniscus, complex tears, as well as meniscal root tears.

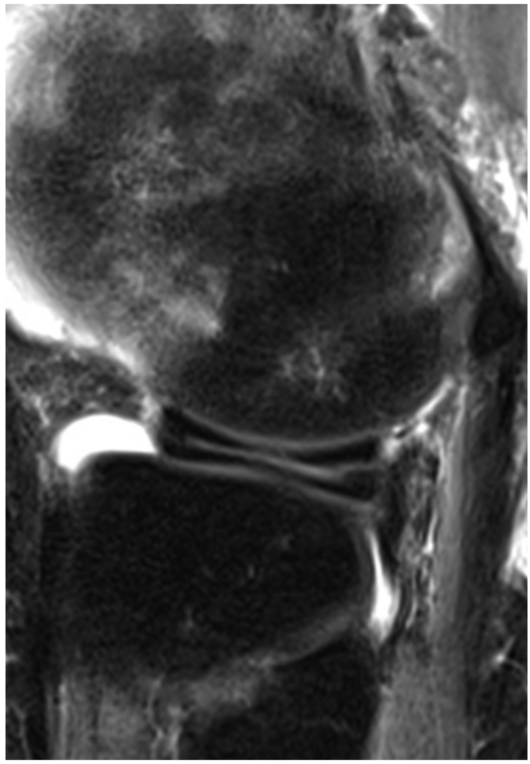

Fig. 14.2 Linearly high signal intensity along the long axis of the lateral meniscus reflects a longitudinal tear

14.5.1 Longitudinal Tear

A longitudinal tear runs parallel to the long axis of the meniscus, perpendicular to the tibial plateau. It can involve a single articular surface or both articular surfaces, separating the meniscus into inner and outer segments (Fig. 14.2). Depending on whether the tear is partial or full thickness, it is considered stable or unstable [15].

Longitudinal tears are typically seen in younger patients after trauma and are highly associated with tears of the ACL [25]. The tear is predominantly seen in the peripheral or middle third of the meniscus and usually originates at the posterior horn [15]. Sagittal images are best suited to demonstrate these tears. Coronal images are used to assess extension into the meniscal body. Peripheral longitudinal tears involving the posterior horn of the lateral meniscus are often difficult to identify, which is due to the complex anatomy and posterior attachments of the meniscus.

14.5.2 Radial Tear

A radial tear involves the free edge of the meniscus perpendicular to the tibial plateau and long axis of the meniscus, separating the meniscus into anterior and posterior portions (Fig. 14.3). The depth of the tear should be classified as partial or complete. Diagnosis of radial tears is difficult on MR imaging, and they constitute a large portion of false-negative MR imaging studies [15, 18, 25]. A considerable number of signs have been described to increase the detection of radial tears:

- *Truncated triangle sign* on sagittal and coronal images describes the amputated edge if slice orientation parallels the tear [11].
- *Cleft sign* describes a gap of the meniscus on sagittal and coronal images [11] (Fig. 14.3a).
- *Marching cleft sign* [11]. Tears that occur at the junction of the anterior horn and body are

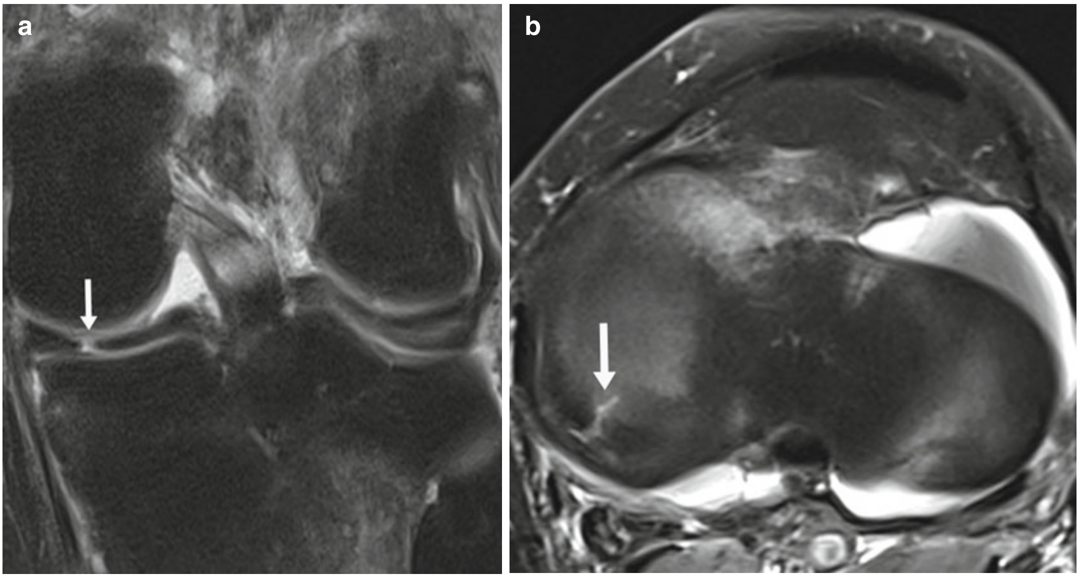

Fig. 14.3 Coronal intermediate-weighted fat-saturated image shows the cleft sign (**a**, *arrow*) of the medial meniscus; axial image confirms the radial tear (**b**, *arrow*)

typically oriented obliquely relative to the imaging planes and therefore take on the appearance of a marching cleft.

- *Ghost meniscus sign* describes the complete absence of focal meniscal tissue [11].

The two most effective signs are the cleft and the truncated triangle signs. These two signs increase detection of radial meniscal tears to 76 %. Taking all signs into combined consideration, sensitivity of the detection of radial meniscal tears increases to 89 % [11]

14.5.3 Parrot-Beak Tear

The parrot-beak tear, also called oblique tear, classically reflects a radial tear centrally with an additional longitudinal component peripherally. On at least one MR image, the free edge is blunted. On sequential images a vertically oriented longitudinal tear becomes visible [15]. This type of tear is most commonly traumatic and usually occurs in younger, athletic patients [15].

14.5.4 Horizontal Tear

Horizontal tears, also called cleavage tears, classically involve either the free edge or one of the articular surfaces and propagates peripherally (Fig. 14.4). This degenerative tear is most commonly seen in the elderly [15]. Meniscal cysts in the meniscocapsular junction can originate from these types of tears [15, 25].

14.5.5 Bucket-Handle Tear

A bucket-handle tear represents a longitudinal-vertical tear with central migration of the inner handle segment and is the most frequent type of displaced tear [10, 15, 25, 26].

Several imaging findings have been described with this type of meniscal tear (Fig. 14.5):

- *Double posterior cruciate ligament (PCL) sign.* Migration of the central fragment into the intercondylar notch anterior to and paralleling the PCL simulates two PCLs (Fig. 14.5b) [25, 26, 29, 35]. This sign is believed to be

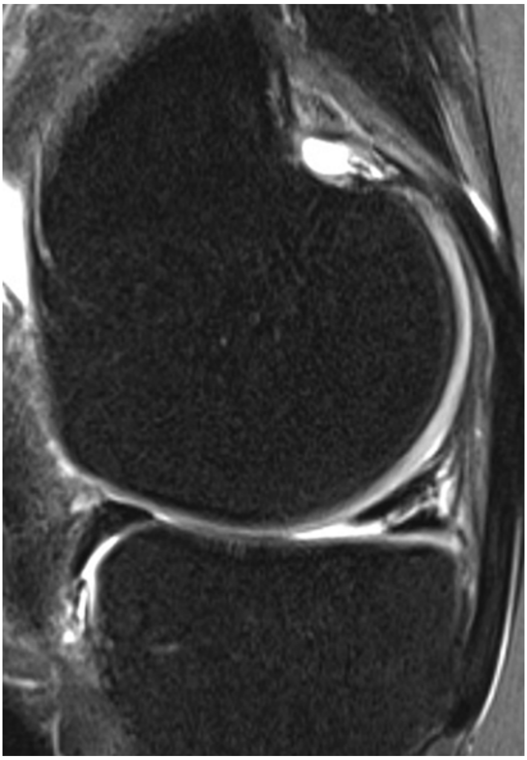

Fig. 14.4 Horizontal tear penetrates the inferior surface of the medial meniscus

highly specific but not sensitive because not always visible [19].

- *Double anterior horn or flipped meniscus sign.* A meniscal fragment is flipped anteriorly leading to a large or even doubled anterior horn [19, 25, 26, 35] (Fig. 14.5c).
- *Fragment within the intercondylar notch sign* [19, 25, 26, 29, 35]. It can be seen on coronal images (Fig. 14.5a).
- *Absent bow-tie sign.* This sign is based on the typical appearance of the normal meniscal body resembling a bow tie on at least two successive sagittal images. If a portion of the meniscal body is displaced and therefore blunted, the result is either lack of visualization of the body or visualization reduced to a single slice on the sagittal sequences [10, 12, 13, 25].
- *Truncated meniscus.* Amputation of the inner zone of the meniscal body on coronal images (Fig. 14.5a) [8].

14.5.6 Flipped Meniscal Tear

A flipped meniscal tear is a special type of a bucket-handle tear [29]. In contrast to the bucket-handle tear, the flipped meniscal tear involves more often the lateral meniscus (Fig. 14.6). The flipped meniscus fragment might be small and can therefore easily be missed. Volume change of the meniscus is an important sign, which alerts the clinician screening thoroughly for a potentially flipped meniscus.

14.5.7 Complex Tear

Complex tears cannot be classified into a single category; containing a combination of different tears should be described as complex [15, 25] (Fig. 14.7). Most frequently a degenerative horizontal tear is preexisting with a new trauma-related vertical component [15, 25]. Complex meniscal tears are frequently associated with meniscal extrusion [3].

14.5.8 Root Tear

Both the medial and lateral menisci have strong posterior attachments, which are called the meniscal roots. These important structures keep the meniscus in place, provide stability to the circumferential hoop fibres of the meniscus and prevent meniscal extrusion. Biomechanical tests showed that functional impairment is equal in root tears as after total meniscectomy [1]. Thus, tears of the meniscal root are considered to be serious injuries (Fig. 14.8). Underdiagnoses of root tears on both MR imaging and arthroscopy have led to increased attention in recent surgical and radiologic literature. Root tears have been described only posteriorly [10]. Knees with meniscal extrusion have to be carefully evaluated for potential root tears. Root tears of the lateral meniscus are highly associated with ACL tears [5, 25].

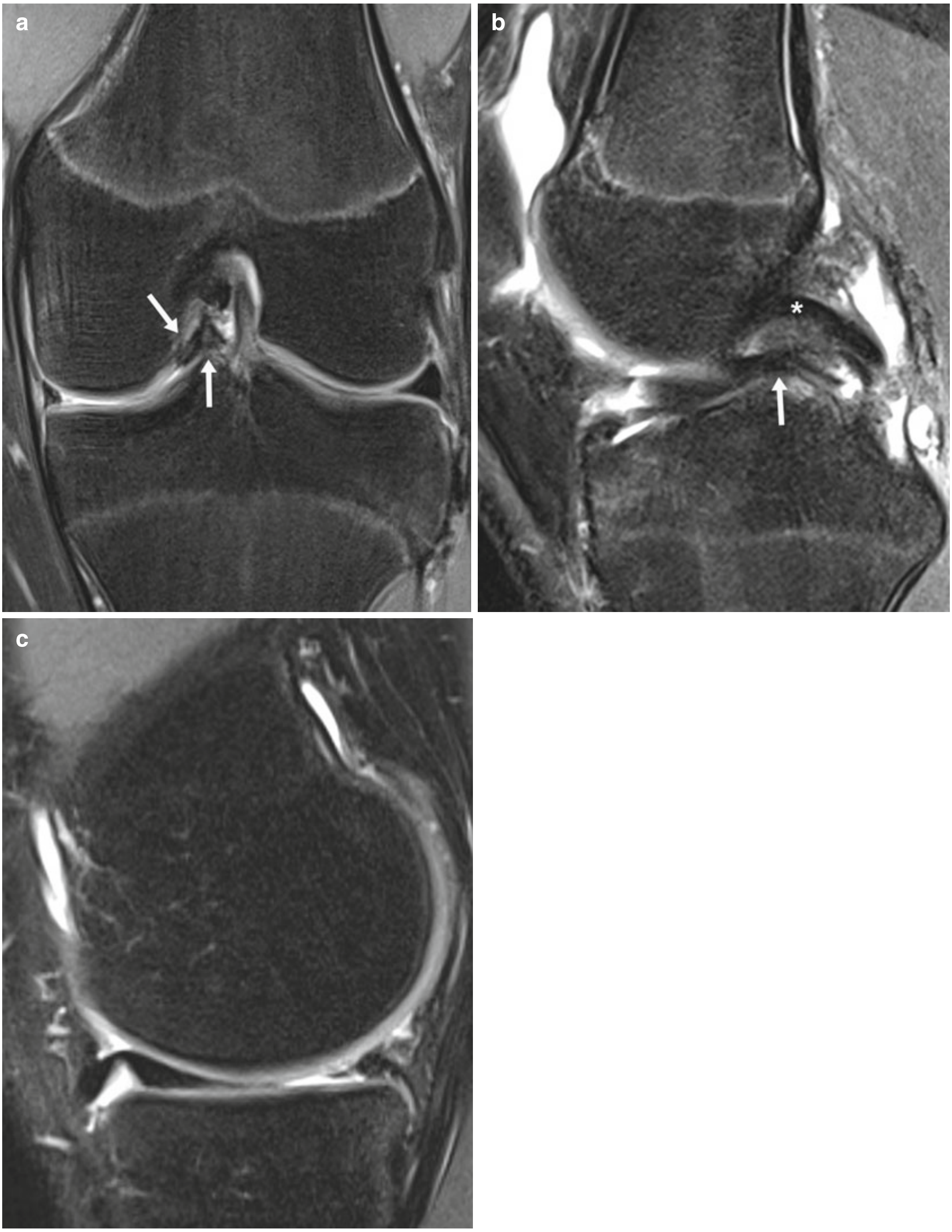

Fig. 14.5 Bucket-handle tears. Coronal image (**a**) shows a meniscal fragment (*arrows*) within the intercondylar notch; the meniscal remnant is truncated. Sagittal image (**b**) shows a meniscal fragment within the intercondylar notch close to the PCL (*asterisk*), known as the double PCL sign. Anterior flipped bucket-handle tear (**c**) of the medial meniscus revealing a double anterior horn sign

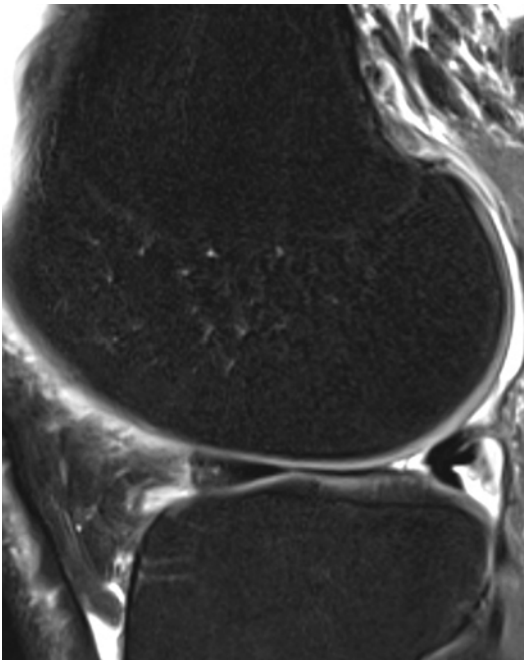

Fig. 14.6 Flipped tear of the lateral meniscus

Fig. 14.7 Complex tear of the medial meniscus (*arrows*)

Fig. 14.8 Root avulsion tear (*arrow*) of the medial meniscus

14.6 Meniscal Degeneration

Intra-meniscal high SI without penetration of the articular surface most likely reflects degeneration. This high SI can be globular or linear. Degeneration represents a fragmentation of collagen bundles caused by the difference in frictional forces of the superior and inferior surface of the meniscus [15].

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Meniscus Ultrasound

15

Burt Klos and Stephan Konijnenberg

Contents

15.1 Introduction

Since 2008 we have been applying ultrasound imaging in sport injuries and trauma of the knee joint.

We used handheld equipment and we progressively improved our skills. We therefore quickly enhanced the image quality.

A special dimension was acquired with the use of dynamic imaging, recording improved images. Our setup of direct feedback from the ultrasound with the feedback from arthroscopic images turned out to reduce the learning curve and gave the possibility of obtaining pictures that

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-662-49188-1_15) contains supplementary material, which is available to authorized users.

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_15

Table 15.1 Advantages/disadvantages of MSU/MRI

	MSU	MRI
Costs	Cheap	Expensive
Learning curve	Steep	Not applicable
Dynamic imaging	++	Only selected centers
Claustrophobia	Not applicable	5 %
Patient interaction	++	Not applicable
Therapeutic intervention	+ Possible	Seldom

had not been seen before by the companies selling the ultrasound equipment. Even up till this moment, very few colleagues consider ultrasound as an important imaging tool.

We think that ultrasound is a reliable tool to study the meniscus without the need to order a more expensive imaging, such as magnetic resonance imaging (MRI).

15.1.1 MRI Verses MSU

Advantages of musculoskeletal ultrasound (MSU) versus MRI are included in Table 15.1. Ultrasound has a steep learning curve, which needs to be overcome by increasing the number of patients analyzed and by interactive feedback.

We use ultrasound in the outpatient clinic during most of our consultation hours.

15.2 Imaging Assessment Meniscus

15.2.1 Radiographs

Degenerative arthritis and chondrocalcinosis are signs of possible meniscus degeneration.

Other lesions, like bone tumors, can be excluded.

15.2.2 Ultrasound

Diagnosis of ligament, meniscus, or cartilage lesions may be assessed with ultrasound imaging.

Dynamic ultrasound is indeed helpful in predicting reparability of lesions. In revision cases it is sometimes difficult to divide scars from fresh lesions. In these cases, dynamic imaging is extremely helpful to detect opening and closing of the meniscus tear. In this chapter all figures are orientated with the femur toward the left side and the tibia toward the right side. If another orientation is used, it is mentioned in the figure caption.

15.2.3 Probes

Ultrasound probes are very important for the overall system performance.

Nowadays most transducers use piezoelectric elements, which transmit, receive, and convert electrical signals and mechanical vibrations.

Improvement of the ultimate quality of ultrasound image depends on the type of probe, the number of piezoelectric elements, the quality of the ultrasound machine, and last but not least the experience of the ultrasonographer.

The probe frequency we use for meniscus ultrasound is mostly between 5 and 12 Mhz.

In the last 8 years we developed methods to visualize the cartilage, cruciate ligaments, and collateral ligaments, first with indirect signs and more recently by direct images. We started performing meniscus and knee ultrasound with smaller hand held equipment and we learned that better imaging could be achieved with stronger high-resolution equipment and special probes.

Dynamic imaging allows for:

- Movements during imaging.
- Displacements, which can be seen as a secondary sign of instability of the meniscus and ACL/PCL or other ligaments.
- Live feedback of the patient, who can sometimes produce a click or locking sensation while the ultrasound probe is on the joint space.
- Intra-articular injections in case of unclear symptoms.
- It can be helpful in patients with pes anserinus tendinitis to inject local anesthetics under ultrasound guidance under the pes tendon.
- With this diagnostic tool, painful tendinitis or scar tissue can be ruled out as a course of knee pain.

Figures 15.1, 15.2, and 15.3 show the improvement of images over the last 8 years.

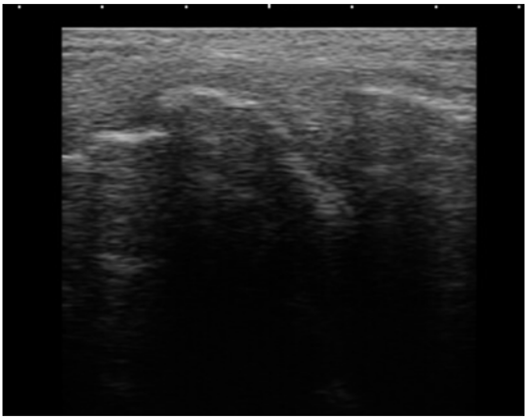


Fig. 15.1 Image meniscus 2006/2008, multifrequency linear probe with 64 piezoelectric elements. left femur, right tibia in prone position, the probe is vertical from the back of the knee

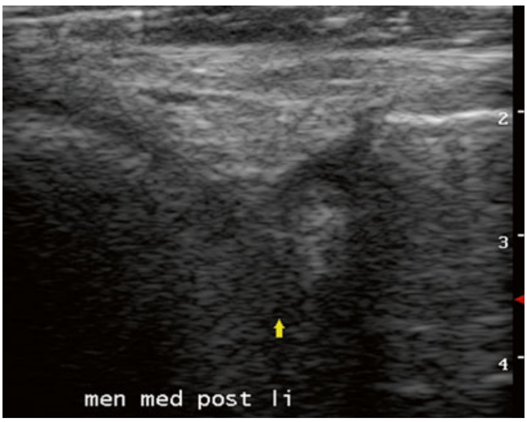


Fig. 15.2 Image meniscus 2008/2009, multifrequency linear probe with 128 piezoelectric elements

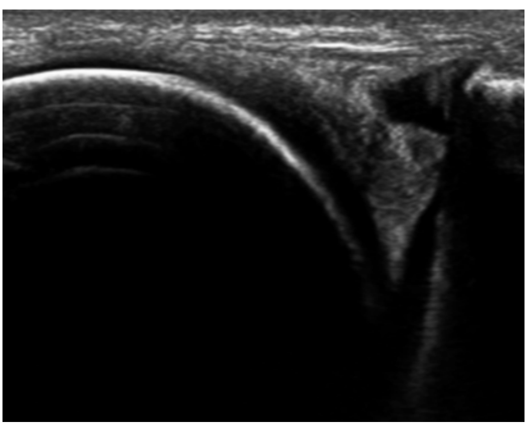


Fig. 15.3 Image meniscus 2015, broadband linear array high resolution probe 5-12 Mhz 256 piezoelectric elements, sonoCT

15.3 Knee Ultrasound Equipment and Setup

15.3.1 Meniscus Scanning Positions

Ultrasound imaging is performed in both supine position and prone positions, additional dynamic positions, stressing the medial or lateral compartments can be helpful. In prone position rotation can be applied to the foot in order to check for meniscus instability with cruciate ligament insufficiency (Fig. 15.4).

Supine with knee in flexion (Fig. 15.5) allows for scanning of the anterior and middle horn, cartilage conditions, and corpora (loose bodies); in full-flexion dynamic examination, ACL resistance or ACL elongation; and in prone position, PCL and posterior horn lesions. Dynamic prone, scanning with rotation of the foot, can show femorotibial subluxation with secondary meniscus opening or pulling forces (Video 15.1). The patient can sometimes feel and recognize the pain with movement of the meniscus posterior horn lesion.

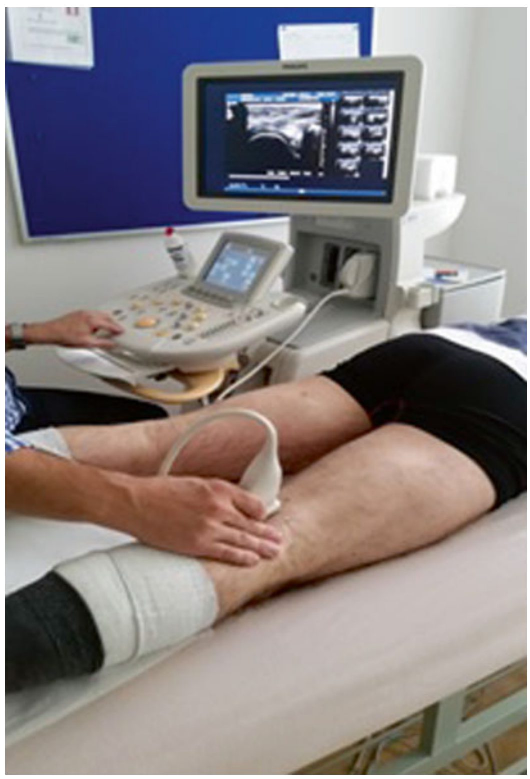


Fig. 15.4 Meniscus ultrasound in prone position, checking posterior horns, PCL , cysts and vascular pathology

Special conditions, which can be better visualized with ultrasound, are fresh combined injuries of ACL and menisci, where excessive fluid can be a problem in MRI images. For instance, we found that avulsion fracture of the lateral tibia plateau (Segond lesions) is 5–10 times more frequently seen in ultrasound than in MRI [3, 5] (Video 15.2).

Fig. 15.5 Meniscus ultrasound of flexed knee (90 degrees)

15.4 History of Meniscus Ultrasound

In 1990 the first research by Jerosch [11] in Germany was published on ultrasound for the knee, showing that the use is limited to cysts, bursitis, and jumper's knee.

In 2002 an Italian study by Azzoni [2] concluded that ultrasound is not accurate enough for diagnosis of meniscus injury.

Since 2008 many reports have been published finding improved scores for sensitivity and specificity comparable with data for MRI [1, 6, 24, 27, 29].

At the same time MRI specificity seems to decrease with degeneration of the joint, showing that the risk of false-positive findings increases with aging.

15.5 Normal Meniscus

Meniscus vascularization is easily detectable by ultrasound. In the lateral meniscus a large vessel sometimes mimics pathology. In this case the vascular Doppler technology may be helpful (Fig. 15.6). The lateral recessus of the lateral meniscus needs to be localized, because it may resemble a meniscus rupture. The meniscus recessus gives a straight line. A meniscus tear shows a blurred line. A meniscus tear shows a blurred line (Fig 15.10 and 15.11)

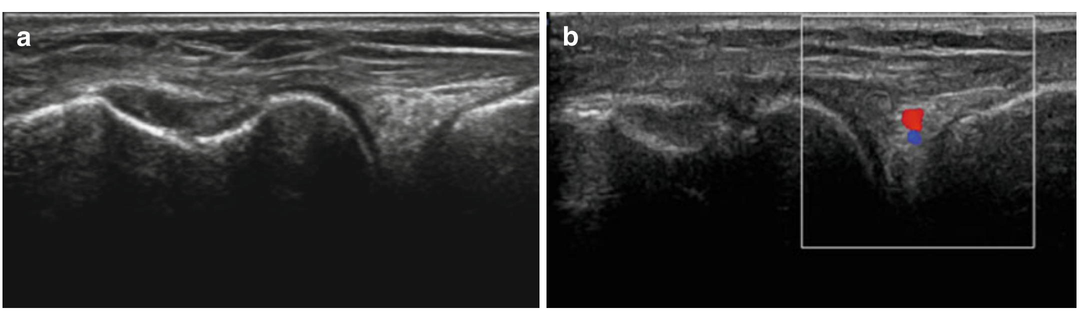


Fig. 15.6 (**a**) Anterolateral meniscus (**b**) Vascular Doppler technology

15.5.1 Lateral Meniscus Vascularization

Ultrasound of normal meniscus with location of vascularization (red zone) (Figs. 15.6 and 15.7)

The presence of a vessel between the lateral meniscus and the anterolateral capsule is a normal consistent finding. This also applies to the medial side. Thus, these ultrasound findings should not be considered pathological (Figs. 15.8 and 15.9).

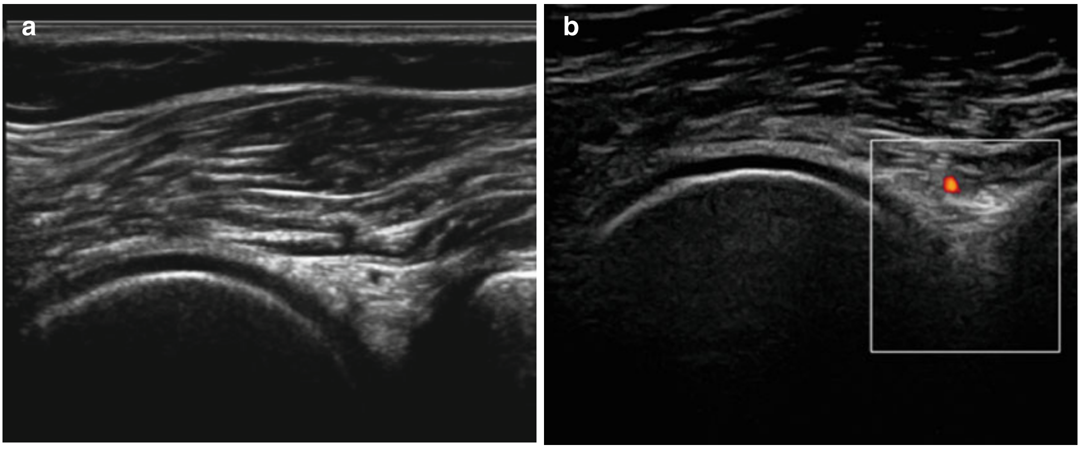


Fig. 15.7 (**a**) Posterolateral meniscus (**b**) Vascular Doppler technology

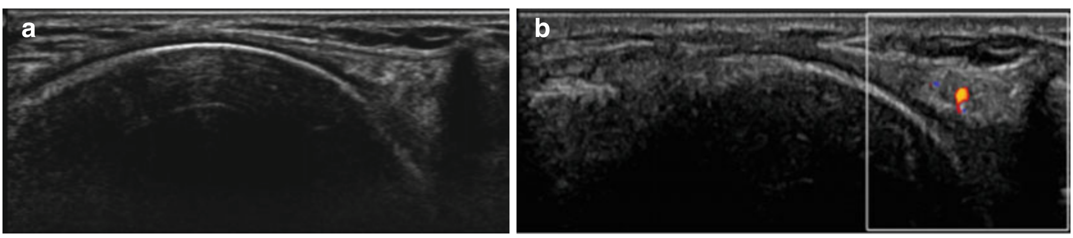


Fig. 15.8 (**a**) Anteromedial meniscus (**b**) Vascular Doppler technology

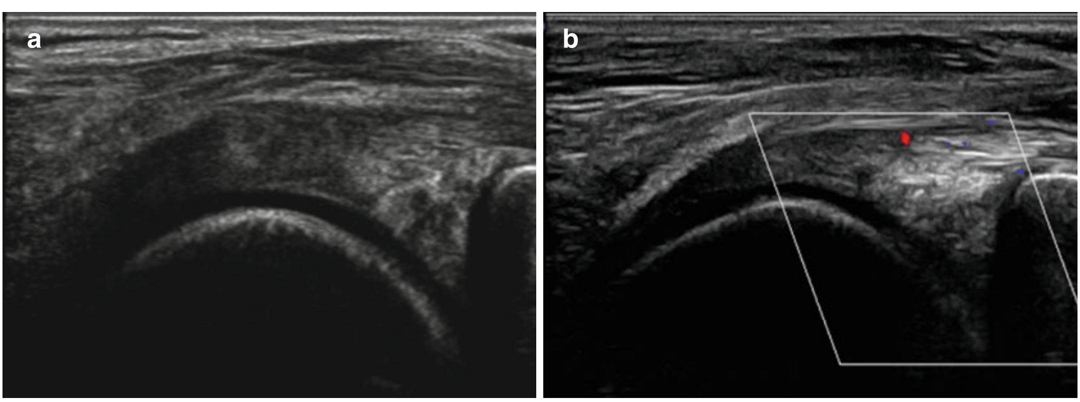


Fig. 15.9 (**a**) Posteromedial meniscus (**b**) Vascular Doppler technology

15.6 Conditions Suggesting Pathology

15.6.1 Lateral Posterior Popliteal Recessus

Normal lateral popliteal recessus meniscus lateral posterior (Fig. 15.10).

To be compared to a meniscus tear (Fig. 15.11).

15.7 Meniscus Pathology

15.7.1 Meniscus Tear

Several types of meniscus lesions can be detected by ultrasound. Direct visualization is nowadays possible in prone position (for the posterior part) if the meniscus is not dislocated. In case of a bucket-handle lesion, we can see a short posterior horn, where the front part is dislocated into the knee joint.

In the corner where the meniscus is twisted to a bucket handle, we can see a double meniscus, often rounded and surrounded by fluid (Figs. 15.12 and 15.13).

15.7.2 Meniscus Flap Tear

Some flap tears can be felt by the patient at the joint line and can be detected by ultrasound. A report on this finding was in presented by Moraux from France in 2008. With this imaging technique, the meniscus can be differentiated from a loose body, before surgery.

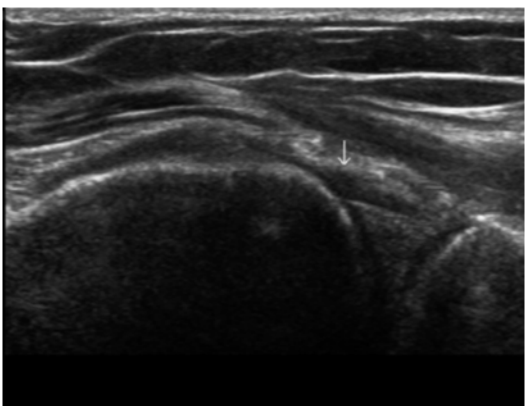


Fig. 15.10 Normal lateral popliteal recessus meniscus lat post

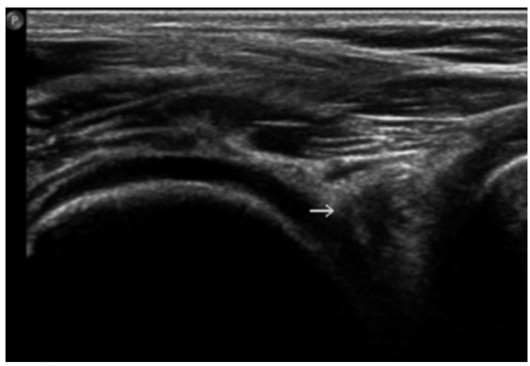


Fig. 15.11 Meniscus tear lateral meniscus

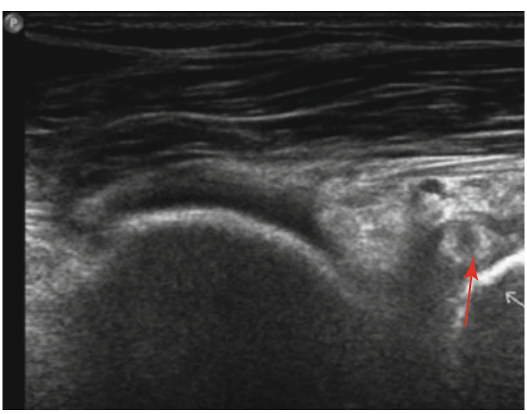


Fig. 15.12 Lateral meniscus posterior lesion with instable flap tear tibia site (see Fig. 15.13)

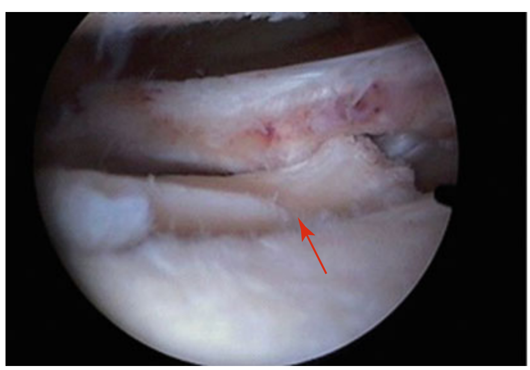


Fig. 15.13 Flap tear posterior lateral meniscus

15.7.3 Anterior Horn Dislocation of the Medial Meniscus

This condition (Fig. 15.14) is dynamically and clinically visualized in weight bearing.

Dynamic ultrasound used during weight bearing shows the anterior dislocation of the anterior horn of the medial meniscus [18, 21].

15.7.4 Meniscus Bucket Handle

The sign of a dislocated meniscus bucket-handle tear is a short meniscus (Fig. 15.15) with defect on the posterior aspect and double contours in the center and middle parts of the meniscus. Cartilage damage can be detected in recurrent and chronic cases (Video 15.3).

15.7.5 Hidden Lesions

We found some lesions more detectable by ultrasound than by MRI (Fig. 15.16 a–c).

Some specific lesions, called hidden lesions, which are located in the periphery of the posterior horn, are difficult to identify on MRI, but can be recognized in ultrasound images.

These lesions are described by Sonnery-Cottet and Neyret [20, 26].

In recent literature from MRI accuracy, it was obvious that especially lesions of the posterior horns of the meniscus can be missed on MRI studies [23].

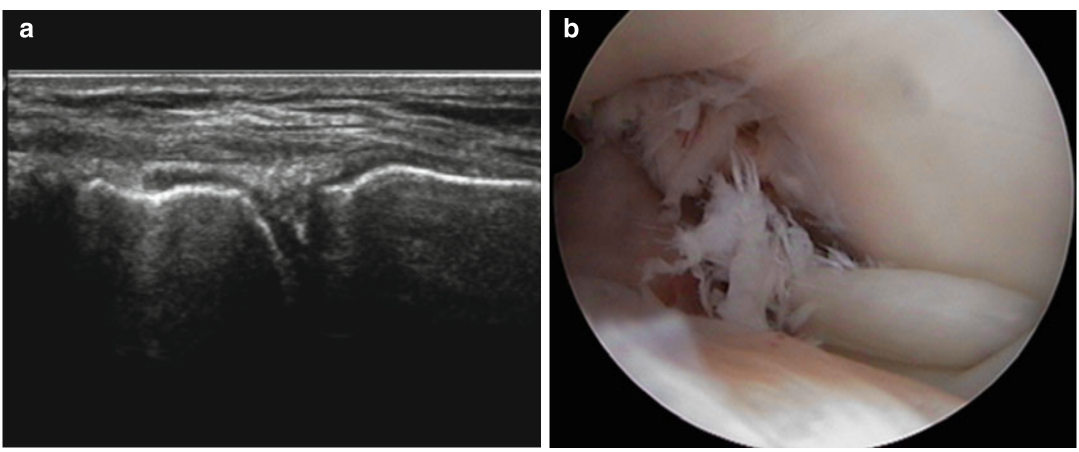
Figs. 15.14 Arthroscopic image meniscus anterior horn dislocation medial meniscus

15.8 Meniscus Combined Lesions

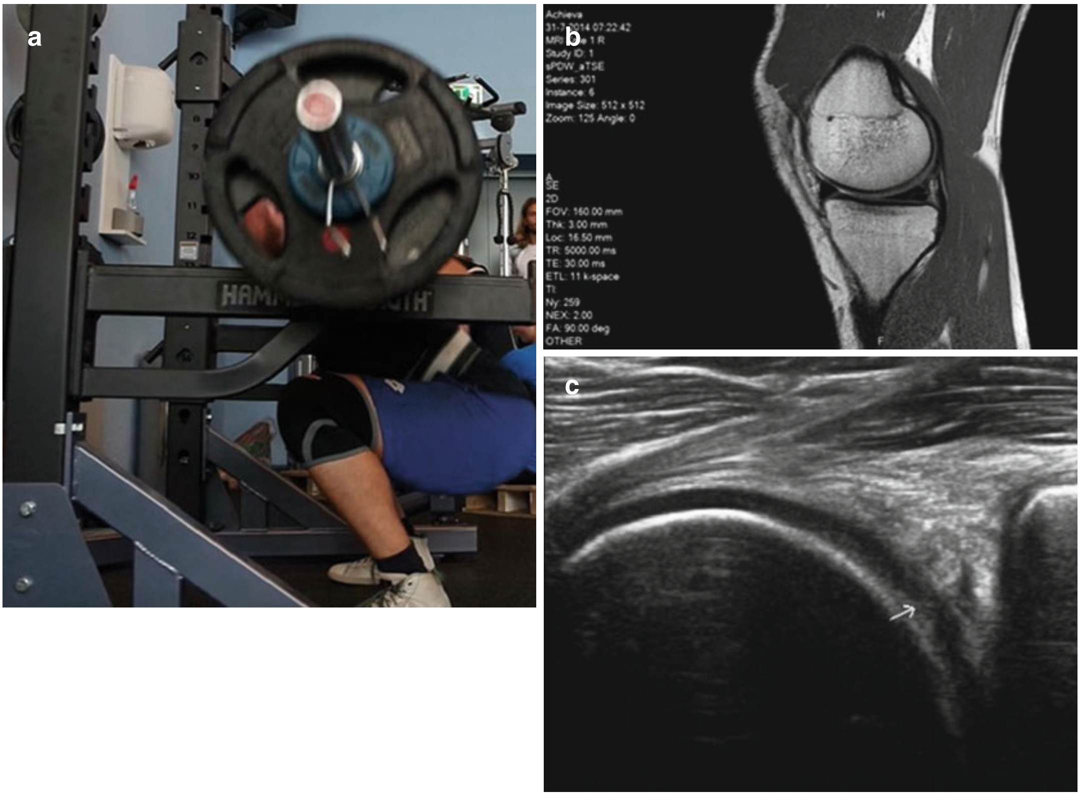
15.8.1 Meniscus and Anterior Cruciate Ligament Instability

In anterior cruciate ligament lesions, the pulling forces and rotation on the posterior parts of the meniscus increase. In prone position it is possible to rotate the knee in 40° of flexion.

In this position the displacement of the posterior medial plateau is visible in relation to the



Figs. 15.15 (**a**) Knee right medial posterior short meniscus (**b**) Arthroscopy image of dislocated medial bucket handle



Figs. 15.16 In this patient 24-year old powerlifter (**a**) the meniscus lesion was not found on MRI (**b**) but seen on dynamic high resolution ultrasound (**c**)

medial femur condyle and the pulling forces opening and closing the posterior part of the medial meniscus (Figs. 15.17, 15.18, and 15.19) (Video 15.1)

15.8.2 Meniscus Follow-Up in ACL-Deficient Knees

In conservative treatment of ACL lesions, the knee kinematics can be analyzed with sequential ultrasound examination to check the force on the posterior horn of the menisci. When a sign of imminent meniscus rupture is present, reconstruction of the ACL is mandatory. This can prevent secondary damage in an ACL-deficient knee. In these cases, the patient can be more easily followed with ultrasound than with MRI [30].

15.9 Meniscus Repair

15.9.1 Ultrasound for Meniscal Repair

We perform repair of meniscus ruptures in:

- Patients under 35 years of age, with reparable lesions and no degeneration (MRI/ultrasound).
- Patients over 35 with total meniscal dislocation especially in ACL cases.
- Hypermobile meniscus with recurrent locking.

Meniscus (re)rupture can occur without obvious trauma or with squatting.

Most patients describe flexion and or rotation from the injured knee while twisting the knee.

Fig. 15.17 Meniscus ultrasound rotation in prone position

The knee is usually painful in acute ruptures, but severe variety is recorded in symptoms.

Examination assesses the amount of swelling and location of pain. Swelling is variable and can limit the range of motion. Extension is usually limited in locked dislocation but can be hard to distinguish with acute swelling.

Dynamic ultrasound is able to detect dislocation and repairability of the meniscus (Video 15.3).

Power Doppler imaging can be performed to check for the vascularization of the meniscus, as most of the surgeons prefer to repair meniscus lesions in the vascularized zone.

Some specific vessels, for instance, a normal feeding vessel, can be detected between the lateral meniscus and the collateral ligaments (Fig. 15.16).

15.9.2 Meniscus Spontaneous Healing

When the meniscus tear is located in a peripheral vascularized part of the meniscus, spontaneous healing can be monitored (Fig. 15.20). If the patient is recording persistent symptoms, a meniscus repair can be scheduled. If the lesion is combined with an ACL deficiency, a combined procedure is advised.

In some cases of conservative treatment of an ACL rupture, we recorded persistent pain on the

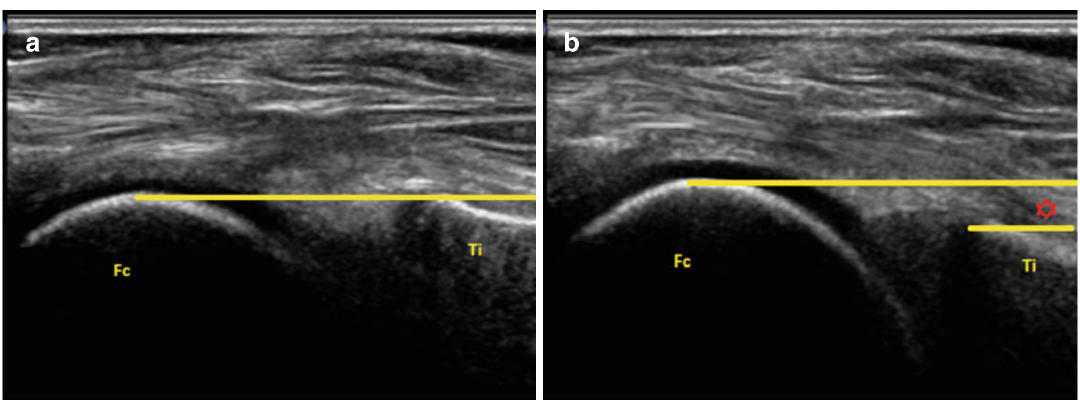


Fig. 15.18 Unaffected side

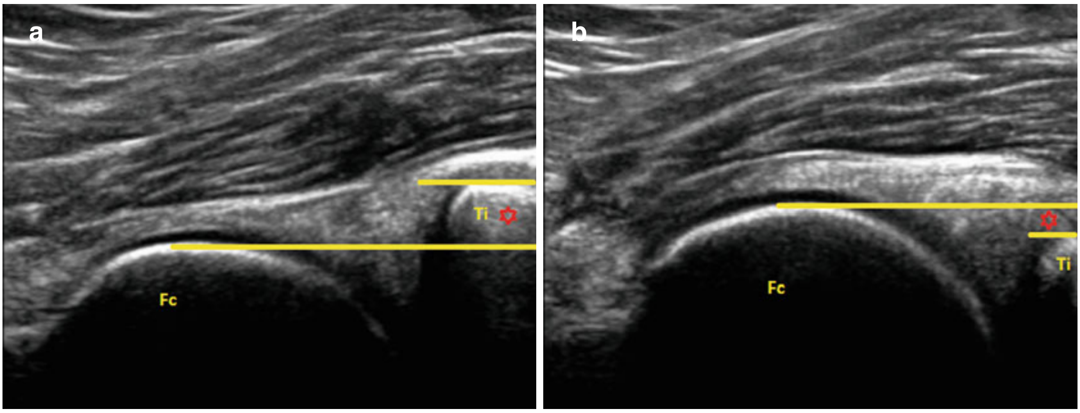


Fig. 15.19 Affected side (instability)

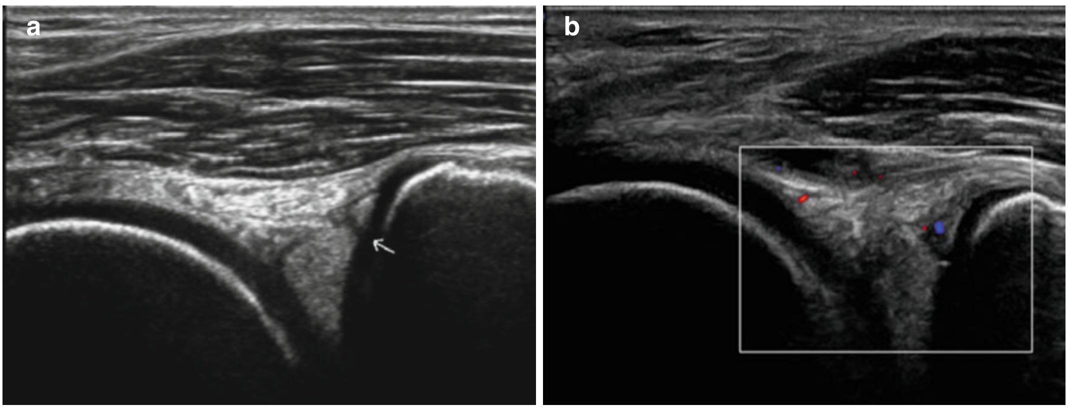


Fig. 15.20 (**a**) Peripheral Medial Meniscal lesion (**b**) Vascular Doppler technology

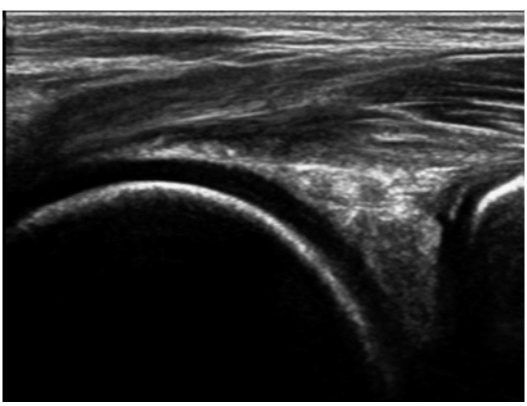


Fig. 15.21 Spontaneous healing 1 month post trauma

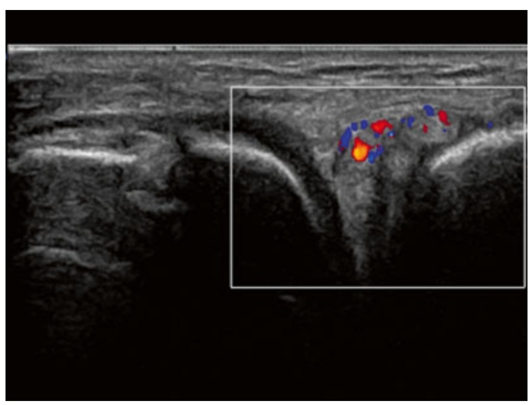


Fig. 15.22 Ultrasound powerdoppler vascularisation posterior horn in healing meniscus

joint space. We found meniscus lesions in these patients even before a rupture could be found with arthroscopy. These lesions have a good prognosis after ACL reconstruction (Fig. 15.21). Trephination of the meniscus in this condition is an option to promote vascularization.

15.9.3 Meniscus Reparability

Peripheral tears can have a good healing capacity, especially if they occur in the vascularization zone.

Ultrasound imaging can monitor healing and help with making a decision for surgery in case of prolonged symptoms (Fig. 15.22) (Video 15.4).

15.9.4 Meniscus Repair

Ultrasound is also used to follow up meniscus healing after repair. We can see small cysts around meniscal implants to impair the healing. Dynamic imaging is used to check the stability of the healing meniscus (Fig. 15.23) (Video 15.5).

Rehabilitation protocols can be adjusted according to the findings in meniscus healing with ultrasound.

Neovascularization with small vessel ingrowth in the red white zone can be seen in the first months after meniscus repair.

15.9.5 Acute Lesions

Fresh lesions of the meniscus are often seen in combination with ligament injuries.

We check for both intra- and extra-articular ligament lesions. It's particularly important to look for avulsion fractures like Segond lesion and medial collateral ligament in acute combined lesions. Impression of the lateral femoral condyle

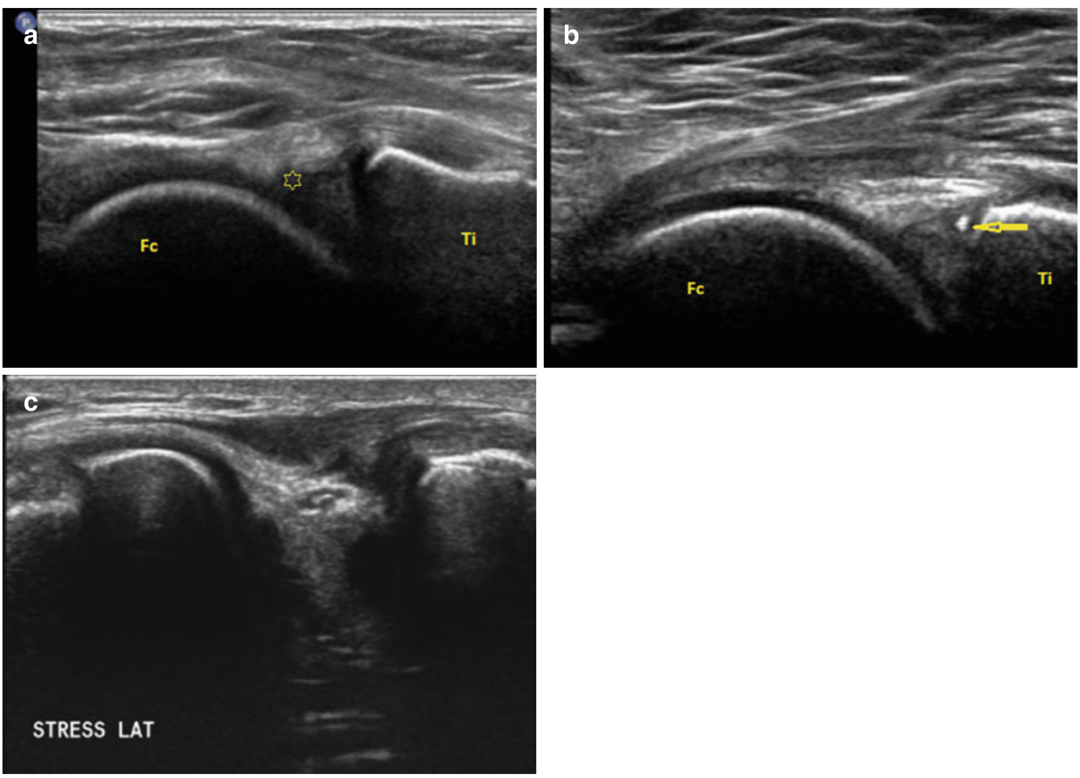


Fig. 15.23 (**a**) Preoperative meniscal lesion medial posterior (**b**) Meniscus repair 1 month post-operative (**c**) Meniscus repair six months post-operative

is seen in high-velocity trauma and is often associated with lateral meniscus rupture [9].

In acute lesions massive fluid in the joint can cause artifacts in the imaging.

To our opinion the acute hematoma is less problematic in ultrasound and sometimes helpful to detect fresh versus old lesions. The example of Segond lesion in acute knees is supporting our finding that ultrasound can be more powerful to detect acute lesions than MRI. This is due to the fluid and hematoma but also due to the possibility to quickly orientate in multiple directions with an ultrasound probe. In the detection of Segond lesions, MSU (Fig. 15.24) can be more reliable than MRI and X-ray [13]. (Videos 15.2) (Table 15.2).

15.10 Specific Conditions

15.10.1 Meniscus Degeneration

Degeneration can be a sign of aging of the meniscus, but it is also seen in cases of long-standing ACL deficiency as a sign of overloading of the meniscus.

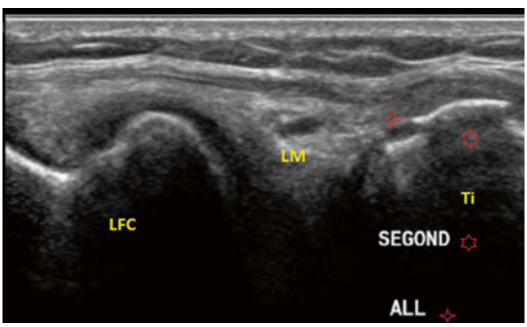


Fig. 15.24 Ultrasound detection of an acute Segond lesion in combined knee injury

Table 15.2 Incidence of Segond lesions in imaging modalities

	Incidence in ACL rupture	
X-ray	9 %	Klos [13]
MRI	3–6 %	Claes [5], Bock [3]
Ultrasound	33 %	Klos [13]

15.10.2 Meniscus Chondrocalcinosis

A meniscus with calcification can be detected in a normal knee X-ray; most frequently both joint spaces are involved.

A meniscus with hardening is more susceptible to injury and tearing, and if mechanical symptoms are persistent, a question for preoperative imaging can be a problem. This condition is usually found in the elderly age groups and the combination of aging and chondrocalcinosis makes MRI imaging more complicated. In the use of ultrasound, fluid around the posterior parts of the meniscus, and cyst formation can be indirect signs of a persistent meniscus mechanical problem (Figs. 15.25 and 15.26).

Fig. 15.25 Chondrocalcinosis on ultrasound

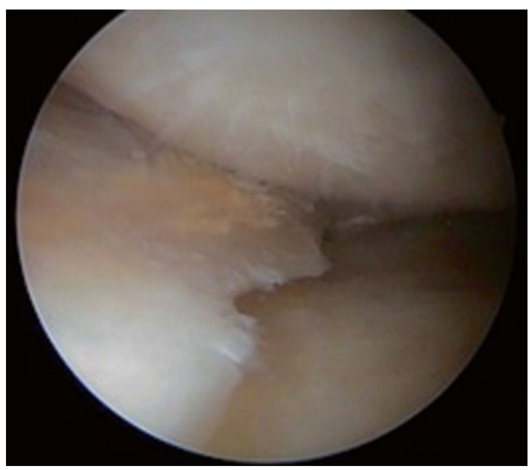


Fig. 15.26 Chondrocalcinosis intra-operative medial meniscus

15.10.3 Meniscus Extrusion

Meniscus extrusion is seen as an indirect sign of meniscus pathology. This sign is indeed described both with MSU and MRI in several papers. Meniscus extrusion is seen both in meniscal degeneration and in other pathological conditions of the meniscus; as the meniscus loses its hydraulic power in both these affections. A meniscal displacement of more than 3 mm is considered abnormal on the medial site, while a displacement above 4 mm is abnormal on the lateral site [28]. A recent study from Noguira-Barbosa confirmed the reliability of ultrasound [17]. Nguyen [16] found both meniscus extrusion and parameniscal cyst formation as sign of meniscal lesion (Fig. 15.27).

15.10.4 Meniscus Cyst

Ultrasound is helpful not only to detect the cysts but also to check for:

- Underlying meniscus pathology (lateral meniscus cyst) [10, 22, 25].
- Primary or secondary cyst formation.
- The size of the cyst walls. If there are signs of a thickening cyst wall, resection of the wall by an open approach can be considered.
- Puncture of the cyst and injection can be considered in patients without the possibility for operative treatment.

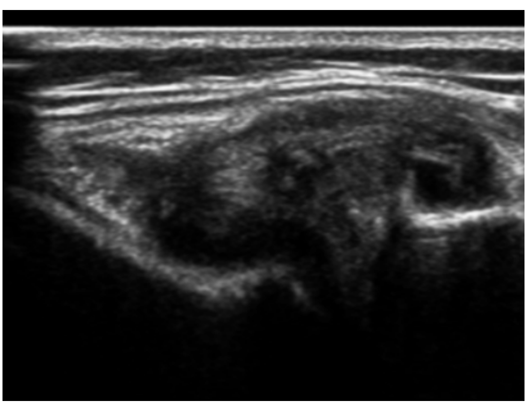


Fig. 15.27 Large meniscus cyst

In case of meniscal tearing, the cyst is directly connected with the tear (Figs. 15.28 and 15.29).

In case of a Baker's cyst, there is usually fluid in the knee joint, which fills the Baker's cyst as a consequence.

15.10.5 Discoid Meniscus

Since ultrasound is used to check dynamic pathology, it is possible to detect instable lesions in discoid meniscus by moving the knee in figure of 4 position with the probe on the lateral

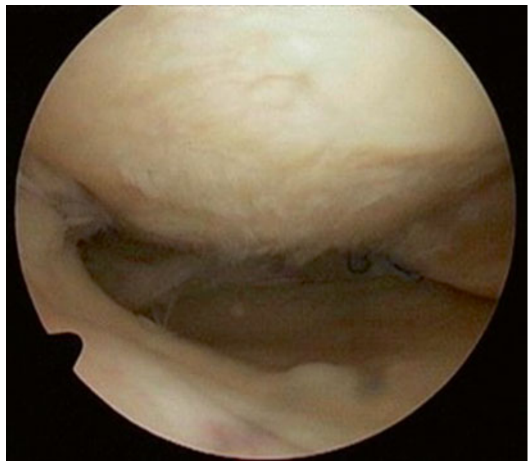


Fig. 15.28 Intra-operative arthroscopic image medial meniscus and condyle

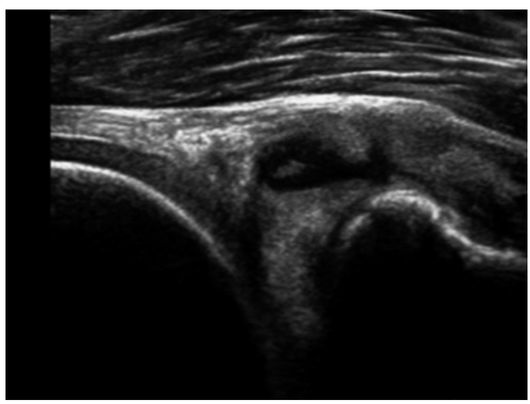


Fig. 15.29 Ultrasound parameniscal cyst with medial meniscus lesion and chondropathy

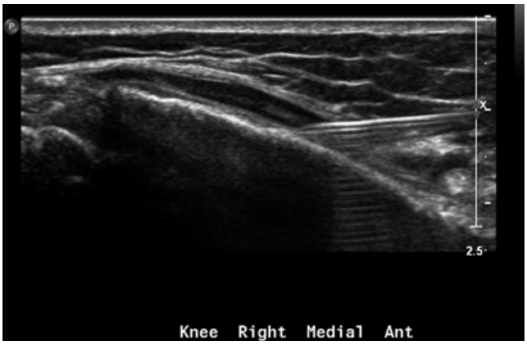


Fig. 15.30 Ultrasound guided injection bursa under the pes anserinus, on the right above needle is injecting corticosteroid to the front of the anteromedial tibia

joint space. Recently Jose and his group published on the possibilities of diagnosis with dynamic ultrasonography [12].

15.11 Complications or Prolonged Symptoms After Surgery

Ultrasound can be used to detect migration of meniscus implants [8].

In particular, vascular complications can be detected with ultrasound; reports of pseudoaneurysm and cysts around meniscus implants are found [4].

Ultrasound is the gold standard technique to diagnose postsurgical thrombosis.

Routine follow-up ultrasound after ACL reconstruction shows 12 % of thrombotic events [7].

In case of prolonged pain or swelling, we use ultrasound to detect bursa or tendinitis around the pes anserinus. Pain release was obtained after injection with lidocaine and/or corticosteroids (Fig. 15.30).

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16 SPECT/CT Imaging of the Meniscus and Cartilage: What Does It Offer?

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Contents

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16.1 Introduction

MRI is considered the gold standard technique for the diagnosis of meniscal pathologies. However, nuclear medicine imaging has progressively improved, and nowadays it may represent a valid substitute to MRI for the diagnosis of meniscal lesions.

This chapter aims to review the scientific and clinical value of SPECT/CT imaging in patients with degenerative meniscal lesions.

16.2 Basics about SPECT/CT Imaging

SPECT/CT is a hybrid imaging consisting of a 3D scintigraphy, single photon emission computerized tomography (SPECT) and conventional computerized tomography (CT) [1–4]. SPECT/CT is a very sensitive nuclear medicine imaging modality, which is able to open a window into bone metabolism and in vivo loading of the knee [3, 5–10].

At the beginning of the investigation, the patient is injected with a bone tracer, mainly a diphosphonate such as 500–700 MBq 99 mTc-HDP or 99 mTc-MDP [1–4]. The bone tracer targets active osteoblasts and is an in vivo marker of bone metabolism [1–4].

Planar scintigraphic images are taken in three phases: the perfusion phase (immediately after injection), the soft tissue phase (from 1 to 5 min after injection), and the delayed metabolic phase

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_16

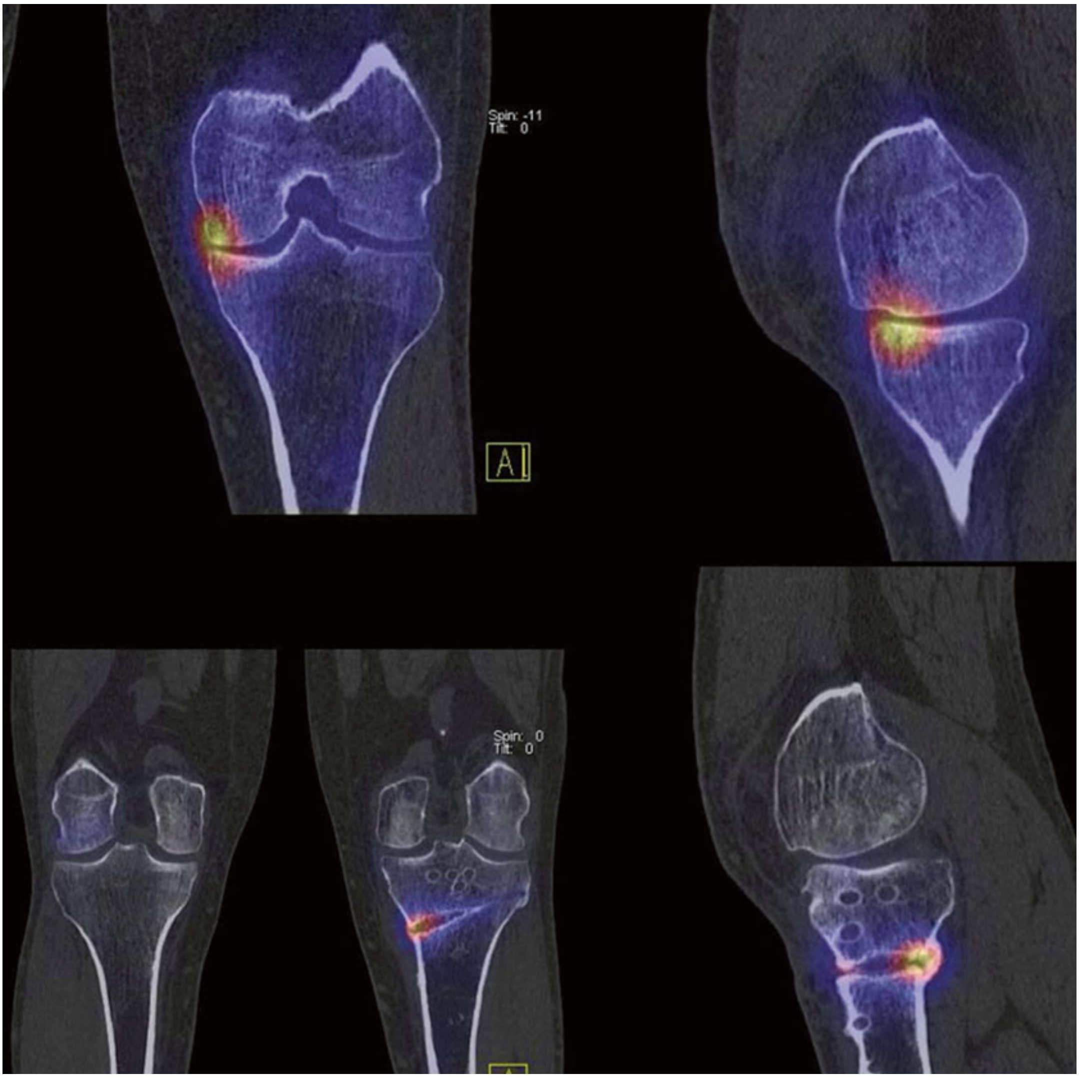

Fig. 16.1 99mTc-HDP-SPECT/CT before and after medial opening wedge high tibial osteotomy. Bone tracer uptake is increased in the medial joint compartment before high tibial osteotomy representing overloading. After HTO, bone tracer uptake is normal

(from 2 h after injection) [1–4]. SPECT/CT images are obtained using a hybrid system equipped with a pair of low-energy, high-resolution collimators [1–4]. This system incorporates a dual-head gamma camera with an integrated mostly 16×0.75-mm slice thickness CT [1–4].

For analysis of SPECT/CT bone tracer uptake, a specific localization scheme should be used [11–15]. The system described by our group defines 9 femoral, 8 patellar, and 13 tibial zones, where the tracer uptake volume is calculated. The BTU should also be quantified. For normalization, a specific area within the femoral shaft should be used. This allows to compare the BTU between patients. CT allows 3D analysis of mechanical and anatomical alignment as well as structural changes [11–15] (Fig. 16.1).

16.3 Current and Potential Use of SPECT/CT

SPECT/CT has demonstrated its clinical value for assessment of early OA changes [10, 11, 13, 14]. This is rather important as the earlier OA is diagnosed, the

Fig. 16.2 99mTc-HDP-SPECT/CT showing medial compartment overloading. The patient presented with medial knee pain after subtotal medial meniscectomy 2 years earlier

Fig. 16.3 Same patient as in Fig. 16.2. 99mTc-HDP-SPECT/CT after medial opening wedge high tibial osteotomy and polyurethane meniscus transplant showing a normalized bone tracer uptake

earlier it can be optimally addressed. It has been reported that SPECT/CT changes precede changes in MRI, CT, and radiographs [10, 11, 13, 14]. Even before structural changes occur in OA, SPECT/CT is able to show changes in bone tracer activity [10, 11, 13, 14] (Figs. 16.2 and 16.3).

16.3.1 Meniscus

Degenerative meniscal lesions are often associated with adjacent overloading of the subchondral bone [16]. This altered in vivo loading of the subchondral bone can be due to an acute trauma or as a result of chronically altered knee biomechanics. Bone scintigraphy as SPECT has been already shown to be a highly valuable method for the assessment of meniscal tears [17, 18]. Recent studies revealed a high diagnostic ability with a sensitivity of 77–84 % and specificity of 74–94 % [17–19]. For medial meniscal lesions, Even-Sapir et al. and Vellala et al. found a sensitivity of 77–91 % and a specificity of 65–89 %, respectively [16, 20]. However, the sensitivity for lateral meniscal lesions was lower with 14–50 % and with a high specificity of 94–95 %, respectively [16, 20].

The typical appearance of acute and chronic meniscal lesions in SPECT and SPECT/CT is currently debated. Several authors have described a crescent pattern of increased bone tracer uptake at the tibial plateau on the transaxial projection [16, 18, 19, 21]. It has also been postulated that increased bone tracer uptake may be the result of traction on the coronary ligaments occurring at the time of meniscal injury [18]. An increased equilibrium activity is also present in the adjacent femoral condyle in posterior horn tears [18, 21].

In a still unpublished study, our own group investigated and quantified the subchondral bone tracer uptake in SPECT/CT of knees with different grades of meniscal lesions. Meniscal status (intact, degenerated, or torn) was graded on MRI. Also extrusion of the meniscus was noted. Patients with history of previous knee surgery as well as evidence of grade 3–4 cartilage lesions were excluded.

Subchondral bone tracer uptake on SPECT/CT was significantly higher in knees with degenerated and torn menisci compared to knees with intact menisci. Significant differences in BTU were also found between the knees with meniscal extrusion and those with menisci not extruded.

This is the first study showing the effect of meniscal integrity on subchondral in vivo joint loading. SPECT/CT may be a very useful tool to visualize subchondral bony changes preceding joint space narrowing in OA [10, 11, 13, 14, 22].

In particular, patients with degenerative meniscal lesions often complain of residual symptoms after partial meniscectomy. Clinically it would be very helpful to have a specific imaging modality, which is able to answer the question which patient with a degenerative meniscal lesions benefits from a partial meniscectomy and which patient needs to undergo OA treatment. SPECT/CT promises guidance in this challenging clinical situation.

Furthermore, in patients after meniscus repair or partial meniscectomy, it is more difficult to unambiguously identify meniscal lesions. Due to the advancements in MR imaging, in many patients structural meniscal lesions are identified so early that in many cases the patient is still asymptomatic [23]. It remains unclear which of these patients will become symptomatic at a later stage. In many of these meniscal lesions in middle-aged or elderly patients, it is questionable if the meniscus tear really is associated with the patients' symptoms. It is more likely that the patient becomes symptomatic due to the increased biomechanical loading of the joint cartilage, which can be due to alignment or loss of meniscal integrity or extrusion of the meniscus. This can be referred to as the phase of early OA and identified on SPECT/CT.

16.3.2 Cartilage

The subchondral bone plate has been identified as a critical zone for origin and progression of OA. SPECT/CT allows combined information on alignment, structural bony abnormalities, and osseous metabolism [24].

In a recent study, the intensity and location of bone tracer uptake as determined with SPECT/CT was correlated with the size and severity of chondral lesions detected with MR imaging [24]. It was found that higher grades of chondral lesion of the knee (grades 3 and 4) at MR imaging, meaning osteochondral lesions, significantly correlated with increased bone tracer uptake on SPECT/CT [24]. Chondral lesions with osseous involvement represented by grades 3 and 4 showed higher SPECT/CT bone tracer uptake than those without osseous involvement (grades 1 and 2) [24].

Another finding was that the size of the chondral lesion was also important. With increasing size, the activity of the bone tracer increased [24].

In conclusion, SPECT/CT may enable the orthopaedic surgeon to choose a chondral repair procedure such as cell-free collagen implants, or autologous chondrocyte transplantation, or osteochondral repair strategy such as mosaicplasty, matrix associated procedures, as it clearly differentiates between chondral and osteochondral lesions [24].

16.3.3 OA

SPECT/CT is able to identify changes of OA more early than any other imaging modality. It was shown that the degree of OA correlates with increased bone tracer uptake on SPECT/CT [10, 11]. The bone tracer uptake is also dependent on mechanical and anatomical alignment [10, 11]. In a varus knee, more bone tracer uptake was found in the medial compartment, and in a valgus knee, more bone tracer uptake was shown in the lateral compartment [10, 11, 14].

SPECT/CT is able to visualize mechanical overloading of knee compartments. In a landmark study, our group evaluated the clinical and radiological outcome after high tibial osteotomy (HTO) due to medial compartment overloading [14]. In addition, the bone tracer uptake (BTU) pattern and intensity on SPECT/CT was assessed over a two-year follow-up [14]. It was found that HTO lead to a significant decrease of BTU in the medial subchondral compartment zones [14]. SPECT/CT tracer uptake patterns and intensity distribution from preoperatively to 12 and 24 months postoperatively correlated significantly with pain and stiffness [14].

Clearly, SPECT/CT has shown to be beneficial in two ways here: first, it allows to assess the patient preoperatively to set the indication for HTO, and second, it allows the assessment of adequate correction and healing after HTO [14].

Conclusion

Although MRI remains the gold standard for patients with meniscal pathologies, SPECT/

CT may be beneficial for those patients as it offers a window into in vivo loading of the joint. This additional information could be useful for the orthopaedic surgeon in guiding optimal treatment in the degenerative knee.

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Synthesis: Differences Between Traumatic and Degenerative Meniscal Lesions

17

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17.1 Introduction

The pattern of a meniscal tear is generally based on the analysis of the clinical history, radiographs, the magnetic resonance imaging (MRI) and the morphology of the torn meniscus as seen during the arthroscopy (if a surgical procedure is performed).

Meniscal tears are usually classified into two main categories: traumatic and degenerative [2]. However, in the clinical practice, we can make the distinction in between four situations: (1) a traumatic meniscal lesion in a stable knee; (2) a traumatic meniscal lesion in an anterior cruciate ligament (ACL) deficient knee; (3) a primary degenerative meniscal lesion (DML); and (4) a meniscal lesion in an osteoarthritic knee (meniscarthrosis). Consequently, for each of those situations, a patient-specific diagnosis and treatment is required.

17.2 Clinical Examination

A careful investigation of the patient history should always precede the physical examination. History of sudden pain secondary to knee hyperflexion, catching, mechanical locking and recurrent effusions should be scrutinized. It is also important to differentiate an acute pain consecutive to a major trauma from a gradual pain coming after a minor trauma.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_17

It is commonly believed that the clinical examination is difficult to learn and its accuracy increases with experience. However, in the literature [13, 15, 16], the reproducibility of physical tests is unclear and rarely reported. There was a significant heterogeneity in terms of sensitivity and specificity amongst all tests. McMurray and Apley tests could be considered as highly specific (mean 0.81 and 0.86, respectively), but with a low sensitivity (mean 0.44 and 0.42, respectively), while joint line tenderness tends to be higher in term of sensitivity (mean 0.69), but lower in specificity (mean 0.55). Unfortunately, a single clinical test cannot accurately make a correct diagnosis. Thus, the combination of three tests (McMurray, joint line palpation and Apley) is probably required to improve the accuracy of the diagnosis. However, one must know that the reliability of these tests tends to decrease when there is a concomitant acute ligamentous injury. Furthermore, the clinical examination is less accurate in patients with degenerative tears compared to young patients with acute injuries [17]. Consequently, in case of a suspected traumatic meniscal tear, it is mandatory to assess the ACL status by a meticulous clinical examination. Then, the treatment will obviously change if the ACL is intact or torn.

17.3 MRI

In case of a degenerative meniscal lesion on the MRI, the presence of a bone marrow oedema, a meniscal extrusion and a synovitis has to be searched, and the cartilage status evaluated.

- The presence of a bone marrow oedema is strongly correlated with the presence of pain in an osteoarthritic knee, whatever is the degenerative state of the meniscus [7]. Hence, a degenerative meniscal lesion is not the major cause of pain when a bone marrow oedema is present, especially on the tibial plateau. In this case, a meniscectomy will not resolve the problem.
- It has been shown that the amount of meniscal subluxation (meniscal extrusion) correlates with the severity of the joint space narrowing [3, 8]. Moreover, this meniscal extrusion is closely associated with a symptomatic knee OA. A medial meniscal extrusion results in an almost complete loss of meniscal function and can be considered as a complete functional meniscectomy. In this case again, the benefits of an arthroscopic meniscectomy remain unclear.
- Finally, studies have shown that in a patient with a meniscal injury, there is a clear association between the synovial inflammation and clinical symptoms, regardless the degenerative state of the underlying cartilage [14].

17.4 Relationship Between Clinical Symptoms and MRI

In a cohort study of 100 patients referred for suspected degenerative meniscal tear, the prevalence of meniscal abnormalities has been assessed by MRI on symptomatic and contralateral asymptomatic knees. Meniscal tears have been found in 57 symptomatic and 36 asymptomatic knees, whereas horizontal medial meniscal tears have been found in 32 symptomatic and 29 asymptomatic knees. In this study, symptomatic knees had a higher prevalence of bone marrow oedema and pericapsular soft tissue abnormalities. Likewise, radial and complex displaced meniscal tears were mostly symptomatic.

In a comparative study by Bhattacharyya et al. [4], including 154 patients (mean age 53 years) with knee OA, they found a prevalence of meniscal tear in asymptomatic patients up to 76 %. In symptomatic patients, a meniscal tear was found in 91 % of cases ($p < 0.005$). The grade of OA was correlated with a higher frequency of meniscal tears. Interestingly, within the symptomatic OA group, there was no significant difference in pain or subjective scores between patients with or without meniscal tears. Nevertheless, the prevalence of meniscal lesions seen on MRI is high after the age of 40, especially in the population with significant OA. However, in this specific group of patients, it is interesting to note that the prevalence of asymptomatic meniscal lesions is also high. Therefore, the presence of a meniscal lesion on the MRI should always be correlated with a good clinical examination before any decision of treatment.

17.5 Radiographs

In case of a suspected traumatic meniscal tear in a young patient, the aim of radiographs is to look for a concomitant fracture that might have occurred during the injury. Anterior-posterior (AP) and lateral views of the injured knee are recommended [2]. In a patient over 40 with a non-traumatic knee pain, the goal of radiographs is to assess the cartilage and degenerative articular changes. Indeed, a degenerative meniscal tear in an osteoarthritic knee should be distinguished of a traumatic and isolated meniscal tear [2] and therefore investigated differently. Thus, bilateral weight-bearing radiographs including AP, lateral, Schuss [11] or Rosenberg [12] views, and skyline view at 30° of flexion should be systematically performed in degenerative cases.

The appearance of osteophytes precedes joint space narrowing in the osteosarthritic process. So, the association of knee pain and the presence of osteophytes have a sensitivity of 83 % and a specificity of 93 % in the diagnosis of OA [1]. Joint space narrowing should be assessed either by the AP view in extension or by the Schuss or Rosenberg view. The Schuss view is especially recommended because it showed a good reproducibility to assess the joint line height especially when superior to 3 mm [5]. Narrowing of the cartilage space of 2 mm or more is strongly correlated with grade 3 or 4 cartilage degeneration [12]. On standing AP and Schuss views, there is no significant difference between pre- and post-meniscectomy joint line height of the medial compartment. It means that the narrowing of the joint space is not due to the meniscus itself, but is always a sign of OA [10]. In fact, joint space narrowing superior to 50 % is associated with severe chondral lesions [6]. Thus, an advanced OA should be defined on radiographs as a joint line narrowing superior to 50 %.

17.6 Histology

A case control study by Meister et al. [9] reported histological differences between torn menisci in stable versus ACL-deficient knees. It was shown that mucinous, hyaline or myxoid degeneration and reduction of chondrocyte concentration were found more frequently amongst meniscal tears in stable knees. They concluded that meniscal tears that occur in stable knees may be favoured by a pre-existing and ongoing underlying process and may represent an early sign of a degenerative disease. In addition, Uysal et al. [18] performed a histological analysis in three subgroups of patient of less than 40 years old: (1) normal meniscus without tear; (2) torn meniscus in stable knee; and (3) torn meniscus and ACL rupture. They found the highest average number of apoptotic cells in the torn meniscus/stable knee group. And they have even formulated the hypothesis that the apoptosis level may predict the occurrence of meniscal tears [18].

Conclusion

There are major differences between traumatic and degenerative meniscal lesions (Table 17.1). One should always bring answers to these two questions: "Are the clinical symptoms really related to the meniscal lesion seen on the MRI? Is the ACL torn or not?" It has been demonstrated that a traumatic meniscal lesion is mainly vertical and symptomatic and that a meniscal repair should always be considered as the first option of treatment. A degenerative Mn lesion is mainly horizontal and very often associated to some degree of osteoarthritis. Thus, a medical treatment should be considered first before arthroscopy.

Table 17.1 Main difference between degenerative and traumatic meniscal tears

	Traumatic tears	Degenerative tears
History, clinical findings	Acute onset, look for ACL integrity	No trauma, stable knee, osteoarthritis
Radiographs	Normal	Joint space narrowing is common
MRI	Vertical lesion, middle and posterior segments, peripheral third of the meniscus, look for ACL status	Horizontal/oblique lesion located in the central 2/3 of the meniscus, search early signs of osteoarthritis: meniscal extrusion, bone marrow oedema, chondral degeneration
Arthroscopy	Vertical longitudinal lesion, synovitis	Horizontal cleavage, complex lesion, cartilage often damaged

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Synthesis

18

Matteo Denti

To diagnose a meniscal tear, it is first important to obtain an accurate medical history. The patient should be asked to describe the position of the knee and the direction of forces at the time of injury; this is despite most patients not reporting a real trauma but more commonly an acute pain which occurred after a twist to the knee under load or a knee flexion.

We must always differentiate traumatic injury from a degenerative lesion, regardless of patient age.

The clinical examination is important, but in meniscal lesions, imaging plays a vital role.

If the degenerative bilateral weight-bearing X-rays are very important in the traumatic injury, MRI is definitely the most used form of investigation.

We must, however, always remember that the result of an MRI is influenced by the quality of the machine and the knowledge of the radiologist in the field of orthopaedic pathologies.

Good cooperation between radiologists and orthopaedic surgeons certainly leads to elevated accuracy (74–79 %), sensitivity (73–84 %) and specificity (75–81 %) in detecting meniscal tears.

It is still important to emphasise that an MRI meniscal tear diagnosis does not necessarily indicate the need for surgery, and a series of conditions must be considered before undertaking meniscal arthroscopy (age, symptoms, clinical examination positive, any comorbid conditions,etc.).

Particular attention is always paid to the bone marrow oedema in the degenerative disease, which can simulate a meniscal problem but does not need, in the first instance, any surgical treatment.

Diagnoses with ultrasound and SPECT/CT are most certainly more sophisticated and should therefore be reserved for centres specialising in this particular area.

Finally, we must always keep in mind that both at MRI level and at arthroscopy level, the classification of meniscal lesions is very important for the orthopaedic surgeon because it can help him/her, both preoperatively and in the operating room, decide on the exact treatment required for treatment for the meniscal lesion, meniscectomy, partial meniscectomy, meniscal repair or transplantation.

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_18

Part IV

Surgical Technique

19 Arthroscopy of the Normal Meniscus

Nicolas Bouguennec, Paolo Adravanti, and Aldo Ampollini

Contents

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19.1 Introduction

During the arthroscopy of a normal meniscus, several important particularities have to be considered. First, the entire meniscus, either the medial or the lateral, cannot be seen once in reason of other anatomical structures of the knee (bone, ligaments), so that several visions and portals are necessary to check it thoroughly. Secondly, meniscus cannot be analyzed alone and must be considered with adjacent anatomical structures. Indeed, to be effective and play their roles, the menisci must have normal anterior and posterior horns but also a continuity at all the circumference [6] and they are assisted in some of their functions (shock absorption, load distribution, knee stability) by insertional ligaments and tendon structures which should be considered and analyzed together because they work like a functional unit [33]. However, in general, arthroscopic description of the normal knee is rare in the literature and few articles on the subject often concern only a part of the knee [15, 17, 27]. Nevertheless, the normal anatomy of the menisci must be known before performing any meniscus-related procedures, especially meniscal replacement (allograft, scaffold, substitute), since a wrong tibia location of the site of fixation improves the risk of failure and because the length of a graft should include insertions of associate structures [29].

In this chapter, we describe the arthroscopic vision of the normal medial and lateral meniscus that includes physiological variations [39].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_19

19.2 Medial Meniscus

19.2.1 Anterior Horn

The anterior horn of the medial meniscus in the adult knee is usually attached to the anterior tibial intercondylar area in front of the anterior cruciate ligament. Four different types of tibial insertion of the medial meniscus were identifiable [7]: type I (insertion is located in the flat intercondylar region of the tibial plateau), type II (insertion is on the downward slope from the medial articular plateau to the intercondylar region), type III (insertion is on the anterior slope of the medial tibial plateau), and type IV (there is no identifiable area on the tibial plateau where it attaches). Type III and type IV are less valid insertions of the anterior horn of the medial meniscus and in the same cases they can cause anterior knee pain [7]. The anterior horn of the medial meniscus is the most common site of variants (VAMM) when the anterior horn of the medial meniscus is not attached to the tibia [24]. Variants of the anterior horn of the medial meniscus of the knee (VAMM) were arthroscopically analyzed and classified into four categories: the ACL (anterior cruciate ligament) type, where the anterior horn of the medial meniscus is attached to the ACL; the transverse ligament type, where the anterior horn of the medial meniscus is attached to the transverse ligament; the coronary ligament type, where the anterior horn of the medial meniscus is attached to the coronary ligament; and the infrapatellar fold type, where the anterior horn of the medial meniscus is attached to the infrapatellar synovial fold [36]. Ali et al. classified the anomalous insertion of the anterior horn of the medial meniscus into the ACL in 3 types, type 1 (inferior third), type 2 (middle third), or type 3 (superior third; intercondylar notch), and he specified that in the more common variants [3]. The anterior horn of the medial meniscus is observed in the usual manner through the anterolateral infrapatellar portal or through the medial infrapatellar portal when it's difficult to achieve a good view of the anterior horn of the medial meniscus through the usual lateral infrapatellar view [36] (Figs. 19.1 and 19.2).

Fig. 19.1 Anterior horn of the medial meniscus from the anteromedial portal

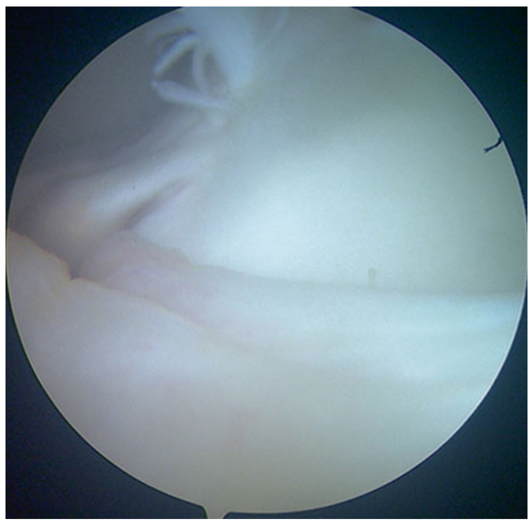


Fig. 19.2 Anterior horn of the medial meniscus from the anterolateral portal

19.2.2 Distal Insertion of the ACL

The morphology of the ACL tibial insertion (Fig. 19.3) is reported in the literature and these studies show a large variability in the size and the anatomy [38]. In some studies the ACL tibial insertion sites were found to be triangular or oval [16, 37] and more variable than that of the femoral attachments. The distal insertion of the ACL is located at the anterior intercondylar fossa of the

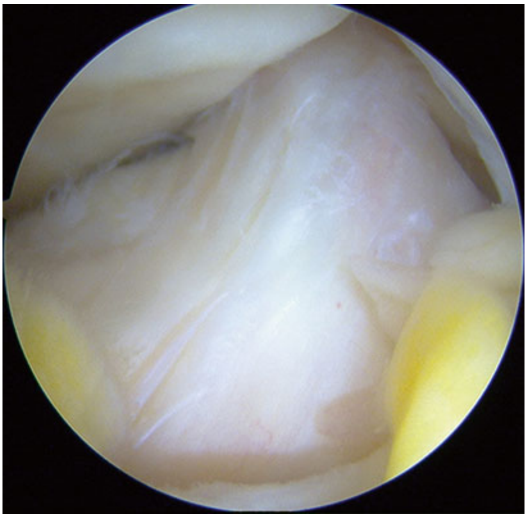


Fig. 19.3 Tibial insertion of the ACL

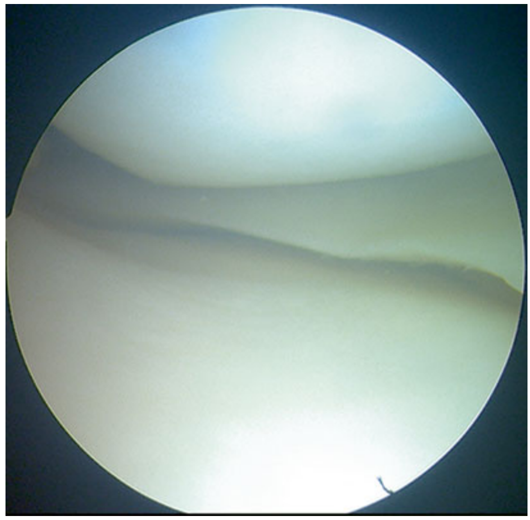


Fig. 19.4 Normal pleating of the free margin of the medial meniscus

tibia (anterolateral to medial tibial spine). In the sagittal plane the transverse ligament coincides with the anterior edge of the ACL tibial footprint [16] and extends from a broad area anterior to and between the intercondylar eminences of the tibia. All the recent studies divided ACL into 2 macroscopically separate bundles [34]. Currently, the center of the tibial attachment site of ACL and the posterior border of the anterior horn of the lateral meniscus and medial tibial spine are generally accepted as the most commonly used landmarks for arthroscopic-assisted ACL reconstruction [13]. In a recent study, Ferretti et al. demonstrated that the anterior root of lateral meniscus may vary and it may not represent the best landmark. They showed that the distance from a line on the center of the intermeniscal ligament to the center of the ACL was 9.12 ± 1.54 mm and a projected line of the medial tibial spine meets a projected line from the center of the ACL at 5.3 ± 1.14 mm. So they concluded that the medial tibial eminence and the intermeniscal ligament may be used as landmarks to guide the correct tunnel placement in an anatomical ACL reconstruction [16].

19.2.3 Body of the Meniscus

The midbody of the medial meniscus is evaluated with a standard anterolateral portal with the knee at 20–30° degree of flexion with the tibia extrarotated and in valgus stress. It's normal to see a pleating of the free margin of the meniscus when the knee is in valgus stress [25] (Fig. 19.4). When the inferior aspect of the medial meniscus is lifted with a probe, it is possible to see the coronary ligaments that provide peripheral attachments between the tibial plateau and the perimeter of both menisci [8]. At its midpoint, the medial meniscus is more firmly attached to the femur through a condensation in the joint capsule known as the deep medial collateral ligament [19].

19.2.4 Deep MCL: Meniscotibial and Meniscofemoral Ligaments

The medial meniscus is intimately attached to the capsule via the meniscotibial and meniscofemoral ligament. The deep medial collateral ligament is a thickening of the medial joint capsule that is most distinct along its anterior border, where it roughly paralleled the anterior aspect of the superficial medial collateral ligament. The deep medial capsular ligament inserts just below the tibial articular margin and may be conceptually divided into meniscotibial (coronary) and meniscofemoral complements [41].

19.2.5 Posterior Horn

The posterior horn of the medial meniscus (PHMM) is located directly behind the medial intercondylar tubercle next to the posterior cruciate ligament [29]. The PHMM is evaluated with a standard anterolateral portal. The arthroscope is pushed from the anterolateral portal within the medial compartment with the knee in extension or at 20–30° degree of flexion with the tibia extrarotated and a valgus force is applied to improve access as much as possible and the posterior horn is explored with a probe through the anteromedial portal. The meniscal root can be inspected with the knee in slight flexion without any valgus or varus force advancing the scope in the notch (Fig. 19.5). Several studies have shown that the peripheral tears of the posterior horn of the medial meniscus are not adequately visualized from anterior portal [42]. For this reason several ways have been described to improve visualization of the posteromedial corner of the knee and the meniscocapsular junction [4]. The arthroscope is introduced through the anterolateral portal in the notch and it is pushed between the posterior cruciate ligament and the lateral face of the medial femoral condyle. Flexion of the knee to about 40° facilitated passage of the cannula. The 30° arthroscope is rotated to provide a view of the posteromedial compartment (Figs. 19.6 and 19.7). The 70° arthroscope is needed in same case [4]. Inspection of the posterior horn of the medial meniscus can be made through a posteromedial portal. The posteromedial portal is made under arthroscopic visualization of the posteromedial capsule. A needle is used to localize the entry point and then the skin incision is performed. The portal entry is proximal to the medial femoral condyle just above the meniscus. The posterior horn of the

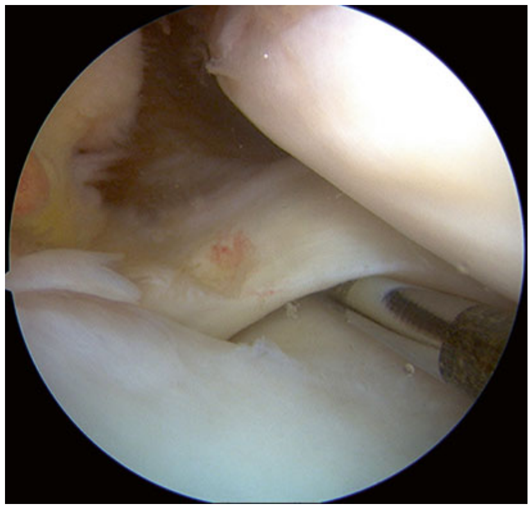
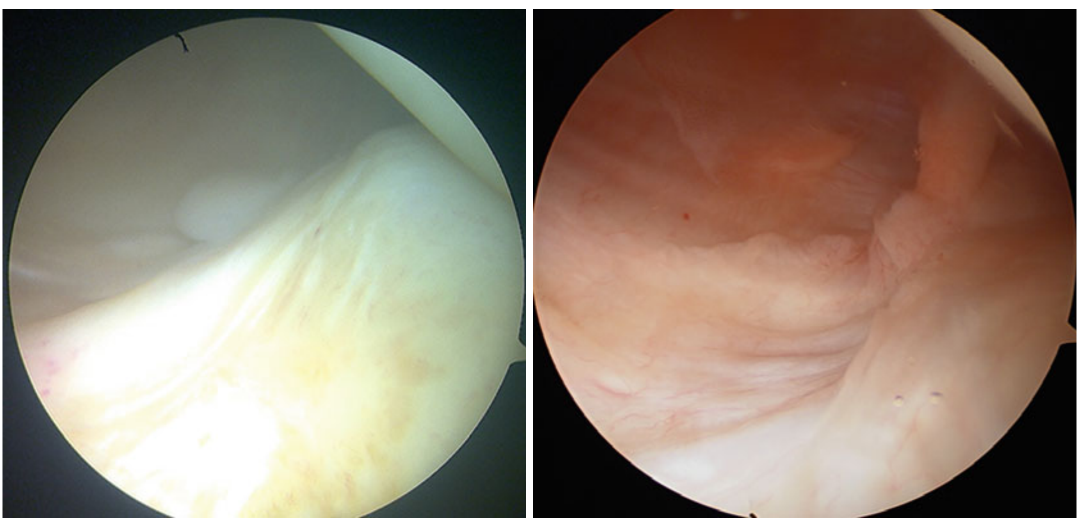


Fig. 19.5 Medial meniscus root



Figs. 19.6 and 19.7 Posteromedial compartment with normal meniscosynovial junction from an anterolateral portal

medial meniscus can be directly visualized by switching the arthroscope to the posteromedial portal.

19.3 Intermeniscal Ligament

With a variable incidence (50–90 %) [12, 32], the anterior intermeniscal ligament, also called as transverse ligament, ligamentum transversum, anterior transverse geniculate ligament, menisco-meniscal ligament, or transverse meniscal ligament of Winslow [12, 29, 32], joins the central part of the anterior horn of the medial meniscus to the external border of the anterior horn of the lateral meniscus [12] and could stabilize the anterior horns. Its thickness is also variable (1.4–4 mm) [12]. It runs at the posterior part of the infrapatellar fat pad and beneath the ligamentum mucosum. De Abreu et al. suggested that a transverse ligament/ligamentum mucosum complex to increase the congruity of anterior part of the meniscus in association with the fat pad would exist [12]. To analyze the intermeniscal ligament, an anterior portal is used (anterolateral or anteromedial) looking forward with the arthroscope. It's better to perform a high portal to allow looking down. The intermeniscal ligament is often difficult to see without a minimal debridement of the fat pad that covers it. The tension of the ligament can be tested with a probe. The oblique meniscomeniscal ligaments are intermeniscal ligaments with a reported prevalence ranging from 1 to 4 %. The oblique meniscomeniscal ligaments are named based on their anterior attachment site. The medial oblique meniscomeniscal ligament attaches to the anterior horn of the medial meniscus and the posterior horn of the lateral meniscus, while the lateral oblique meniscomeniscal ligament attaches to the anterior horn of the lateral meniscus and the posterior horn of the medial meniscus [40].

19.4 Lateral Meniscus

To analyze the different part of the lateral meniscus, the figure-4 position or "Cabot's" position is recommended (except for the femoral insertion of the popliteus tendon and for proximal insertion of meniscofemoral ligaments) as it allows an opening of the lateral joint space. The ACL tibial insertion sites were found to be triangular or oval in most specimens in some studies [9, 11].

19.4.1 Anterior Horn

The anterior horn of the lateral meniscus is in continuity with an insertional ligament [33] which can appear in continuity with the distal insertion of the ACL [29] and which is attached on the subchondral bone [33]. This insertional ligament is between the insertion of the ACL, the lateral tibial spine, and the articular margin of the lateral tibial plateau [23]. To evaluate the anterior horn, Johnson et al. [23] recommended an anterolateral portal for the arthroscope and an anteromedial portal for the probe (Fig. 19.8). A modified higher anterolateral portal can also be used to have a better view [11, 26]. Other authors used a high anteromedial portal [9, 31]. Choi et al. proposed an anteromedial portal done 3 cm medially relative to the patellar tendon and 1.5 cm above the joint line [11]. When an anteromedial portal is chosen, the fat pad has to be detached of the femur (cutting the ligamentum mucosum) to be pushed forward.

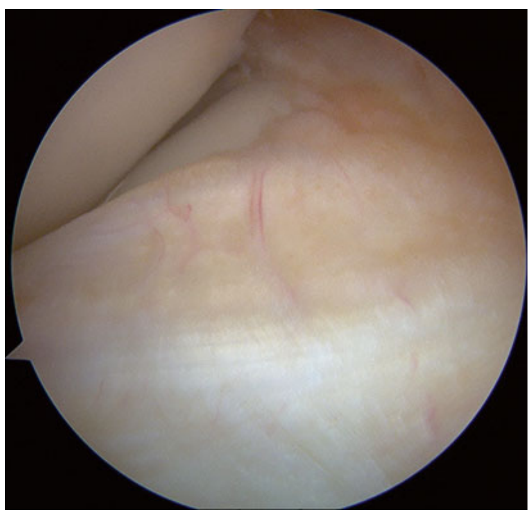


Fig. 19.8 Anterior horn of the lateral meniscus from an anterolateral portal

19.4.2 Midbody of the Meniscus

Fox et al. [19] resumed that superficial aspect of the meniscus appears with a smooth and lubricated aspect. The lateral border is attached to the lateral knee capsule and the inner border is more thin and regular. A coronary ligament joins the lateral border of the meniscus and the tibia [8].

The midbody is classically evaluated with a standard anterolateral portal [18] or with an anterolateral optical portal which can be high and above the infrapatellar fat pad [26]. Unlike the medial meniscus that is in contact with the medial collateral ligament, the midbody of the lateral meniscus is not in direct contact with the lateral collateral ligament.

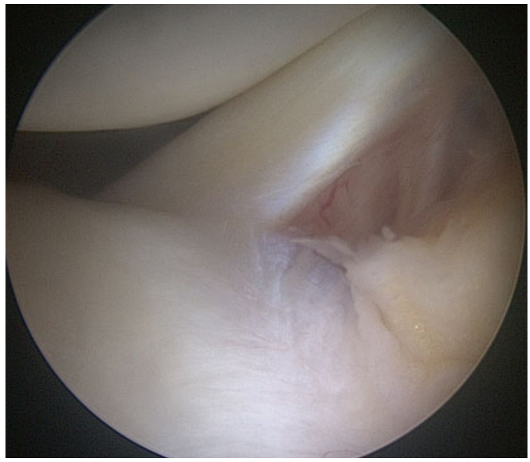


Fig. 19.9 Popliteus tendon seen behind the lateral meniscus from an anterolateral portal in Cabot's position

19.4.3 Popliteus Tendon

The popliteus tendon is intra-articular and extra-synovial. The femoral insertion and the musculotendinous junction cannot be seen arthroscopically [15, 17], but a part of the course of the tendon can be seen at the posterior part of the lateral meniscus and the relief of the femoral insertion can be seen in the lateral gutter. Fineberg and al. [17] reported that 44 %, i.e., 18 mm of the midportion, can be analyzed arthroscopically even if this portion is the least injured comparatively to other portions. Its tension is an indirect sign of integrity [43]. So, the midportion of the popliteus tendon is seen with the arthroscope in an anterior portal through the lateral femoro-tibial joint space looking behind the meniscus with the knee in Cabot's or figure-4 position (Fig. 19.9). The tightness can be evaluated with a probe pulling forward. As reported by Ferrari, the tendon is quite horizontal when the knee is flexed at 90° and becomes more vertical with extension [15]. Movement of the tendon around the lateral femoral condyle can be seen applying internal or external rotation at 30° of flexion [15]. The femoral insertion can be indirectly evaluated also with an anterolateral portal with arthroscope in the lateral gutter with 20–30° of flexion without rotation [15, 17]. It's an indirect way to analyze the insertion because for a normal knee, the popliteus tendon closes the lateral gutter. When there's an avulsion of the insertion, there's the "lateral gutter drive-through sign" described by Feng et al. [14]: an increased space exists between the femoral condyle and the popliteus tendon allowing to put the arthroscope deeper in the lateral gutter.

19.4.4 Popliteomeniscal Fasciculi

Popliteomeniscal fasciculi (Fig. 19.10) connect the lateral meniscus and the popliteus tendon at the level of the popliteus hiatus [43] and are separated in two parts: an anteroinferior and a posterosuperior. Those structures are not constant and are found in 40–100 % of population [27, 28, 35, 44]. Arthroscopic evaluation is very difficult in normal knee and is facilitated in case of ACL or posterolateral lesion.

19.4.5 Meniscofemoral Ligaments: Humphrey and Wrisberg Ligaments

Function of meniscofemoral ligaments (MFL) remains uncertain. It could serve to stabilize the posterior horn during flexion, could decrease the traction effect of the popliteus muscle, and could

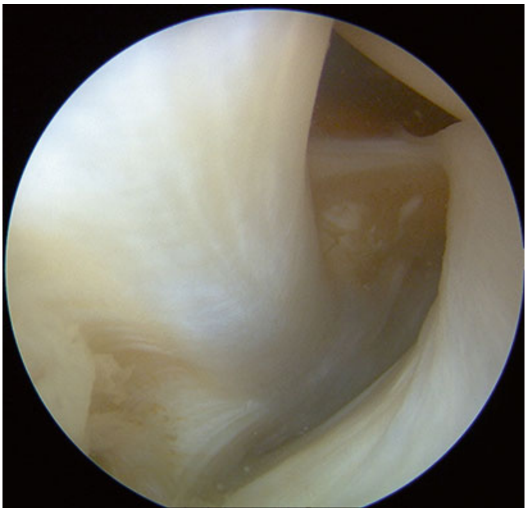


Fig. 19.10 Popliteomeniscal fasciculi

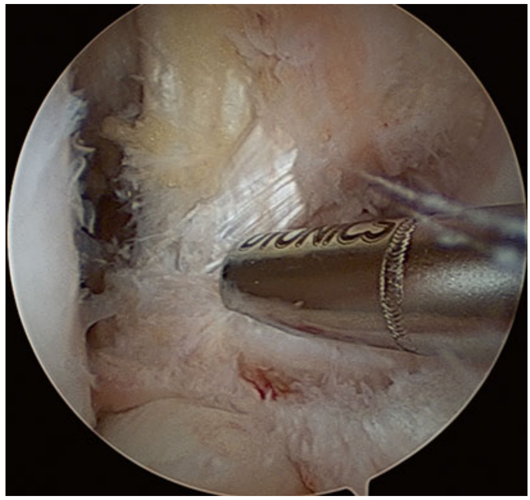


Fig. 19.11 Anterior meniscofemoral ligament or Humphrey ligament in front of the PCL. The ACL has been removed after a complete rupture and before a reconstruction

supplement the PCL to decrease tibial posterior translation [5, 20, 22] with biomechanical properties similar to the PCL [30]. There are classically two ligaments described: an anterior relative to the PCL (Humphrey ligament) and a posterior (Wrisberg ligament). As reported by Cho et al. [10], normal anatomy of those structures must be known because there can be interpreted as lateral meniscal tears on preoperative magnetic resonance imagery (MRI).

The arthroscopic portal will depend on the ligament that has to be explored. For the Humphrey ligament, an anterior portal (rather an anterolateral portal) is recommended, whereas for the Wrisberg ligament, a posterolateral portal is recommended because it's harder to see it with an anterior portal. Moreover, Gupte et al. pointed out the difficulty to identify the MFL and the posterior cruciate ligament (PCL) because they are really attached [21]. The same authors [20] suggested to identify the MFL (path and distal insertion) when the knee is flexed at 90° of flexion:

- The anterior MFL (aMFL) can be seen at the medial side of the ACL in front of the PCL with an anterolateral or an anteromedial portal (Fig. 19.11). Looking for the insertion of the MFL at the femur to analyze the obliquity of the fibers is more important for the aMFL than for the PCL, as well as searching with an instrument a cleavage plane between the aMFL and the PCL. Synovial fold has to be sometimes debrided. For the distal insertion, they used the "tug test": in Cabot's position, a hook pull on the aMFL induces a movement of the posterior horn of the lateral meniscus if structures are intact.
- The posterior MFL (pMFL) is more difficult to identify with an anterior portal as it is necessary to look at the lateral side of the PCL retracting it medially. The body of the ligament is difficult to see and it is especially the distal insertion which could be evaluated using again the "tug test." To facilitate the vision of the pMFL, a 70° scope can be used with an anterior portal [20] or a posteromedial portal with transseptal passage can be performed [1].

19.5 Posterior Horn

The posterior horn of the lateral meniscus is in continuity with an insertional ligament [33] which is broad and flat and extends from the posterior part of the lateral tibial spine to the medial tibial spine [29], between the lateral tibial spine, the posterior part of the ACL distal insertion, and the articular border of the lateral tibial plateau [23]. The posterior horn is the most difficult to see and there are several ways to explore it: with an anteromedial portal for the arthroscope [23] which is pushed at the lateral border of the ACL in Cabot's position (Fig. 19.12) and with a standard anterolateral portal with the arthroscope in the lateral femoro-tibial joint in Cabot's position (Figs. 19.13 and 19.14), pushing the arthroscope in the intercondylar notch between the femoral condyle and the ACL to reach the posterolateral part of the knee. The 30° scope is then replaced by a 70° scope [2]; finally, Ahn et al. proposed to perform a posterolateral portal [2] where the arthroscope is placed in the anteromedial portal and pushed in the posterolateral corner with the knee flexed at 90°. The posterolateral portal is then performed with transillumination.

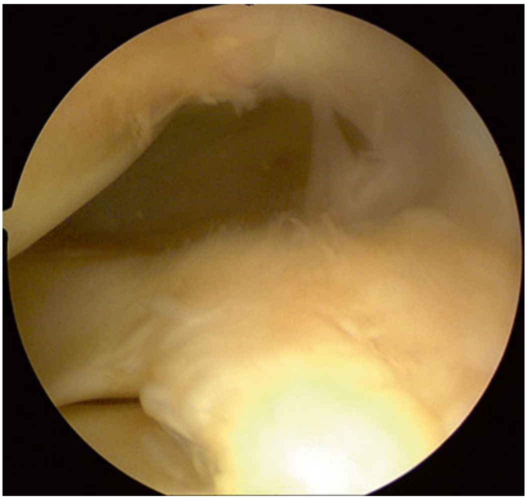
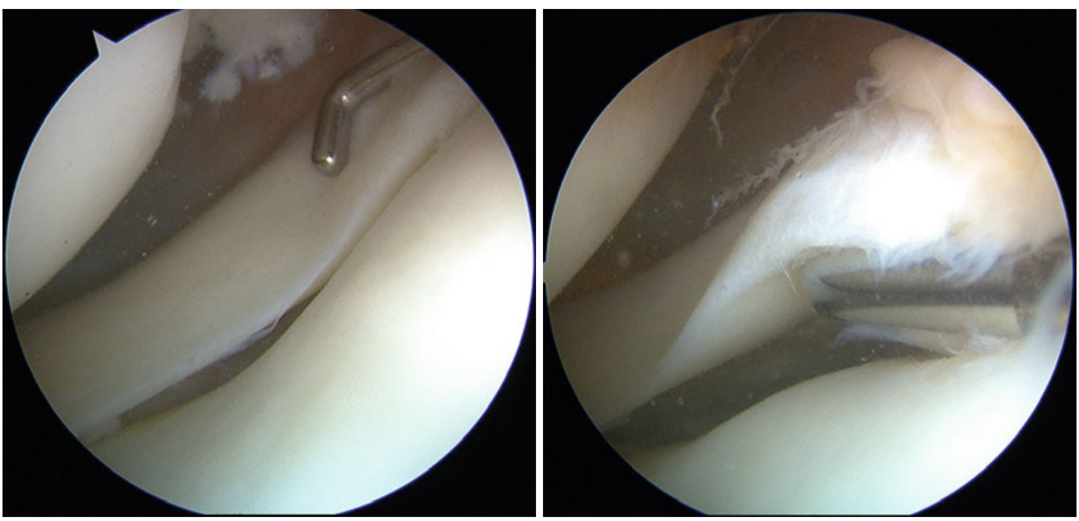


Fig. 19.12 Posterior horn of the lateral meniscus. The arthroscope is pushed from an anteromedial portal at the lateral border of the ACL in Cabot's position

A posteromedial portal is not recommended to see the posterior horn of the lateral meniscus since its anterior position in the intercondylar notch does not allow a direct visualization using such an accessory portal and because of the discomfort implied by the posterior part of the femoral condyle and the PCL insertion [23]. Anterior and posterior bony insertions of the lateral meniscus are separated of less than one centimeter and are very close to the anterior and posterior border of the ACL distal insertion so care must be taken when performing a meniscal horn surgery to avoid injury of those structures. Kohn et al. [29] and Johnson et al. [23] added that this data should be taken in account when an ACL



Figs. 19.13 and 19.14 Posterior horn of the lateral meniscus from an anterolateral portal in Cabot's position

reconstruction is additionally provided to a meniscal replacement to avoid any convergence of tunnels.

Conclusion

With an appropriate technique, all the compartments of the knee can be analyzed even if some parts remain difficult to see especially in the posterior compartments and in the gutters. The exploration should be cautious to prevent damages of the cartilage and to view is not enough and a testing with the probe must be systematic, for the different parts of the menisci but also for the associated structures. Finally, caution is also recommended for the interpretation of the differences with the normal meniscus because there are a lot of physiological variations that do not necessitate any treatment.

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Meniscectomy Medial: Lateral

20

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Contents

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20.1 Introduction

Arthroscopic resections of parts of the menisci probably comply for the majority of procedures of the knee. As many degenerative lesions of the menisci do not heal in response to conservative treatment, surgical intervention is frequently recommended in symptomatic patients. While the benefit of a partial meniscectomy has been recently questioned by various authors of randomized controlled trials comparing arthroscopy to nonoperative treatment [9, 11, 15, 16, 20, 23, 24], it appears that the keystones and technical details of a partial meniscectomy have insufficiently been described and therefore the process quality may vary at large in real life.

Further, in many institutions (specifically university and teaching hospitals), the partial

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_20

resection of the medial meniscus posterior horn (MMPH) may be considered a "beginner's procedure." However, we feel that this procedure is technically demanding and to easily a compromised result may be achieved if the distinct surgical steps have not been performed precisely, potentially leading to iatrogenic cartilage lesions or an exaggerated resection of meniscal tissue with the subsequent onset of osteoarthritis.

It is the scope of this chapter to outline the features important for a surgeon performing an arthroscopic meniscectomy. Potential pitfalls during the procedure are described and information is provided on how to prevent these.

20.2 Indication for Surgery

A good indication for surgery requires a matching of the history of patient's symptoms, the findings of the clinical examination, and the findings from MR imaging.

A typical history reported with the presence of a medial meniscal lesion includes a knee pain localized on the medial side of his knee and mainly during or after physical exertion including sports. The patient may report a gradual onset of symptoms or a sudden onset as a result of a certain trauma to the knee joint or a deep squat.

In many cases a slight swelling of the knee joint may be noticed by the patient. In case of unstable fragments of the meniscus, the patient will experience a sharp pain or an aggravation of pain on the medial side with rotation of the knee (e.g., getting into or out of a car in a tight parking spot). In many times the patient may have stopped sports participation to avoid pain episodes.

During clinical examination, the physician should strictly check on medial joint line tenderness. We prefer to test this with the knee flexed to 90°. Specific meniscus tests such as the McMurray test are mandatory and may reveal a pain in response to rotational stress to the tibia.

The MRI of the knee should reveal a pathological signal to the MMPH in order to indicate surgery. Sometimes it remains unclear whether a grade II or grade III lesion is present. However as the specificity of MR imaging for meniscus lesions is about 99 % (i.e., the probability for a false-positive prediction), a surgeon has to have a good reason for surgery if the MRI does not reveal any pathological changes to the meniscus.

The most frequent reason for meniscus surgery is the presence of a meniscal tear in the posterior horn of the medial meniscus MMPH. It may appear as a flap tear or a radial tear on MR imaging. In case the patient is symptomatic and he has failed a nonoperative treatment program such as physiotherapy or NSAIDs over 6–12 weeks, the patient should be scheduled for surgery.

20.3 Surgical Preparation and Patient Positioning

Usually an arthroscopic meniscectomy is performed under general or spinal anesthesia but an option could be local anesthesia if the surgeon is well familiar with that technique. A tourniquet is frequently used; however experienced surgeons prefer to only apply the tourniquet without inflation as in most cases a tourniquet will not be needed [14]. A pump may be used for inflow; however inflow under gravity is also considered to be sufficient. It is very important during patient positioning to assure strong fixation of the thigh to later apply valgus or varus stress to the knee to open the joint during surgery. We prefer a leg holder attached to the mid or the femur (Fig. 20.1). Alternatively a lateral support at the thigh may be used.

20.4 Diagnostic Arthroscopy and Portal Placement

After a standardized team timeout to assure correct identity of the patient and the involved leg, a standard high anterolateral portal is placed close to the lateral border of the patellar tendon and just below the rim of the patella at about 70° degrees of knee flexion. The

Fig. 20.1 Patient positioning before surgery with the mid of the thigh firmly attached to a leg holder

Fig. 20.2 Firm valgus stress with the knee near full extension is required for good visualization of the posterior horn of the medial meniscus

arthroscope will be introduced and a diagnostic round will be performed including documentation of findings in all four compartments. In order to visualize the posteromedial region of the knee, usually a distinct valgus stress applied to the knee is required in all patients (Fig. 20.2). The surgeon himself applies this stress to the tibia; he will feel tension in the medial structures of the knee. The 30° scope has to be oriented that the posterior horn of the medial meniscus can be visualized. According to the main pathology, the anteromedial portal will then be established. In case of a lesion in the posterior horn of the medial meniscus, the portal is fairly close to the anterior horn of the medial meniscus to allow the instruments to reach the lesion properly. In our routine we always perform a spinal needle tests (yellow needle, 10 cm of length) to assure correct portal placement (Fig. 20.3). The portal is then placed with the 11 blade scalpel in a horizontal orientation to avoid lesion to the anterior horn of the meniscus (Fig. 20.4). Following this a probe is introduced and the lesion will be evaluated if a repair or a benign neglect of the meniscus is indicated (Fig. 20.5). Unfortunately degenerative lesions and radial tears often require a partial meniscectomy.

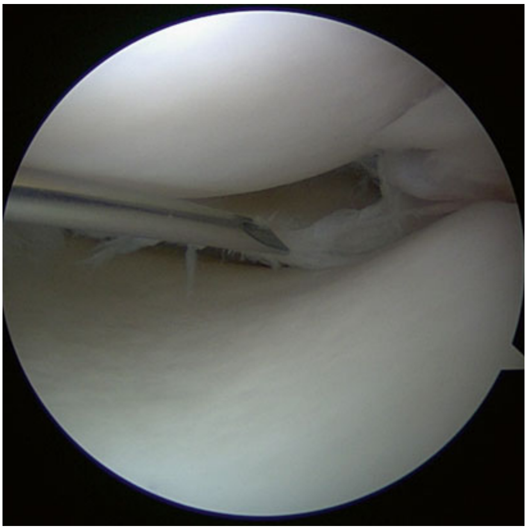

Fig. 20.3 A "spinal needle test" is recommended prior to medial portal placement to assure that the lesion can be reached with the surgical instruments

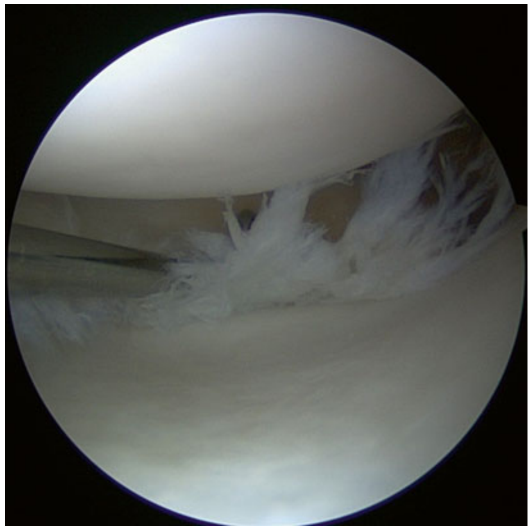

Fig. 20.5 Probe evaluation of meniscus tissue to evaluate the extent of the tear necessary to decide on treatment strategy

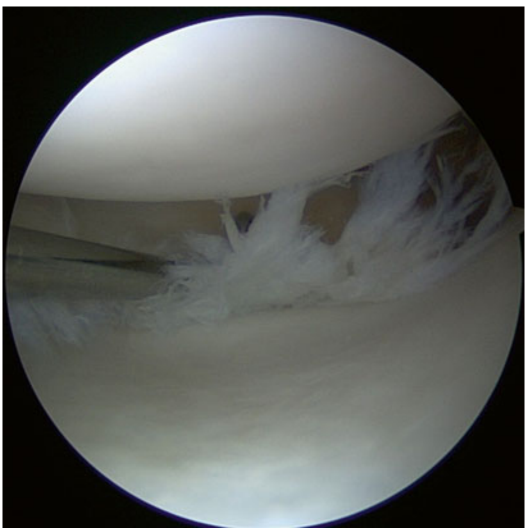

Fig. 20.4 Medial portal placement for lesions of the posterior horn of the medial meniscus (*Note*: the blade is oriented in a horizontal fashion to avoid iatrogenic lesion of the anterior horn)

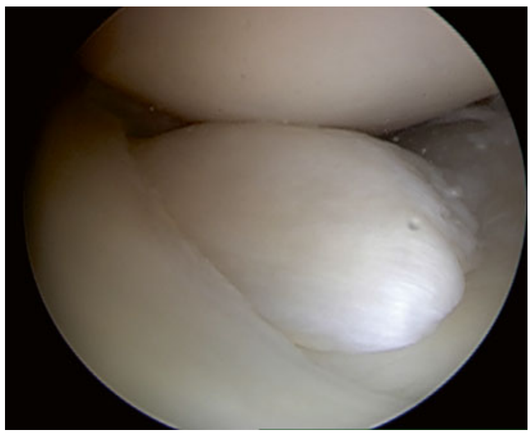

Fig. 20.6 Typical symptomatic flap tear of the medial meniscus requiring partial meniscectomy

20.5 Surgical Strategy During Medial Meniscectomy

A complete resection of meniscus tissue as it was performed in former days during open knee surgery is obsolete and should never be carried out. However, mechanically unstable parts of the meniscus should be removed to avoid pathological stresses to the articular cartilage and catching of meniscus tissue during knee motion with subsequent irritation of the joint capsule (Fig. 20.6). The surgeon should follow the principle to remove "as much as necessary, but as little as possible" of the meniscus tissue. It should be the goal to establish a stable rim of the remaining meniscus at the end of surgery. In case of a flap tear of the medial meniscus (MM), we prefer to first perform resection near the

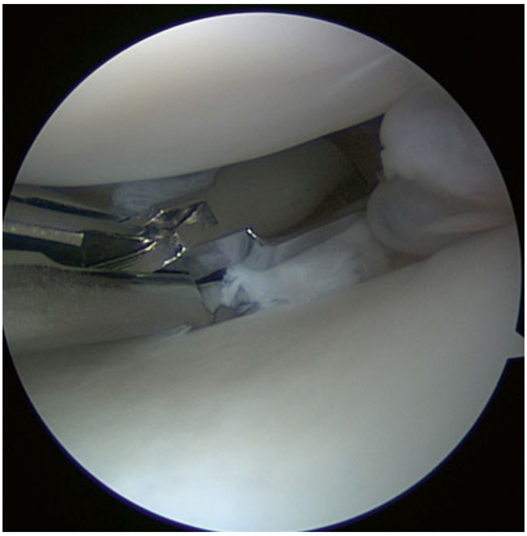

Fig. 20.7 Resection of meniscus tissue in the posterior horn of the medial meniscus using a 10° upcurved "duck-bill biter"

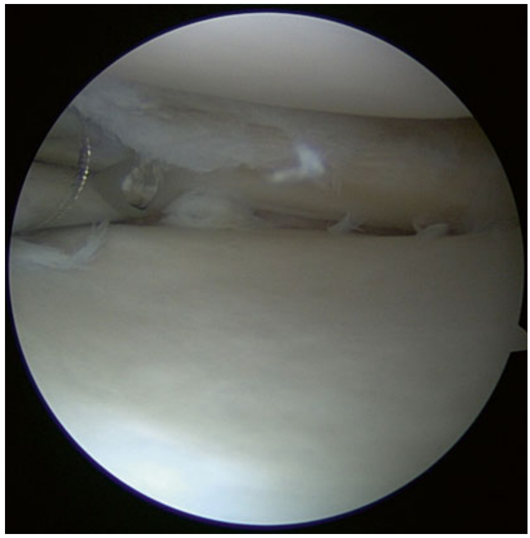

Fig. 20.8 Removal of loose pieces of meniscus tissue and smoothening of the remnant meniscus wall using a shaver (here: 4.5 mm bone cutter)

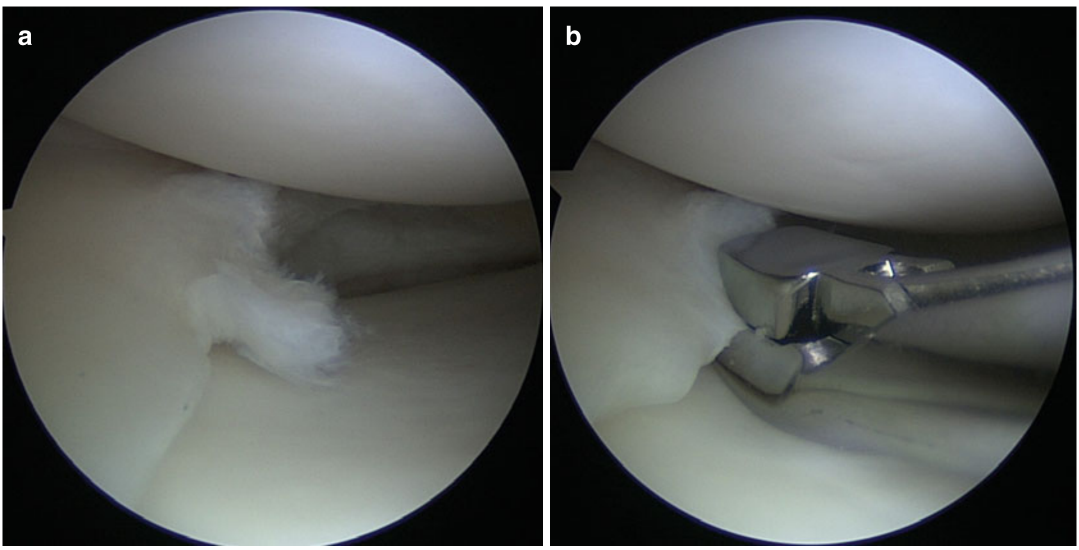

Fig. 20.9 (**a**) Remaining meniscal flap at the midportion of the meniscus. (**b**) Resection of midportion tissue from contralateral side through anterolateral portal

posterior horn of the meniscus. A 10° upcurved biter (e.g., duckbill biter, Smith & Nephew Inc.) may be used for tissue resection (Fig. 20.7). Additionally, a shaver (4.5 mm) may be used to remove loose bodies and to smoothen the tissue remnant (Fig. 20.8). If the lesion extends to the midportion of the medial meniscus, we recommend to switch portals in order to use the resecting instrument from the contralateral side and to approach the lesion in a more rectangular way (Fig. 20.9). An alternative to using a punch and shaver is the use of a suction punch. Other authors favor the use of electric cautery to avoid lose meniscus pieces in the joint [21]. However, cautery should only be used by experienced surgeons as it always offers the risk of iatrogenic cartilage damage [2].

20.6 Pitfalls During Meniscectomy

It may occur that the vision is inadequate and the posterior horn o the medial meniscus may not be visualized. In these cases a check of the integrity of the arthroscope has to be performed; potentially the light cable has to be changed. If the pathological tissue cannot be reached with the available instruments, the surgeon has to reevaluate portal placement; maybe another portal should be established. Despite perfect portal placement and strong valgus stress, the posterior horn of the medial meniscus may not be visualized sufficiently and a resection under visual control without damage to the articular cartilage may not be possible. We refer these situations to the status "tight knee." It is important to say that in these situations the surgeon should stop proceeding with surgery as planned. We prefer transcutaneous puncture of the MCL using a spinal needle to gradually open the joint in this situation [3, 8, 13] (Fig. 20.10a, b). This is done to avoid iatrogenic rupture of the MCL in response to excessive valgus stress. While transcutaneous needling of the distal and most posterior MCL fibers is well tolerated by the patient and in our hands does not require modification of the postoperative treatment plan, an iatrogenic rupture of the MCL may lead to prolonged medial instability and tenderness and should therefore be avoided. Alternatively a microfracture awl may be used to weaken the posteromedial capsule until the joint can be opened as needed.

In terms of resection, the surgeon might be tempted to exaggerate resection in the midportion while leaving unstable tissue in place in the posterior horn as it may be technically more demanding to resect this. With respect to the further onset of osteoarthritis, we strongly recommend to keep the resection in the midportion as sparse as possible. In degenerative tears frequently an unstable flap is present at the undersurface of the midportion. This can easily be resected from the contralateral side without compromising the whole midportion and the upper rim of the meniscus.

20.7 Specific Features to Lateral Meniscectomy

The lateral meniscus (LM) has specific anatomical features. Its thickness is greater and the accessibility to the anterior horn is more difficult. The popliteal hiatus provides higher mobility and meniscectomy must preserve as much as possible the meniscal wall on this part. In case of complete resection of the popliteal hiatus, the posterior horn becomes too unstable to be preserved. This situation is similar to a total/subtotal meniscectomy. The LM presents also anatomical variations

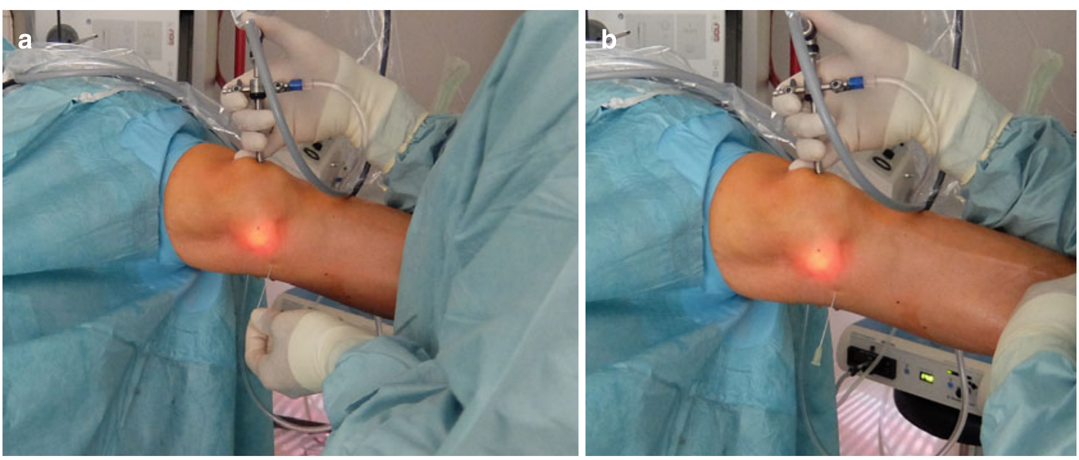

Fig. 20.10 (**a**, **b**) Weakening of the posterior fibers of the MCL through transcutaneous puncture of the meniscus with spinal needle for medial joint line opening

(discoid meniscus) that may require a meniscectomy. Finally, meniscal cysts are more frequently developed from the LM, in connection with meniscal lesions, longitudinal or horizontal.

20.7.1 Approaches

Two approaches are usually sufficient to achieve a lateral meniscectomy. The anterolateral approach is sufficient to fully explore the meniscus from the anterior to the posterior horn. It is performed in the same way as for the medial meniscectomy. The anteromedial approach is usually located more proximally and more anteriorly than for a medial meniscus lesion to avoid impingement with the lateral tibial spine.

The introduction of instruments through the medial approach may be difficult when the knee is placed in Cabot's position (synonym for Anglo-American "figure-of-four position") as the capsular layers slide away from the skin incision. To avoid this, it is advisable to make the entry point in Cabot's position, which allows direct access to the lateral compartment. As in medial meniscectomy, it is strongly advised to perform a "spinal needle test" to assure the ideal access point to the lateral compartment before the portal is established with the scalpel. When the anterolateral approach is not performed in Cabot's position, it is sometimes necessary to repeat the arthrotomy with scalpel blade no. 11.

The anterolateral approach is used for the scope and the anteromedial approach as an instrumental approach. To reach the posterior part of the lateral meniscus, it is sometimes necessary to use the medial approach for the scope. Never hesitate to change the instrumental and arthroscopic ways to improve the conditions of vision on one hand but also the ergonomic placement of the other instruments.

20.7.2 Technical Features to Lateral Meniscectomies

Treatment of lateral bucket handle tears and longitudinal vertical lesions (Fig. 20.11a, b)

In case of a dislocated bucket handle tear which is not chosen to be repaired, it is still essential to reduce the lesion before partial meniscectomy.

- The probe is introduced through a high anteromedial approach. It is sometimes tricky and requires to put the knee in 90° of flexion with varus stress to open the lateral compartment (Cabot's or "figure-of-four" position)
- The resection of the posterior attachment is done by arthroscopic scissors or basket forceps through the high anteromedial approach.

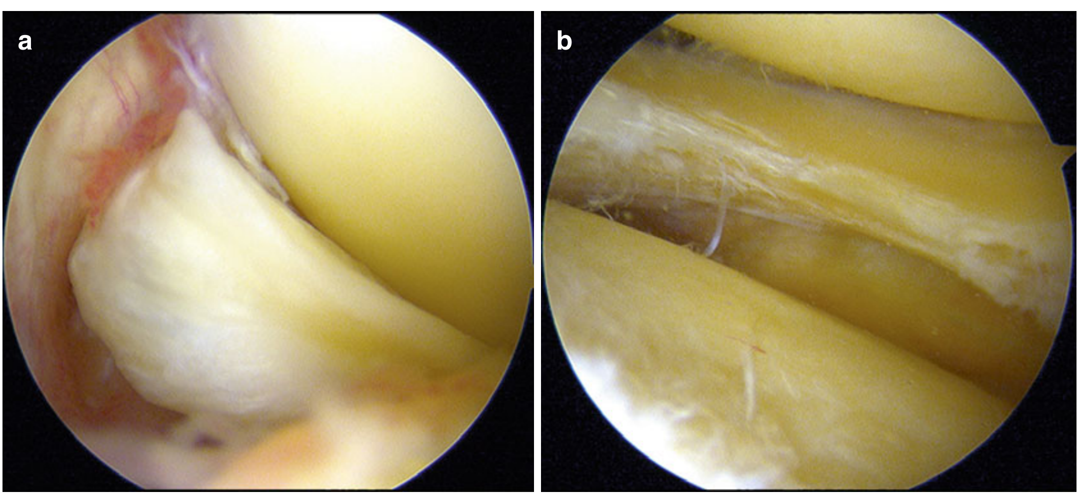

Fig. 20.11 (**a**) Bucket handle of the lateral meniscus. (**b**) After resection

- The resection of the anterior attachment is performed using a basket forceps or a scalpel inserted through the medial approach. When completing the meniscal resection, the tissue should immediately be resected entirely, to avoid a flap, which is more difficult to trim down when the bucket handle has been removed.
- Extraction of the meniscus is done with grasping forceps introduced through the medial portal. Finally the meniscus is further trimmed with basket forceps to achieve a stable rim.

20.7.3 Treatment of Vertical Radial Lesions

Vertical radial lesions are common in the mid-portion; the resection through the anteromedial approach is easy because the instrument is directly facing the lesion (Fig. 20.12a, b). The resection is carried out on either side of the lesion with the basket forceps by fragmentation. At the end of the procedure, the meniscus must have a smooth and stable rim. Care must be taken to respect the popliteal hiatus.

20.7.4 Treatment of a Lateral Meniscal Flap

The pedicle of the flap is cut, and the meniscus edge resected to avoid the formation of a step (Fig. 20.13a, b). There is always a chance to lose the flap after resection when it falls to the posterolateral recess of the joint. The instruments are passed through the anteromedial portal. In case of a posterior flap, the anterolateral instrumental portal may be used.

20.7.5 Treatment of Horizontal Cleavage

This type of injury often extends from anterior to posterior. The first step is to palpate the lesion to assess its extent and especially its relations with the popliteal hiatus. Meniscectomy is performed with the basket forceps by fragmentation using alternating portals: lateral portal for the posterior horn and medial portal for the anterior and midportion.

It is sometimes difficult to reach the anterior part of the meniscus. In this situation a 90° angulated forceps is very helpful. It is introduced

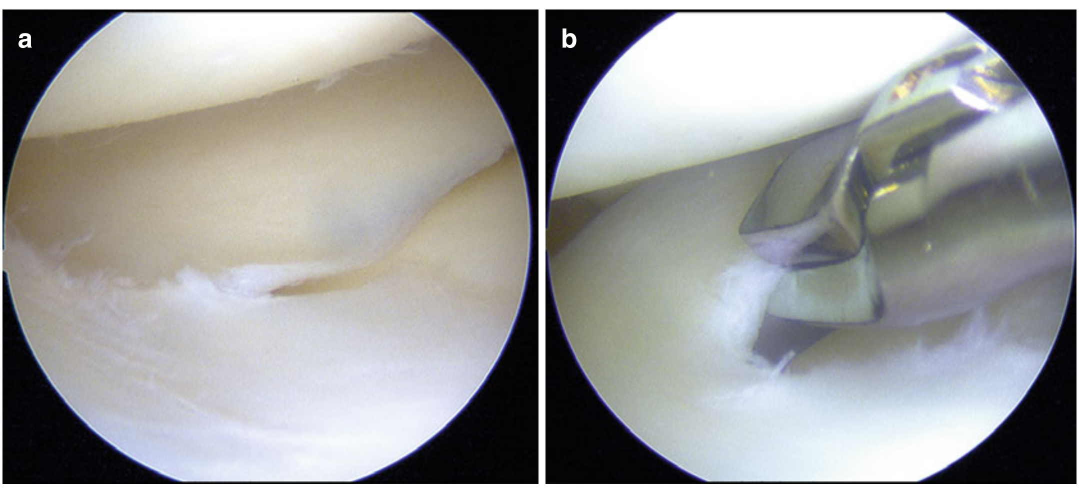

Fig. 20.12 (**a**) Radial tear in the midportion of the lateral meniscus. (**b**) Resection preserving the meniscus wall and the popliteus hiatus

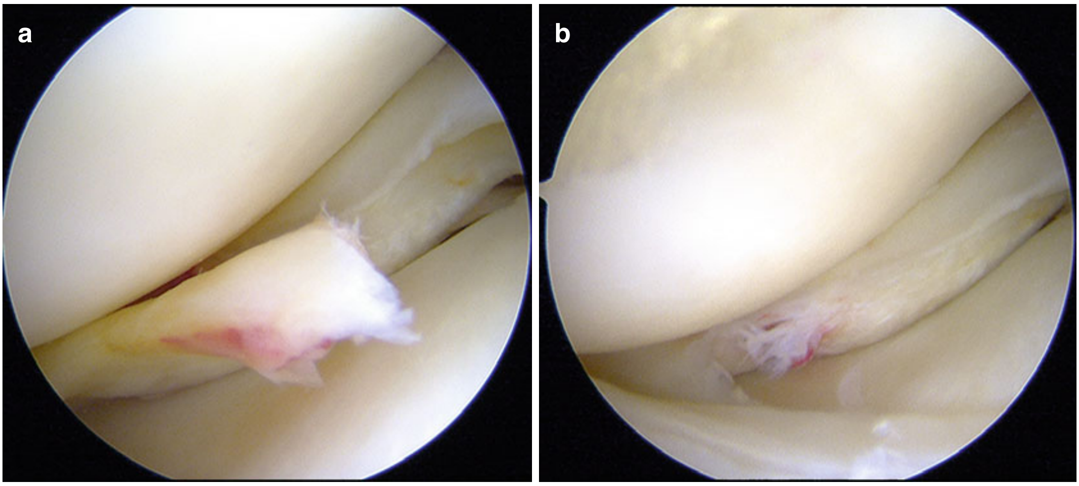

Fig. 20.13 Flap tear of the LMPH before (**a**) and after (**b**) partial meniscectomy

through the medial portal. The shaver may be used to treat anterior lesions (straight or curved shaver). In case of an extended lesion, it is recommended to preserve the upper side or the lower side of the meniscus if it is stable to avoid a subtotal meniscectomy.

20.7.6 Treatment of Meniscal Cyst

In 1981, Cross and Watson [7] recommended resection of the cyst associated with an open meniscectomy. Meniscal lesion treatment reduced significantly the risk of recurrence. Muddu et al. [17] suggested a treatment by infiltration of corticosteroids. With the development of arthroscopy, Seger and Woods [19] or Parisien [18] used the shaver to perform intra-articular debridement of the cyst.

The goals of arthroscopic treatment are first to treat the meniscal lesion respecting the meniscal wall and second to treat the cyst with excision of the content (Figs. 20.14 and 20.15). Arthroscopy has also reduced the extent of tissue resection during meniscectomy.

The procedure begins with the treatment of the meniscal lesion respecting the meniscal wall.

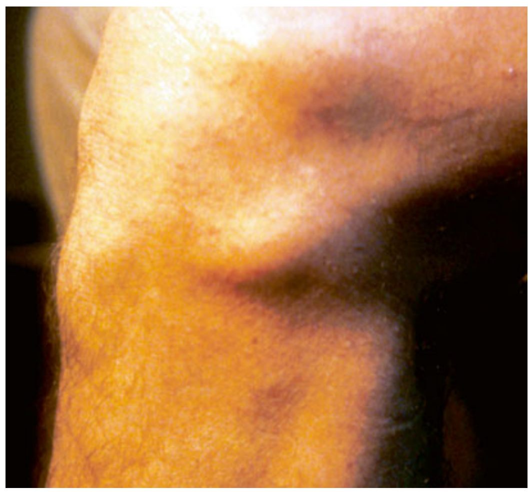

Fig. 20.14 Clinical characteristics of lateral meniscal cyst

It is necessary then to open the connection to the cyst using the stylus or even largely enlarge the gap using basket forceps or shaver [10] (Fig. 20.16).

Meniscal resection next to the cyst must be completed and reach the meniscal wall. A thick meniscal wall needs to be preserved on both sides of the connection to not destabilize the remaining meniscus.

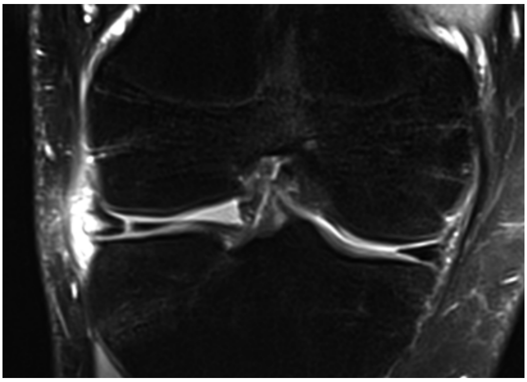

Fig. 20.15 MRI of a lateral meniscus tear associated with a meniscal cyst

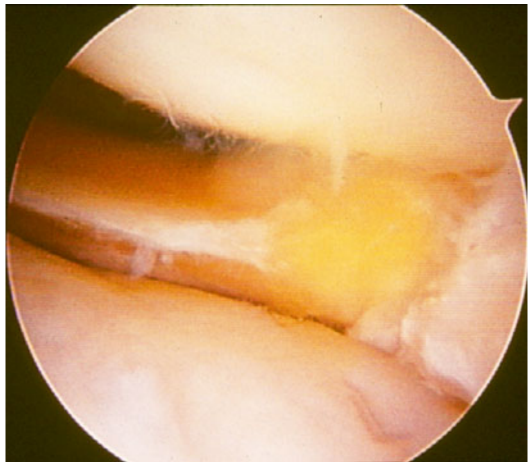

Fig. 20.16 Arthroscopic debridement of meniscal cyst after partial meniscectomy

The last step of the procedure is the removal of the content of the cyst. It is best removed using a shaver introduced through the connection to the cyst and it may cause bleeding promoting the healing. The use of curved shaver is useful when the connection is located in the anterior segment. Hulet (Thesis, 1993) reported that in most cases recurrence of the cyst is due to insufficient treatment of the meniscal lesion. The use of angulated instruments and both antero-mediolateral approaches are imperative to remove the whole lesion.

In a more recent study, Hulet et al. [12] analyzed retrospectively 105 cysts of the lateral meniscus treated arthroscopically at a mean follow-up of 5 years. Meniscal lesions were found in all cases. Meniscectomy was performed in 104 cases associated with either debridement of the cyst arthroscopically (91 cases) or direct approach for resection (14 cases). The result was excellent or good in 87 % of cases. The authors concluded that the expected result was good with arthroscopic debridement of the cyst.

The patient should be informed before surgery about the alternative of an open and direct approach and its constraints. The risk of residual swelling (common) or recurrence of the cyst should clearly be explained to the patient.

20.7.7 Treatment of Discoid Meniscus

This type of meniscus can cause painful lateral compartment syndrome, especially associated with a lesion (Fig. 20.17a, b). The partial meniscectomy or "meniscoplasty" is sometimes difficult. The correct shape of the meniscus must be restored. Fragmentation by basket forceps is very effective. The forceps is first introduced through the anteromedial approach; meniscoplasty begins at the posterior segment or midportion. The meniscal fragment is then removed. The remaining meniscus is trimmed down to obtain a regular meniscus edge [22]. It is the goal of the procedure to preserve enough meniscal tissue and leave the meniscal wall intact [6].

20.7.8 Indications for Lateral Meniscectomy

Except specific lesions such as meniscal cyst or discoid meniscus, we could summarize the indications for lateral meniscectomy to the following situations [1]:

In case of traumatic meniscal lesion on stable knee

Lesions of small size and asymptomatic should be treated conservatively especially when the patient is not participating in sports. Symptomatic lesions in the white zone should be treated with partial meniscectomy and healthy meniscal tissue must be preserved under all circumstances. For symptomatic lesions in the red zone, lateral meniscectomy

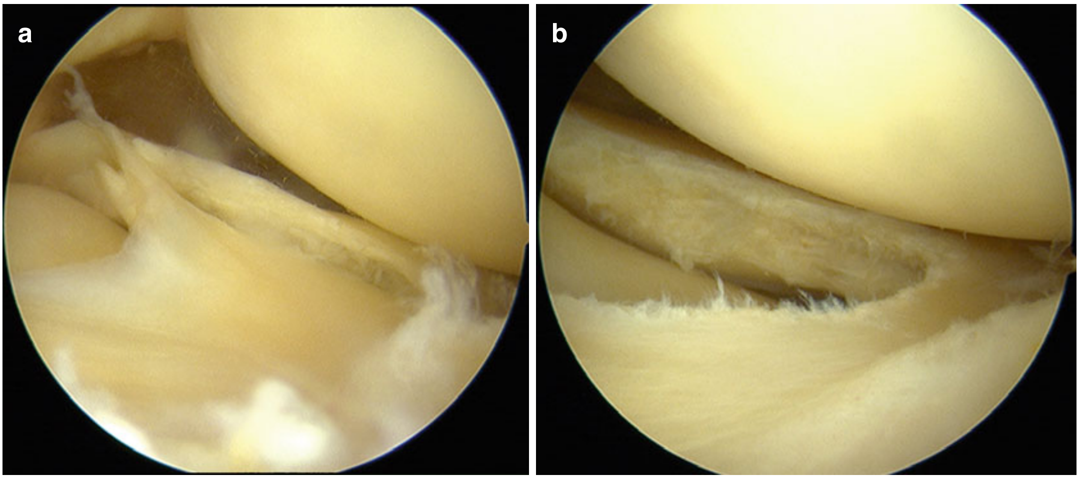

Fig. 20.17 (**a**) Radial tear on a discoid lateral meniscus. (**b**) Treatment by partial meniscectomy and meniscoplasty

should be avoided due to detrimental consequences to the articular cartilage in the medium and long term. A meniscal repair should be performed even in the case of a potential failure.

In case of traumatic meniscal lesion in an unstable knee

The treatments of the meniscal and anterior cruciate ligament lesions are inseparable. ACL reconstruction plays an important role in the healing of the meniscal lesion. Furthermore, in an unstable knee, meniscectomy is a poor prognostic factor for cartilage status in the short and long term. Meniscectomy should be considered in case of symptomatic meniscal lesion that cannot be repaired or neglected.

In case of degenerative meniscal injury on stable knee

A degenerative lesion often presents as a complex lesion. A meniscal cyst is sometimes associated. Arthroscopic treatment should be discussed after failure of well-conducted medical treatment. The partial meniscectomy should be performed retaining a maximum of healthy meniscal tissue.

20.8 Termination of the Procedure

Before termination of the arthroscopic procedure, the surgeon should assure that a stable rim of the remaining tissue has been achieved. Loose bodies should be removed especially from the posterior recessus. Here, simultaneous "shaking and suction" may help to clear the joint from remaining loose tissues. Following this the irrigation fluid should be removed. Wound closure can be achieved with steri strips, stitches, or none. A wound drainage may be applied; however in most cases it is not necessary. Intra-articular application of local anesthetic as a single shot combined with morphine may be performed according to the surgeon's preferences.

20.9 Complications

Complications after meniscectomy are rare. The infection rate has been reported to be less than 0.1 %. Deep vein thrombosis can be associated with the use of a tourniquet and a history of clotting disorder (e.g., factor V Leiden thrombophilia disease). If there is excessive postoperative bleeding, puncture of fluid may be necessary during the first days after the procedure. An iatrogenic lesion of the MCL may occur in response to excessive valgus stress during the procedure. This incidence predominantly occurs in female patients over 40 years of age and it will usually lead to tenderness over the medial side and medial instability of the knee for several weeks.

20.10 Postoperative Regimen and Rehabilitation

This surgery is mostly performed as an outpatient surgery. The procedure can be done under local anesthesia; however, other forms of anesthesia are used more commonly, spinal, femoral block, and general anesthesia.

Patients come out the same day of surgery. The surgeon must give information to the patient about the surgery and its expected consequences.

The surgical report is very important. It must be detailed and must specify the amount of meniscus removed and the remaining tissue. Finally, it is important to indicate whether this meniscectomy was difficult or easy. This is an indicator for the evolution and prognosis of meniscectomy. It must also detail the cartilaginous status based on the ICRS (International Cartilage Repair Society) classification and the extension of the lesions involved in the long-term prognosis. The iconography is important, either as photos or video. Archiving is an interesting contribution to the patient's clinical record and mandatory by authorities in many countries.

Walking with full weight bearing without crutches may be allowed immediately. Return to sports is possible one month after surgery in the absence of complications and especially in case of traumatic meniscal tear. However, in case of degenerative lesions, return to sports mainly depends on the cartilage status.

In general, rehabilitation should be gentle and avoid pain. The goal is to regain ROM of the knee without pain; muscle reinforcement is done carefully and is associated with anterior/posterior muscular chains stretching.

Finally, it should be explained that recovery after lateral meniscectomy is usually longer than after medial meniscectomy. At long term [4, 5], subjective and clinical results are similar but radiological progression was significantly worse after lateral meniscectomy. The factors of good prognosis are young age of the patient, the absence of cartilage defect at the time of surgery, and an intact meniscal wall.

Conclusion

Partial meniscectomy is a frequent arthroscopic procedure. To be successful the surgeon has to follow a certain algorithm. Several pitfalls during the procedure may occur and the surgeon must be aware of them.

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Biomechanics of Meniscal Repair

21

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21.1 Introduction

The menisci are essential to the normal biomechanics and functioning of the knee. Their complex functions include load transmission, shock absorption, stability, and proprioception [16, 47]. To that end, the delicate meniscal collagen network, particularly its circumferential collagen fibers, continuously translates the axial load corresponding to the body weight into hoop stresses. This action contributes to dissipate energy, which is crucial to joint preservation. The integrity of both the collagen network and the strong attachments to the tibia of both meniscal horns is essential to completely fulfilling that function.

Until recently, either a complete or partial resection was considered the gold standard treatment for meniscal tears. However, removal of meniscal tissue has led to increased contact stresses, which in turn bring on accelerated wear and permanent cartilage deterioration [26, 27]. This sequential damage can be understood considering that taking away as little as 15–34 % of the meniscal tissue increases joint surface pressures by 350 % [30].

In order to maintain the aforementioned biomechanical properties, tissue repair has become the norm in recent years, particularly with acute tears. Although continuous refinements of the surgical technique and the devices used in meniscal repair have been introduced in the last decade, the number of meniscal repairs is still low when compared to arthroscopic meniscectomy [41].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_21

Still, meniscal repair is successful in the long term in up to 75 % of cases when rightfully indicated. The success of meniscal repair depends on the correct preparation of the meniscal bed and the surgical technique used. However, it is also influenced by biological factors, which will be discussed in another chapter.

This chapter aims to review the mechanical characteristics and indications for meniscal repair. The different types of sutures described and their biomechanical properties are also discussed in light of the current scientific evidence.

21.2 Meniscus Biomechanical Considerations

The meniscus is a fibrocartilaginous structure composed of a network of collagen fibrils (90 % type I and in small part types II, III, V, and VI), fibrocondrocytes, and water. The arrangement of collagen fibrils has been defined as being "arcade-like." The orientation of the fibrils mainly runs radially in the inner two-thirds of the meniscus and in a circular direction in the outer third. At the meniscal surface, the collagen fibrillar network is woven into a mesh-like matrix (Fig. 21.1). This microstructure is believed to be crucial to determining the meniscal function that consists of the conversion of the axial compressive load into a circumferential force or hoop stress [1, 5, 32, 37], which ultimately dissipates energy and protects the cartilage surfaces (Fig. 21.2).

The medial meniscus translates approximately 5 mm on the anteroposterior plane, which allows for adequate femoral rollback during knee flexion. Further, the posterior horn of the medial meniscus acts as a wedge to block anterior translation [22, 44]. Thus, apart from contributing to the load dissipation, the medial meniscus provides anteroposterior stability due to it being an agonist to the ACL [16]. It is demonstrated by the significant increase in ACL strain seen after meniscectomy. Therefore, a medial meniscectomy combined with an ACL deficiency can lead to increased anterior tibial translation [44].

Although meniscal repair is certainly less detrimental to knee homeostasis than meniscal resection, the ultrastructure and biomechanics of the meniscus are complex and they are never fully restored after a meniscal tear. Therefore, a repaired meniscus will never have the same degree of chondroprotection and mechanical function of native tissue.

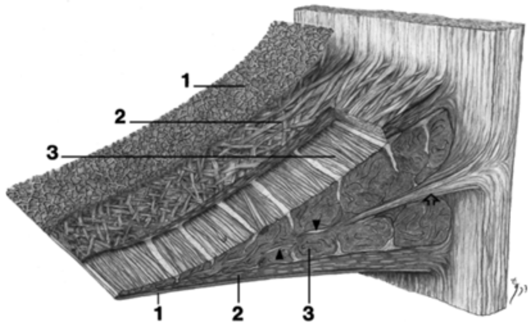

Fig. 21.1 Cross-sectional view of meniscus demonstrating the collagen fiber network. (*1*) Superficial mesh layer, (*2*) lamellar network, and (*3*) circumferential fibers (Reprinted with permission from Springer. Petersen et al. [32])

21.3 Meniscus Repair: Results

Although indications for meniscal repair are beyond the scope of this chapter, they are summarized in Table 21.1.

The results of meniscal repair significantly vary depending on the published series. However, there is some agreement as to which tears have a better prognosis. Rubman et al. assessed the results of 198 meniscal tears that have had a major segment in the central avascular region repaired with an arthroscopically assisted inside-out technique. At a minimum of 2-years follow-up, 80 % of the cases were found asymptomatic for tibiofemoral joint symptoms while the rest required a new arthroscopic procedure. When this second surgery was performed, it was seen that the initial tear was healed or partially healed in 64 % of the cases whereas there was no healing in the remaining cases. Based on these results, those authors recommend meniscal repair even in tears that are not entirely in the red-red zone. They have also suggested that lateral meniscal repairs have a worse prognosis than medial meniscal repairs [38]. More recently, Kurzweil et al. completed a

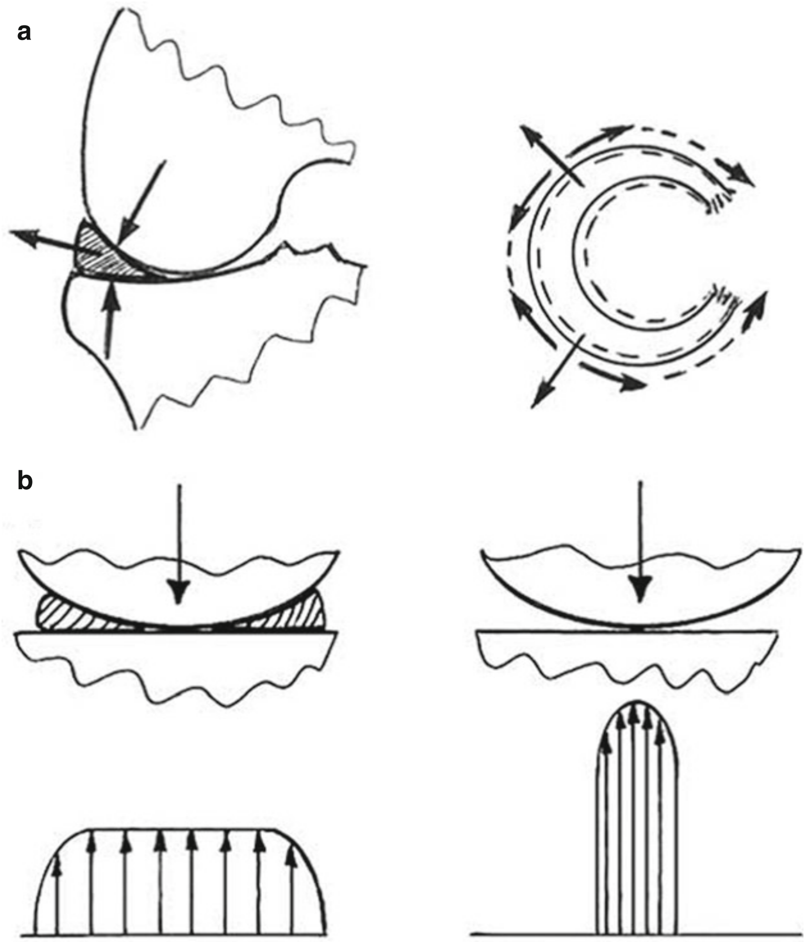

Fig. 21.2 Load transfer through the knee joint. The menisci extrude under axial joint load and contact stress force is distributed (**a**). The removal of the meniscus leads to peak axial load on a smaller tibial surface (**b**). (Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery McDermott et al. [27])

Table 21.1 Accepted indications and contraindications for meniscal repair

Indications	Contraindications
Meniscal tear with tibiofemoral joint-line pain	Tear in the inner one-third region (white-white)
Active patient < 60 years	Patient > 60 years or sedentary (except those with traumatic red-red tear that must be repaired to save meniscus)
Concurrent knee ligament reconstruction or osteotomy	Patient unwilling to follow postoperative rehabilitation program
Meniscal tear reducible, good tissue integrity, normal position in joint one repaired	Chronic degenerative tear with tissue of poor quality not amenable to suture repair
Peripheral single longitudinal tear (red-red) in one plane; reparable in all cases, with high success rates	Longitudinal tear of >10 mm in length
Red-white tear in middle one-third region with vascular supply present	Incomplete radial tear that does not extend outer one-third region
Tear in outer and middle one-third regions (red-white) on one plane (longitudinal, radial, or horizontal); often reparable	
Complex tear in multiple planes (double or triple longitudinal or flap tear) in outer-third and middle-third regions (red-white); repair rather than excision	

systematic review to evaluate the existing evidence on horizontal cleavage tears and to test the hypothesis that when these tears are surgically repaired, they have a low rate of success. The success rate encountered in that study was 77.8 % and they concluded, based on existing studies, that horizontal cleavage tears show a success rate comparable to the repairs of other types of meniscal tears [20].

Current knowledge also agrees that the rate of healing is more favorable for small and acute tears as well as when the repair is performed in association with an ACL reconstruction [11, 14, 30, 39, 46, 49, 50]. In a recent large case-controlled study that included more than 9000 patients undergoing meniscal repair, Lyman et al. [23] concluded that meniscectomy after meniscal repair is infrequently performed (8.9 %). It supports the concept that repairing a meniscus is a safe and effective procedure in the long term. Furthermore, the risk of undergoing subsequent meniscectomies is even lower in patients undergoing a concomitant ACL reconstruction in cases of isolated meniscal repairs for the elderly as well as in patients undergoing meniscal repair carried out by very skilled surgeons.

In spite of these results, the indication for meniscal repair is not so clear in many cases. Some meniscal tears have no absolute indication for repair or meniscectomy and decision-making is based on a number of factors. Those factors include the type of tear, location, associated injuries, the age and activity of the patient, and the surgeon's experience. Accordingly, the ideal candidate seems to be a young patient who has a stable knee and an acute, vertical, longitudinal meniscus tear located in its most peripheral vascular third [37]. In recent years, there has been a trend toward broadening the indications for meniscal repair to the detriment of meniscectomy.

21.4 Sutures: Methods and Devices

Repair techniques classically fall into two categories: open and arthroscopic. Open repair techniques were initially used [9, 10] but arthroscopic approaches soon evolved to minimize the risks associated with open surgery [17, 18, 40]. Over the last two decades, almost all meniscus repairs have been done arthroscopically and this method has become the gold standard. There are three arthroscopic suturing procedures: (1) outside-in, (2) inside-out, and (3) all-inside, all named for the origin of suture delivery.

Arthroscopic inside-out repair of torn menisci using a bent-tip needle was first introduced by Henning et al. [17]. This method requires an additional posterior incision to effectively tie the suture down onto the joint capsule. Inside-out repair offers a success rate of up to 80 % for isolated meniscal repairs and up to 90 % when performed with a concomitant ACL reconstruction. For that reason, it has long been considered the gold standard for arthroscopic meniscus repair. The outside-in method was developed some years later to minimize the risk of neurovascular injuries related to the additional posterior exposures [29, 48]. It is a simple, minimally invasive and inexpensive technique that is most suited to repairing anterior horn and meniscal body tears. This is due to the fact that the posterior horns are much more difficult to reach from outside the joint. In 1991, Morgan introduced the all-inside technique [28] and this technique has experienced the greatest development due to its safety, ease of use, and shorter surgical times. First-generation all-inside repair devices were rigid so as to provide good fixation. They showed some good clinical outcomes. However, their high failure rates and the articular cartilage scuffing occurring during manipulation or by coming into contact with the articulating surfaces have made them unsuitable for meniscal repair [3, 12, 28, 43]. More recently, flexible suture- and anchor-based repair devices have been developed and they are now preferred for the management of tears located at the body and posterior horn of both menisci. The newest suture implants are built with dual anchors connected by a pre-tied, sliding, and self-locking knot. Thus, they allow for variable tensioning across the meniscal tear. Suture methods and devices are summarized in Table 21.2.

Table 21.2 Overview of available meniscal repair devices

Suture	Rigid implants	Suture repair systems
Inside-out (generic flexible needles and pre-bent cannulas)	Meniscus Arrow (BionX implants)	FasT-Fix/Ultra FasT-Fix (Smith & Nephew Endoscopy)
Outside-in (generic intravenous cannulae)	Meniscal Dart (Arthrex)	MaxFire (Biomet)
All-inside (Meniscal Viper [Arthrex])	BioStinger (ConMed Linvatec)	Meniscal Cinch/Meniscal Viper (Arthrex)
	Meniscal Screw (Biomet)	RapidLoc/Omnispan (DePuy Mitek)
	Clearfix Screw (Mitek)	Sequent (ConMed Linvatec)
		NovoStitch (Ceterix Ortho)

All these types of sutures permit great versatility in terms of suture placement and stitch configuration. Namely, they are horizontal, vertical, or, even, oblique mattress sutures. The biomechanical properties of each one have been extensively studied and they will be commented on later in Sect. 21.6 of this chapter.

21.5 Biomechanical Testing

Following the pioneering study of Kohn and Siebert [19], a number of studies have evaluated the biomechanical properties of the different sutures and all-inside devices developed to repair the meniscus. These studies analyzed meniscal repair at different time points during the healing process. They can be classified as:

Time-Zero Studies Most of these studies use the *tensile fixation strength* (*TFS*) to assess the biomechanical properties of the sutures and devices [18]. The sutured meniscal specimen (either with stitches or with devices) is mounted on a testing machine and loaded to failure to test the repair. To that end, axial tension is applied in a direction parallel to the long axis of the tear. The value obtained is usually represented by a force-elongation curve and measured in newtons. The slope of the curve indicates the stiffness of the meniscal repair (Figs. 21.3, 21.4, and 21.5). However, there is no consensus with regard to the exact testing conditions among studies and the results obtained show a high degree of variability, which makes comparisons difficult. Fisher et al. first introduced the concept of shear forces to further refine the analysis of meniscal sutures and/or the fixation devices. They found the resistance to pullout loads to be different from the resistance to longitudinal shear loads [13].

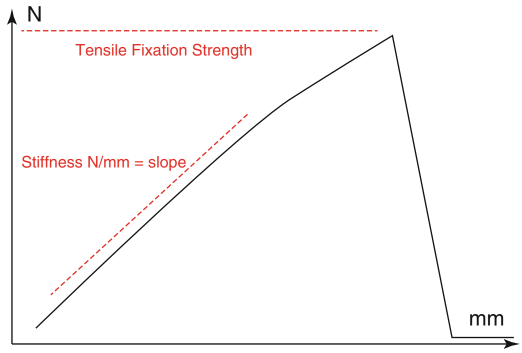

Fig. 21.3 Current representation of a tensile fixation strength and stiffness curve

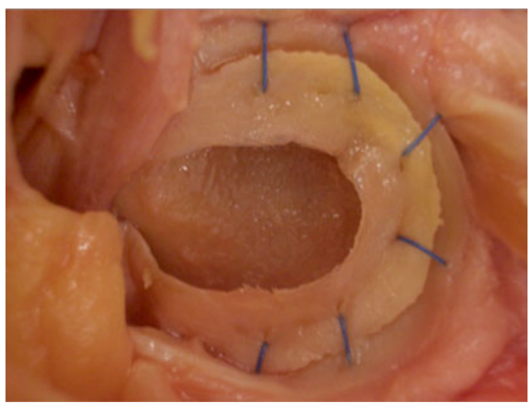

Fig. 21.4 Knee dissection of a left cadaveric knee showing a lateral meniscus repair including the popliteus tendon. The lateral femoral condyle has been osteotomized

Healing Phase At this point (between weeks 0 and 12 after meniscal repair), several mechanical

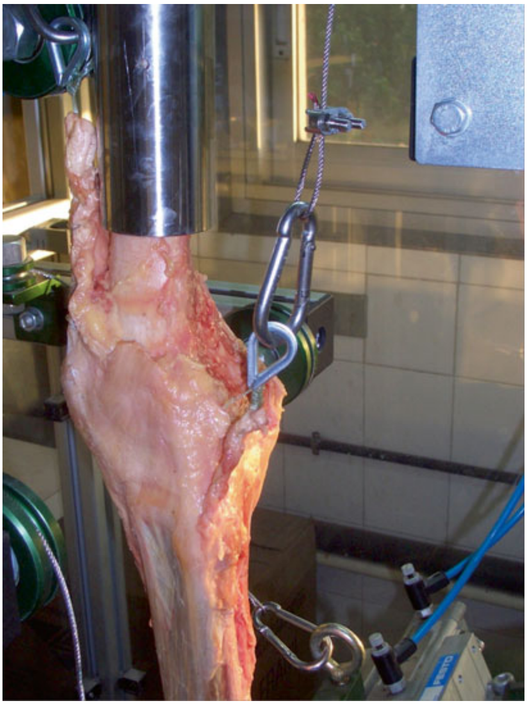

Fig. 21.5 The same knee with the meniscus already repaired and the osteotomy fixed, mounted in a gait simulator to test the repair (Courtesy of X. Pelfort M.D.)

and biological factors can be assessed. The TFS can be used to evaluate the effect of the *hydrolysis* time on sutures and/or devices. This method is used in tissue-culture models and requires an incubation period for the repaired meniscus before TFS can be studied. Some other tests can also be used in this period as the *cyclical loading* test. This is a dynamic test that analyzes the effect of repetitive loading on the meniscus. The *compression forces* test in turn is designed to assess complications that might be produced by new all-inside devices. It is done by applying tibiofemoral compression forces to a repaired meniscus.

Late Healing Phase At this time point, the objective is to assess the biomechanical characteristics of the resultant scar tissue. This point is relevant as healing and remodeling of meniscal tears is dependent on location of the tear, vascularity, and subsequent physical therapy. Thus it is possible that different repair devices may influence remodeling to differing extents in vivo.

21.6 Biomechanical Studies: Current Knowledge

Kohn and Siebert [19] compared vertical and horizontal mattress sutures by measuring the TFS in excised cadaveric menisci. Vertical sutures showed a pullout strength that was significantly higher than that of horizontal sutures, suggesting that horizontal sutures are weaker. They assumed that vertical sutures captured more circumferential collagen fibers, thus providing higher failure strength. Of late, these results have been confirmed by a number of studies [7, 33, 36, 42]. For this reason, vertical sutures are commonly considered the gold standard of meniscal repair in terms of strength as this type of stitch mainly fails when the suture breaks. Recently, variations of this vertical mattress stitch have been described to further increase their failure load. Abdelkafy et al. developed a cruciate suture that holds both circumferential and radial collagen fibers of the meniscus on a three-dimensional plane. This cruciate stitch is able to capture greater meniscal tissue volume and thereby possesses higher fixation strength in the repaired meniscal tear [1, 2].

Nevertheless, not only the suture but also the type of meniscus tear itself might influence the approach needed to perform a meniscus repair. While the anterior horn is better approached with an outside-in technique, the body and posterior horn of the meniscus are better treated by the inside-out or all-inside suture technique [15, 45]. The first-generation all-inside devices had some shortcomings that have been largely corrected in more recent devices. Currently, the newer generation meniscal repair devices exhibit biomechanical properties similar to inside-out sutures [8].

With regard to the material used to suture, Buckland et al. [8] recently analyzed the biomechanical outcome after different techniques and devices for meniscus repair. They hypothesized that modern devices show at least the same load-to-failure force as suture repair. Overall, they found that sutures had a significantly higher load-to-failure and greater stiffness than devices. With respect to the suture material, the top three suture repairs were vertical sutures performed with PDS 0, Orthocord 00, and Ethibond 0. They exhibit the highest load-to-failure rate. With regard to the devices, second-generation devices were significantly stronger and stiffer than first-generation devices, being the Meniscal Viper (Arthrex), MaxFire (Biomet), and FasT-Fix (Smith&Nephew) the top three in terms of strength. These results were obtained when a vertical mattress suture configuration was used. Therefore, the authors concluded that the vertically oriented repair remains the gold standard based on biomechanical testing. However, some meniscal repair devices exhibit similar biomechanical properties to suture repairs and so both suture repairs and devices may have a place in current meniscal restoration.

When analyzing meniscal repair, forces acting in vivo are difficult to reproduce in vitro. Becker et al. analyzed in cadaveric models the forces acting in medial meniscal repair. They compared five different types of biodegradable implants (Arrow, Dart, Fastener, Stinger, and Meniscal Screw) and horizontal suture (No. 2 Ethibond). The knees were mounted in a testing machine and extended from 90° of flexion to 0° under a constant load of 350 N. They found that the meniscofemoral pressure did not increase after meniscus repair with biodegradable implants or sutures increased significantly in both compartments with knee flexion from 0° to 90°, suggesting that, when well positioned, biodegradable implants for meniscus repair do not affect the articulating surfaces [6].

Furthermore, the possible influence of some mobile anatomical structures on the meniscal repair has been rarely assessed. Pelfort et al. investigated in cadaveric model the feasibility of a lateral meniscal repair whether the popliteal tendon was included or not. As no standards have been described regarding cycle number and force for the testing of meniscal repair techniques, they used 1.000 knee cycles (cycle numbers ranging between 1000 and 1500 cycles are thought to correspond to the stress applied within 1 week of postoperative physical therapy). In this experimental model, the repair of the lateral meniscus, including the popliteal tendon, did not seem to have any repercussion on suture viability [31].

21.7 Biomechanical Studies: Limitations

The main limitation of most of these biomechanical studies is that cyclic testing was not performed and the shear forces, to assess the quality of the repair, have not been tested. Recently, Massoudi et al. compared the biomechanical behavior of the all-inside suture-based repair with an inside-out suture repair and an all-inside anchor-based repair. They used both cyclic loading and load-to-failure testing. The results show that the all-inside suture-based repairs and the inside-out repairs exhibit significantly higher load-to-failure than the all-inside anchor-based repairs. The stiffness values for the three repairs were not different and suture failure was the predominant mode of failure across all repair techniques [24].

Another common limitation is the number of sutures used to repair the meniscus. While two or more stitches may be needed to properly fix a meniscal tear in the clinical setting, most of the experimental studies compared meniscal repairs performed with a single stitch. Ramappa et al. [35] conducted a paired biomechanical evaluation of meniscal repair using new all-inside devices in comparison with the gold standard inside-out suture in a porcine model. To that end, they compared the biomechanical characteristics of running sutures delivered by the Sequent meniscal repair device (ConMed Linvatec) with 2 vertical mattress sutures applied using the Ultra FasT-Fix (Smith&Nephew) device as well as with 2 vertical mattress sutures using an inside-out repair technique with No. 0 Hi-Fi suture. They observed that the running suture displays the least amount of displacement during cyclic loading but a failure load similar to anchor-based all-inside vertical sutures, as previously suggested by Lee et al. [21].

A third limitation commonly found in most of the abovementioned studies is that they are mainly designed to assess the biomechanical behavior of different types of sutures or devices applied to longitudinal meniscal tears located in the red-red or red-white zone. However, the paucity of meniscal vascularity and the differences in the ability to heal in different zones of the meniscal tissue are well known [34]. Furthermore, horizontal meniscal tears are believed to be of degenerative origin and so their repair is controversial [20, 34]. Even so, current literature does not give credence to the clinical outcomes of surgically repaired horizontal cleavage tears having an unacceptable low rate of success. On the contrary, according to a recent systematic review, existing studies show a success rate comparable to that of repairs of other types of meniscal tears. This suggests that they can be successfully performed [20].

Finally, radial tears are also challenging to repair. They might only be treated when they extend beyond the outer third of the meniscus, in the most vascularized area. Recent studies experimentally compared the classically performed horizontal sutures with different vertical or oblique compositions for the treatment of this type of tear. The results suggest that the biomechanical properties of a vertical all-inside technique are superior to those of a horizontal inside-out technique [4]. Matsubara et al. [25] further demonstrated that a cross-suture technique significantly improves the structural properties of repaired complete radial meniscal tears as they have been proven to provide greater stability than a double horizontal suture technique. These results suggest that the repair of a radial meniscal tear is feasible when using an improved surgical technique.

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Meniscus Repair: Updated Techniques (Open and Arthroscopic)

22

Nicolas Pujol and Romain Seil

Contents

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22.1 Introduction

Meniscus repair was first reported by Annandale in 1885 [4, 16]. However, the interest in preserving the meniscus increased dramatically after the publication of long-term follow-up studies which reported degenerative changes and joint space narrowing following meniscectomy [25, 49]. Like other procedures in knee surgery, the meniscus repair has benefited from technical advances in arthroscopy.

The first arthroscopic repair was performed by Ikeuchi in 1969 and published later [28]. Following this, arthroscopic meniscus repair has become the procedure of choice for many years to treat traumatic vertical lesions that occur in a vascularized zone (stable knee or during an ACL reconstruction), because of their favorable results when compared to meniscectomy [41, 55]. Additionally, the techniques have evolved from open repairs to all-inside arthroscopic repairs with hybrid devices or suture systems. Hence, this chapter will discuss several modern meniscus repair techniques, which are adaptable to repair meniscus lesions.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_22

22.2 Arthroscopic Assessment

When a meniscus repair is carried out under arthroscopic visualization, some common steps, which are independent of the technique, are required to be followed. The most important steps of a meniscus repair technique are summarized in Table 22.1. Firstly, the patient is placed in a supine position, and then a regional or general anesthesia is induced. Moreover, using a standard knee arthroscopic setup, anterolateral and anteromedial portals are established. Through the next step, the knee is held in slight flexion with the application of valgus stress in order to achieve access to the posterior part of the medial meniscus. In fact, the pie crusting technique may be useful to improve a posterior view in tight knees when required [6, 29] (Fig. 22.1). Likewise, it has been reported as safe and reproducible when the access to the posterior segment of the medial meniscus is difficult. This is known as a percutaneous needling of the medial collateral ligament. Furthermore, to access the posterior part of the lateral meniscus, the knee is flexed at 90° and varus stress is applied in the "figure of four" position without lateral release.

Table 22.1 Keypoints for all-inside repair

Abrasion	Aggressive removal of all fibrous tissue	"Partial peripheral meniscectomy"
Suture placement	3–5 mm interval between devices	5–10 mm interval between anchors, same device
Orientation	Maximum of meniscal tissue into the suture	Vertical > oblique > horizontal Double row > single row
Number of sutures	Between 2 and 8	Do not hesitate to add sutures

Even though imaging techniques can be helpful, the characteristics of a tear are best assessed arthroscopically. Through this procedure, the type (vertical longitudinal, horizontal, radial, complex) and length of the tear are determined and the distance from the meniscosynovial junction is measured using a probe. Similarly, a stable tear is also defined using a probe.

When probed, the meniscus cannot be displaced into the intercondylar notch, and the inner edge of the meniscus cannot touch the central part of the femoral condyle. From this, the peripheral 20–30 % of the medial meniscus and the peripheral 10–25 % of the lateral meniscus are vascularized [47]. Moreover, the location of the tear is classified into zones, according to Arnoczky and Warren [5]. Zone 0 represents the peripheral meniscosynovial junction; zone 1, the red-red zone; zone 2, the red-white zone; and zone 3, the white-white zone. In addition, the tears in the red-red and the red-white zone are amenable to repair, whereas the meniscus repair for tears in the white-white zone has poor healing potential, although it can still be an option in very young patients, especially in regard to lateral meniscus tears [24, 39] as a salvage procedure.

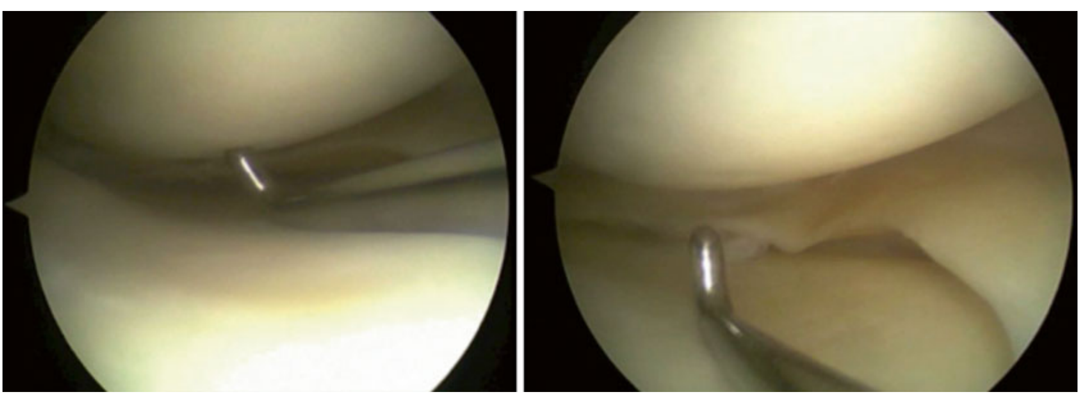

Fig. 22.1 Release of the medial collateral ligament to access the posterior side of the medial meniscus in tight knees

Nevertheless, in case of a bucket-handle tear, the reducibility has to be assessed, as an old bucket-handle tear can develop plastic deformity, which will lead to redislocation after reduction and/or repair [56]. In fact, the tensile forces are so important that they may compromise the fixation, regardless of the device implanted, and decrease the chance of healing. What is more, the cartilage status and cruciate ligaments are also assessed. Consequently, at the end of the diagnostic arthroscopy, the surgeon is able to determine if the lesion is repairable, in a patient who would normally have a recent traumatic vertical tear in a stable or stabilized knee.

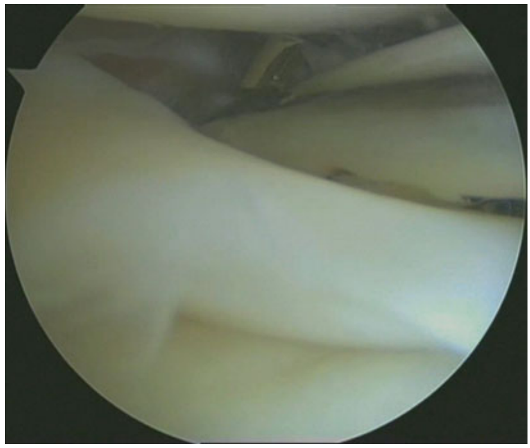

Fig. 22.3 Meniscal abrasion with a basket punch

22.3 Debridement/Abrasion

In order to remove the fibrous tissue present in the meniscus lesion (even if it is an acute lesion), the walls of the tear are debrided using a basket punch, a rasp, or a shaver (Figs. 22.2 and 22.3). This procedure is a mandatory step in order to promote the healing response [43], and the abrasion should be a partial peripheral meniscectomy of the outer edge of the meniscus, using the same principles of abrading a nonunion of a bone shaft. In some cases, multiple perforations can be made with a needle in the meniscus rim to stimulate the bleeding through vascular channels. Furthermore, marrow-stimulating techniques [3], using either cannulated reamer or K-wire pins around the intercondylar notch, can also be considered as an additional simple method for augmentation of meniscus healing.

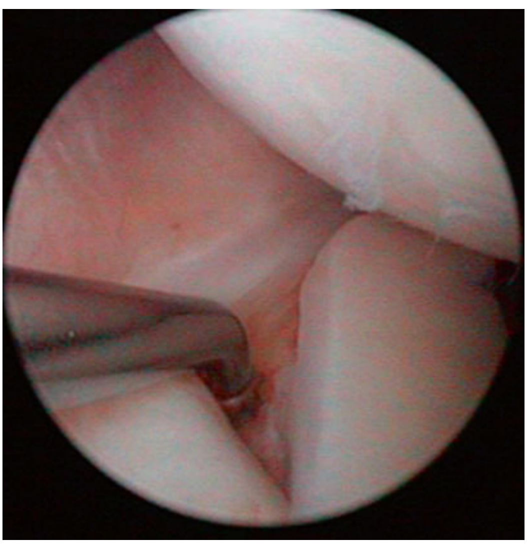

Fig. 22.2 Meniscal abrasion with a rasp

22.4 Suture Placement

Initially, in relation to the suture materials, a 3–5 mm interval is recommended [13]. When using sutures only, these should be nonabsorbable or slowly absorbable [7, 15]. Moreover, vertically or oblique oriented sutures [17, 32] have been considered the gold standard for meniscus repair due to better ultimate failure loads (Fig. 22.4). Likewise, large diameter sutures increase fixation strength [31].

There is no major difference between all-inside and outside-in [11] or inside-out [51] sutures for meniscal repair [10, 19]. Also, studies in relation to double-row sutures, including cross-stitch sutures, which are supposed to enhance fixation strength (Figs. 22.5 and 22.6), have been recently published [1, 21]. In fact, our general recommendation is to use an all-inside technique for the posterior or middle segments and an outside-in technique for the middle or anterior segments of the meniscus.

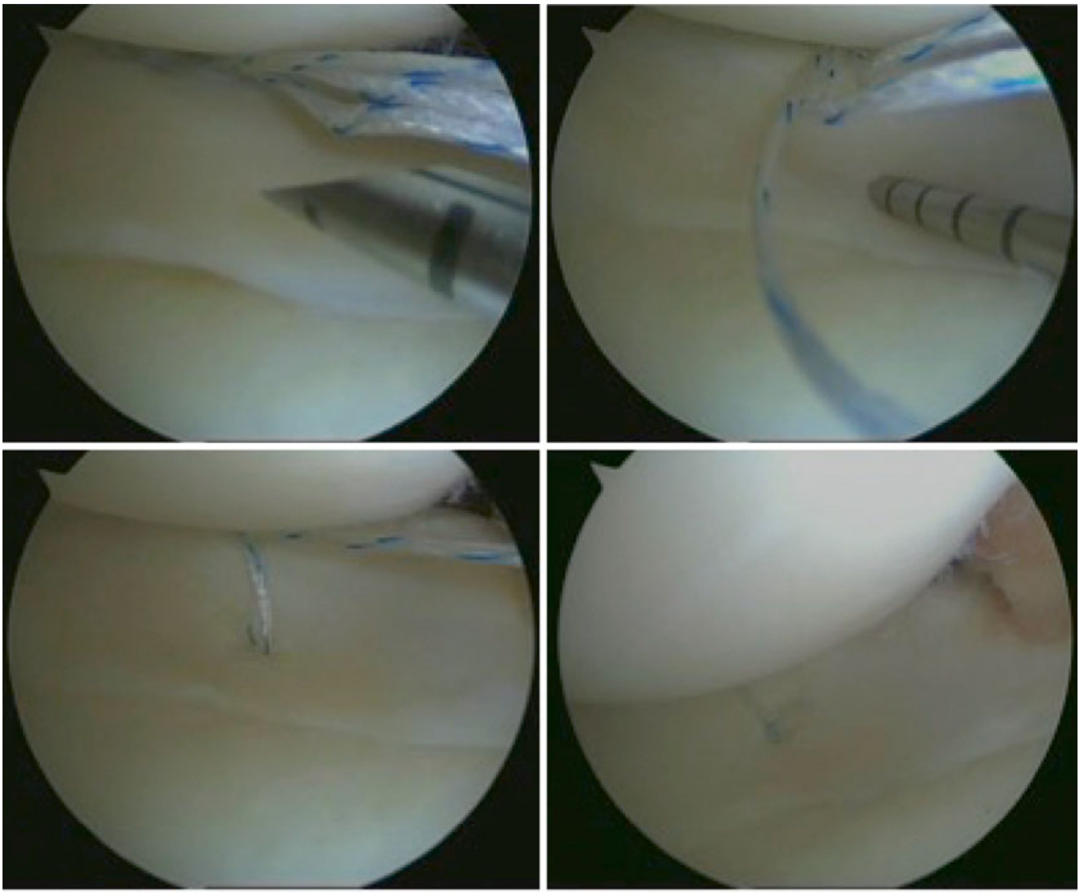

Fig. 22.4 All-inside meniscal repair with vertical suture

22.5 Fixation by All-Inside Devices

There are several all-inside arthroscopic meniscus repair devices [7, 20, 34, 46, 51]. The common approach of these devices is to deliver anchors containing self-adjusting sutures across the meniscus repair site. Two passes are required for a single stitch and both passes of the insertion needle place an anchor attached to the joining suture extra-articularly behind the peripheral meniscus on the capsular surface. Once deployed, the suture is tensioned to close the gap in the meniscus, and a pretied, sliding, self-locking knot is tightened to compress the meniscus repair site (Figs. 22.4, 22.5, and 22.6).

Whatever the device and location of the meniscus tear (medial or lateral) are, the implants or the sutures are routinely inserted through the ipsilateral portal for the posterior segment and the contralateral portal for the middle segment of the meniscus. Following this, the delivery system is introduced into the appropriate portal through a metallic cannula to avoid soft tissue entrapment, as well as to protect the cartilage from the needle. The system is positioned in front of the axial meniscus fragment and then passed through both parts of the meniscus and through the joint capsule. Additionally, it is useful to check the rotation of the needle, in order to make it as perpendicular to the surface of the meniscus as possible. When the needle is introduced, the device is turned 180° to be parallel to the tibial plateau, and then the first suture bar is released. The delivery needle is then positioned at least 5 mm from the first implant in a vertical,

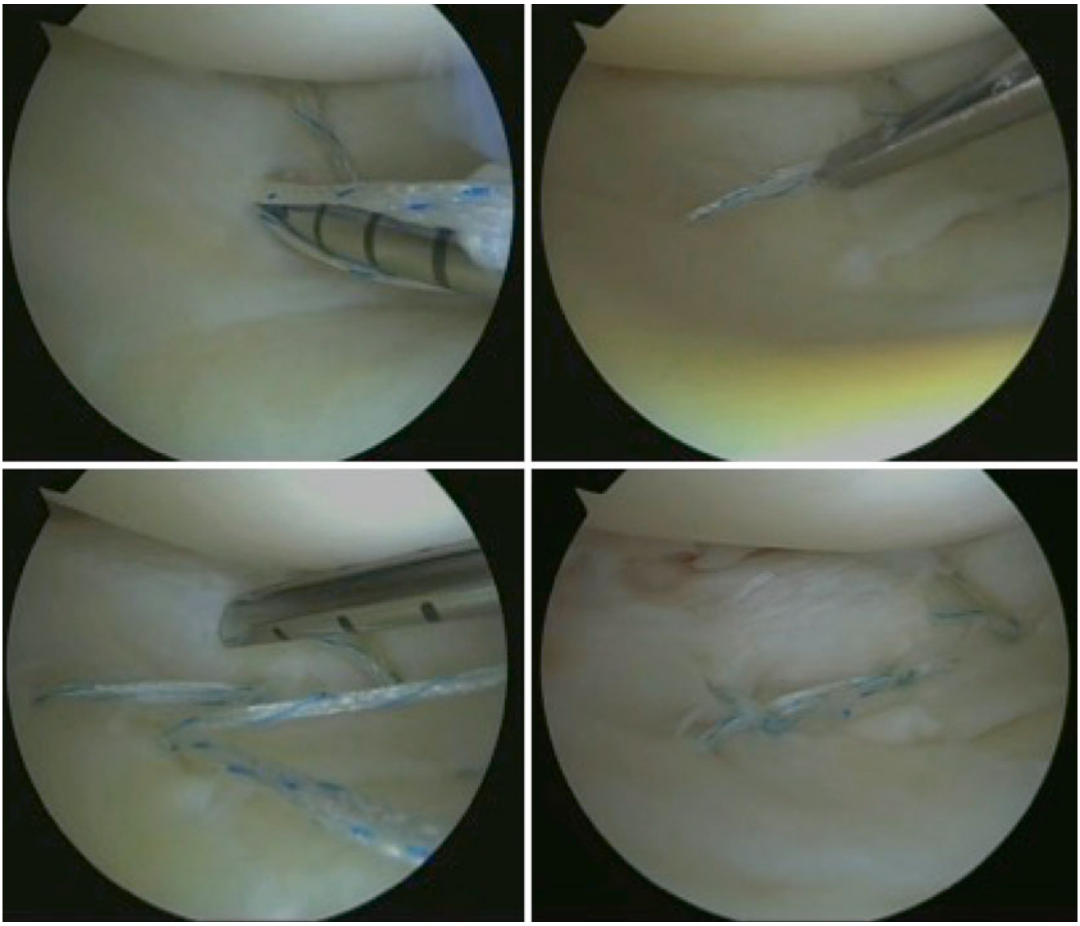

Fig. 22.5 Meniscal repair with two all-inside devices (crossed vertical and horizontal sutures)

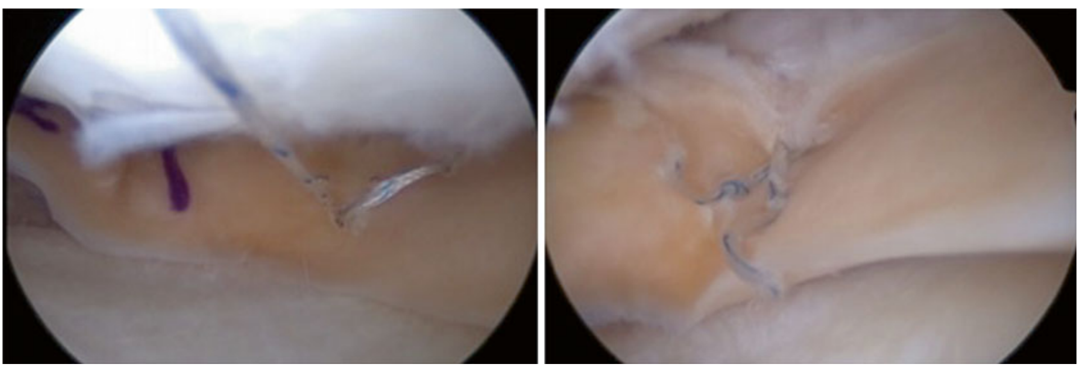

Fig. 22.6 Double row meniscal repair (crossed oblique sutures)

horizontal, or oblique manner and the second suture bar is released. Once carried out, the delivery needle is removed from the joint, leaving the free end of the suture out of the knee, before the suture is pulled to advance the sliding knot. Moreover, with the knot pusher, the pre-tied self-sliding knot is tightened appropriately, as the suture is cut with the knot pusher. Additional devices are inserted every 5 mm until the repair is complete.

Nevertheless, fixation with all-inside sutures without devices is possible. The meniscal Viper® is a system that is designed so that a needle passing through the meniscus tear captures a suture loop from the instrument's tip [22]. Firstly, the tip of the Viper® is placed posterior to the tear. Secondly, the ring of the handle is then pushed forward, in order to advance the needle anteriorly, which passes through the tissue across the tear and captures the suture loop. Thirdly, both the device and the suture are removed from the knee joint, and knots are made with the suture and tied. When compared with other techniques, this one has the advantages that bioabsorbable fixation devices do not.

22.6 Inside-Out Technique

When performing an inside-out meniscus repair, a safety incision is made on the appropriate side of the knee with the joint at 90° of flexion. On the medial side, a 3 cm skin incision is made posterior to the medial collateral ligament and is carried through fascia along the anterior border of the sartorius muscle. Following this, the sartorius is retracted posteriorly in order to protect the saphenous vein. It has been shown that care should be taken to protect the infrapatellar branches of the saphenous nerve. For meniscus repair, sutures are passed through needles from inside to outside the joint, using posterior retractors to retrieve needles in the safety zone. Once all the sutures are passed, the needles are removed and the sutures are tightened and sequentially tied over the capsule.

Even though it is rare, some complications have been reported. Indeed, saphenous neuropathy has been reported [12] as the major complication, which can often cause a minor nuisance. Nevertheless, these lesions of infrapatellar branches of the saphenous nerve are difficult to predict, even with careful dissection and needle placement [18]. Therefore, although it was very popular in the 1990s [26, 50], this technique has become more and more rarely used.

22.7 Outside-In Technique

The outside-in technique was first described 30 years ago by Warren [54]. Due to neurovascular risks [18] and difficulties to repair posterior segment tears with this technique [48], our recommendation is to use it for middle and anterior segments of the meniscus (these areas are difficult to access by all-inside device techniques and the risks of iatrogenic neural lesions are low).

The method described makes use of two 18G spinal needles traversing the meniscus with two #0 PDS sutures. The first needle is placed from outside to pierce through the capsule to the desired area of the meniscus repair. Once the needle is placed, #0 PDS is passed across the spinal needle and retrieved from the anterior portal with a grasper anteriorly, and a small incision is made at the area of the needle down to the capsule. Moreover, this is repeated with a second needle. Once both #0 PDS sutures are passed through the meniscus and delivered to the anterior portal, a "shuttle relay" is made with one of the sutures, leaving only one suture with 2 strands outside. Then the 2 strands are tied over the capsule (Fig. 22.7).

22.8 Posteromedial Sutures for Meniscocapsular Lesions of the Medial Meniscus

22.8.1 General Principles

Posteromedial meniscocapsular lesions are associated to 15–30 % of ACL injuries [2, 9, 35, 52, 53]. Their presence may be explained by a sudden traction of the hamstrings or of the semimembranosus on the posterior meniscal attachment which may occur during the so-called medial "contrecoup" injury [30] of the ACL injury mechanism. The medial contrecoup causes an important stress on the posteromedial soft tissues during the subsequent violent reduction of the tibia after subluxation of the lateral tibial plateau.

Although described in the 1980s by Hamberg et al. [23], they have been largely forgotten and

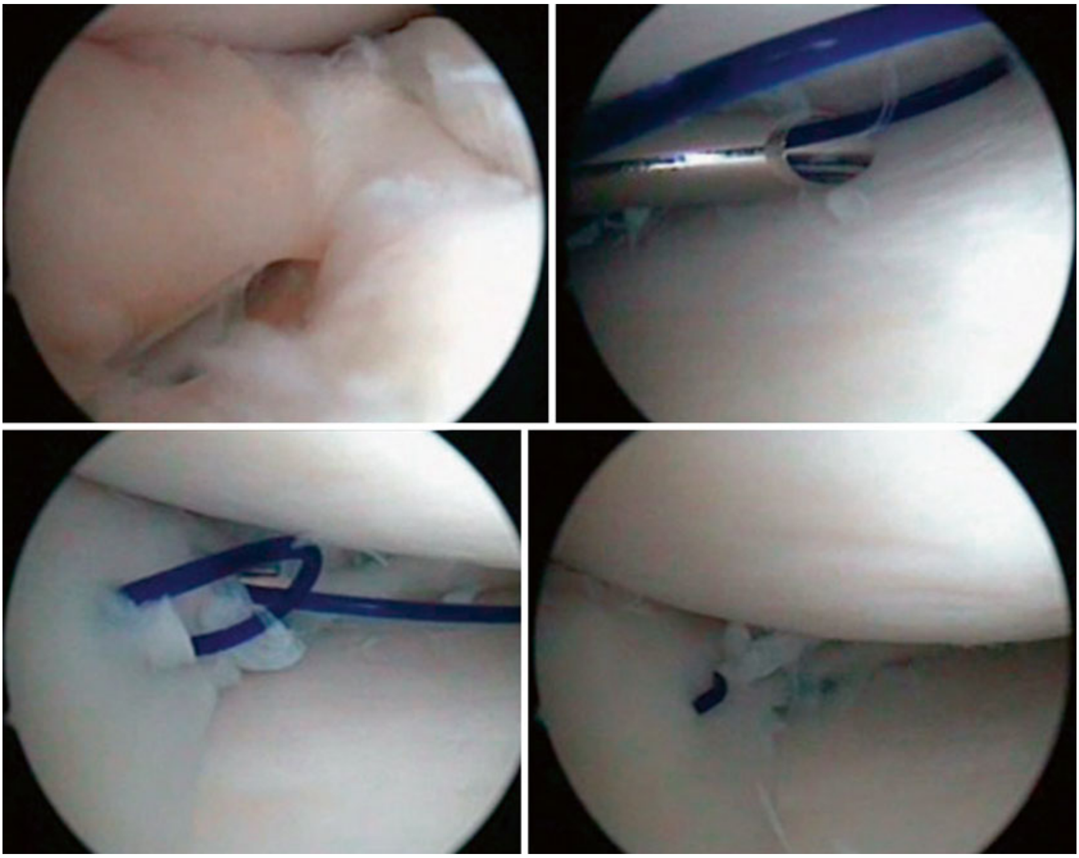

Fig. 22.7 Horizontal outside-in meniscal repair

only recently been rediscovered [2, 9, 35, 53]. The reason for this is related to the fact that they cannot be visualized through traditional anterior visualization during arthroscopy and that they can typically not be detected through magnetic resonance imaging. Their biomechanical consequences have been largely ignored so far. They are currently under investigation. In a recent cadaver study, Amis et al. found that the presence of this type of lesion was clinically detectable. An association of an ACL tear resulted in a further 30 % increase in external rotation and anterior translation laxity compared to the single ACL-deficient knee. An isolated ACL reconstruction was not sufficient to eliminate this additional laxity, but it could be addressed by additional meniscal repair. Surgeons should therefore identify these lesions at the time of surgical intervention. Clinical studies need to be conducted to confirm these findings in vivo.

22.8.2 Surgical Technique

In order to diagnose these medial meniscocapsular lesions, a specific visualization of the posteromedial compartment of the knee is required. This can be achieved either through a direct posteromedial approach [2] or from an anterolateral portal by passing the arthroscope through the femoral intercondylar notch underneath the posterior cruciate ligament (Gillquist approach). In order to visualize the meniscocapsular ramp, the knee needs to be flexed at 90°. In this position, the posteromedial capsule gets slack, allowing the posterior recess to appear. In the extended knee, the posterior capsular recess is closed with the posterior capsule being tightly applied to the posterior tibial plateau, meniscus, and femoral condyle, thus not allowing these lesions to be diagnosed

Fig. 22.8 Posterior capsulomeniscal lesion of the medial meniscus

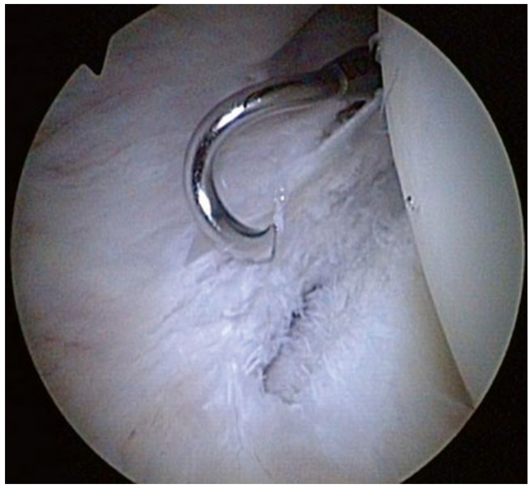

Fig. 22.9 Repair through posteromedial portal with a hook

by traditional imaging techniques. In most of the cases, the inspection of the posteromedial ramp with a 30° arthroscope is sufficient to diagnose the presence of this type of injury. An additional percutaneous needle palpation of the menisco-capsular junction through a posteromedial portal may be helpful to rule out the so-called hidden lesions [53]. 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. The latter may be retracted from the posterior meniscal wall. Whereas it repositions itself in most of these cases during knee extension, this may not be the case in some rather chronic injuries.

A traditional anterior repair with all-inside hybrid anchors may be insufficient to close the gap between the posterior meniscal wall and the capsule, especially if the latter remains retracted in the extended knee. Therefore, we recommend a systematic direct repair through a posteromedial approach in the flexed knee as described by Morgan [37] and Ahn et al. [2]. After palpation of the lesion (Fig. 22.8), a thorough debridement of the synovial membrane is recommended. In some cases this may reveal the presence of a larger lesion as initially anticipated because parts

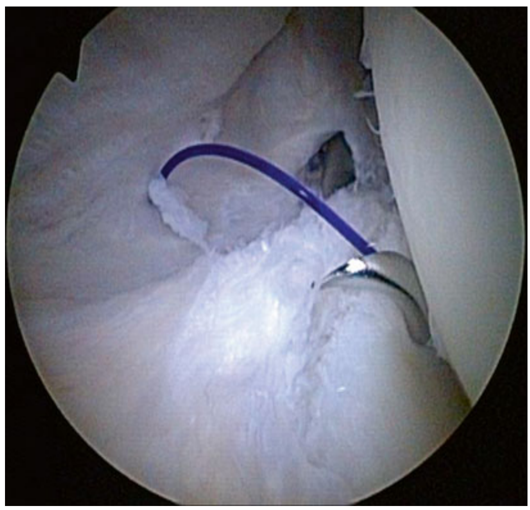

Fig. 22.10 Posteromedial suture

of the tear may be covered by a thin soft tissue layer. The repair requires curved and inclined (45–60° left or right) suture-passing instruments (Figs. 22.9 and 22.10), similar to those which are used for capsulolabral repairs in the shoulder (i.e., Spectrum – ConMed Linvatec or similar). Our preferred suture material is currently a resorbable #0 PDS suture. Generally 1–3 sutures are required to allow for adequate gap closure (Fig. 22.11). These repairs are technically difficult and require

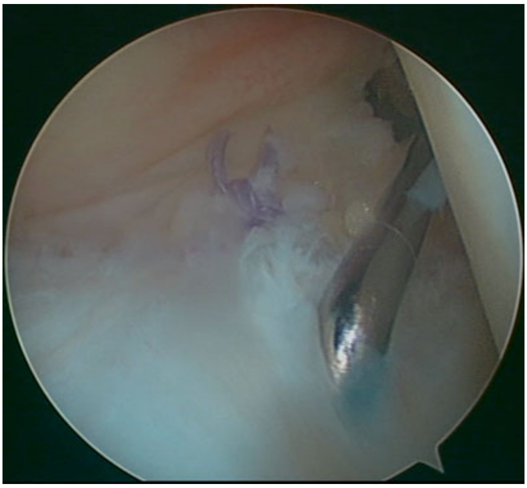

Fig. 22.11 Posteromedial suture, final aspect

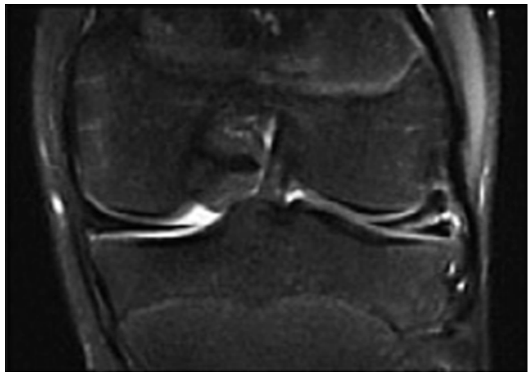

Fig. 22.12 Grade 3 horizontal cleavage of the lateral meniscus in a young patient

a long arthroscopic experience including knowledge in arthroscopic knot-tying techniques. A systematic cannula positioning at the posteromedial portal may be necessary during the learning phase. Later on, the use of half-pipe cannulas may facilitate the introduction of the curved suture instruments and allow for an adequate suture management and soft tissue control during knot tying. Rehabilitation guidelines include immediate full weight bearing with the knee blocked in full extension with a brace. Passive knee flexion is limited to 90° for 6 weeks and deep squatting should be avoided for 4 months after surgery. So far, no results have been published on meniscal repair for these specific lesions. Our own results are encouraging, but further work is required to present evidence-based data.

22.9 Open Meniscus Repair for Horizontal Cleavage in Young Patients

22.9.1 General Principles

Symptomatic horizontal meniscus lesions occurring in young patients are often extensive and located both in the vascular and avascular zone [8]. A meniscectomy of such lesions would be a subtotal meniscectomy, which is unacceptable in young patients, unless the lesion is irreparable, due to the risk of deterioration and flattening of the articular cartilage surfaces and subchondral bone sclerosis with time [40]. The horizontal tears of the meniscus in young patients were first described by Biedert and referred to as "intrasubstance tears" [8]. Unlike vertical tears, they are not traumatic, but nor are they strictly degenerative. Nonetheless, the etiology remains unknown, but it may be due to overuse.

Even though they are similar, degenerative meniscus lesions in patients over 50 with early signs of osteoarthritis should be differentiated from lesions that occur in younger patients without osteoarthritis. However, in order to determine the classification, an MRI [14] is utilized, and the lesion appears as a horizontal hypersignal on T2 sequences. In grade 2 tears, the signal is limited to the meniscus body, whereas it extends into the joint surface in grade 3 (Fig. 22.12). Additionally, a meniscus cyst is commonly encountered [27, 36]. After a failed medical treatment (rest, intra-articular injections) of 6 months, surgery can be considered.

22.9.2 Surgical Technique

All-inside arthroscopic meniscus repair is the most modern technique used to treat vertical traumatic lesions. Surgeons are able to insert strong vertical sutures, placed perpendicular to the lesion, although perpendicular stitches are difficult to place under arthroscopy in horizontal

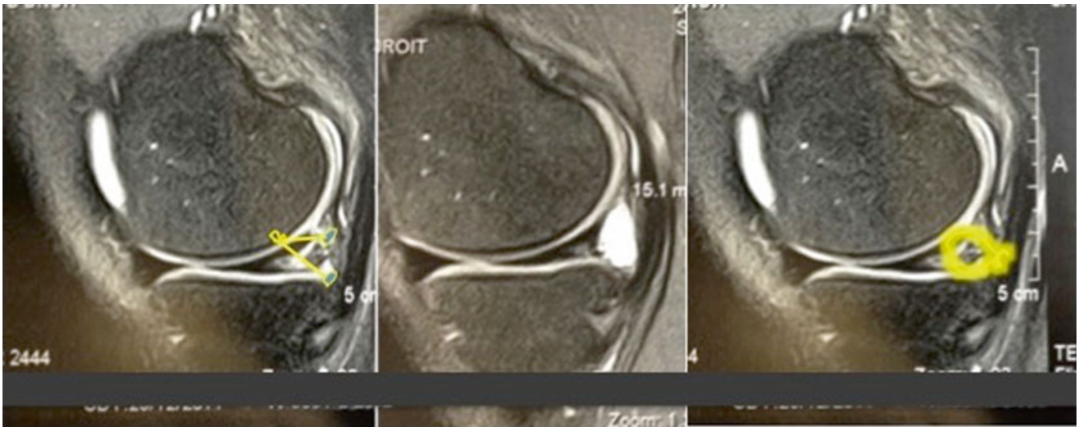

Fig. 22.13 Failure of all-inside meniscal repair of a grade 2 lesion

tears, especially in grade 2 lesions. Nonetheless, unless it is possible to suture the lesion at the articular side of the cleavage, the arthroscopic technique does not allow a closure of the gap between the two layers at the meniscosynovial junction. Several failures and recurrence of cysts have been encountered using all-inside arthroscopic sutures for horizontal cleavages (Fig. 22.13). Furthermore, by an open approach, meniscus cysts can be completely removed before repair, the meniscosynovial junction can be abrased and the lesion closed by strong vertical sutures [42, 44].

In addition, anteromedial and anterolateral portals were created and a diagnostic arthroscopy was performed first. The meniscus tear was identified in the cases of grade 3 lesions, while in the case of grade 2 lesions, no lesion was identified during arthroscopy. If present in grade 3 lesions, unstable meniscus fragments and fibrous tissue were removed using a motorized shaver or basket forceps (Fig. 22.14). Moreover, to repair the medial meniscus tear, a posteromedial mini-arthrotomy was performed. However, to repair the lateral meniscus tear, a posterolateral mini-arthrotomy was performed (Fig. 22.15).

The capsule was open on the upper side of the meniscus, and the meniscosynovial junction was detached vertically in order to create access to the horizontal cleavage, and the lesion was abraded with a rasp and a curette. The meniscus repair was performed by vertical sutures with type N°0 polydioxamone (PDS; Ethicon, Somerville, NJ, USA), in order to close the two layers, and through this procedure no drainage was used.

Fig. 22.14 Arthroscopic abrasion of the horizontal cleavage

All patients followed the same rehabilitation protocol. In the first postoperative week, a passive range of motion from 0° to 90° was initiated, allowing partial weight bearing for 4 weeks. For the first 4 weeks, a hinged knee brace locked in full extension was used. Through all this, jogging was not permitted until 3 months post operation, and a return to pivoting sports was not allowed until 6–7 months after surgery.

Several papers have been published [3, 44] and a recent literature review recommended meniscus preservation in such complex lesions [33]. When

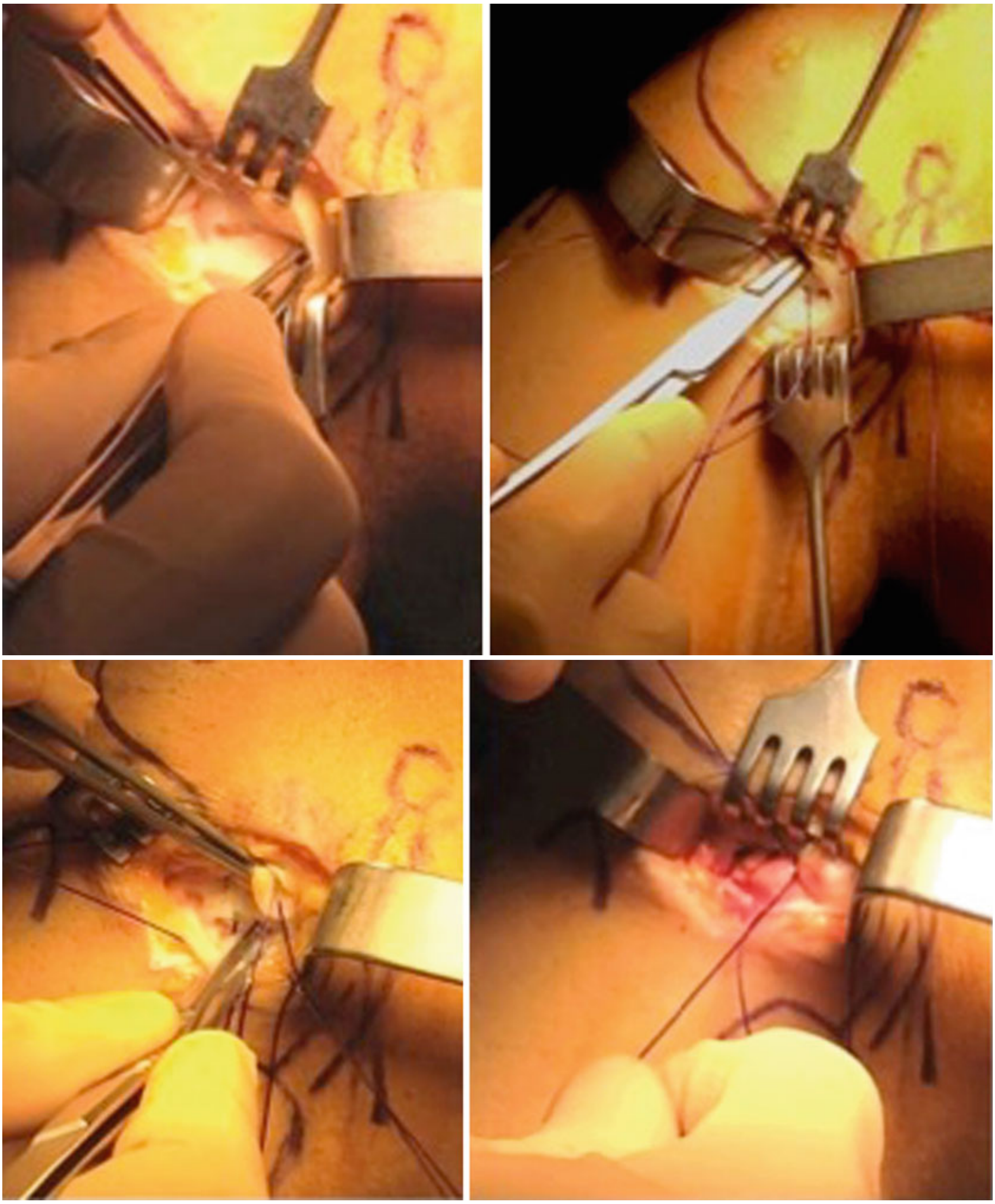

Fig. 22.15 Open meniscal repair technique for horizontal cleavages

medical treatment fails, open meniscus repair of horizontal cleavage provides good midterm functional results while preserving the maximum amount of meniscus tissue. Furthermore, studies, relating to long-term outcomes, are needed to corroborate the potential preservation of the cartilage with time.

Conclusion

Meniscus repair techniques are well established and allow surgeons to address tears of different complexities and locations. There is not one but many different repairable meniscus lesions and consequently not just one but various treatment methods. In order to be able to repair all repairable meniscus lesions, the surgeon has to adapt all the presented techniques to different indications.

With good indications and the best choice for the surgical technique, results of meniscus repairs are excellent. They provide good early to midterm clinical outcomes [38] and prevent degenerative changes in the long term [45, 46]. Therefore, it has been deduced that it is a vital requirement for future development and improvement to maintain the meniscus repairs.

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Meniscal Repair: Enhancement of Healing Process

23

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Contents

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23.1 Introduction

The current prevailing trend in repairing meniscus-related lesions is to maintain the tissue intact whenever possible. In the 1980s DeHaven et al., aware of the benefits of sparing the meniscus and in the footsteps of pioneer Thomas Annandale [11], first described a large series of patients treated with the technique of open meniscal repair, with satisfactory results maintained over time [10].

In the following decades, many repair techniques have been described, including excision of the loose fragments, rasping of the torn meniscus and of the parameniscal synovium, and the use of sutures, both vertical and horizontal mattress, as well as the use of specifically developed biodegradable fixation devices [58].

The vascular supply is a fundamental factor to determine the potential of meniscal repair [37]; indeed, most of the current meniscal repair techniques are effective in the vascularized zone of the meniscus but fail to encourage healing in the avascular zone. For this reason, aiming for improved healing of the meniscus, in addition to fixation techniques and devices, several biologic adjunctive methods have been proposed. These include very basic ones, such as vascular access channels, trephination, abrasion, and gluing, or more complicated ones, such as synovial flaps, the application of fibrin clots, or the combination with mesenchymal stem cell concentrates [56].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_23

Understanding how the meniscus naturally heals tears can help the development and the application of biological enhancement techniques for the meniscal repair. In particular, these approaches are based on vascular source to supply healing factors or alternative solutions to increase the healing potential, above all in case of repair in avascular areas of the meniscus.

23.2 Vascular Access Channel, Trephination, and Abrasion

Vascular access channels are created by removing a core of the tissue from the periphery of the meniscus (red zone) to the tear, thus connecting a lesion in the avascular portion (white zone) of the meniscus to the peripheral blood supply. However this technique can negatively affect the biomechanics and the function of the meniscus [25], and thus its clinical use has been limited.

Trephination is a technique introduced to create a pathway for vascular migration without imparting significant damage to the collagen architecture of the meniscus. This procedure can be used for small stable tears located on the outer area near the meniscus and joint capsule junction, where a good blood supply is instead available. Through the arthroscopy portals and usually using a spinal needle, multiple holes are made through the peripheral aspect of the meniscus rim to produce a series of bleeding puncture sites and promote bleeding, thus enhancing vascular ingrowth and healing process (Fig. 23.1). The channels should be equally spaced with controlled depth of insertion through the rim portion of the meniscus. As demonstrated by Zhang et al. in the dog model, trephination enables fibrovascular scar proliferation in the damaged meniscal section due to the blood flow from the vascular zone to the avascular zone so that meniscal cells were responsible to promote healing synergically with endothelial cells from the capillaries and synovial cells [75, 76]. Zhang et al. also reported at least partial healing by combined trephination and meniscal defect suturing of longitudinal tears in the avascular area after 6 months in a goat model [76].

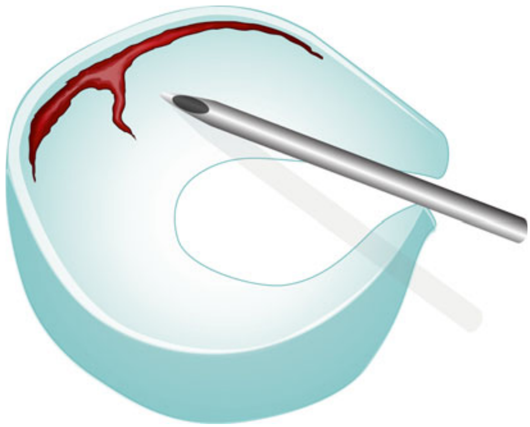

Fig. 23.1 Trephination

The clinical application of this technique allowed satisfactory results. Fox et al. [19] reported good to excellent results for 90 % of patients with incomplete meniscal tears treated with trephination. In another clinical study, 36 patients underwent arthroscopic trephination plus suturing and 28 patients had suturing alone for the treatment of meniscal tears. At the final evaluation (follow-up between 25 and 78 months), trephination appeared to reduce the clinical failure rate [77]. In a further clinical study, Shelbourne et al. reported good results in 332 lateral meniscus tears treated with abrasion or trephining but not repaired at the time of anterior cruciate ligament (ACL) reconstruction [59].

On the other hand, Forriol et al. showed that the trephination technique alone did not allow the healing of the tear due to the fact that, although the vessels penetrate the meniscus, they do not reach the wound. The authors showed that trephination was effective only if combined with the injection of different biologically active substances [18].

As an alternative to trephination, abrasion or rasping of the adjacent synovium and the surface of the meniscus has been proposed to stimulate bleeding and release beneficial growth factors to create a healing environment in the repair region (Fig. 23.2). This technically simple method has been supported by preclinical results and confirmed by some preliminary clinical findings. Uchio et al. evaluated retrospectively 47 patients,

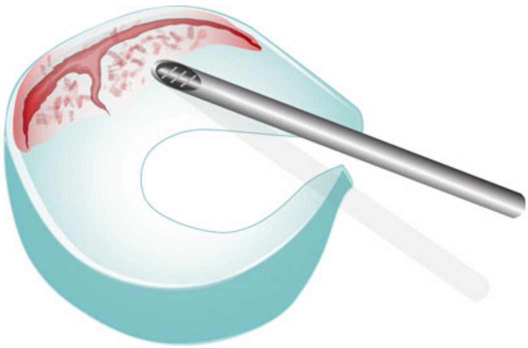

Fig. 23.2 Abrasion

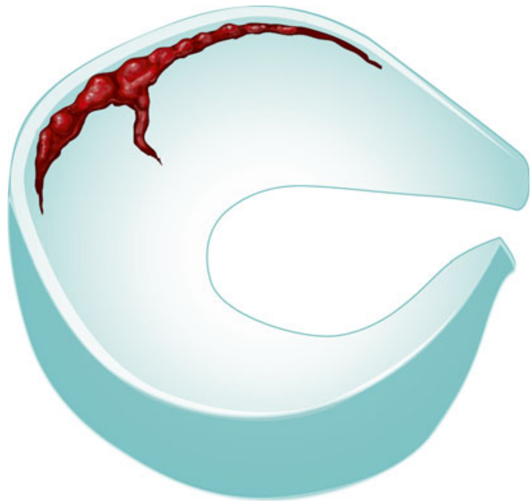

Fig. 23.3 Fibrin clot

who underwent arthroscopic second look; only 8 % did not heal while 71 % healed completely, even in cases not in the red-red zone [66].

23.3 Fibrin Glue and Fibrin Clot

Fibrin glue has been suggested for suture reinforcement. Ishimura et al. performed meniscal repair by arthroscopic rasping followed by fibrin glue application, which produced good results, even if sutures where added to ensure a positive outcome when the tissues presented degenerative changes, which makes the evaluation of the mechanical advantage and the specific contribution to the healing of fibrin glue difficult to estimate [30].

The fibrin clot was introduced as an augmentation tool in the early 1980s and might be considered as the first attempt to exploit the properties of the blood component in the regenerative process. The fibrin clot consists of fibrin and platelets, whose alpha granules and dense granules contain many cytokines and other growth factors able to stimulate cell proliferation [65]. The key point of this technique is to use the factors found within a hematoma, which normally forms when an injury occurs but that cannot form in an avascular zone of the meniscus. Placing a fibrin clot in a stable lesion within the avascular zone of the meniscus helps to provide both a chemotactic and mitogenic stimulus to the reparative process; indeed, the clot contains platelet-derived growth factor (PDGF) and fibronectin, which are chemotactic, stimulate local cell activity within the meniscus, and attract synovial cells [1, 26]. Moreover, fibrin clots can serve as a temporary scaffold on which the resident cells, probably arising from the synovial membrane and the adjacent meniscal tissue, can start growing and repair the tissue defect.

Fibrin clot, which in this view can be considered the forerunner of platelet-rich plasma (PRP), can be prepared with a simple, rapid, and cheap process. Usually it is produced from 20 to 30 ml of the peripheral blood of the patient, which is placed in a sterile glass beaker. Then, the blood is stirred gently with a glass rod, until a fibrin clot precipitates on the surface of the stick, on average after 3–5 min. The clot is then prepared to match the lesion (Fig. 23.3). In a study on twelve adult mongrel dogs, Arnoczky et al. demonstrated the efficacy of an autologous fibrin clot on morphological healing of two-millimeter-diameter full-thickness lesions in the avascular portion of the medial meniscus. By 6 months, the menisci treated with the fibrin clot appeared to be healed with a mature fibrocartilage-like tissue, whereas the controls showed no growth with only a small layer of the tissue filling the lesion [1].

These preclinical findings were then confirmed clinically by Henning et al. who reported the effect of fibrin clots in a series of 153 meniscal tears, mainly associated with ACL

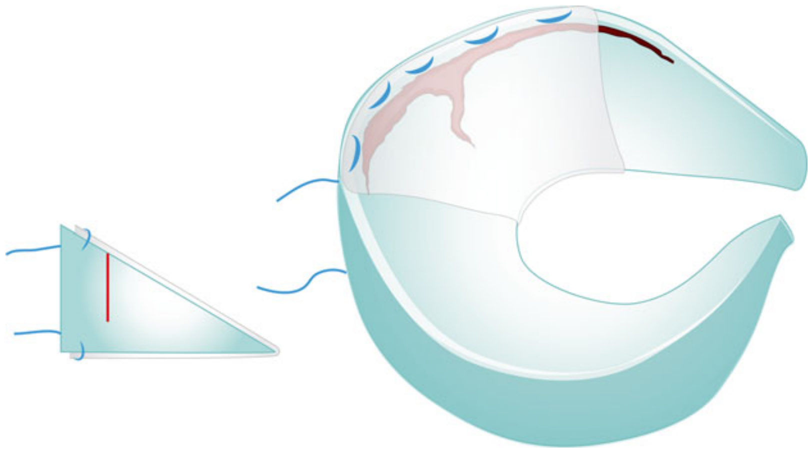

Fig. 23.4 Fascia sheath coverage

reconstruction. The failure rate of meniscal repair was lower in the menisci treated with the fibrin clot in comparison to those treated without (8 % vs 41 %) [26]. The same authors subsequently suggested a combined procedure, based on the use of both fibrin clots and fascia sheath coverage, obtained from the distal anterolateral thigh and sutured on the meniscal repair area (Fig. 23.4). This combined approach was technically demanding and more invasive, and therefore its application has not been further reported after preliminary findings suggesting a good outcome for the treatment of complex meniscus tears [27].

Other studies have focused on reporting the effects of fibrin clot augmentation. Van Trommel et al. treated a small series of patients ($n=5$) affected by radial tear of the posterolateral meniscus [68]; a second-look arthroscopy performed between 3 and 5 months from surgery showed peripheral healing in all cases, with all the patients able to return to their pre-injury sport activity level. The results were then maintained for at least up to 5 years after surgery, as evaluated with MRI.

More recently, these results were confirmed in a series of twelve consecutive patients treated for complete radial tears of the meniscus with arthroscopic inside-out repair with fibrin clots. MRI as well as second-look arthroscopy showed complete healing in 92 % of the patients, producing a significant improvement in the functional outcomes [51].

Unlike the aforementioned studies, in a goat model, Ritchie et al. observed that fibrin clot augmentation led to poorer results than parameniscal synovial abrasion in case of meniscal tears of the central avascular zone, thus underlying and confirming the wide differences in terms of healing potential between tears of the vascular and avascular zone [54].

Potential contraindications for the use of fibrin clots include the additional time to prepare a clot and the awkward handling of the clot, as there are no standardized techniques for fibrin clot use during meniscal repair. Moreover, the preparation of exogenous fibrin clot increases the possibility of infections when the clot is introduced into the joint. Among problems related to this technique, fibrin clots can often be destroyed near the arthroscopic portal and get stuck in the subcutaneous fat layer. In addition, placing a fibrin clot in the target area is challenging because it can adhere to surgical instruments, thus making its placement hard, and maintenance of the clot in situ at the repair site is difficult.

To overcome these limitations, Sethi et al. developed an in situ technique for delivering "local growth factors" of the blood clot that do not depend on exogenous fibrin clot preparation: the synovium directly above the tear site is abraded and the negative intra-articular pressure produced in the knee joint induces bleeding from the abraded synovial site. At this point the knee position causes the blood to run down the synovial wall, thus reaching the meniscal cleft and forming a clot adherent to the edges of the separated meniscal tear [58].

23.4 Growth Factors and Platelet-Rich Plasma

The aim of biological augmentation strategies is to overcome the intrinsic-limited healing potential related to poor vascularity by promoting chemotaxis, cell proliferation, and matrix production.

Concerning meniscus healing, it is important to provide angiogenic stimuli especially to the meniscal tears in the avascular area that have been shown to have a low healing potential. Thus, in this view, the use of growth factors has been proposed, whose main role should be to enhance healing of meniscus lesions stimulating the formation and invasion of new blood vessels. Long-term studies have shown significantly better clinical outcomes when the menisci are repaired at the time of ACL reconstruction. It has been recently demonstrated that this positive combination not only depends closely on the positive influence of the knee stability in an ACL reconstructed knee [61] but also on the intra-articular bleeding with the release of different families of growth factors [8].

Indeed, in a study on twenty patients who underwent partial medial meniscectomy and twenty patients who underwent single-bundle ACL reconstruction with hamstring grafts, it was found that 30 min after the end of the procedure, PDGF and vascular endothelial growth factor (VEGF) and its receptor VEGFR2 concentration of ACL reconstruction patients were significantly higher than those of partial meniscectomy patients. In particular, VEGF is the most important angiogenic factor [14] and thus it might contribute to a better healing response. Similarly, Ochi et al. reported that the abrasion of the edge of meniscal tears in the avascular zone of meniscus in a rabbit model provoked the increase of the expression of PDGF and transforming growth factors-β (TGF-β), probably participating in the meniscal healing [42].

The effects of growth factors have been evaluated on meniscus explants or on isolated meniscus cells in culture [2, 32, 39, 45], as well as in preclinical studies [18, 35, 49], although with poor results. Indeed, it seems that VEGF alone was not able to ameliorate the outcome of meniscal lesions, probably because VEGF alone does not stimulate the complex process of vasculogenesis successfully. A combination of growth factors would instead theoretically offer the advantage of recapitulating better at least some of the events leading to correct vessel wall assembly [14].

The smartest way to exploit the potential of a “cocktail” of growth factors is to use the platelet-rich plasma approach (PRP), which is a portion of the plasma fraction of autologous blood having a platelet concentration above baseline that is known to contain a number of proteins, cytokines, and different families of growth factors. PRP can be easily obtained through the centrifugation of a variable amount of blood (6–60 ml, depending on the production system and on the necessity), thus resulting in an approximately three- to eightfold increase in platelet concentration with respect to the whole blood.

Interest in PRP has largely increased over the last two decades and currently PRP is used alone or as a completion of the traditional approaches in many clinical fields, including orthopedics. Indeed, its autologous origin, easy preparation, and an interest in the addition of minimally manipulated biological products make PRP an attractive solution.

The platelet concentrate can be obtained as a liquid product, particularly indicated for infiltrative use or when platelets are activated before their use, as a sticky gel or putty, and thus more indicated during the surgical procedures as it can be sutured into the repair site and delivered under direct visualization. These activating agents (calcium chloride, thrombin, type I collagen,...) are fundamental to achieve an additional platelet aggregation, thrombin generation, fibrin formation, and consequently the release of growth factors including PDGF, TGF-β1, VEGF, and insulin-like growth factors-1 (IFG-1) [13].

It has been shown that in vitro meniscal cells presented an increased expression of mRNA of extracellular matrix proteins when cultured in PRP in comparison to controls [29]. Some animal studies have also confirmed the positive effects of PRP augmentation in terms of tissue regeneration. In a rabbit model, PRP delivered by a gelatin hydrogel delivery system was able to affect positively the healing of full-thickness meniscal tears created in the avascular region of rabbits [29]. However, in another study on rabbits, PRP in combination with a hyaluronan collagen composite matrix failed to improve significantly meniscus healing in the avascular zone after 3 months, controversial results that might be partially explained by the high inter-animal variability.

Clinically, beneficial effects of PRP were reported in the treatment of rotator cuff tears [52], Achilles tendon ruptures [55], chronic tendinosis [15, 71], muscle injuries [38], ACL rupture [57], and cartilage defects [16]. However, the use of PRP remains controversial in orthopedics [60], as a number of randomized clinical trials have reported no clinical efficacy for different pathologies, such as patellar tendon healing [7], lateral epicondylitis [36], Achilles tendinopathy [9], and rotator cuff tears [4].

These conflicting results might be ascribed to the large heterogeneity of PRP products. Indeed, there are various PRP preparation kits, and each of them presents different proportions of growth factors, anticoagulant, activating agent, presence of leukocytes, initial blood volume, PRP volume, and final platelet amount. Indeed, despite intense research activity on PRP and its potential effect on musculoskeletal tissues, the most appropriate characteristics that the perfect PRP should possess have not been identified yet. This is particularly true for the meniscal tissue, as the few data in the literature do not allow the most effective PRP product for the biological support of meniscus regeneration to be identified. Indeed, very few clinical data about PRP and meniscus have been published until now, and in particular there are no prospective randomized controlled studies evaluating the use of PRP to augment meniscal repair.

The rationale of PRP use in meniscal repair is the possibility to deliver a local concentration of growth factors and other cytokines directly into the repair site, with the final aim of enhancing vascularity [6]. However, in a recent level III study, Griffin and colleagues evaluated the possible effect of PRP during meniscal repair in terms of reduction of the likelihood of subsequent meniscectomy and functional outcome scores, including clinical and patient-reported outcomes, such as postoperative ROM and return to work and to sports/baseline activity [23]. The results showed no difference in the percentage of patients who underwent reoperation between the PRP group (27 %) and the non-PRP group (25 %). Similarly, no differences were observed in terms of functional outcome measures between the two groups, as well as return to work and sport activities. The authors concluded that in their limited study group, outcomes after meniscal repair with or without PRP appear similar. However, given the lack of power and the type of the study, modest size outcome differences might have been masked.

In another level III case-control study by Pujol and colleagues, 34 patients underwent arthroscopic surgery for an open meniscal repair to treat symptomatic grade II or grade III horizontal meniscal tears. In 17 of these patients, PRP was introduced into the lesion at the end of the procedure. At a minimum 2 years' follow-up, significantly better results were found in the PRP group concerning pain and sports parameters of the KOOS scale, showing a slight improvement by the addition of PRP [50].

Therefore, although there are theoretic effects of PRP augmentation in orthopedic soft tissue healing, the clinical benefit has still not been clarified. One of the reasons for this lack of evidence might be the dilution of the PRP in the joint under arthroscopy, although other explanations, including the modalities of outcome assessment, should be searched for. For all these reasons, future larger prospective studies are needed to determine definitively whether PRP should be used with meniscal repair. Moreover, it would be also useful to determine whether PRP and other biologics, alone or synergically, may positively affect more complex tear types.

23.5 Synovial Flaps

The use of free or pedicle flaps (Fig. 23.5) was first introduced in the preclinical setting in 1986 [70]. This approach to meniscal repair has been then extensively tested in the animal model, with positive results in terms of healing improvement [5, 21, 22, 34, 73]. In the sheep model, Ghadialli et al. [22] reported an improvement in the repair of different shapes of meniscal damage by suturing a flap of the synovium into the wound. A repair tissue was observed at 3 months, with a morphology that was intermediate between the hyaline cartilage and fibrocartilage, which the authors interpreted as metaplasia from the synovium. In a canine model, Gershuni et al. [21] had similar findings for the repair of lateral meniscal lesions in the avascular zone by suturing a vascularized synovial flap into the tear. The authors hypothesized that reparative cells coming from the capillary endothelium or the synovial tissue itself, or reaching the tear by general circulation through the capillaries of the synovial flap might explain the healing observed. Similarly, Kobuna et al. found repair of 19 out of 21 longitudinal tears of dog meniscus, using a synovial pedicle that promoted a neovascularization of vessels reaching the suture site from the parameniscal area [34].

Fig. 23.5 Synovial flap

Despite these promising findings, there is currently a lack of clinical reports. Only one study by Kimura et al. reported second-look arthroscopy results: 7 patients with a damaged medial meniscus received, through a 3-cm long anteromedial arthrotomy, a synovial flap from the parameniscal synovium sutured as a coverage after being reflected [33]. All patients presented healing of the meniscal tear at the second-look arthroscopy evaluation, with significant improvement of the healing rate with respect to conventional meniscal repairs.

Besides these positive preliminary findings, the literature does not offer any more recent studies reporting the use of synovial flaps to improve meniscal repair with a stronger study design, and thus there is a lack of conclusive evidence to support this meniscus-healing strategy.

23.6 Mesenchymal Stem Cells

Mesenchymal stem cells (MSCs) are an attracting choice for regenerative therapies, not only for their ability to differentiate toward different cell lineages but also their molecular-signaling activity, able to promote activation and proliferation of resident cells [3, 17].

Different cell types have been previously used in studies on meniscus healing: MSCs, articular chondrocytes, and autologous fibrochondrocytes, producing favorable results both in vitro and in vivo [41, 48, 64, 74]. However, the use of autologous fibrochondrocytes/chondrocytes and the need for their culture expansion require a two-step surgery, with high costs and morbidity [24]. Allogeneic and xenogeneic sources have then been tested in animal models, with promising results, even though these techniques present serious translational issues [53, 72].

Progenitor cells, such as MSCs, can be instead successfully isolated from various sources (bone marrow, adipose tissue, muscle, and synovium) [3, 20] and present the advantage of being easily expandable without losing their differentiation potential in a variety of mesenchymal tissues [17, 43, 44, 69]. Thus, they are gaining increasing interest as a biological augmentation to improve the limited healing potential of meniscal tears. With regard to this specific field, the aim is to provide both cell precursors and their signaling activity to the lesion site, where cell infiltration is unlikely due the peculiar joint anatomy. MSCs have been shown preclinically to allow the repair of meniscal defects in the avascular zone, by producing a meniscal-like tissue with abundant extracellular matrix around the cells [12, 31, 62, 63, 74]. Several studies on animal models have suggested the potential of MSCs to favor meniscus healing, showing the regenerative effects of intra-articular injections. After being injected into the joint, MSCs adhere to the damaged meniscus, differentiate into cells resembling meniscal fibrochondrocytes, and promote type I and type II collagen formation. Horie et al. injected allogeneic MSCs from a single rabbit into a 15-mm defect in the avascular zone of the anterior horn of the meniscus of 15 New Zealand rabbits. MSCs significantly improved histological features with respect to controls at 24 weeks [28]. Similarly, MSCs counteracted meniscal degeneration in a swine model [40].

Besides this positive preclinical experience, there are very few data on the application of MSCs for the healing of meniscal defects in the clinical setting. Through a randomized double-blind controlled study, Vangsness et al. investigated the safety of a single intra-articular injection of allogeneic MSCs derived from the bone marrow aspirate, injected into the knee of 55 patients who underwent partial medial meniscectomy. The ability to promote meniscus regeneration, and the effects on osteoarthritic changes in the affected joint were also evaluated. Patients were randomized between two treatment groups to receive allogeneic MSCs in low (group 50 million cells) or high (150 million cells) concentration, plus a control group, which received hyaluronic acid. No important safety issues were observed within the 2 years of follow-up. Both treatment groups had better pain improvement than controls for up to 24 months of follow-up, and those who received the higher dose had a substantial improvement in pain compared with the control group at 12 months. Quantitative MRI showed a significant increase in meniscus volume in 24 % and 6 % of patients in the high- and low-concentration groups, respectively, 12 months after meniscectomy. These findings, obtained in a double-blind study, showed a symptom-reducing effect in an osteoarthritic knee compared with the vehicle control, hyaluronic acid, which is currently indicated for pain relief for mild-to-moderate osteoarthritis. Additional studies may be warranted to further investigate these findings and the potential of this biological approach applied as augmentation to favor meniscal repair [67].

Similarly, the safety of intra-articular injections of adipose-derived stem cells (ASCs) has been suggested [46]. However, only a single case dealing with the intra-articular administration of ASCs for a grade II meniscal tear in a 32-year-old woman has currently been reported [47]. After obtaining both autologous ASCs and PRP, the mixture was injected under ultrasound guidance into the knee joint of the patient. After 3 months improvement of the symptoms was reported, together with almost complete disappearance of the tear at the meniscus.

Combing preclinical and preliminary clinical findings, the use of MSCs shows promising results in promoting meniscal regeneration, even though several translational issues are still to be overcome and the study of these therapies applied to meniscal repair is still in its infancy.

Conclusion

The meniscus is a crucial player in knee homeostasis, and its preservation is now considered necessary to obtain satisfactory clinical results, above all in the long-term follow-up to avoid the future onset of arthritis. Nevertheless, repair procedures result in variable outcomes. In this view several biologic strategies to enhance the meniscus-healing potential have been proposed in recent decades. They are focused on the delivery of "factors" or "agents" to promote the tissue healing, particularly in the avascular zone of the meniscus so that many more patients might benefit from these procedures for the preservation of the meniscus tissue.

However, despite the theoretical benefits of most of these approaches, their clinical effect has been less clearly demonstrated. Larger, randomized clinical studies are still needed to show the true value of these treatment options in the management of lesions of the avascular region of the meniscus, as well as to compare the different techniques, particularly in relation to the more innovative strategies like the use of PRP and MSCs. Moreover, longer follow-ups would allow more informative data to help answer the question of whether meniscal repair might really benefit from these kinds of treatments.

Finally, the high costs of some of these approaches might drastically limit their clinical use, and thus further research should be addressed to find more affordable techniques and define the best indications to optimize the target and the healing potential of these strategies to favor meniscal repair.

Acknowledgments The authors would like to thank to Silvia Bassini, Biomechanics and Technology Innovation Laboratory, Rizzoli Orthopaedic Institute, Bologna, Italy, and Keith Smith, Task Force, Rizzoli Orthopaedic Institute, Bologna, Italy.

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Meniscal Cysts

24

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24.1 Introduction

A cyst is defined as a cavum filled with fluid and coated from inside with a monolayer of cells. The meniscal cyst is located close to the meniscus' periphery and most commonly associated with a horizontal meniscal lesion. Fibroblasts coat the cavum of the meniscal cyst surrounded by a thick layer of fibrous tissue (Fig. 24.1a, b). The Alcian-blue staining shows an increase of hyaluronic acid within the capsule.

Cysts around the knee are localized either intra-articular or extra-articular. Intra-articular cysts can arise from the anterior cruciate ligament [20, 63], posterior cruciate ligament [19, 37], infrapatellar fat pad [2], or transverse meniscal ligament [42]. Intra-articular cysts are rare with an incidence of 1 % [32]. Most of the intra-articular cysts are clinically asymptomatic. Kurdwig et al. reported that 76 out of 85 intra-articular soft tissue masses are asymptomatic and incidentally diagnosed. The prevalence and the size of asymptomatic meniscal cysts were studied in 102 asymptomatic knees [59]. Subjects with a mean age of 42.8 years (18–72 years) received magnetic resonance imaging (MRI) examination. Four medial meniscal cysts were

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_24

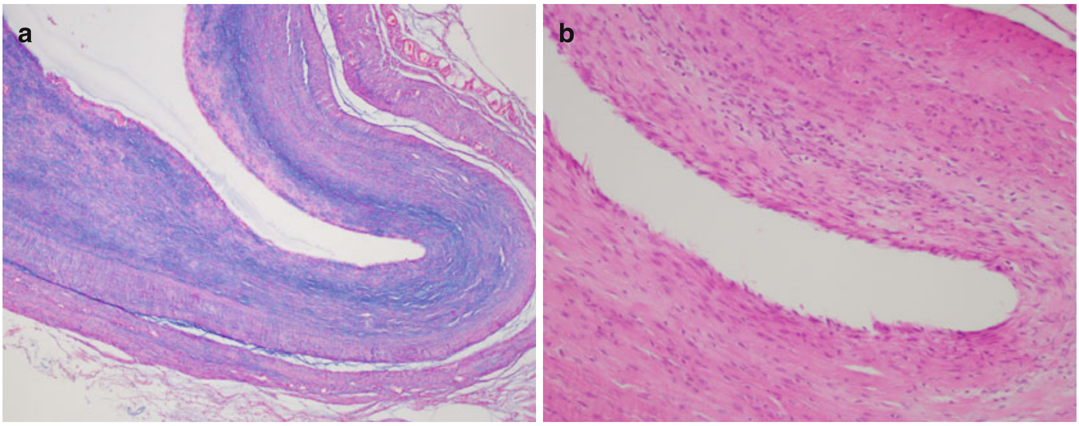

Fig. 24.1 (**a**) Alcian-blue staining, 40× showing increase in hyaluronic acid in the fibrous tissue. (**b**) Hematoxylin-eosin (HE), 100× showing the incomplete coating of the cavum with synovial tissue

found and showed an average size of 9 mm × 6 mm × 13 mm. The maximal diameter was less than 16 mm. No lateral meniscal cyst was identified in the study. Nineteen synovial cysts were diagnosed in the popliteal space.

Parameniscal cysts are most commonly located at the level of the medial or lateral joint line caused due to the strong association to the meniscus. Extra-articular cyst can also arise from the posterolateral capsule without having contact to the meniscus [24].

24.2 Etiology and Pathology of Meniscal Cysts

Two main theories about the meniscal cysts formation have been proposed. One theory suggests that synovial cells are displaced into the meniscus and produce mucin resulting in a cyst formation (Fig. 24.2) [56].

The mechanism might be induced due to abnormal stress or trauma on a meniscus [4]. Some studies report about a proportion of up to 50 % of traumatic genesis [27, 36].

A myxoid degenerative process has been identified histologically [6, 34]. The yellow color of the meniscal tissue frequently seen during arthroscopy is caused by the myxoid degeneration [21].

Figure 24.3 shows an arthroscopic view of the intermediate and posterior zone of the medial meniscus with central myxoid degeneration of the tissue.

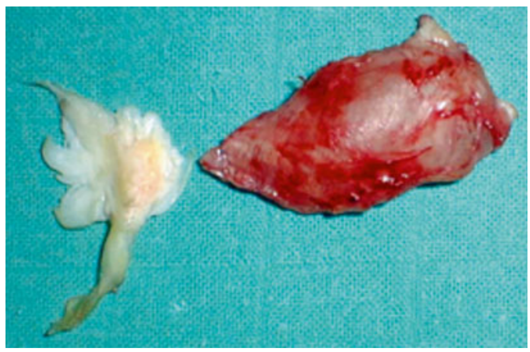

Fig. 24.2 Macroscopic view of a lateral meniscal cyst associated with a meniscal tear

In some studies, a cyst-lesion relationship of up to 100 % of the cases has been reported [25, 50]. However, there is no correlation between the size of the meniscal lesion and the size of the cyst. Large meniscal lesions may show very small cyst formation, and large cysts might be seen with small or no meniscal lesions [48].

The second theory presumes that the cyst formation occurs due to extrusion of the synovial fluid through the torn meniscal tissue [4, 21, 31, 60]. Cystic degeneration of the meniscus may cause either enlargement of the meniscus' periphery (i.e., intrameniscal cyst) or extrusion into the parameniscal tissue (i.e., parameniscal cyst) [16]. Signal characteristics of the fluid in MRI within the meniscal cysts had shown comparable intensity to the synovial fluid in over 96 % of the cases [3]. The second theory might be more likely due to the fact that, in 98 % or higher, meniscal cysts are associated with

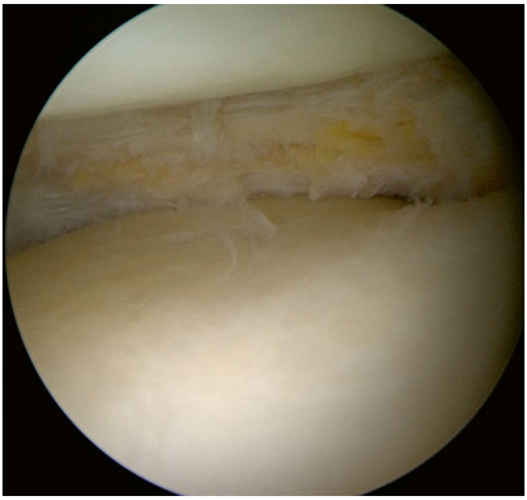

Fig. 24.3 Arthroscopic view of the intermediate and posterior zone of the medial meniscus. Partial resection of the meniscus was performed. The myxoid degeneration is visible inside the meniscus

horizontal meniscal lesions [9, 25, 27, 60]. However, it has been reported that the meniscal lesion does not need to reach the articular surface (Grade-III lesion) [3, 6]. This goes in line with the theory by Reagan et al. [48]. He presumes an initial meniscal lesion within the meniscal substance as classified by Stoller [57]. The lesion may progress either to the meniscus' periphery or to the inner circumference. In case the meniscal lesion progresses to the periphery, cyst formation may occur without presenting a Grade-III meniscal lesion.

Meniscal cysts can be classified as parameniscal, intrameniscal, or a combination of both. One may presume that cyst formation starts within the meniscal tissue as a result of degeneration followed by the expression into the parameniscal tissue. A high percentage of cysts are missing because they are asymptomatic at the early stage especially prior any extrusion. When cysts increase in size and extrude, they may become symptomatic. A critical size of 12 mm of the meniscal lesion has been considered for the formation of parameniscal cysts [62].

The extension of the medial and lateral parameniscal cysts was studied according to MRI [16]. Three layers are distinguished on the medial site of the knee: the crural fascia (layer I), superficial (layer II), and the deep layer of the medial collateral ligament (layer III). Histological studies showed that the medial meniscus is attached to the joint capsule but separated from the medial collateral ligament by loose connective tissue [54]. Thus, the cyst can easily enlarge into the connective tissue before extruded anterior or posterior from the medial collateral ligament. Medial meniscal cysts are predominantly located more at the posterior horn of the meniscus and less superficial [8, 51].

Lateral meniscal cysts are most frequently located in the midportion of the meniscus and show an extrusion either anteriorly (35 %) or posteriorly (66 %) [28].

Table 24.1 Incidence of meniscal cysts and the percentage of location at the medial and lateral meniscus

Publication	Incidence (%)	Lateral meniscus (%)	Medial meniscus (%)
Anderson et al. [3]	8	58.7	41.3
Hulet et al. [28]		79	21
Campbell et al. [9]	4	34	66
De Smet et al. [17]	1.8	36	64
Tyson et al. [60]	2.6	64	36
Raine and Gonet [47]	20		

24.3 Incidence of Meniscal Cysts

The incidence of meniscal cysts ranges between 1.8 and 20 % [3, 9, 17, 34, 47, 60] (Table 24.1). There are controversial findings regarding the location. Some authors report that meniscal cysts occur predominantly on the medial site and others on the lateral one.

Meniscal cysts are commonly found in young to middle-aged patients [27].

24.4 Clinical Evaluation and Diagnostic

The most common clinical sign seems to be the joint line tenderness especially under loading and sometimes in association with swelling at the level of the medial or lateral joint line (Fig. 24.4a, lateral; b, c, medial). Often these patients present a history of symptoms for months or years. The main symptom is pain. Effusion, locking, or giving way seems to be less common.

Fig. 24.4 Outside view of the knee showing the lump caused by the cyst. Typical presentation of a lateral meniscal cyst (the left knee)

Lateral meniscal cysts are easier to diagnose by physical examination than medial ones because of their relatively anterior and more subcutaneous position. A mass might be palpable solid or fluctuant in consistence. The size of the cyst may change in regard to the degree of knee flexion. Usually, there is a connection between the cyst and the anterior horn of the meniscus. There is a potential risk that large lateral meniscal cysts may cause peroneal nerve palsy [30]. Patients presenting unexplained nerve palsy should receive an MRI of the knee and the proximal tibiofibular joint.

It has been reported that only 16 % of all medial or lateral meniscal cysts are palpable during physical examination [15]. However, parameniscal cysts are better palpable on the lateral site with 20–60 % than on the medial site with 6 % [9, 17].

The accuracy of the joint line fullness and joint line tenderness was studied in meniscal pathologies [13]. Joint line fullness did not correlate well with the presence of meniscal cysts and showed a very low predictive value of 29 % only. The accuracy, sensitivity, and specificity of the joint line fullness in detecting meniscal pathologies were 73 %, 70 %, and 82 %, respectively. The joint line tenderness showed an accuracy, sensitivity, and specificity of 68 %, 87 %, and 30 %, respectively. The finding goes in line with others [41]. The authors report about a mass palpation in 58 out of 636 cases at the level of the joint line having the knee at 45° of flexion. Thirty of these patients presented a cyst formation during arthroscopy only. However, no MRI was evaluated in the study and

Fig. 24.5 Imaging sample of meniscal cyst. A *Standard X-ray showing an erosion of the lateral tibial plateau*

thus some cysts might be missed. The knee position of 45° of knee flexion is in contrast to what A. Pisani described [46]. He reported that the cysts become less prominent or even disappear at a knee flexion angle of 45° (Pisani's sign).

Routine radiographs should include an anteroposterior weight-bearing and lateral view. The Rosenberg view is more sensitive than the anteroposterior view in the assessment of joint space narrowing and should be recommended [5]. The radiographies may look normal, but sometimes erosion at the tibial plateau or femoral condyle can be observed, due to increased pressure by the cyst [1, 58] (Fig. 24.5). Wang et al. have showed also that medial or lateral meniscal extrusion is associated with subchondral bone marrow lesions and bone cysts [61].

The diagnosis of meniscal cysts is nowadays mainly based on MRI (Fig. 24.6a–f). The appearance of meniscal cysts in MRI showed in 91 % meniscal cysts immediately adjacent to the meniscal lesion. Only 4 % of the cysts seem to be

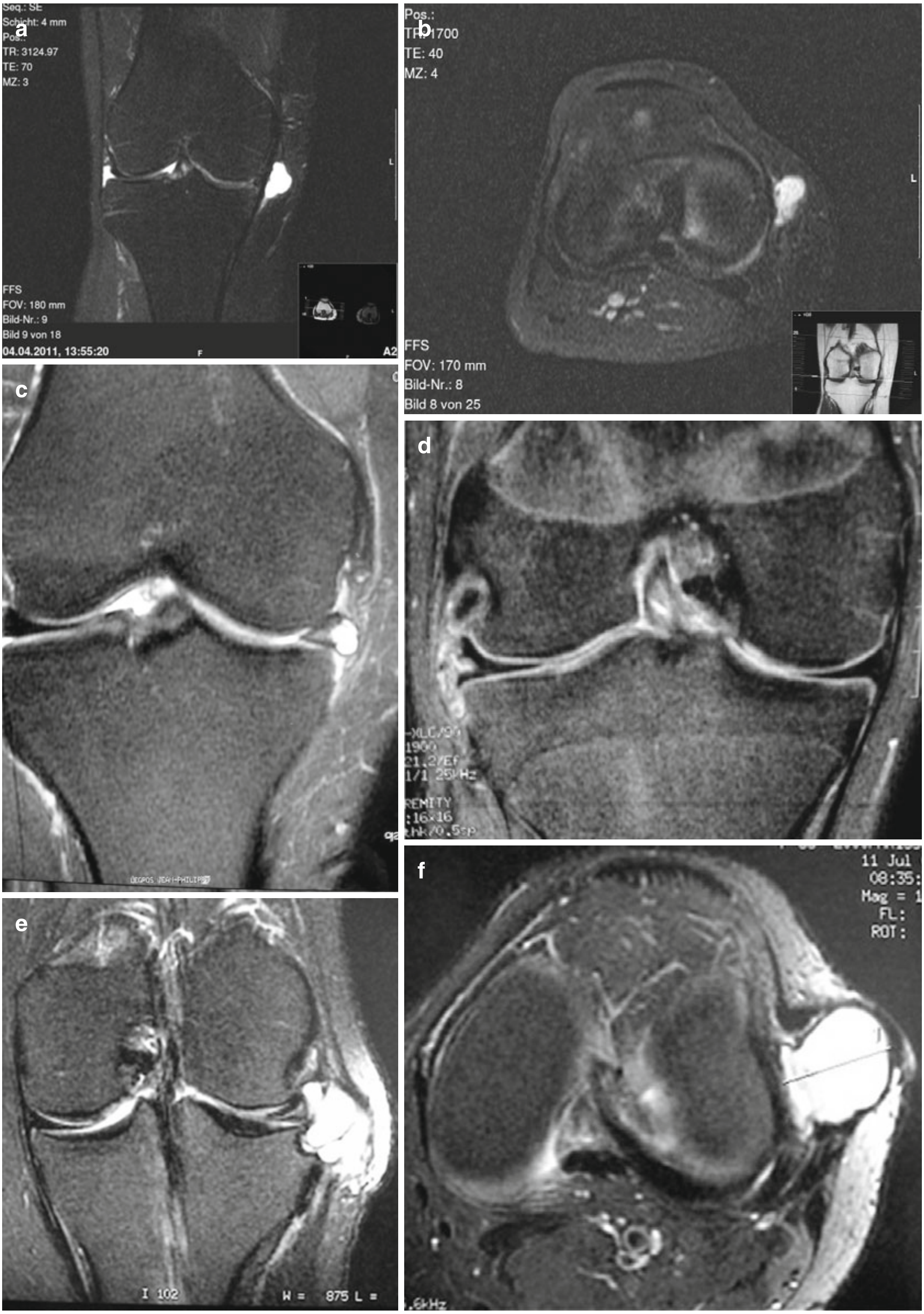

Fig. 24.6 MRI imaging. (**a**, **b**) MRI of the right knee. (**a**) Coronal plane (T2W-SPIRT), (**b**) axial plane (PSW-TSE-SP). The images show a large parameniscal cyst of the medial meniscus. (**c**) MRI T2 showing a medial meniscal cyst and the associated meniscal tear. (**d**–**f**) MRI T2 showing a lateral meniscal cyst and the associated meniscal tear

separated from the meniscus [60]. Magnetic resonance imaging (MRI) is the first diagnostic step to search for and assess the meniscal cysts (Fig. 24.6). The MRI is critical to define precisely the meniscal tear. This imaging exam allowed a meticulous exploration of the size, location, extension to the articular surface of the meniscus, and the communication between the cyst and the tear. MRI is very useful to locate the cyst and to search for associated intra-articular damage [63] (especially articular cartilage lesions) and differential diagnosis (*cyst of the Hoffa ligaments* (Fig. 24.7a) and *cyst of the tibiofibular joint and its surgical excision* (Fig. 24.7b, c) and preoperative planning).

Some patients, such as patients with pacemaker, for instance, show contraindications for MRI examination. In these patients, ultrasound or CT-arthrography might be considered as a useful tool [12]. Ultrasound is an easy to perform and cheap technique, which might be used in diagnosing meniscal cysts (Fig. 24.8).

The sensitivity and specificity of detecting meniscal lesions with ultrasound has been reported of 70–80 % and use to be significantly lower in comparison to MRI [23, 53]. However, the more recently developed high-resolution ultrasonography (HRUS) shows significant higher sensitivity and specificity of 94–97 % and 86–100 %, respectively ([49, 55]).

Despite the fact that CT-arthrography provides a high sensitivity and specificity in detecting meniscal pathologies, it should not be considered for routine diagnostics due to the availability of MRI technology as a noninvasive tool and without any exposure to radiation [35]. The sensitivity and specificity for CT-arthrography of 91.7–100 % and 98.1 %, respectively, have been reported [35].

Differential diagnosis includes meniscal lesion without cyst, loose bodies, exostosis, bursal inflammation, ganglion, tendinitis, and tumor.

24.5 Treatment of Meniscal Cysts

Meniscal cysts can be treated conservatively or by surgery. Surgery should include both resection or repair of the meniscal lesion and removal or debridement of the meniscal cyst [48].

24.5.1 Conservative Treatment

Injection of steroids into the cyst [4] or ultrasound-guided percutaneous drainage might be an option for treating meniscal cysts nonsurgically [40]. The steroid injection may stop the inflammatory process and production of fluid and may induce fibrosis of the cyst and closure of the cavum. The injection of steroids lasts often for a short term of several weeks only [40]. Others had reported more promising results [38]. Ultrasound-guided percutaneous drainage of meniscal cysts was evaluated by MRI. Ten out of 18 patients (13 medial and 5 lateral) experienced complete relief of symptoms but 6 of them complained again after an initial pain-free period. Cyst aspiration may be considered in patients presenting contraindication for surgical treatment. Fluid aspiration causes reduction of swelling, but the cyst formation remains intact and a high risk of recurrence can be expected.

24.5.2 Surgical Treatment

Meniscal cysts formation occurs mainly in conjunction with meniscal lesions. Hulet et al. studied a series of 105 lateral meniscal cysts retrospectively and reported a prevalence of Grade-III meniscal lesions in 99 % of the patients [27]. Reagan [40] suggested that there are several stages to the development of lateral meniscal cysts and that a complete meniscal lesion depends on the stage of progression, in a given patient [48]. Among the different types of meniscal tears, the predominant form is a horizontal component presenting itself as a cleavage [11, 25, 39, 44] (Fig. 24.9a, b).

Glasgow reported 72 tears and described 30 simple horizontal cleavages, 23 oblique-horizontal cleavages, and 4 discoid menisci [25]. Hulet et al. found that a horizontal component (56 % horizontal cleavages and 10 complex lesions) accounted for 64 % of the cases [27]. The majority of these lesions were radial slits (44 %). Horizontal cleavage is the most frequently encountered tear in lateral meniscal cysts. Meniscal cysts are located in the midportion of the lateral meniscus with an extension to

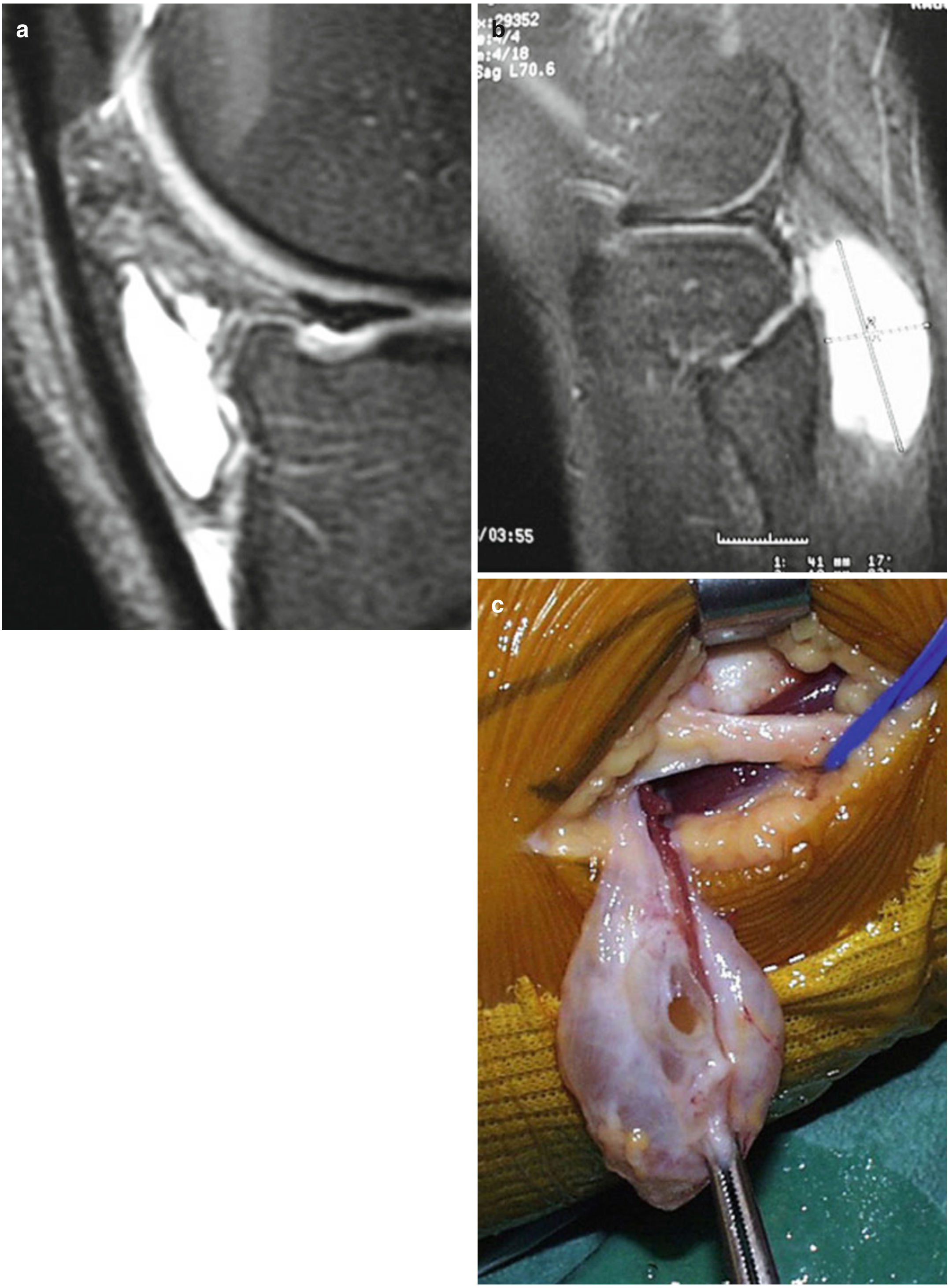

Fig. 24.7 *Differential diagnosis for the meniscal cyst.* Cyst of the Hoffa ligaments (**a**, **b**). (**b**) Cyst of the tibiofibular joint and its surgical excision. (Cyst of the Hoffa ligaments **a** and cyst of the tibiofibular joint and its surgical excision (**b**, **c**) and preoperative planning)

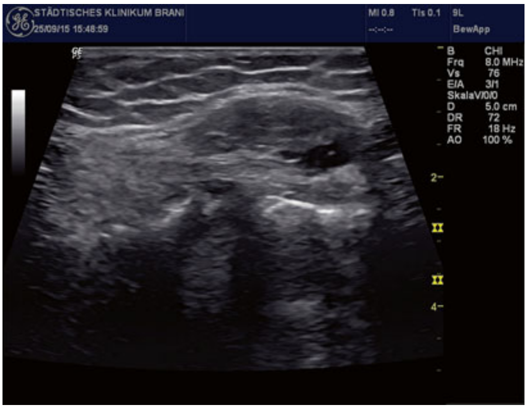

Fig. 24.8 Ultrasound image showing the longitudinal projection of the cyst close to the medial meniscus

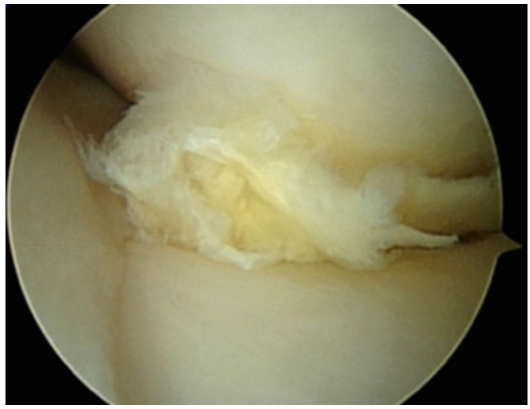

Fig. 24.9 Lateral meniscus tear with cyst of the lateral meniscus

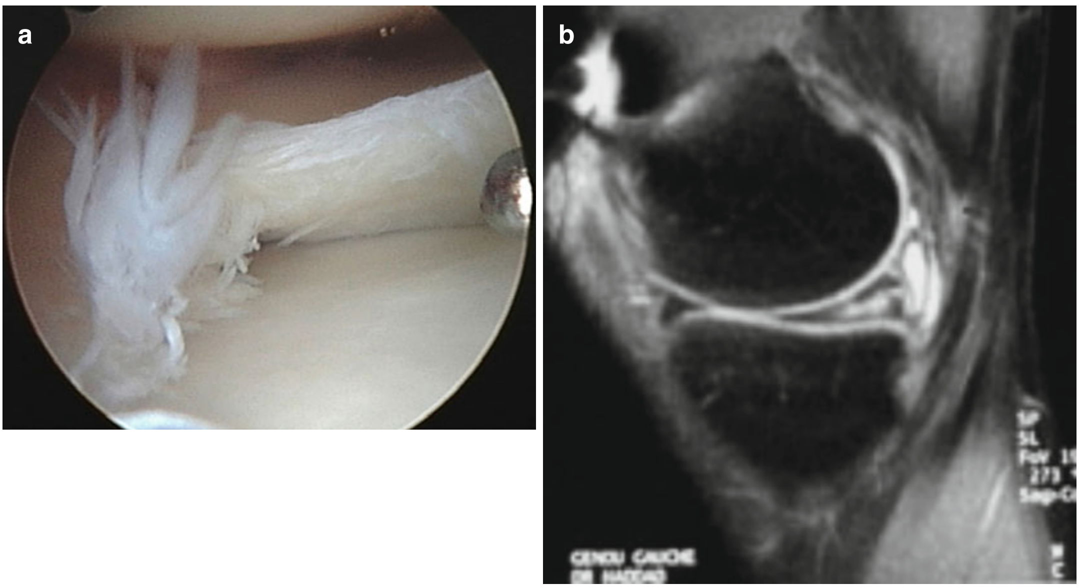

Fig. 24.10 (**a**, **b**) Medial meniscal cyst with an intra-articular arthroscopic view (Courtesy Personal Collection Philippe Beaufils)

the anterior portion in 21 % of the cases. Concerning the medial meniscus, Saidi et al. reported 5 cases [52]. In these five cases, all the meniscal tears had developed from the posterior segment. In a retrospective MRI review, Campbell and Mitchell found a majority of medial meniscal cyst ($n=72$) [9]. In this report, the meniscal tear was a horizontal cleavage in 90 % of cases, and the location of the medial meniscal cyst was adjacent to the posterior horn in 74 % of cases (Fig. 24.10a, b).

For that reason, arthroscopy should be performed in order to treat the meniscal pathology followed by resection or debridement of the cyst. There are different options in the management of the meniscal lesion.

Patients scheduled for meniscal surgery should receive MRI prior to surgery in order to diagnose the exact location and size of both the meniscal lesion and the cyst. The intra-articular pathology needs to be addressed in conjunction with the treatment of the cyst.

Horizontal meniscal lesions require partial or subtotal meniscus resection showing the myxoid degeneration (yellow substance) [14] (Fig. 24.11a, b). In addition, horizontal lesions with extension into the meniscal-synovial junction should receive vertical sutures in order to close the lesion (Fig. 24.12a, b). However, no clinical data are available yet, which have proven the novel concept.

Different techniques for arthroscopic surgery have been described [26, 29].

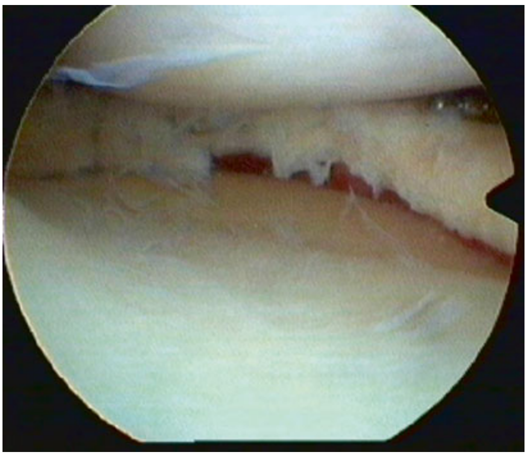

Fig. 24.11 Horizontal meniscal lesions require partial or subtotal meniscus resection showing the myxoid degeneration (*yellow substance*)

Standard arthroscopy portals should be used initially. Sometimes an inferomedial or inferolateral portal is required in addition for better visualization of either the medial or lateral compartment [18]. A spinal needle introduced percutaneously through the cystic mass may help to identify the sinus tract between cyst and meniscus (Fig. 24.13). A meniscal punch may be entered into the cyst in order to widen the sinus tract. Thus, the fluid of the cyst can be drained into the joint. Additionally, a small-motorized shaver may be introduced into the cyst, assisting in cystic decompression and stimulating inflammation and scarring of the cyst [33].

An arthroscopic technique has been described recently for lateral parameniscal cyst compression using a very superomedial portal at the most proximal part of the suprapatellar pouch, just medial to the quadriceps tendon [26].

Some surgeons recommend suturing the remnants of the sinus tract within the meniscus after partial meniscectomy, although it may not be necessary. Drainage of the cyst into the knee via the natural tract seems to be sufficient [33, 52]. Open resection could be performed when the cyst is too large.

Open resection of the cyst in addition to arthroscopy was compared with solely arthroscopic treatment of parameniscal cysts [52]. No difference in

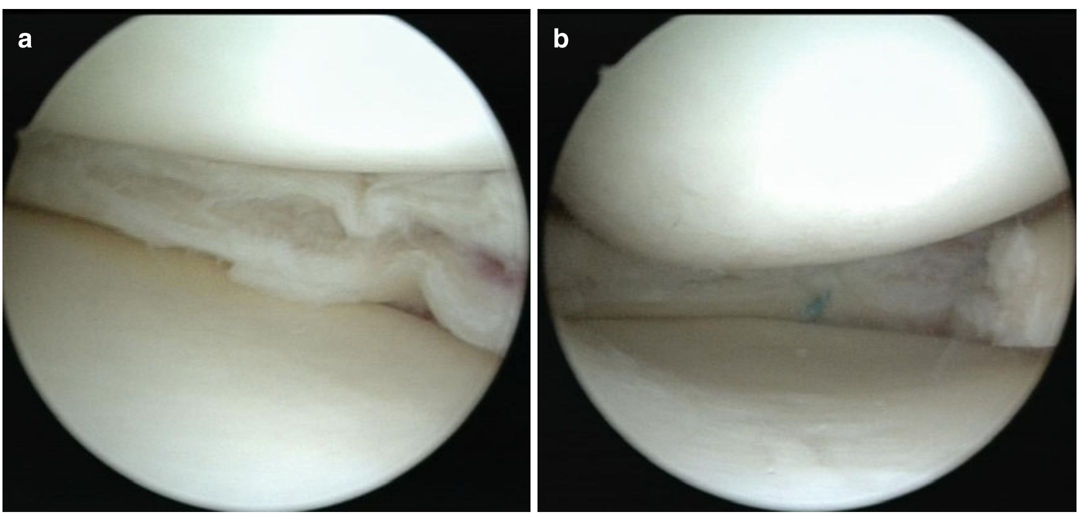

Fig. 24.12 (**a**, **b**) Arthroscopic view of the closure of the horizontal lesion of the medial meniscus after partial resection. In order to improve the healing, a fibrin clot might be inserted

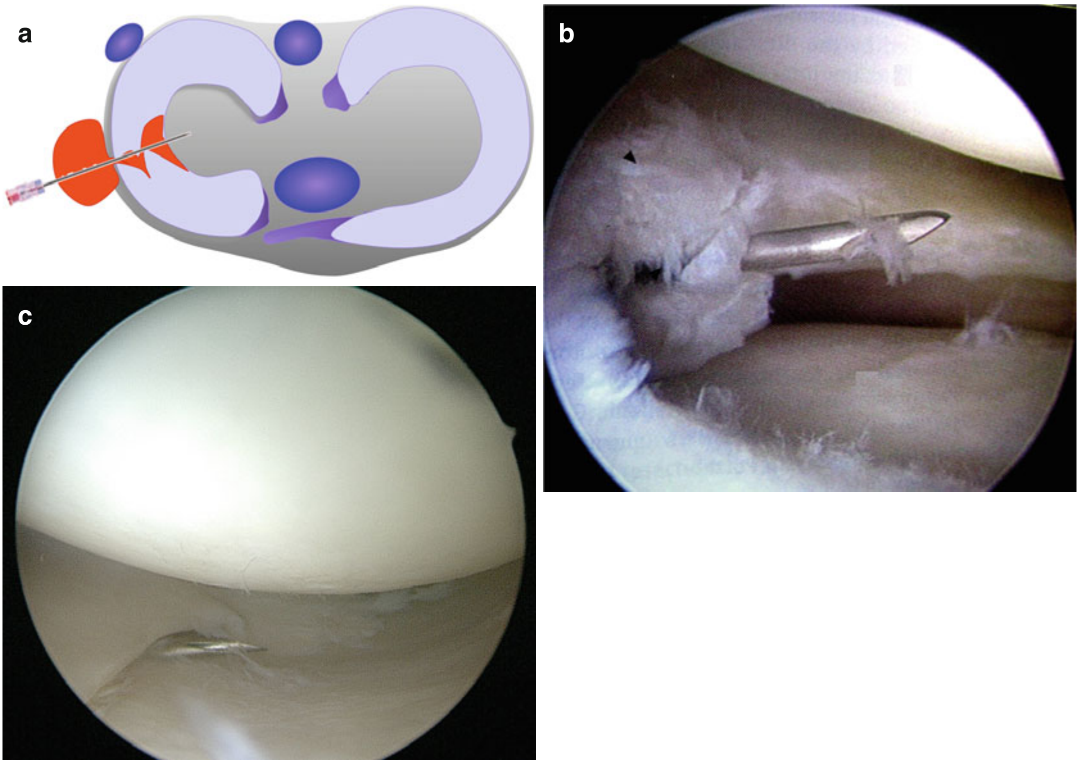

Fig. 24.13 A spinal needle introduced percutaneously through the cystic mass may help to identify the sinus tract between cyst and meniscus

clinical outcome was reported. The isolated treatment of meniscal lesions by partial meniscus resection has shown inferior results. Good and excellent results have been reported in 50 % of the patients in comparison to a combined arthroscopic debridement and open resection procedure with 80 % of excellent results [48].

Special attention is required in multiple lobular cysts. A complete decompression can only be achieved with open surgery (Fig. 24.16).

A clinical and surgical algorithm for treatment of meniscal cysts is proposed when a symptomatic lateral meniscal cyst is suspected clinically (Fig. 24.14).

MRI is the first diagnostic step to search a meniscal tear. If a meniscal cyst is suspected clinically, an MRI is the diagnostic test of choice. The MRI is critical in identifying additional diagnoses and to precisely delineate the lateral meniscal tear (size, location, extension to the articular surface of the meniscus, communication with the cyst) and the cyst.

If the tear was clearly opened into the joint, arthroscopy is first performed to characterize the meniscal tear (Fig. 24.15).

In the case of a smaller tear, cystectomy should be performed (most often with open technique); then the repair suture technique should be tried to preserve the meniscal tissue. In the case of important and complex tears, arthroscopic partial meniscectomy and cyst decompression were indicated.

If the tear was not opened into the joint, an arthroscopy should be performed with diligent search on both menisci surfaces of a meniscal tear, followed by an open cystectomy and meniscal suture laterally to medially.

Depending on the location of the tear, the cyst could be decompressed arthroscopically for the anterior horn. In all cases, meniscal tissue preservation should be attempted to preserve the knee biomechanics. The meniscal tear is usually a primary lesion and results from a degenerative breakdown of the ultrastructure of the meniscal collagen.

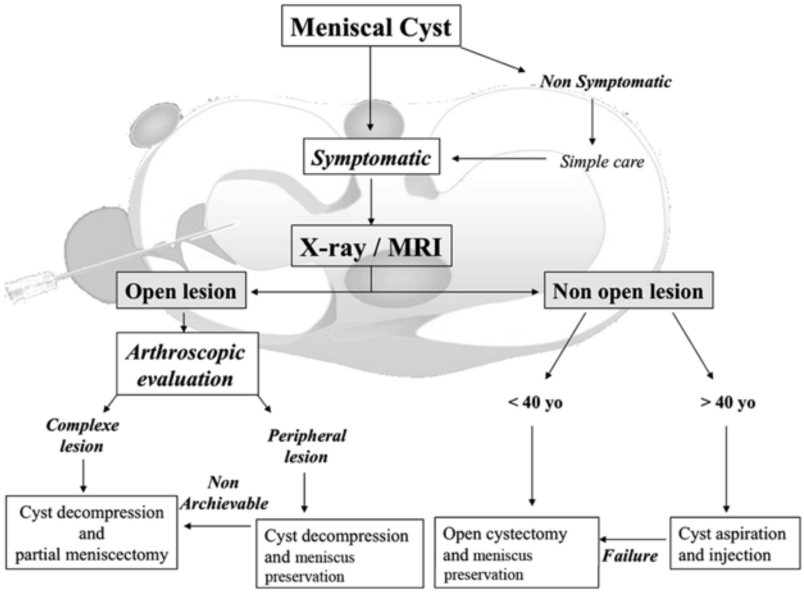

Fig. 24.14 A clinical and surgical algorithm for treatment of meniscal cysts is proposed when a symptomatic lateral meniscal cyst is suspected clinically

24.6 Results

Good and excellent outcome has been reported in up to 85 % for the medial meniscus in numerous studies [22, 25, 27, 39, 40, 43, 45, 48]. Similar results are also reported for the lateral meniscus, showing clearly that functional outcome is related to the meniscal lesion and not the presence of a cyst [5]. The patients with lateral meniscal cysts treated by arthroscopic resection were clinically followed up after 5 years [27]. The recurrence rate was 10.5 % (11 patients). The author also reported that 77 % of the active patients returned to their previous level of activity and 16 % showed lower performance. Ninety-one out of 104 patients received arthroscopic resection, and 14 patients had open surgery.

Biedert [7] had encouraged this management in a randomized clinical trial of treatment of intra-substance meniscal lesion of the medial meniscus. Forty patients of 31 years of age were included and they all had horizontal Grade-II meniscal lesions.

The same surgeon performed four treatments: conservative treatment (75 % nearly normal or normal at final evaluation), arthroscopic suture repair with access channels (90 % nearly normal or normal at final evaluation), arthroscopic minimal central resection (43 % nearly normal or normal at final evaluation), and suture and arthroscopic partial meniscectomy (100 % nearly normal or normal at final evaluation).

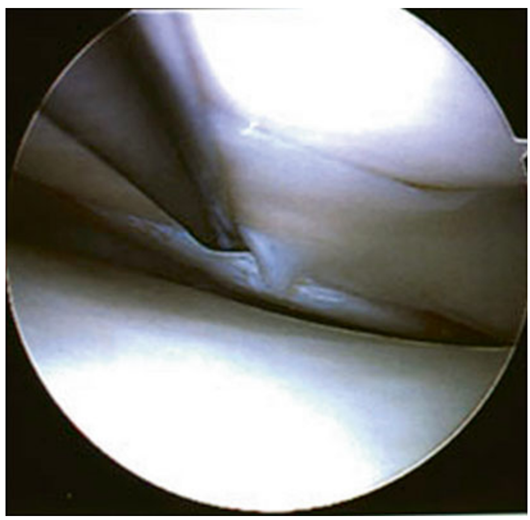

Fig. 24.15 Careful examination of the inner and upper surfaces of the menisci

A recurrent rate of cysts formation has been reported ranging between 9.5 and 15.6 % [39, 48]. Early revision arthroscopy is likely when insufficient meniscus resection has been performed. Late revision arthroscopy in contrast is rather caused due to progression in meniscus degeneration. Revision surgery showed no effect on the final outcome. The incidence of osteoarthritis was 9 % at an average of 5 years of follow-up. The amount of meniscus resection seems to correlate directly with the development of osteoarthritis [10]. The 10-year follow-up of 98 patients showed a much higher incidence of osteoarthritis of 38 % [28]. Arthroscopic suture repair is an effective alternative to meniscectomy to prevent the development of osteoarthritis of the knee joint. The number of cases treated in this way, with their follow-up periods, is still insufficient.

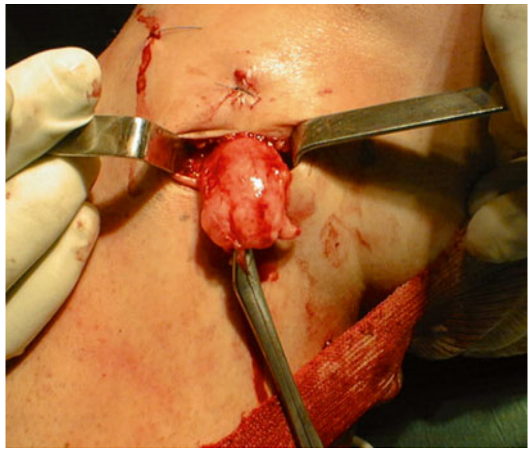

Fig. 24.16 Open resection of a large multiple lobular cyst

Conclusion

The incidence of meniscal cyst is low. Meniscal cyst is a particular entity in meniscal pathology. When a symptomatic meniscal cyst is suspected clinically, magnetic resonance imaging (MRI) is the first diagnostic step to explore the meniscal tear. Asymptomatic meniscal cyst should be treated conservatively. Data reported in the literature suggest the following management protocol for patients with a symptomatic meniscal cyst based on careful examination of the surfaces of the menisci during arthroscopy. In all cases, meniscal tissue preservation should be the rule for the future of the knee. As seen in the long-term results following lateral or medial meniscectomy, attempts to preserve the meniscus are clearly justified. The meniscal tear is usually a primary lesion and results from a degenerative breakdown of the ultrastructure of the meniscal collagen with myxoid degeneration. Ultimately, one essential question remains: whether or not a meniscus undergoing myxoid degeneration is likely to function properly or, more likely, to progressively fail because of repetitive shear forces concentrated centrally. Nevertheless, a meniscus that is functioning at some level is still preferable to no meniscus (Fig. 24.16).

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Discoid Meniscus and Meniscoplasty in Children

25

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Contents

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-662-49188-1_25) contains supplementary material, which is available to authorized users.

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25.1 Introduction

The discoid meniscus, although a relatively rare congenital anatomic abnormality of the lateral meniscus, is the most common anatomic meniscal variant. First described by Young in 1889 [1], its incidence has been estimated to be around 5 % in the general population, ranging from 0.4 to 16.6 % in different series in the literature [2–4] with a higher prevalence among Asian populations [3–9]. Most discoid menisci are located on the lateral side. However, rare descriptions of medial discoid menisci have been sporadically reported in the literature [5, 8, 10]. The incidence of bilateral discoid lateral menisci (DLM) is estimated to be as high as 20 %; however, the true incidence of bilateral DLM may be underestimated because the contralateral knees in most patients are asymptomatic. In a recent MRI and arthroscopic studies, it was found that the incidence of bilateral DLM ranges from 65 to 90 % [11, 12].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_25

Historically, pathogenesis theories ranged from an embryologic arrest in development resulting in incomplete resorption of the central meniscus to theories regarding this anomaly as a congenital anatomic variant, which is currently accepted.

Watanabe et al. presented in 1969 the most commonly used classification system for lateral discoid meniscus, describing three types based on arthroscopic appearance [13]: type I, the most common type in most series, is a complete discoid meniscus which covers the entire tibial plateau with intact peripheral attachments. Type II is an incomplete discoid meniscus, covering a variable percentage of the tibial plateau, with intact attachments. Type III, the least common, is an unstable discoid meniscus, also known as the Wrisberg ligament type, as it is characterized by absent normal posterior attachments with only the meniscofemoral ligament of Wrisberg providing posterior stabilization, resulting in significant meniscal mobility which often manifests clinically. Unstable DLMs are commonly symptomatic and require surgical treatment. In general, discoid menisci with normal peripheral attachments tend to be asymptomatic, and this is the case in many children, therefore requiring no treatment [10, 14, 15]. However, with tissue variability and abnormal knee kinematics with high shear stresses, discoid menisci are at an increased risk for the development of tears, which are often revealed clinically during childhood. Patients often present with mild, vague lateral joint line pain and swelling with or without an inciting event. Mechanical symptoms are present in displaced tears or an unstable variant, manifesting as palpable or audible 'clicking', 'snapping', or 'popping' or even an extension block.

Radiographs are a mandatory part of the evaluation and may reveal widening of the lateral joint space, lateral femoral condyle flattening, concavity of the tibial plateau, meniscal calcification, and tibial spine hypoplasia. Concomitant osteochondritis dissecans of the lateral femoral condyle has also been reported and should be looked for [16, 17]. MRI, aiding not only in diagnosis but also in decision-making and preoperative planning, demonstrates irregular continuity of the anterior and posterior horns of the lateral meniscus (absent 'bow tie') in three or more consecutive 5-mm cuts. Intra-substance tears and displaced flaps are often well visualized; however, unstable type III variants are more difficult to detect on MRI [16, 18]. In these symptomatic cases, surgery is indicated [9], with the goal of symptom relief and meniscal tissue preservation to obtain functionality as well as avoid early degeneration [19].

In the past, total meniscectomy was widely acceptable for the treatment of discoid meniscus [20, 21]. However, later reports showed the advantages of arthroscopic saucerization [22]. Although it is no longer considered an appropriate treatment choice, it is still performed in situations where meniscal preservation is not feasible. The available evidence reveals fair to poor long-term clinical outcomes in patients after total meniscectomy, with radiographic follow-up that has demonstrated high rates of degenerative changes and arthrosis of the involved compartment. These patients should be closely followed for early symptomatic appearance as the option of meniscal transplantation might be considered in these cases.

Currently, treatment guidelines are based on the type of meniscal variant, its stability, presence of a tear, tear type, symptom severity and duration, and the patient's age. Treatment options include observation; partial meniscectomy or saucerization, with or without repair or reattachment of an unstable peripheral rim; and total meniscectomy. Asymptomatic discoid menisci are often identified incidentally (during radiographic or MRI evaluation) and are usually addressed with observation alone. Symptomatic stable discoid menisci (types I and II) are usually treated with arthroscopic 'saucerization' [23–28]. The goal in this procedure is to retain a peripheral rim (ideally, a residual rim width of 6–8 mm) resembling a normal meniscus, in order to more closely reproduce meniscal anatomy and function and to avoid re-tear. If significant instability persists after saucerization, a repair is required to stabilize the unstable residual portion to the capsule. Type III DLM with an unstable rim is ideally treated with combined saucerization and repair of the peripheral rim to stabilize the reshaped meniscus to the capsule. Addressing these variants commonly requires multiple sutures, as they tend to be highly unstable. Various meniscal repair techniques can be utilized for this purpose, such as the ‘inside-out’ technique, the ‘outside-in’ technique, and the ‘all-inside’ technique. Indications for technique choice are based on repair location, tear type, and the surgeon’s preference. Anterior rim instability, i.e. is more easily addressed with an outside-in technique.

This chapter presents an easy and efficient MRI diagnostic classification and describes treatment options and techniques for DLM tears and instability.

25.2 Novel MRI Classification

Various DLM classifications based on arthroscopic findings have been reported, and treatment guidelines according to these classifications have been suggested [29–31]. Tear pattern classifications were based on arthroscopic findings and include horizontal tears, peripheral tears, horizontal and peripheral tears, posterolateral corner loss, and others. The magnetic resonance imaging (MRI) classification can provide more information to the surgeon, although the final decision is made during arthroscopy. The MRI classification can aid surgeons in predicting the occurrence of peripheral tears and degree of instability as well as plan the treatment method preoperatively [32]. However, this MRI classification is not sufficient, and other aspects, such as a careful history and physical examination, are always essential.

The novel MRI classification, introduced in 2009, is constructed of four categories: no shift, antero-central shift, postero-central shift, and central shift. In the ‘no shift’ category, the peripheral portion of the discoid meniscus is not separated from the capsule, and the entire meniscus is not displaced (Fig. 25.1). Even in cases where the thickness of the anterior and posterior horns in the sagittal images exhibit differences and the discoid meniscus appears displaced, they are classified as no shift if the peripheral portion is not separated from the capsule. In the ‘antero-central shift’ category, the periphery of the posterior horn is detached from the capsule, and the entire meniscus is displaced anteriorly or anterocentrally; in this category, the anterior horn has a thick appearance in the sagittal images (Fig. 25.2). An ‘antero-central shift’ is therefore defined if the signal loss is observed in more than 2 cuts in the posterior side of coronal images and a 2-fold increase is observed in the sagittal images. In the ‘postero-central shift’ category, the periphery of the anterior horn is detached from the capsule, and the entire discoid

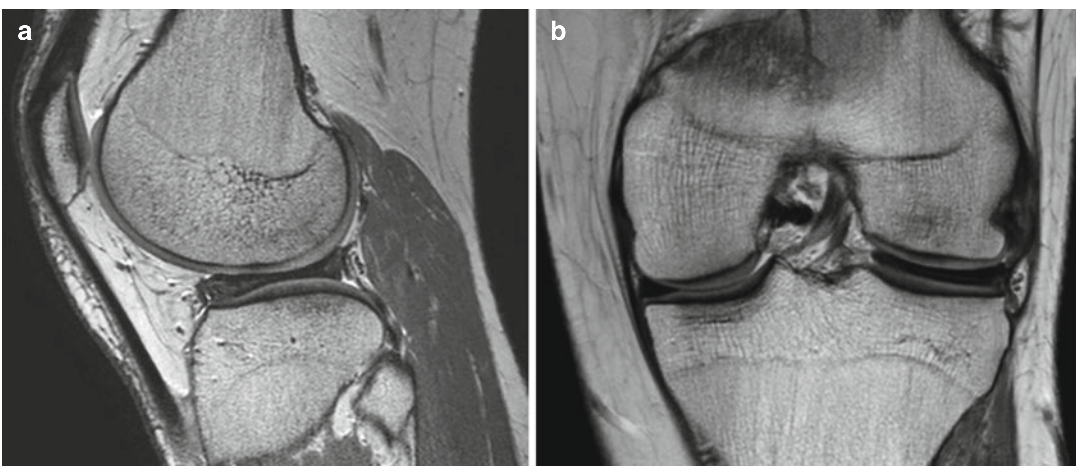


Fig. 25.1 (**a**) Coronal and (**b**) sagittal images show only degeneration of discoid lateral meniscus without shifting

Fig. 25.2 (**a**) Coronal and (**b**) sagittal images show anterior shift of the discoid lateral meniscus (*arrow*). The posterior part of the meniscus is not seen because of an anterior shift of the meniscus

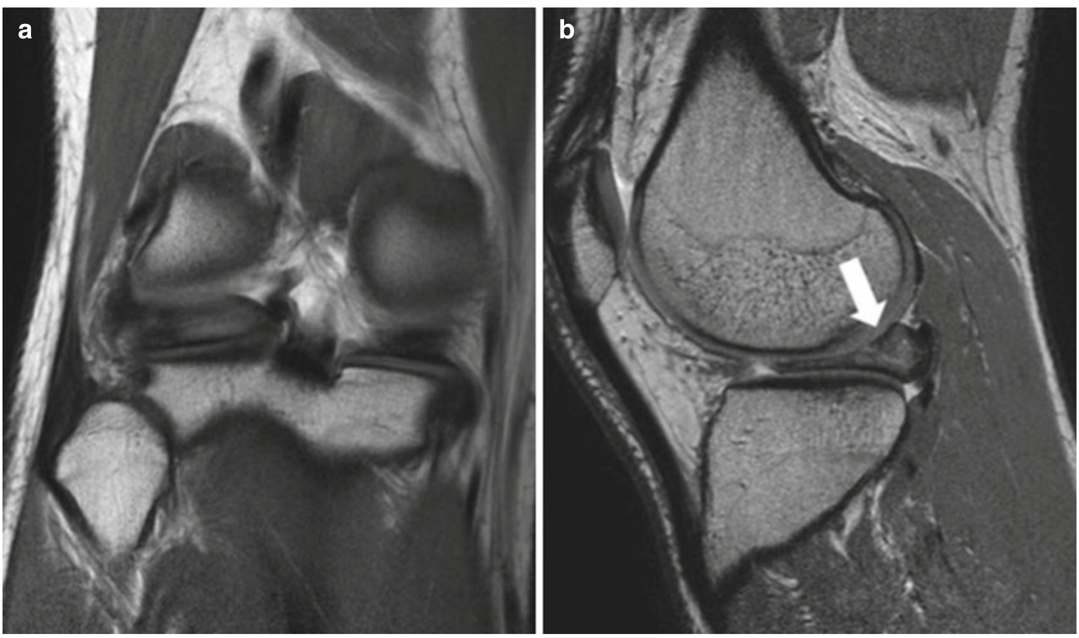


Fig. 25.3 (**a**) Coronal and (**b**) sagittal images show a posterior shift of the discoid lateral meniscus (*arrow*). The anterior part of the meniscus is not seen because of a posterior shift of the meniscus

meniscus is displaced posteriorly or postero-centrally. In this category, the posterior horn has a very thick appearance in the sagittal images (Fig. 25.3). A 'postero-central shift' is therefore defined if the signal loss is observed in more than 2 cuts on the anterior side of the coronal images and a 2-fold increase is observed in the sagittal images. In the 'central shift' category, the

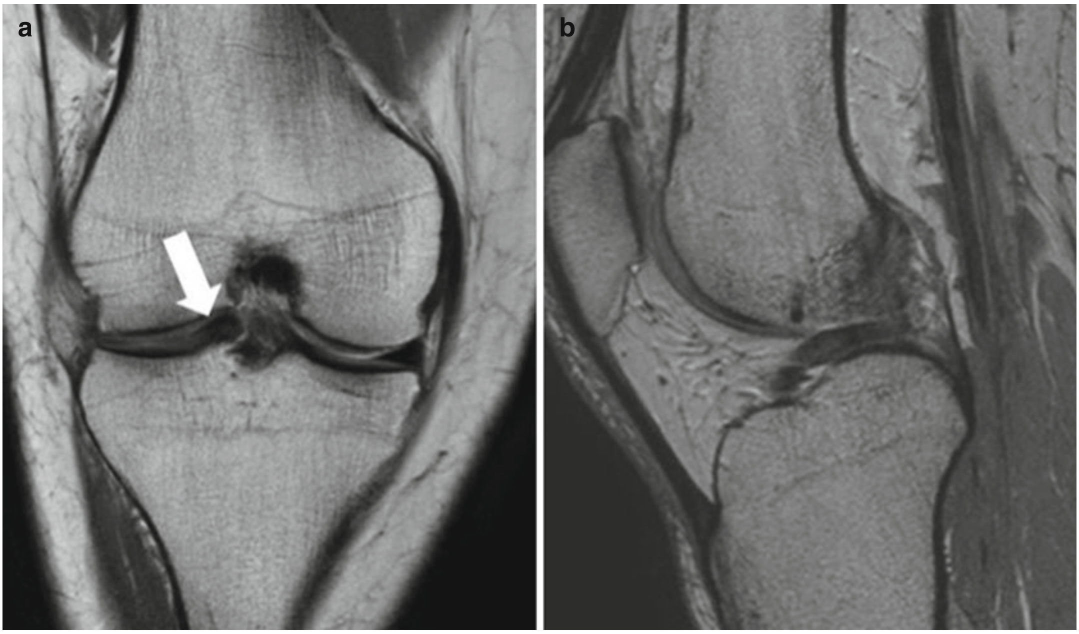


Fig. 25.4 (**a**) Coronal and (**b**) sagittal images show degeneration of the discoid lateral meniscus (*arrow*) without anterior or posterior shifting (central shift type)

periphery of the posterolateral portion is torn or lost, and the entire discoid meniscus is displaced centrally towards the intercondylar notch (Fig. 25.4). Central shift is therefore defined if central displacement with signal loss of the peripheral portion is noticed.

In a study of 82 knees utilizing the novel MRI classification, 43 knees were diagnosed as 'no shift', 6 as 'antero-central shift', 15 as 'postero-central shift', and 12 as 'central shift' [32]. Shift-type knees had a significantly larger number of peripheral tears, and repairs were performed in the shift-type knees (55 %) more frequently than in the no-shift-type knees (28 %) (Fig. 25.5). Among 82 knees, 31 were repaired simultaneously after a central partial meniscectomy. Therefore, the novel MRI classification presented here was useful in terms of preoperative planning of saucerization and detecting/identifying peripheral rim instability prior to arthroscopic surgery (Video 25.1). However, this MRI classification is not sufficient and other aspects must be considered as follows: A DLM with a peripheral tear might appear as having no shift, if it is reduced at the time the MRI is performed. It is therefore still important to correlate/incorporate clinical findings with the imaging findings. If a loud click is present in cases of DLM, a peripheral tear must be suspected and should be addressed by careful arthroscopic examination. In addition, DLMs frequently have horizontal and inferior tears that are not easily identified with arthroscopy and can be often missed without suspecting these possibilities and without a thorough arthroscopic examination. MRI can provide valuable information about the existence of horizontal tears that cannot be obtained from arthroscopy. Careful arthroscopic evaluation should be made because these types of tears are commonly associated with all types of DLM. Also, a peripheral longitudinal tear starts from the popliteal hiatus and extends to the posterior or anterior horn. The entire DLM is moved to the intercondylar notch and is easily reduced to its anatomic position with a loud click or clunk during knee flexion and extension, in the early stage of the peripheral tear. However, in the late stage the displaced DLM may be fixed at the intercondylar notch, thus redefined as a 'shift-type knee'. In such cases limitation in knee range of motion – especially a flexion contracture – will be evident on physical examination. After considering all the factors, the novel MRI classification

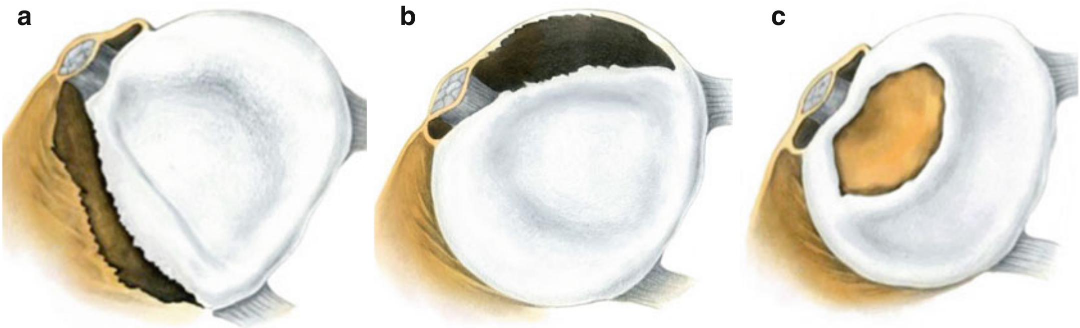


Fig. 25.5 Three types of the discoid lateral meniscus based on arthroscopic findings. (**a**) Meniscocapsular junction, anterior horn type (MC-A type); the drawing shows a peripheral tear of the anterior horn. (**b**) Meniscocapsular junction, posterior horn type (MC-P type); the drawing shows a peripheral tear of the posterior horn. (**c**) Posterolateral corner loss type; the drawing shows posterolateral corner loss of the discoid lateral meniscus

provides more information to surgeons in choosing the appropriate treatment method, although the final decision regarding the appropriate procedure is made during arthroscopy after a thorough analysis of the tear.

25.3 Arthroscopic Partial Meniscectomy with Repair of the Peripheral Tear for Discoid Lateral Meniscus in Children

25.3.1 Diagnostic Arthroscopic Examination

A standard arthroscopic diagnostic examination is initially performed under general anaesthesia, using a 4.0 mm arthroscope [33, 34]. The 2.7 mm arthroscope is rarely used only if the joint cavity is insufficient to allow diagnosis with a standard arthroscope. Routine diagnostic examination is performed using the standard anterolateral viewing portal. For simplified evaluations and to access the anterolateral compartment, the arthroscope is moved to the antero-medial portal, enabling a more thorough inspection as thick meniscal tissue may disturb optimal visualization of the DLM. Careful probing is performed to identify discoid meniscus type and tear shape and to evaluate the stability of the peripheral rim [11, 34, 35]. In cases of DLM, it is often difficult to visualize peripheral longitudinal tears at the posterior horn through the standard anterior portals due to the thick meniscal tissue. Peripheral rim tears at the posterior horn of the lateral meniscus could be examined with the arthroscope inserted through the antero-medial portal and passed through the intercondylar notch between the anterior cruciate ligament and the lateral femoral condyle. A 70° arthroscope could be used for better visualization. Also, switching the scope to a posterolateral portal enables peripheral rim tears of the posterior horn to be positively verified.

25.3.2 Partial Central Meniscectomy

Partial central meniscectomy is performed in a ‘1-piece’ fashion or ‘piecemeal technique’. The goal of partial central meniscectomy is to remove the central portion of the thickened meniscus and the torn unstable portion and to leave a stable rim of more than 6 mm from the peripheral capsular attachment. In children, inspection of the medial meniscus could be helpful to determine the size of the remaining peripheral rim after saucerization (Fig. 25.6). Sometimes the meniscal morphology could not be properly verified owing to peripheral rim instability, and a single-stitch suture is then performed to reduce

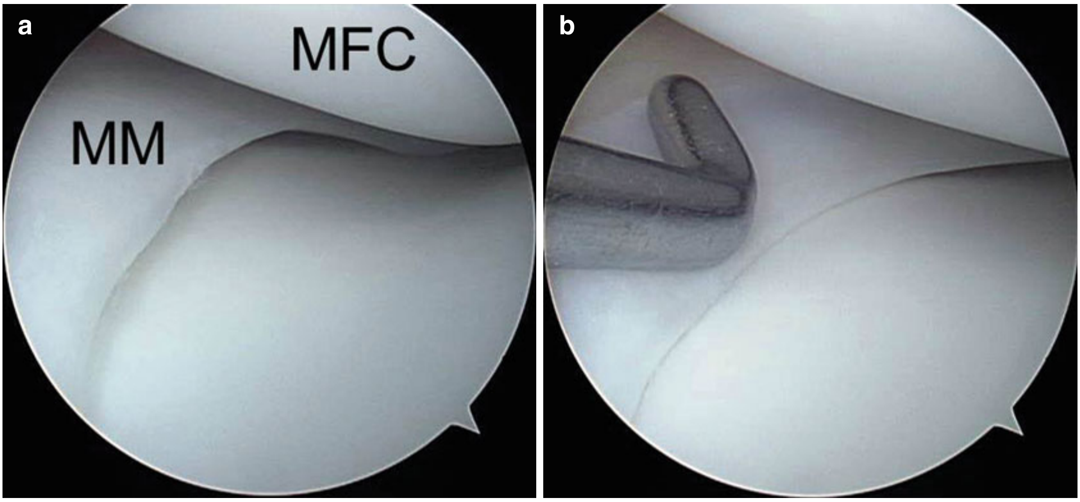


Fig. 25.6 Arthroscopic findings show the width of the medial meniscus that can be measured with probe (*MFC* medial femoral condyle, *MM* medial meniscus)

the meniscus prior to the central partial meniscectomy (Fig. 25.7). Using Iris scissors through the anterolateral portal, the anterior and mid portion of the discoid meniscus is cut leaving a margin of more than 6 mm from the periphery of the meniscus and the posterior portion of the discoid meniscus is cut to similar margins from the periphery of the meniscus using arthroscopic scissors or basket forceps through the anterolateral portal (Fig. 25.8). Iris scissors are useful to cut the anterior or mid portion of the discoid meniscus and trim the thickened portion of the discoid meniscus. After extracting the central portion of the discoid meniscus in one piece, the inner rim of meniscus is smoothed with a basket forceps or a motorized shaver. For horizontal tears, since the lower leaf is usually unstable, only the lower leaf is resected. Once the desired amount of meniscal tissue has been removed, the thickness of the inner edge is much greater than that after routine partial meniscus excision. Additional remaining thickened portions of meniscus are also trimmed using a basket forceps or Iris scissors, to avoid potential extension block. In order to remove a flap tear of the inferior rim of the anterior horn, the use of a basket forceps or a shaver through the submeniscal portal could be useful (Fig. 25.9).

25.3.3 Meniscus Suture Repair for Peripheral Tears

Once the central portion of the meniscus has been removed, the remaining peripheral rim must be carefully probed to ensure that there are no additional tears and that the rim is balanced and stable. At this point, when the peripheral rim tear of the DLM is reducible with a probe, the suture repair is performed. In cases where posterolateral corner loss of the DLM is too extensive and irreducible with a probe, subtotal or total meniscectomy should be considered. The number of sutures needed for repair could be used as a measure for tear size as the actual measurements are usually difficult to perform. Although not optimal, this provides a rough estimate of tear size, as stitches are placed at roughly 3- to 4-mm intervals. Our preferred repair technique is performed using absorbable sutures (No. 0 PDS: Ethicon, Somerville, NJ, USA) after debridement of the tear sites using a motorized shaver. In order to suture tears from the anterior horn to the posterolateral corner, a modified outside-in technique is preferred using a suture hook (Linvatec, Largo, FL) with a straight neck and a spinal needle preloaded with a No. 0 nylon, enabling to pull out the PDS [36]. This technique is performed using

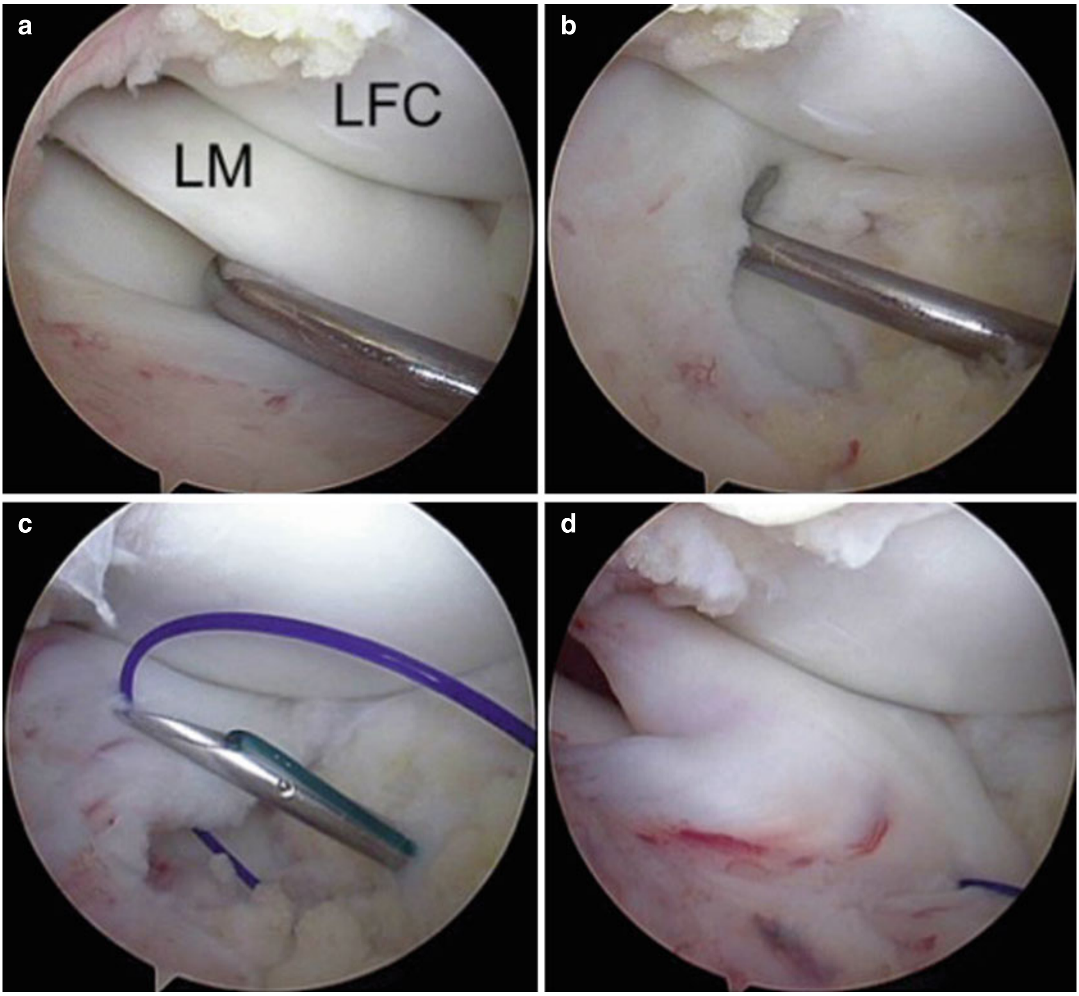


Fig. 25.7 Arthroscopic findings show (**a**) complete discoid lateral meniscus and (**b**) a meniscocapsular junction tear between the lateral meniscus anterior horn and the joint capsule. (**c**, **d**) A polydioxanone suture for reduction purposes, is placed to verify meniscal morphology, before undertaking central partial meniscectomy (*LFC* lateral femoral condyle, *LM* lateral meniscus)

a small posterolateral incision for easy retrieval and suture tying. In order to suture tears in the posterior horn, a modified all-inside technique is preferred using a suture hook with a 45° curved neck through a single posterolateral portal. If a tear could not be repaired due to posterolateral corner loss of more than 1 cm, an arthroscopic subtotal meniscectomy is performed.

Fig. 25.9 In order to remove a flap tear of the inferior rim of the anterior horn, a basket forceps or a shaver through the submeniscal portal can be used (*LFC* lateral femoral condyle, *LM* lateral meniscus)

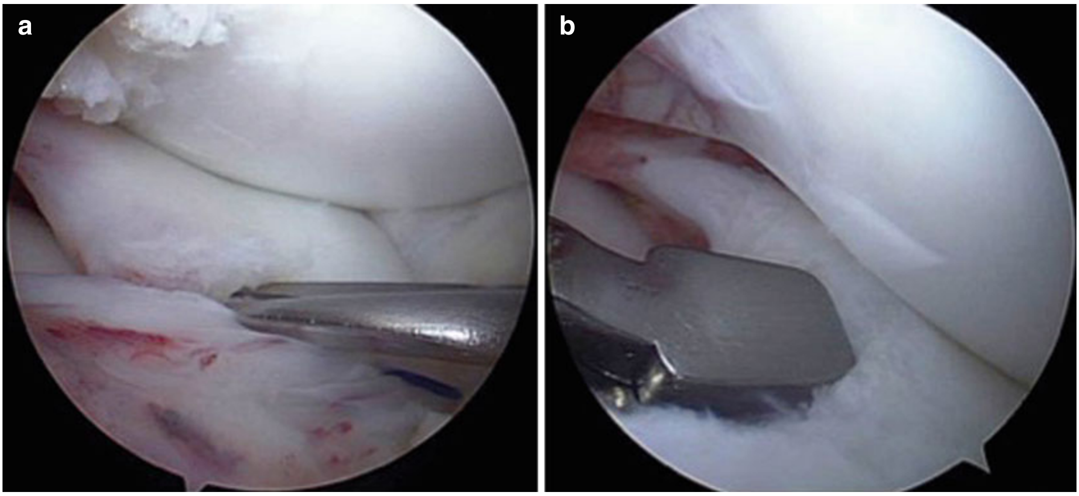
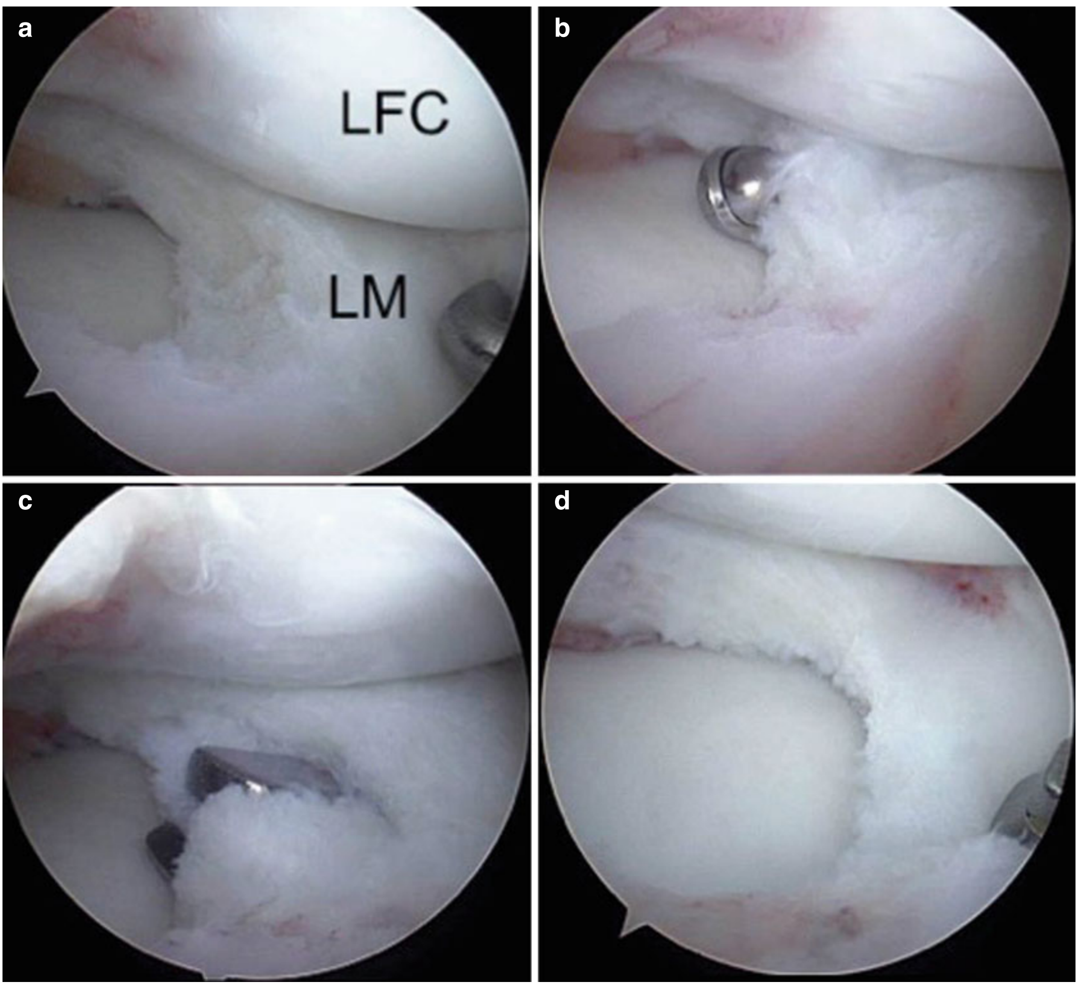


Fig. 25.8 (**a**) The discoid meniscus was cut with an Iris scissors through the anterolateral portal or (**b**) basket forceps inserted from the antero-medial portal



25.3.4 The Modified Outside-In Technique for Tears from the Anterior Horn to the Posterolateral Corner

The modified outside-in suture technique is performed using a spinal needle which is used in the standard outside-in suture technique [37] and a suture hook (Linvatec TM; Largo, FL, USA) which is generally used for the all-inside suture technique (Video 25.2). First, an arthroscope is introduced through the antero-medial portal, and a semilunar-shaped straight suture hook (Linvatec TM) is inserted through the anterolateral portal. First, the meniscus is pierced from the lower surface to the upper surface by orienting the suture hook in a vertical direction (Fig. 25.10). Next, the No. 0 PDS (Ethicon, Somerville, NJ, USA) suture material is advanced through the cannulated suture hook. After withdrawing the suture hook from the joint, the suture ends are retrieved through the ipsilateral portal using a suture retriever (Fig. 25.11).

Under arthroscopic vision, a spinal needle, with a preloaded MAXON 2-0, is inserted above

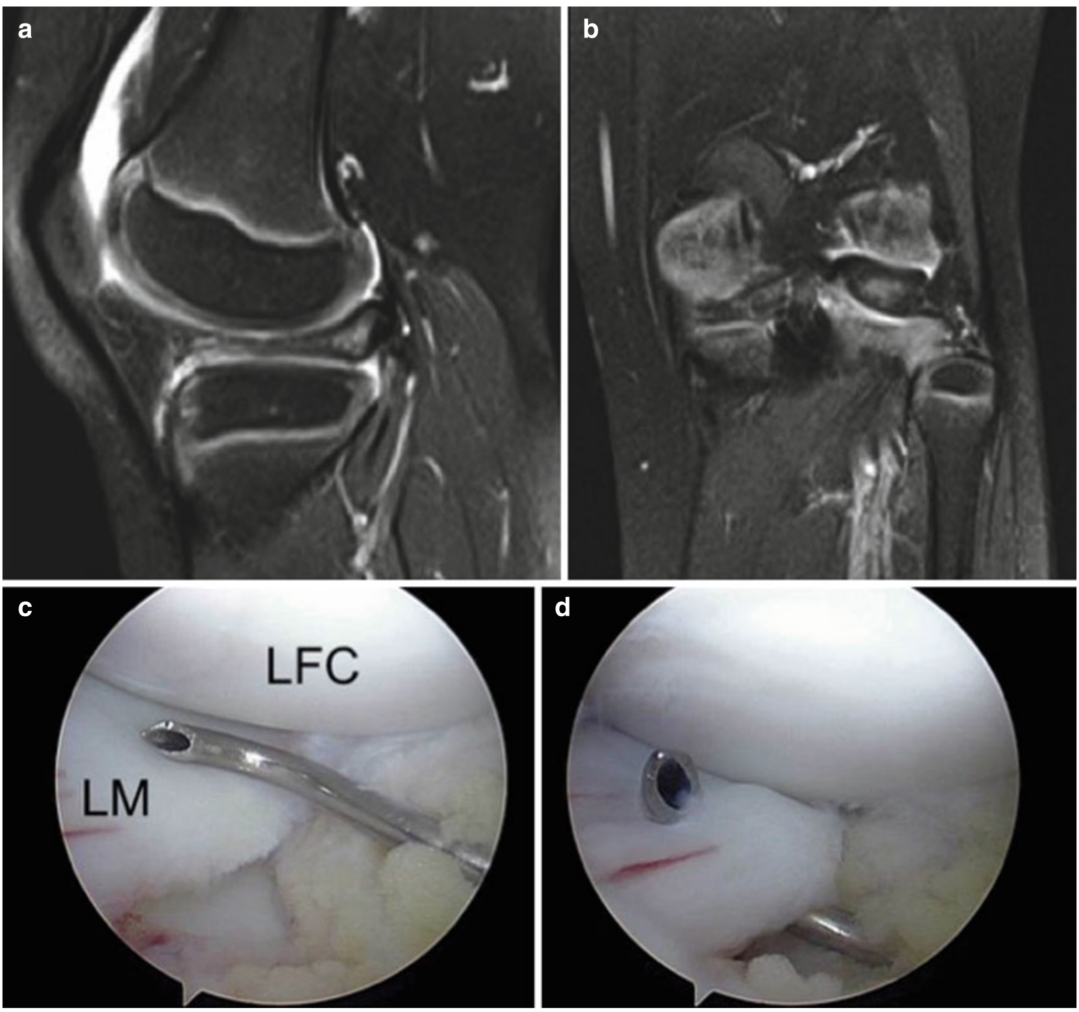


Fig. 25.10 (**a**) Sagittal and (**b**) coronal images of an 8-year-old boy show postero-central shift type of the discoid lateral meniscus in right knee. (**c**) Arthroscopic photograph showing a meniscocapsular junction tear between the anterior horn of the lateral meniscus and the joint capsule. (**d**) Suture hook inserted into the anterolateral portal is penetrated through the anterior horn of the lateral meniscus (*LFC* lateral femoral condyle, *LM* lateral meniscus)

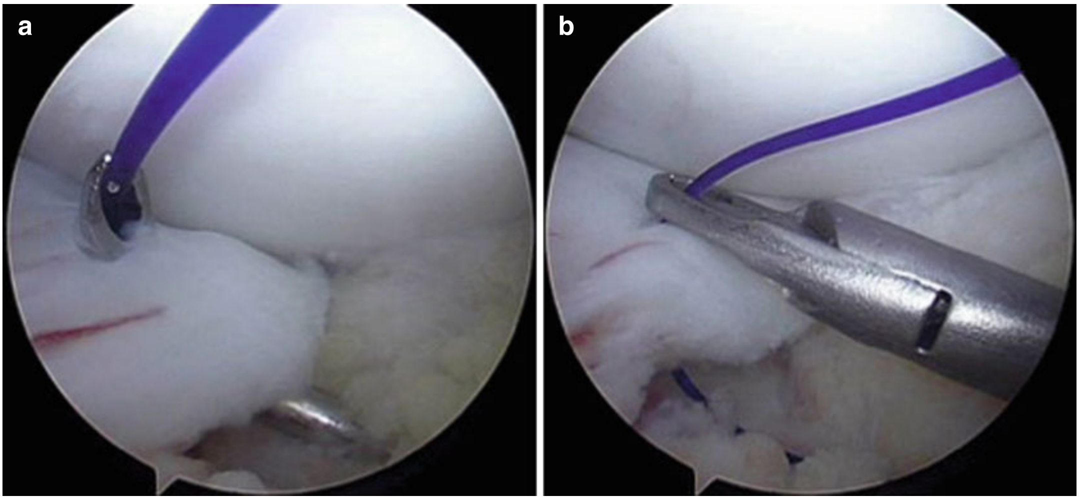


Fig. 25.11 (**a**) After passing the PDS suture, (**b**) the suture end is retrieved through the anterolateral portal using a suture retriever

the meniscus in order to pull out the previously inserted PDS through the torn meniscus (Figs. 25.12 and 25.13). The MAXON 2-0 loop is then manipulated so that it is oriented in front of the No. 0 PDS. The No. 0 PDS is retrieved through the MAXON loop with a suture retriever and the suture ends are pulled outside the capsule by pulling the MAXON loop outwards. An additional spinal needle, preloaded with a MAXON 2-0, is reinserted – this time below the meniscus – in order to pull out the other end of the previously passed PDS through the torn meniscus. The loop is positioned in front of the PDS suture end below the meniscus. This end is now retrieved through the MAXON loop and is then pulled outside the capsule by pulling the MAXON loop outwards. The torn meniscus is reduced by pulling both ends of the No. 0 PDS, which now holds the circumferential fibres of the meniscus (Fig. 25.14).

A 1–2 cm-sized skin incision is made close to the two ends of the PDS suture. Using a curved haemostat, the area is dissected down to the level of the retinaculum. The two PDS suture ends are then retrieved through the incision confirming there is no soft tissue interposed between the free ends of the PDS, apart from the retinaculum. After reduction of the meniscus, both suture ends are tied with optimal tension, achieved by manipulating a probe inserted through the anterolateral portal. After placement of the sutures, the gap between the meniscus and the joint capsule is closed.

25.3.5 The Modified All-Inside Technique for Posterior Horn Tears

In DLM, it is very difficult to find the peripheral longitudinal tear at the posterior horn through standard anterior portals due to thick meniscal tissue that often obstructs optimal visualization and inspection of this portion of the meniscus [36] (Video 25.3). The posterolateral (PL) compartment can be approached by passing a 30° arthroscope between the anterior cruciate ligament and the lateral femoral condyle (Fig. 25.15). Once a peripheral longitudinal tear of the lateral meniscus posterior horn (LMPH) is identified via standard diagnostic arthroscopy, a 70° arthroscope can be used for better visualization (Fig. 25.16). Various anatomic structures in the PL compartment, such as the LMPH, the PL capsule, and the lateral femoral condyle, are examined using a 30° arthroscope inserted at the antero-medial portal and passed through the intercondylar notch.

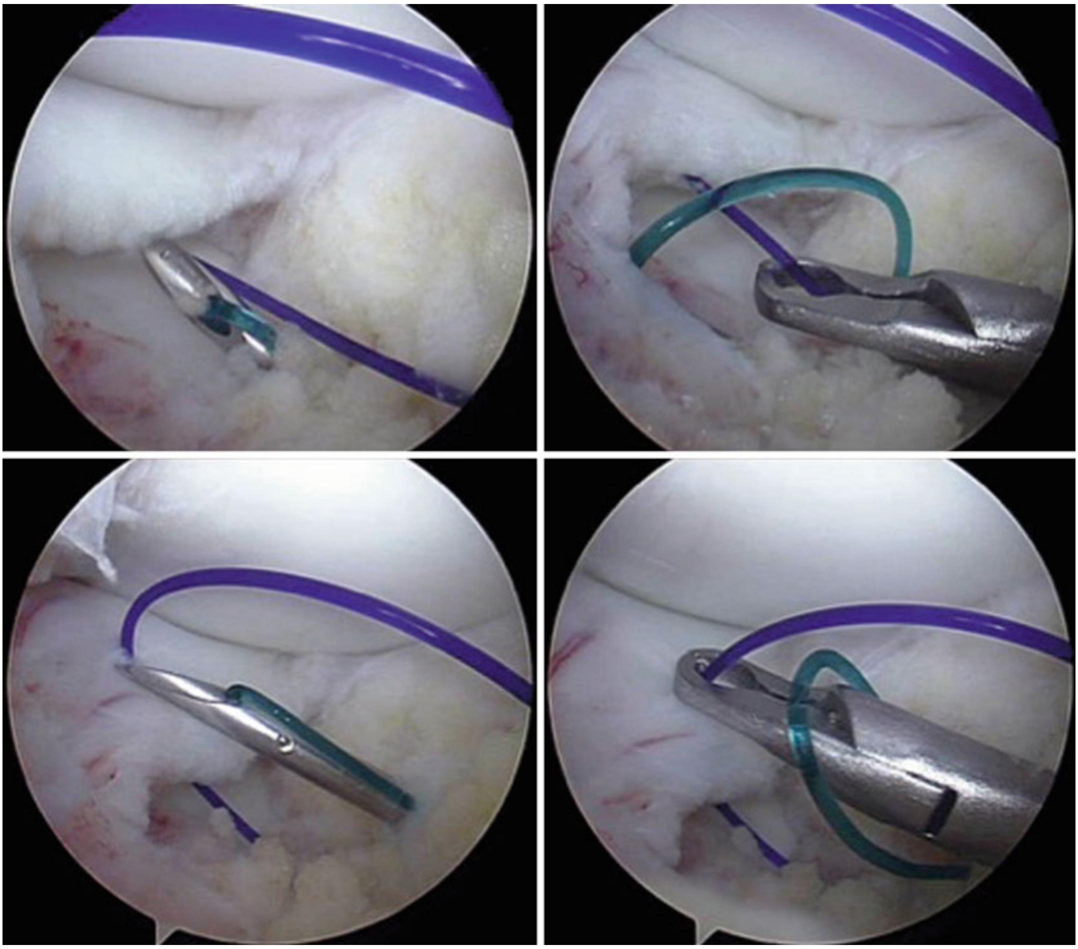


Fig. 25.12 Both suture ends are retrieved through the MAXON loop with a suture retriever

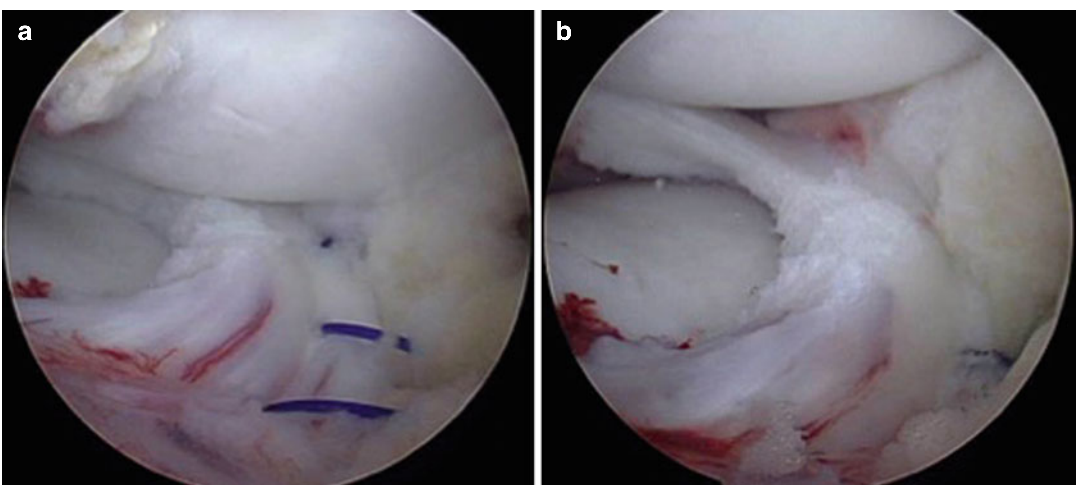


Fig. 25.13 (**a**) The torn meniscus is reduced by pulling both ends of the No. 0 PDS, which now holds the circumferential fibres of the meniscus. (**b**) After tying, anatomic coaptation of the lateral meniscus anterior horn tear is seen with 3 vertical sutures

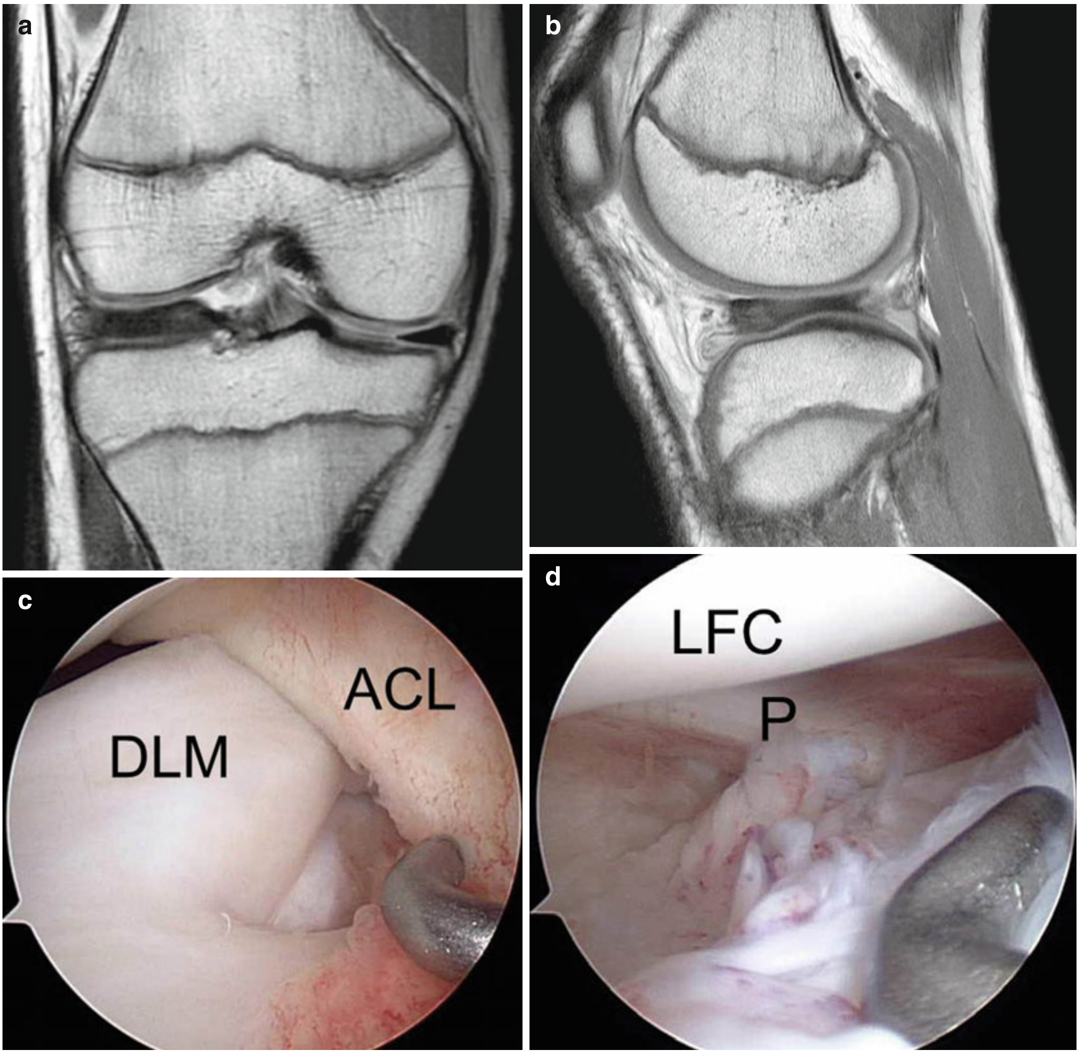


Fig. 25.14 (**a**) Coronal and (**b**) sagittal images of a 7-year-old boy show antero-central shift type of the discoid lateral meniscus in the right knee. (**c**, **d**) Arthroscopic photograph showing a complete type of discoid lateral meniscus with meniscocapsular junction tear at the lateral meniscus posterior horn around popliteal hiatus (*LFC* lateral femoral condyle, *ACL* anterior cruciate ligament, *DLM* discoid lateral meniscus, *P* popliteus tendon)

While keeping the knee flexed at 90° for maximal joint distension and to avoid neurovascular injury, a 16-gauge spinal needle is inserted at the posterolateral (PL) corner using a transillumination technique and a PL portal is established, without the use of a cannula. A probe is inserted to examine the extent, degree, and shape of the peripheral tear at the LMPH. The arthroscope is switched to the PL portal by use of a switching stick to examine the PL compartment and the torn LMPH from a different view.

In more anatomically confined PL compartments, it is often difficult to manipulate the instruments sufficiently. The arthroscopic all-inside suture of LMPH tear through a single PL portal was developed to address such limitations. Our suturing technique allows greater freedom in suture hook manoeuvring by creating a single PL portal without using a cannula. This technique allows excellent visualization of the PL compartment, anatomic coaptation of the torn meniscus, and strong efficient knot tying while avoiding

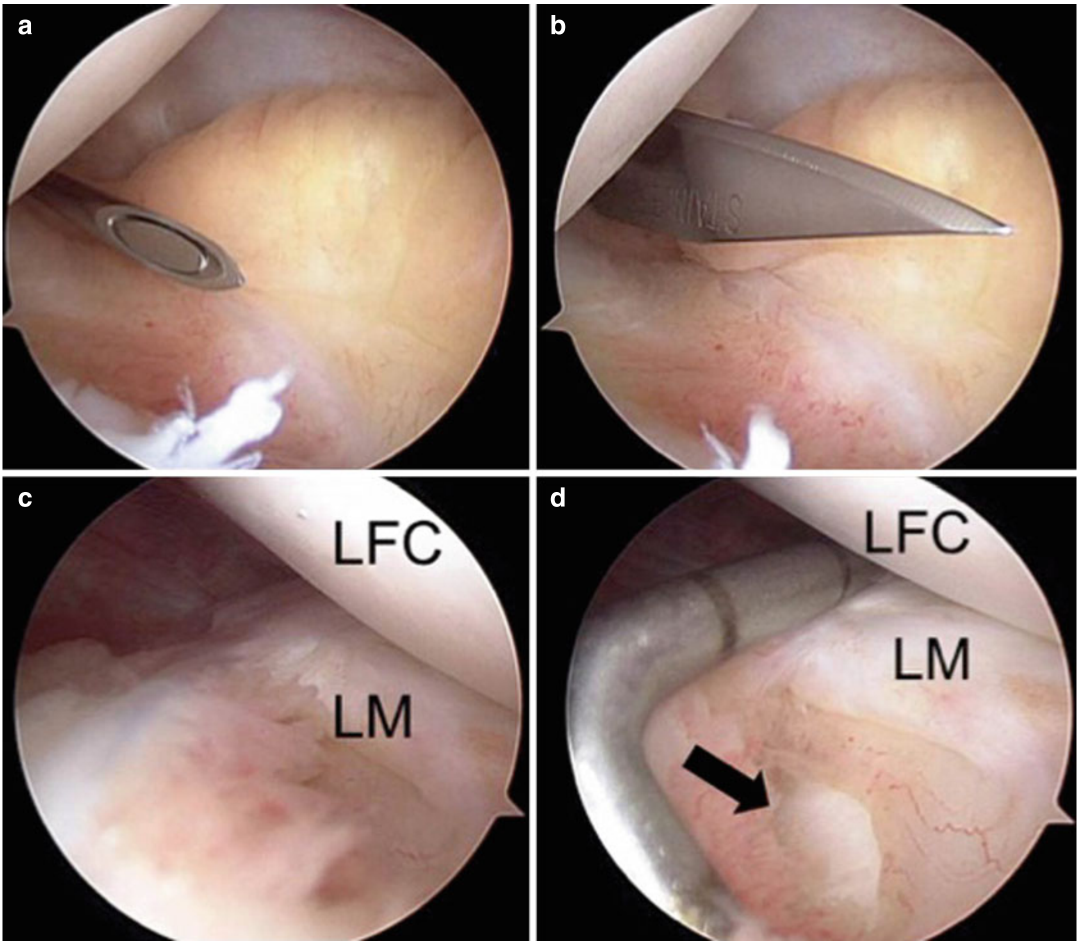


Fig. 25.15 (**a**, **b**) The posterolateral portal is created under direct arthroscopic visualization of 30° arthroscope inserted from antero-medial portal. (**c**, **d**) The 30° arthroscope inserted from posterolateral portal shows the longitudinal tear (*arrow*) of the posterior horn of the lateral meniscus around the meniscocapsular junction (*LFC* lateral femoral condyle, *LM* lateral meniscus)

inadvertent injury to the remnant meniscus and the articular cartilage. We recommend this technique for suture placement in peripheral longitudinal tear of the LMPH.

With a 70° arthroscope inserted from the antero-medial portal and passed through the intercondylar notch to view the PL compartment, a shaver or rasp is introduced through the PL portal for debridement of both tear portions. The 70° arthroscope allows better visualization. Inserting and manipulating instruments without a cannula allow easier instrumentation manoeuvring in the relatively restricted PL compartment. After preparation of the tear site, a 45° angled suture hook loaded with a No. 0 PDS is introduced through the PL portal, and a suture is performed starting from the tear site of the inner tear penetrating the most central portion in an inferior to superior direction (Figs. 25.17, 25.18, and 25.19). During this procedure, care must be taken not to damage the cartilage of the femoral condyle, as the hook is closest to the condyle during this procedure. Both ends of the No. 0 PDS are pulled out with a suture retriever through the PL portal. The superior end of the suture is marked with a straight haemostat, and the inferior suture end is left alone. A suture hook loaded with 2-0 MAXON is inserted through the

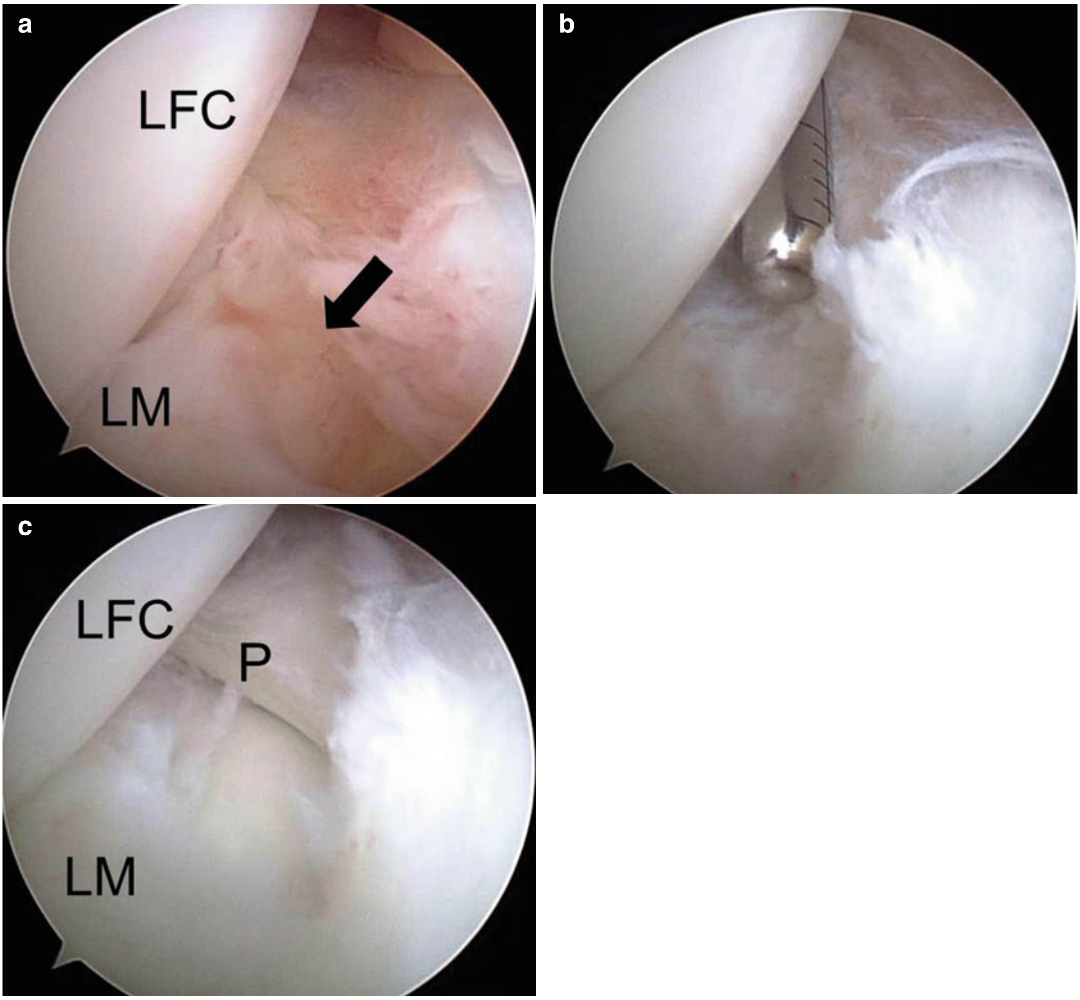


Fig. 25.16 (**a**) The 70° arthroscope inserted from the antero-medial portal to the posterolateral compartment shows the longitudinal tear of posterior horn of lateral meniscus (*arrow*). (**b**, **c**) A shaver or rasp is introduced through the posterolateral portal without a cannula for debridement of both sides of the tear (*LFC* lateral femoral condyle, *LM* lateral meniscus, *P* popliteus tendon)

PL portal and used to pierce the peripheral rim of the meniscus at the capsular side from the superior to the inferior surface in the same manner. After both ends of the 2-0 MAXON are pulled out with a suture retriever through the PL portal, the superior end of the suture is marked with a straight haemostat. The inferior ends of the PDS and MAXON are held together and pulled out simultaneously through the PL portal using a suture retriever without soft tissue interposition between both ends. In doing so, any soft tissue (such as joint capsule or fat) entrapped between the sutures can be extracted. Next, the inferior end of the 2-0 MAXON is tied to the inferior end of PDS and the haemostat holding the superior end of the MAXON wire is then pulled. The PDS is passed through both sides of the meniscal tear and the MAXON wire is changed to a No. 0 PDS from the tibial to the femoral surface. Both ends of the PDS are held together and simultaneously pulled through the PL portal using a suture retriever. The SMC (Samsung Medical Center) knot is made outside and slipped inside the joint using a knot pusher through a previously inserted cannula in the PL portal. Depending on the size of a tear, additional sutures can be performed.

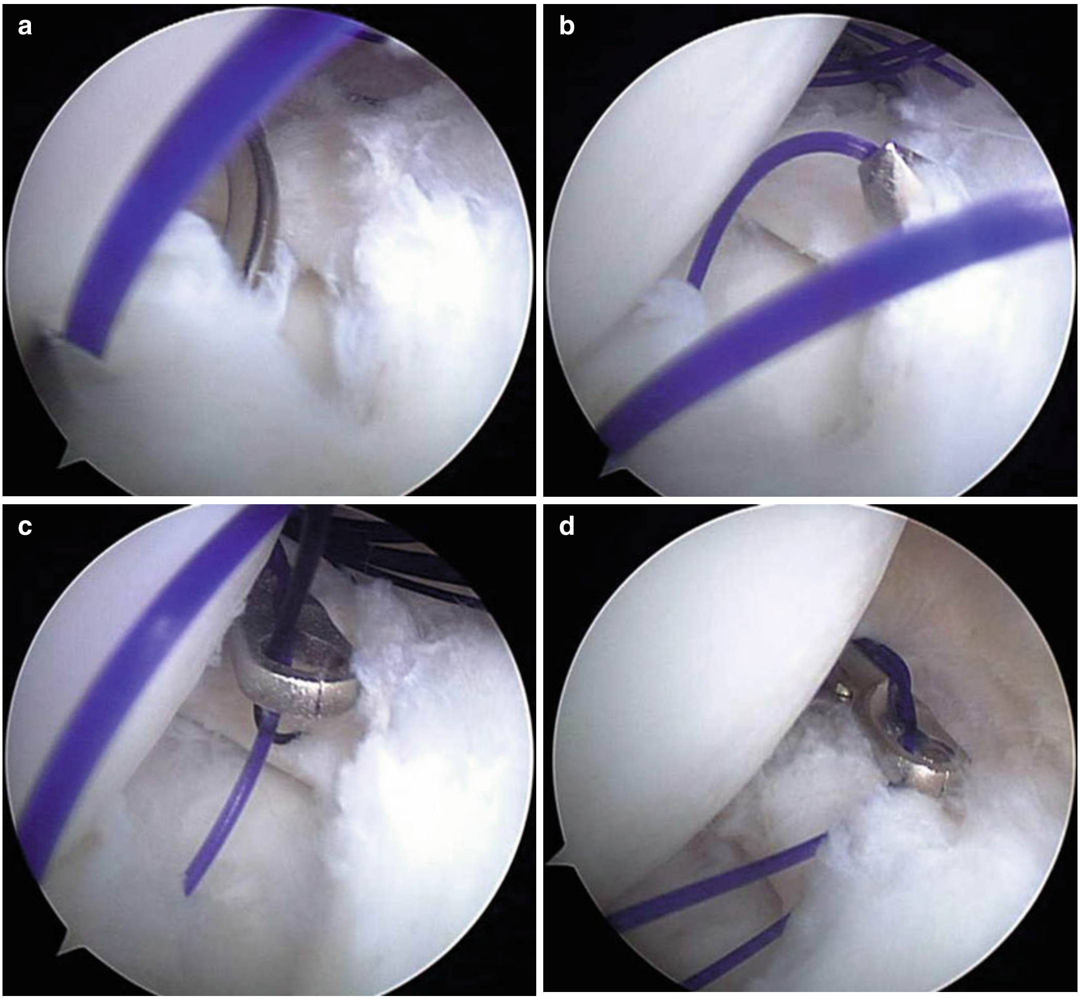


Fig. 25.17 (**a**) The 70° arthroscope shows a suture passage made starting from the inner tear penetrating the most central fragment from inferior to superior. (**b**) After passing the PDS suture, (**c**, **d**) both ends of PDS are held together and retrieved at the same time through the posterolateral portal using a suture retriever

Usually 2-3 sutures are adequate for repair of longitudinal tears in the LMPH.

25.3.6 Postoperative Care

The protocol for postoperative rehabilitation follows guidelines similar to those advocated for rehabilitation after ACL (ligamentous) reconstruction of the knee. The knee is immobilized in a full extension brace for 2 weeks. The affected knee joint is permitted gradual range of motion, which is initiated with a range of motion/limited-motion brace, in which at least 90° of flexion is expected to be achieved during a 4- and 6-week postoperative period. Squatting, or deep flexion, greater than 120°, which places the repair site at risk for re-tear, is restricted for at least 8 weeks following the repair. Patients are also restricted for 6 months from sport activities that include jumping, cutting, or twisting manoeuvres. Crutches are used full time for the first 4 weeks postoperatively to protect the repair site from loading. Patients are allowed to initiate full weight bearing by the 6th postoperative week.

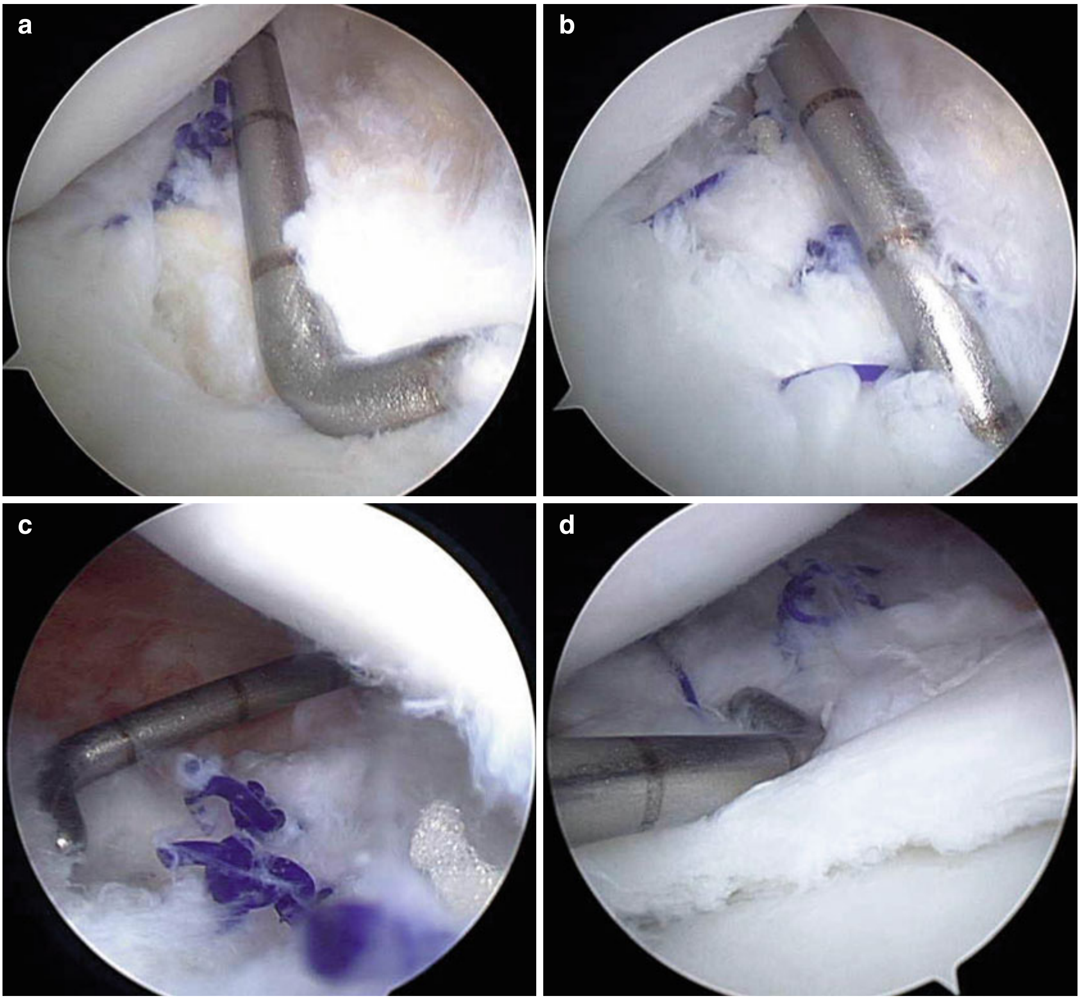


Fig. 25.18 (**a**) The 70° arthroscope shows vertical sutures at the longitudinal tear of the posterior horn of lateral meniscus. (**b**) And then, 2 more stitches are performed with the same technique. (**c**) The 30° arthroscope, inserted from posterolateral portal and (**d**) anterolateral portal, also shows anatomic coaptation of the lateral meniscus posterior horn tear with three vertical sutures

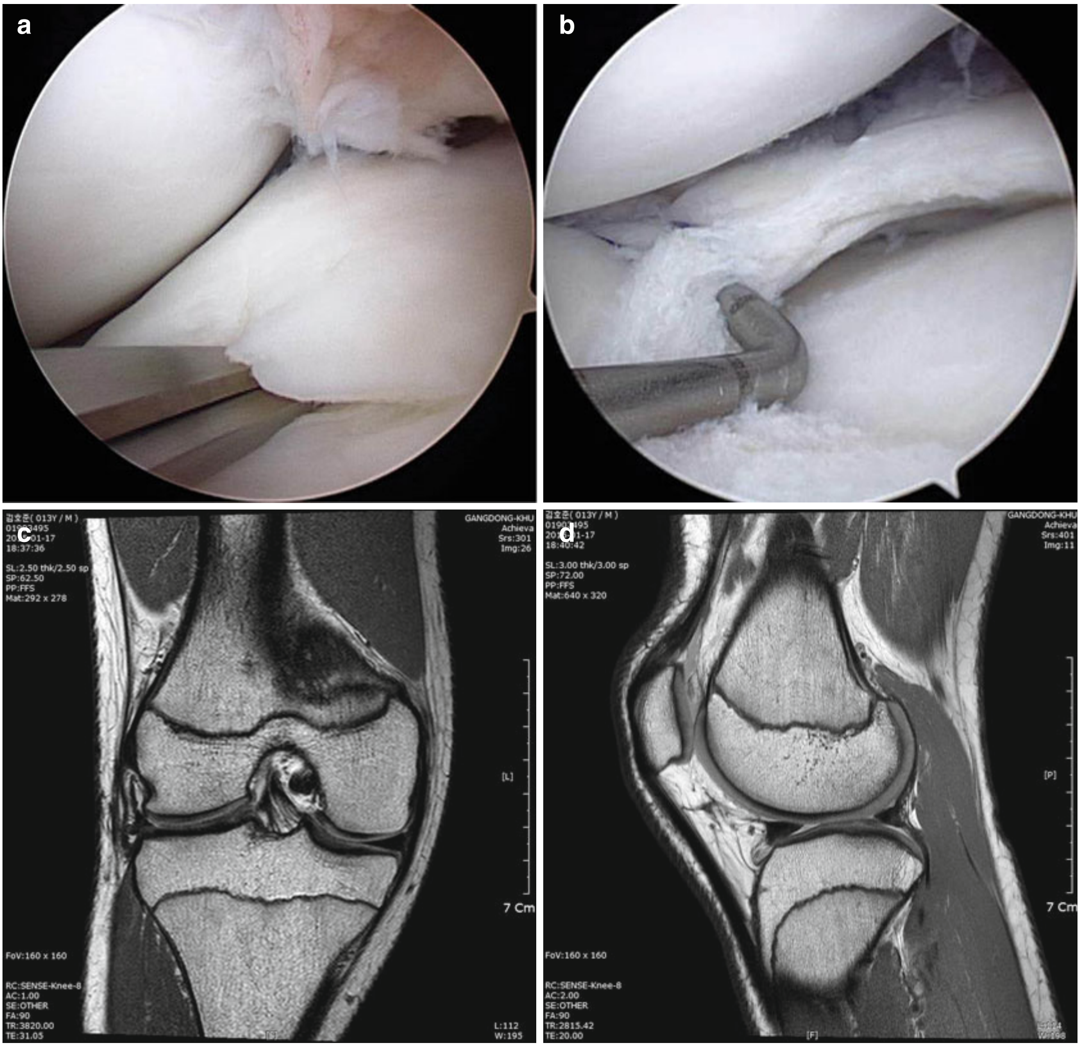


Fig. 25.19 (**a**, **b**) Discoid meniscus is managed with partial central meniscectomy using Iris scissor; a tear between the meniscus and the posterior capsule was closed after tying 3 all-inside sutures. The width of the medial meniscus can be measured with a probe. (**c**, **d**) Coronal and sagittal magnetic resonance imaging shows complete healing of the tear site with a lateral meniscus of normal shape at 6 months follow-up

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Repair in Children

26

Loïc Geffroy, Camille Thévenin-Lemoine, Jacques Menetrey, and Franck Accadbled

Contents

26.1 Introduction

Traumatic meniscal tears become more and more frequent in children and adolescents, in relation with an intense participation from an early age in pivoting sports [1, 2] but also to a better diagnosis, mostly due to the widespread use of MRI for knee disorders. Meniscal tears may occur on ACL-deficient knees but also on stable knees [3]. Discoid meniscus tears will not be discussed here as they are dealt with in a different section.

The concept of meniscal sparing prevails in this age group, even more than in adults [4–6]. The deleterious effect of total and subtotal

Electronic supplementary material The online version of this chapter (doi:10.1007/978-3-662-49188-1_26) contains supplementary material, which is available to authorized users.

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_26

meniscectomies has been clearly demonstrated, leading to functional impairment and midterm knee osteoarthritis [6]. In presence of a meniscal tear, repair should always be favored, partial meniscectomy should be avoided, whereas total meniscectomy is part of history now.

26.2 Diagnosis

Most meniscal tears are the result of sports-related twisting injuries of the knee (soccer, ski, basketball, rugby, etc.) [7]. Symptoms include pain and/or catching sensation in 90 % of cases, and, to a lesser extent, swelling and/or giving way [8]. Locking in a flexed position usually occurs in case of a bucket-handle tear, often in an ACL-deficient knee. Symptoms can be very mild or even absent in children, especially in those patients with chronic anterior instability. When planning an ACL reconstruction, we recommend performing systematically an MRI within 3 months before the procedure to check for newly appeared meniscal lesions. Early reconstruction of an ACL-deficient knee prevents secondary medial meniscal tears [9].

Classic clinical tests such as Apley's or MacMurray's are relatively specific but not really sensitive in children [10]. Flexion deformity of a meniscal origin may only generate a loss of physiological hyperextension. It is therefore advisable to evaluate both legs out of the table to unmask this deformity, while examining the patient lying prone.

MRI is now the gold standard even though it has a lower sensitivity than in adults. Meniscal blood supply can be responsible for false positives with horizontal hypersignals, especially in the younger individuals [10, 11]. A linear meniscal hypersignal not reaching the articular surface suggests a false positive [12]. Thus, only grade III hypersignals according to the Crues classification should be considered as genuine meniscal tears [13]. CT arthrogram is an invasive and radiating procedure which is only indicated in case of previously repaired menisci.

26.3 Indications for Repair

26.3.1 Lesions Types

They are the same as in the adult population:

- Vertical, sometimes progressing to bucket-handle tears
- Radial
- Horizontal, often associated with a peripheral cyst
- Avulsion of the anterior or posterior horn
- Complex, combining at least two lesions in different planes

Vertical tears are the most common, often in ACL-deficient knees [14]. Chronic anterior instability generates secondary medial meniscus tears, that are often complex, severe, and therefore difficult to repair when managed late [15, 16]. Peripheral lesions to the posterior horn of the medial meniscus, so-called ramp lesions [17], can be overlooked by traditional anterior portal views. It has been recommended recently to perform systematically an intercondylar view and an accessory posteromedial portal to check this particular type of lesion during ACL reconstruction procedure [18].

Radial and horizontal tears seem to have a lower potential for healing than vertical tears [7, 19, 20].

26.3.2 Rationale for Repair

26.3.2.1 Blood Supply

Vascularization of the meniscus in an adult individual is limited to its peripheral third (the so called red-red zone) [21], thus explaining the low potential for healing of more central tears [22]. Blood supply to the meniscus indeed decreases with aging. Vessels enter the menisci from the joint capsule accompanied by loose connective tissue. At birth, nearly the whole meniscus is vascularized. In the second year of life, an avascular area develops inside the inner circumference. In the second decade, vascularization occurs only in the lateral third. After 50 years of age, only the lateral quarter of the meniscal base is vascularized [23, 24]. This supports indications for repair extended to the inner third in children, especially in the younger individuals [20, 25, 26].

26.3.2.2 Age of the Lesion

Diagnosis of meniscal tears is often delayed in children, up to 12 months [27]. This does not preclude healing after repair and good functional results [14, 26–28]. Several studies showed that the variable of time to surgery did not appear to have a significant effect on healing [26, 29, 30], whereas more recently, Terzidis et al. reported better results after repair of recent lesions [7]. We consider that an old meniscal tear is still suitable for repair if it does not show major structural damage on arthroscopic inspection and probing [31]. It is preferable to proceed with repair and risk the need for a revision surgery, as some meniscal tissue will certainly be spared eventually, thanks to at least partial healing.

26.4 Principles of Repair

The procedure is always performed under general anesthesia. Patient's positioning depends on the surgeons' preference. We like having both legs hanging with a knee clamp placed around the tourniquet. Meniscal repair is performed arthroscopically, using a standard 4.5 mm diameter, 30° arthroscope [32]. Valgus/varus stress for joint space opening should be cautious, to avoid any physeal injury around the knee.

Regardless of the type of meniscal tear, repair always starts with refreshing the edges using an arthroscopic rasp or a shaver (Video 26.1). In case of an ACL-deficient knee, ligament reconstruction needs to be performed timely, during the same procedure at best, because meniscal repair on an unstable knee is bound to fail.

Repair in children uses the same devices and surgical techniques as in adults. Decision to use one technique or another is based mostly upon the location of the lesion. Nonabsorbable or long-lasting absorbable sutures are recommended as well as vertical sutures over horizontal or oblique constructs.

26.4.1 Inside-Out Sutures

This technique addresses posterior and middle segment tears. A double-barreled guide is introduced via the arthroscopic portal, and then two-eyed needles are pushed through the meniscus. The suture is tied onto the posteromedial or posterolateral capsule, requiring an additional incision (Fig. 26.1). Great care is taken with the posterolateral retroligamentous approach to spare the fibular nerve (Fig. 26.2).

26.4.2 Outside-In Sutures

This technique addresses anterior and middle segment tears. Two needles are positioned through the skin and into the joint under arthroscopic control. The suture is introduced through one needle and then retrieved with a forceps and passed into a loop or "shuttle" introduced through the second needle. Dedicated devices are useful (i.e., Meniscus Mender, Smith & Nephew). The suture is then tied outside onto the capsule (Video 26.2). As mentioned above, peripheral tears to the posterior horn of the medial meniscus ("ramp" lesions) are best repaired via an accessory posteromedial portal with an intercondylar view control (Fig. 26.3). Repair here requires suture passers initially designed for rotator cuff repair.

26.4.3 All-Inside Sutures

This technique addresses posterior and middle segment tears. Single-use devices including pre-tied knots are necessary. The most popular are Fast-Fix 360 (Smith & Nephew) and Omnispan (Mitek). Fast-Fix 360 is fitted with an adjustable plastic sheath to adapt the depth to the location of the tear and also to the age of the patient (Videos 26.3 and 26.4).

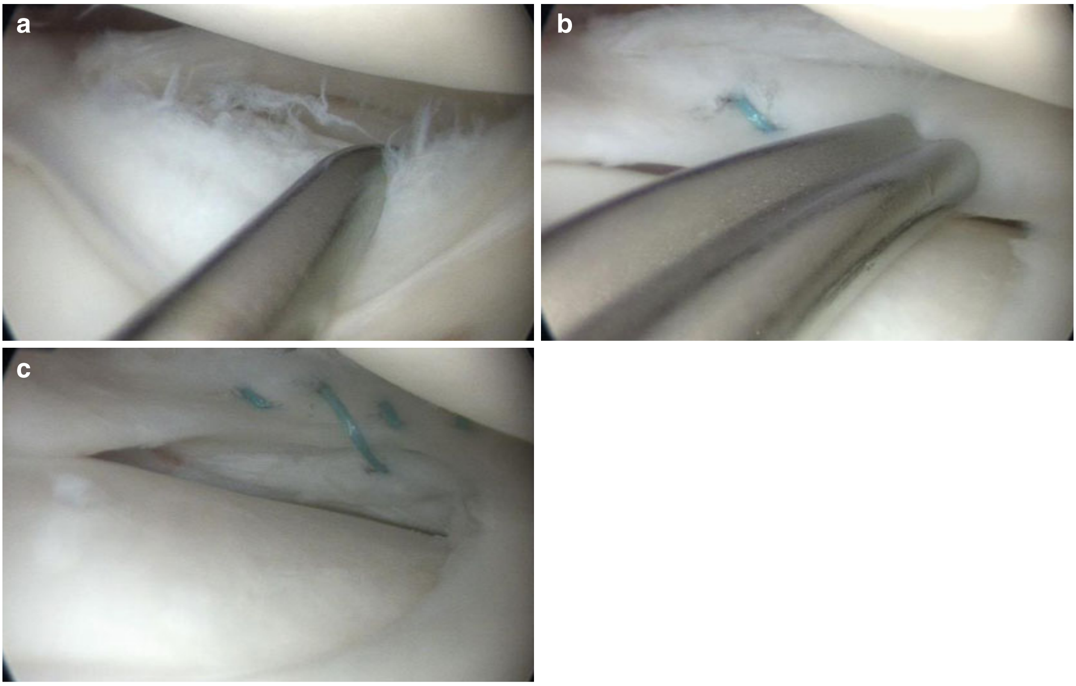

Fig. 26.1 Inside-out repair. (**a**) Vertical tear to the posterior segment of the lateral meniscus. (**b**) Inside-out suture with double-barreled aimer. (**c**) Final result

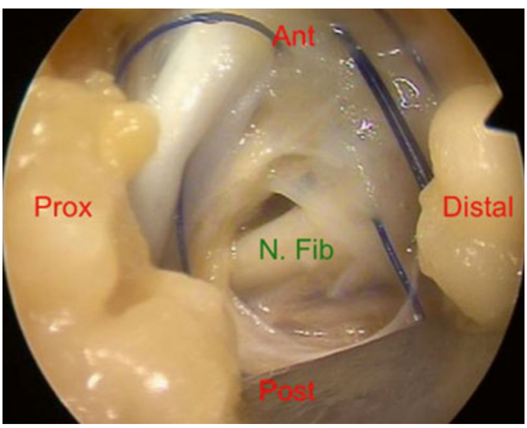

Fig. 26.2 Retroligamentous approach showing outside-in suture transfixing the fibular nerve, fortunately with no clinical consequence

26.5 Repair Technique According to the Type of Lesion

26.5.1 Vertical Tears

Most of the vertical meniscal tears involve the posterior segment. They may progress anteriorly to involve the middle and then the anterior segment, creating a bucket-handle tear, eventually dislocated into the notch. This type of tear is best managed with inside-out or all-inside repair or even a combination of the two. In case of a chronically dislocated bucket handle with a plastic deformity, inside-out sutures are useful to pull the meniscus posteriorly. Alternatively, reduction can be maintained by the probe introduced via a Gillquist portal. Short, stable tears above 8 mm long to the posterior segment of either meniscus encountered during ACL reconstruction are best managed with an all-inside suture.

26.5.2 Horizontal Tears and Meniscal Cysts

Horizontal tears are rather rare in non-discoid menisci [33, 34]. They are often connected to a peripheral cyst and mostly involve the middle segment of the lateral meniscus (Fig. 26.4). The lesion is first abraded and then sutured using the appropriate technique, usually outside-in stitches. When a cyst has been identified on the MRI, it can be either debrided with a shaver introduced from the joint through the meniscal

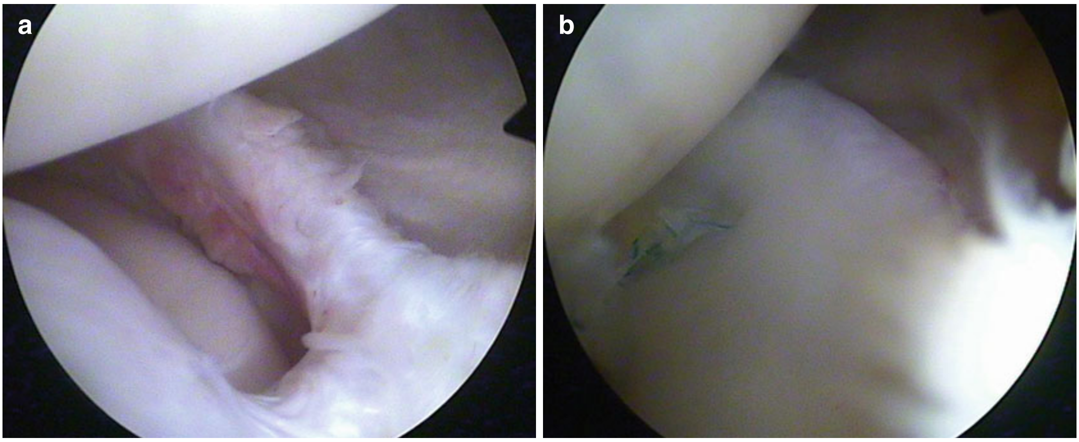

Fig. 26.3 All-inside repair of a posterior tear of the medial meniscus. (**a**) Posteromedial portal view of the tear. (**b**) Final view of repair

lesion or excised using a mini open incision, especially when more voluminous. In that latter situation, the incision is made over the bulk of the probe which is pushed through the lesion, and then the meniscal tear is repaired by vertical stitches using a regular needle holder from the outside. The capsule should be hermetically closed over the meniscal rim to prevent any recurrences of the cyst.

26.5.3 Meniscal Horn Avulsion

This particular type is very rare in children [35]. It can be a bony avulsion from the tibia. Treatment consists of placing a pull-out suture using an ACL reconstruction tibia aimer.

26.5.4 Radial Tears

Radial tears are rarely seen in children and are usually associated with degenerate meniscus. They are managed with partial trimming taking away the lesion. Deeper tears are best managed with a horizontal suture closing the cleft or an "X"-shape suture.

26.5.5 Meniscal Substitution (Actifit®)

Meniscal substitution is an option in adolescents with a history of subtotal meniscectomy presenting with a painful knee and no or mild signs of osteoarthritis. Only patients with a remaining peripheral meniscal stump are eligible for meniscal substitution. Most of the cases involve the lateral compartment after a meniscectomy for discoid. Although encouraging results were reported in young adults, there is yet no literature in children and adolescents [36] (Video 26.5).

26.6 Postoperative Course

There is no clear consensus concerning weight bearing, mobilization, or time to resume sports activities. An extension brace is usually applied for 3–4 weeks although a long leg cast is preferable below 10 years of age. Weight bearing is encouraged as tolerated. Crouching is avoided for the first 4 months. Sports activities are resumed gradually after 4 months, starting with nonpivoting activities.

26.7 Results

Recent studies demonstrated the satisfactory clinical results of meniscal repair in children [14, 26, 31]. Van der Have et al. in 2011 evaluated 49 repairs using the inside-out technique with a vertical mattress suture and 31 concomitant with an ACL reconstruction [26]. Nine repairs involved the inner meniscal third. They deplored only 2

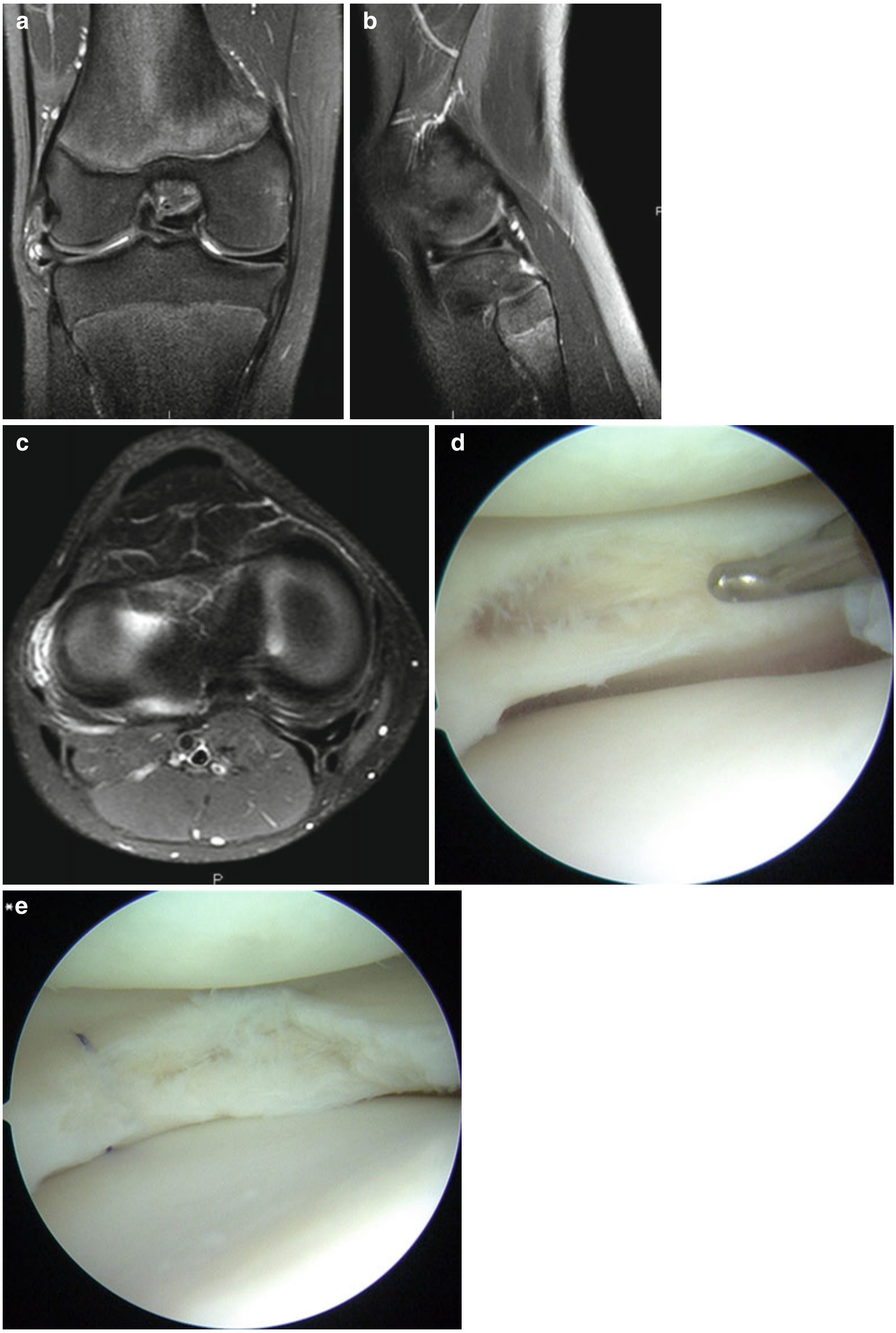

Fig. 26.4 Horizontal tear to the middle and posterior segment of the lateral meniscus, associated with a cyst, in a 14-year-old boy. (**a**) MRI, coronal view. (**b**) MRI, sagittal view. (**c**) MRI, axial view. (**d**) Arthroscopic view prior to repair. (**e**) Arthroscopic view after outside-in vertical suture

revisions at a mean 27-month follow-up. In 2012, Kraus et al. reported on 25 repairs, mostly all inside, of which 11 were concomitant to an ACL reconstruction [14]. Five repairs were located in the inner third. Four patients required a revision arthroscopy at a mean 27-month follow-up.

Absence of symptoms is not equivalent to meniscal healing, which can only be confirmed arthroscopically or with a CT arthroscan which often demonstrates incomplete healing, although sufficient to keep the meniscus stable, asymptomatic [20, 37], and protective for the articular cartilage [38].

Conclusion

Meniscal sparing should be a priority in all situations in children. Repair requires the same techniques as in adults and should be attempted whenever the meniscal tissue enables it. Patients and families must be informed of the risk of failure and potential need for revision arthroscopy.

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Rehabilitation and Return to Sport

27

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Contents

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27.1 Introduction

Meniscal tears and related problems are a common issue in an active population. Lately there has been an increasing interest in the re-establishment of the correct joint homeostasis and return to activity after meniscal surgery.

Meniscus, ligaments and articular cartilage structures are commonly involved in sports knee injuries. Meniscal surgery approach is extremely varied and frequently associated with other procedures, such as anterior cruciate ligament reconstruction (ACLR). It is common knowledge that a holistic approach to the joint and the patient should be applied in sports medicine and orthopaedic rehabilitation.

The final goal of each rehabilitation path should be to restore the function while minimizing the risk of re-injury. This challenging goal has to be pursued through a real team approach. Surgery and functional recovery are part of the same "injury to return to sport (RTS) process".

The rehabilitation physician has to be aware of the type of surgery and lesion pattern, while the surgeon should be conscious of the power of a complete functional recovery programme.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_27

Long-term results have to be addressed too, as it is well accepted that even partial meniscectomy can lead to osteoarthritis in the affected compartment [3].

In this chapter we will present an overview of the current concepts in meniscus rehabilitation and RTS, suggesting a strategy to approach the patient with meniscal tear.

27.2 Scientific Background (The State of Art in Meniscus Rehabilitation and Return to Sport)

Emerging evidence regarding meniscus rehabilitation has recently strengthened the standard approach after meniscal procedures.

It is generally accepted that different meniscal tears and surgical procedures may need a different rehabilitation strategy. The greater distinction we have to do in terms of surgery is between *partial meniscectomy* and *salvage procedures*: meniscal repair, meniscal allograft transplantation (MAT) and meniscal scaffold/implant. Associated surgeries, such as ACLR, osteotomies and cartilage procedures, may drive the rehabilitation programme (Fig. 27.1). Lesion patterns (medial/lateral, acute/chronic, size) and patient features (age, expectations, activity level and motivations) have also to be considered.

The main aspects that have been studied in literature regard knee motion, weight-bearing (WB) and return to activity.

27.2.1 Progressive Knee Motion

Kelln et al. [5] demonstrated that the use of a cycle ergometer and early active range of motion (ROM) were beneficial to patients after partial knee meniscectomy. The intervention group exhibited better gait pattern than the control group.

Barber [2] and Shelbourne et al. [10] found no significant differences in the healing rate and managing of symptoms when applying or not a brace after meniscal repair. Shelbourne also found that the accelerated rehabilitation group (including no brace) showed shorter time to restore ROM, higher quadriceps strength and more rapid return to activity.

Other authors recommend the use of knee bracing in complex meniscal repairs and transplants [4].

So, it is recommended to introduce early progressive knee motion following meniscal surgery to optimize functional outcome [7].

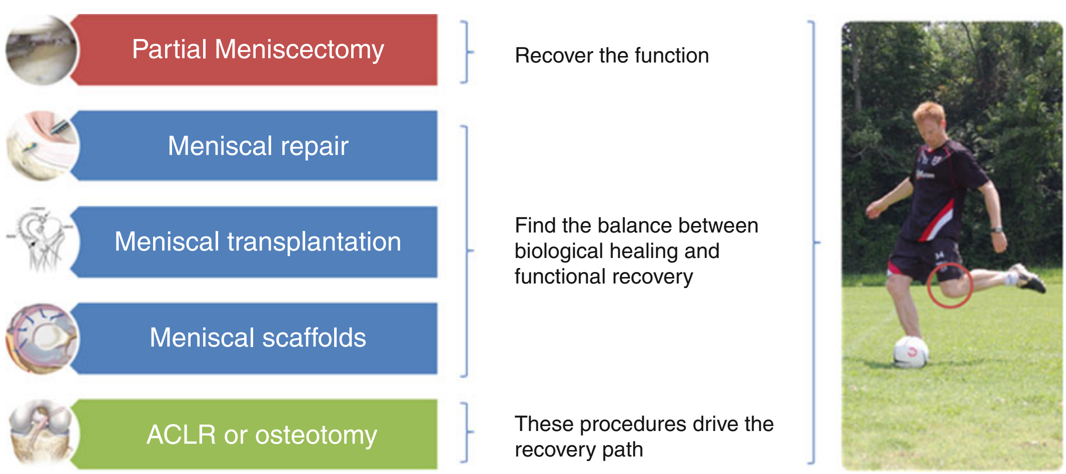

Fig. 27.1 The universe of meniscus surgical procedures and their recommendation in terms of rehabilitation and return to sport. The key concept is considering the whole patient and not just the lesion site

27.2.2 Progressive Weight-Bearing

Barber [2] and Shelbourne et al. [10] in the above mentioned papers stated that after meniscal repair, immediate weight-bearing as tolerated was associated to a more rapid return to full activity [10] and no significant difference in the healing rates of meniscal repair if compared to a standard rehabilitation protocol [2].

Other authors [4] recommend partial WB for the first 2 weeks and progress to full WB in 3–4 weeks after meniscal repair.

Regarding meniscectomy it is well known that lateral procedures need a more cautious approach compared to medial ones.

There is no agreement about WB after meniscal repair procedures even if it seems logical to give progressive stimuli while protecting the sutures.

27.2.3 Return to Activity

According to the current clinical guidelines [7], three authors stated that accelerated rehabilitation after meniscal repair is associated to faster recovery with no deleterious effects.

The time to RTS varies a lot between the different meniscal procedures and should be based on meeting objective criteria before RTS.

27.3 Rehabilitation Strategies

The main goal of rehabilitation following meniscal surgery is the functional recovery and the return to sport minimizing the risk of joint surface deterioration.

Rehabilitation should begin early, be progressive and had a multidisciplinary approach.

We strongly believe that organizational and clinical principles are the basis to optimize the recovery process.

27.3.1 Organizational Principles

The *multidisciplinary approach* is very important in the recovery process. During rehabilitation the patient is part of a team including the orthopaedic surgeon, the sports medicine physician and the physiotherapist. The orthopaedic surgeon, being aware of the specific condition of the tissues involved in the surgery, decides on precaution regarding the use of brace, WB and ROM. The sports medicine physician elaborates the rehabilitation protocol based on orthopaedic prescription, treatment guidelines and his/her own experience. The physiotherapist is the one who daily interacts with the patient.

A *close communication* between surgical and rehabilitation teams is essential for successful recovery and return to sport. Communication is crucial to explain the patient the goals of rehabilitation, to monitor his/her progression and to be aware of complications.

The *proper facility* consists of rehabilitation gyms, rehabilitation pools and sport fields (Fig. 27.2).

The gym is considered the main rehabilitation area with an average of 60 % of the total number of sessions. During each session manual and physical therapies are carried out, as well as performing stage-specific exercises. After the suture removal, the patient can begin

Fig. 27.2 The use of the gym, pool and field at well-defined moments of rehabilitation is critical for the achievement of the best functional recovery

rehabilitation in the pool which will cover about 20 % of the total sessions. The aquatic environment offers many advantages, such as offering the opportunity of working in the absence of gravity, controlling WB progression, facilitating joint mobilization and simulating specific complex patterns which are then transferred to the original sport environment. The sport field is the main facility of the last phase allowing patients to return to sport.

27.3.2 Clinical Principles

The rehabilitation protocol should be *individualized*, *progressive* and *supervised*:

- Individualized, according to the characteristics of the patient (age, sport level, personal expectations and motivation), the type of lesion (location and size) and the type of surgery (surgical technique and associated surgery).
- Progressive, according to the orthopaedic surgeon's precautions and to the clinical and functional responses of the patient.
- Supervised and editable depending on any complications ("we have to slow down") and positive feedback ("we can accelerate"). Periodic checkups and functional assessments with the orthopaedic surgeon and the sports medicine doctor are scheduled.

Regarding the method we adopt a *criteria-based rehabilitation strategy* rather than following fixed time lines. This approach represents the current concept to ensure a proper biological healing response and guarantee appropriate progression in order to optimize patients' outcome [1].

Our protocol is divided into four functional steps, consisting of treatment goals and specific interventions. In order to proceed from one step to another, patients should pass established clinical and functional criteria (green traffic lights). If one of the criteria is not satisfied, it is recommended to remain in one step for an extended period of time before proceeding to the next level.

27.4 First Step: Walking Without Crutches

27.4.1 Criteria to Be Achieved

- Surgeon's approval
- Absence/minimal pain and swelling
- Full knee extension
- Recovery of the correct gait cycle

27.4.2 Specific Interventions

- Physical modalities
- Posterior muscle chain stretching
- Patella mobilization (Fig. 27.3)

Fig. 27.3 Patella mobilization is one of the first interventions we usually apply to prevent arthrofibrosis

- Active mobilization of the ankle
- Isometric exercises (quadriceps, hamstrings and gluteus)
- Co-contraction of the quadriceps
- Normal gait pattern exercises with feedback
- Pendulum
- Cryotherapy

27.5 Second Step: When Running on a Treadmill

27.5.1 Criteria to Be Achieved

- No pain walking
- Knee flexion more than 120°
- Walk on a treadmill for at least 10 min without pain or swelling
- Adequate muscle tone of trunk, thigh and limb

27.5.2 Specific Interventions

- Aerobic reconditioning
- Cycling on a stationary bike
- Elliptical machine
- Aquatic training (Fig. 27.4)
- Isotonic open-chain strengthening exercises
- Proprioception exercises
- Core stability
- Trampoline and water running

27.6 Third Step: When Starting On-Field Rehabilitation

27.6.1 Criteria to Be Achieved

- Less than a 20 % deficit between the two quadriceps and hamstrings at the isokinetic test
- Run on a treadmill for at least 10 min at 8 km/h without pain or swelling

27.6.2 Specific Interventions

- Closed (CKC) and open kinetic chain (OKC) exercises (isotonic and isokinetic)
- Advanced proprioceptive exercises (Fig. 27.5)
- Running on treadmill
- Plyometrics
- Neuromuscular training

27.7 Fourth Step: When Return to the Team

27.7.1 Criteria to Be Achieved

- Surgeon's approval
- Complete ROM

Fig. 27.4 The aquatic environment offers many advantages, such as offering the opportunity of working in the absence of gravity and controlling WB progression

Fig. 27.5 Advance proprioception enhancing neuromuscular control

Fig. 27.6 Performing prevention programmes and education in maintaining them is very important in terms of reducing the re-injury rate

- No strength deficit between quadriceps and hamstrings at the isokinetic test
- Complete recovery of match fitness (aerobic and anaerobic threshold test)
- Complete on-field rehabilitation

27.7.2 Specific Interventions

- Functional and sports-specific movements
- Aerobic and anaerobic reconditioning
- Advanced OKC and CKC exercises
- Education in prevention programmes (Fig. 27.6)

27.8 Considerations and Precautions According to the Type of Surgery

Medial Meniscectomy We can apply an accelerated rehabilitation protocol, no restrictions on WB and ROM recovery.

Lateral Meniscectomy We should pay attention to knee effusion response and more cautious on load progression. Compared to medial meniscectomy, longer time to obtain the pre-injury level has been demonstrated [9].

Meniscal Repair Restrict ROM for strengthening exercises depending on suture location. For example, for medial meniscus posterior horn suture, a range between 0° and 90° is initially recommended [11].

Meniscal Allograft Transplantation Cautious on WB, flexion recovery and CKC exercises. MAT is associated with longer time to recovery and return to sport due to frequent joint co-morbidities. Despite the longer recovery time, MAT would not preclude professional football players returning to sport at the maximum level [8].

Conclusion

As previously stated, the different surgical meniscus treatments require a different rehabilitation progression, and the timing of recovery is very different. We know that a healed meniscus is only the beginning of successful return to activity [6], and the application of a criteria-based rehabilitation protocol must be emphasized to ensure optimal return to performance [1].

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28 Partial Meniscectomy and Meniscal Suture: Graft Rehabilitation Guidelines

Eric Margalet, Robert Pascual, and Jordi Puig

Contents

Meniscal injuries represent a high percentage of knee injuries. For meniscal lesions, different types of surgical treatments are available: partial meniscectomy, meniscal suture or graft [1–3]. Rehabilitation of these injuries can be grouped into two types: partial meniscectomy and meniscal suture with meniscal graft. The guideline is divided into several sections: objectives, precautions/contraindications, treatment with the physiotherapist, and home treatment. The phases described hereafter are theoretical and moving to the next phase depends on achieving the objectives rather than on temporal factors [4–10].

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_28

28.1 Guidelines for Partial Meniscectomy

GOALS	POST-OPERATIVE WEEKS			
	PHASE 1		*PHASE 2*	
	1-2	3-4	5-6	7-8
Range of motion				
0-90°	■			
0-120°		■		
>120°			■	■
Full extension	■	■	■	■
Weight-bearing				
25% body weight	■			
50% body weight		■		
Total weight-bearing			■	■
Physiotherapy				
Patella mobilization	■	■		
EMS	■	■	■	■
Anti-inflammatory treatment	■	■	■	■
Pain treatment	■	■	■	■
Discharge massage		■	■	■
Proprioception training	■	■	■	■
Stretching		■	■	■
Strengthening				
Quadriceps isometrics	■	■		
Hamstrings isometrics	■	■		
Gluteus isometrics	■	■		
Towel exercises (flex-ext)	■	■		
Passive exercises	■	■		
Squats		■	■	■
Eliptical machines			■	■
Leg press			■	■
Resistance exercises			■	■
Aquatic therapy		■	■	■
Cycling		■	■	■
Cryotherapy	■	■	■	■

28.2 Phase 1

28.2.1 1–2 Postoperative Weeks

28.2.1.1 Goals

- Achieve full extension.
- Flexion range of motion (ROM) < 90° (0–90°).
- Control of inflammation and pain.
- Bending work without pain.
- Therapeutic exercises at home.
- Good walking with crutches (partial load).
- Cryotherapy.

28.2.1.2 Precautions/Contraindications

- Avoid prolonged periods of standing and walking.
- No bending force.
- No walking without crutches.

28.2.1.3 Exercise Program

At Home

- Passive exercises (towel) (Fig. 28.1a, b)
- Isometric exercises (quadriceps, hamstring, gluteus) (Figs. 28.2a, b and 28.3a, b)
- Sitting and moving the knee with extension and flexion of 90° without walking (Fig. 28.4a, b)
- Cryotherapy
- Bipedal proprioception

Physiotherapy

- Beginning of the third week of rehabilitation

28.2.2 3–4 Postoperative Weeks

28.2.2.1 Goals

- Achieve full extension.
- Flexion ROM > 90° (0–120°).
- Flexion/extension, passive and active.

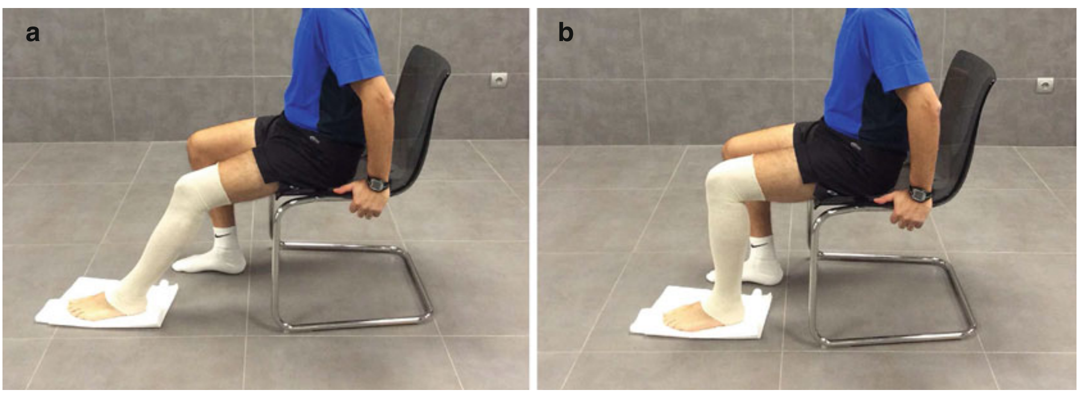

Fig. 28.1 (**a**, **b**) Towel exercise

Fig. 28.2 (**a**, **b**) Isometric quadriceps

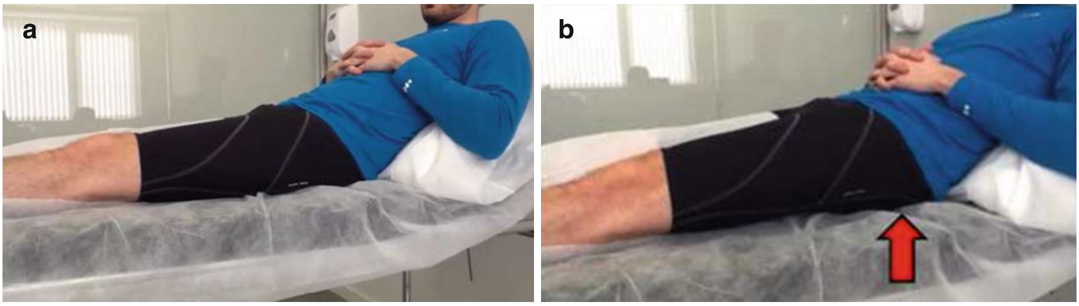

Fig. 28.3 (**a**, **b**) Isometric gluteus

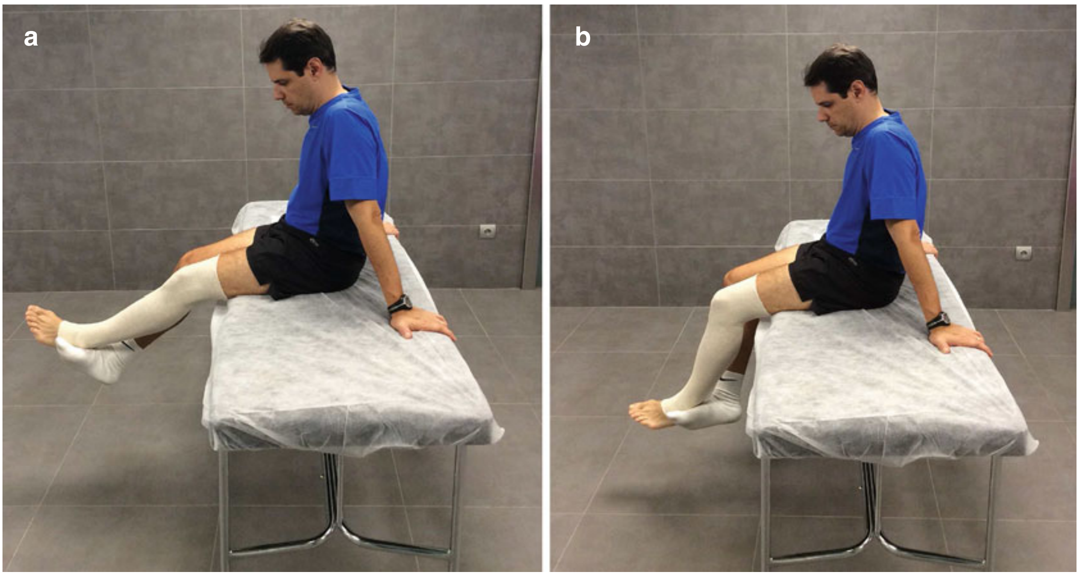

Fig. 28.4 (**a**, **b**) Passive flexion

- Progressive loading with crutches (cease use of crutches at 4 weeks).
- Strengthening anterior and posterior musculature.

28.2.2.2 Precautions/Contraindications

- Control of inflammation and pain.
- Unforced weight-bearing.

28.2.2.3 Exercise Program

At Home

- Passive exercises (towel)
- Isometric exercises (quadriceps, hamstring, gluteus)
- Electromyography (EMG)
- Cycling (max. 20–30′)
- Bilateral proprioception
- Aquatic therapy (walking, flexion–extension) (Figs. 28.5, 28.6, 28.7, and 28.8)
- Stretching
- Cryotherapy

Physiotherapy

- Patella mobilization
- ROM flexion < 120°
- Complete extension
- EMG
- Squats (supervised by physiotherapist)
- Bilateral proprioception
- Cryotherapy
- Stretching

Fig. 28.5 Stretching in balneotherapy

Fig. 28.6 Aquatic therapy (walking, flexion-extension exercises)

- Discharge massage
- Ultrasound therapy/TENS/magnetotherapy

28.3 Phase 2

28.3.1 5–6 Postoperative Weeks

28.3.1.1 Goals

- Get full flexion (ROM > 120°).
- Improve muscle control.
- Reintroduction into daily life.
- Good walking.
- Good elasticity of the muscle groups in the leg.

28.3.1.2 Precautions/Contraindications

- Monitor with daily activities that do not cause pain or swelling.
- Monitor the exercise program.
- Avoid running or impact sports.

Fig. 28.7 Aquatic therapy (walking, flexion-extension exercises)

Fig. 28.8 Aquatic therapy (walking, flexion-extension exercises)

28.3.1.3 Exercise Program

At Home

- EMG
- Leg press
- Elliptical machine
- Squats
- Cycling
- Resistance exercise
- Bilateral/unilateral proprioception
- Aquatic therapy (walking, flexion–extension, swimming)

- Stretching
- Cryotherapy

Physiotherapy
- Achieve complete flexion (ROM > 120°).
- EMG
- Bilateral/unilateral proprioception
- Cryotherapy
- Stretching
- Discharge massage

28.3.2 7–8 Postoperative Weeks

28.3.2.1 Goals
- The patient can run without pain.
- Follow leg program in gym for maintenance and progression.
- Improve muscle control.
- Reintroduction into sports.
- Perform activities of daily living without pain.
- Good elasticity of the muscle groups in the leg.

28.3.2.2 Precautions/Contraindications
- Avoid pain with sports activity.
- Avoid pain with activities of daily living.

28.3.2.3 Exercise Program

At Home
- EMG
- Leg press
- Elliptical machine
- Resistance exercise
- Squats
- Cycling
- Bilateral/unilateral proprioception
- Aquatic therapy (walking, flexion–extension)
- Stretching
- Cryotherapy

Physiotherapy
- EMG
- Bilateral/unilateral proprioception
- Cryotherapy
- Stretching
- Discharge massage

28.4 Guideline for Meniscal Suture/Meniscal Graft

GOALS	POST-OPERATIVE WEEKS			
	PHASE 1		*PHASE 2*	
	0-4	**5-6**	**7-8**	**8-12**
Range of motion				
0-90°	■			
0-120°		■		
>120°			■	■
Full extension	■	■	■	■
Weight-bearing				
0% body weight	■			
25% body weight		■		
50% body weight		■		
Total weight-bearing			■	■
Physiotherapy				
Patella mobilization	■	■		
EMS	■	■	■	■
Anti-inflammatory treatment		■	■	■
Pain treatment	■	■	■	■
Discharge massage			■	■
Proprioception training	■	■	■	■
Stretching			■	■
Strengthening				
Quadriceps isometrics	■	■		
Hamstrings isometrics		■		
Gluteus isometrics	■	■		
Towel exercises (flex-ext)		■		
Passive exercises	■	■		
Squats			■	■
Eliptical machines			■	■
Leg press			■	■
Resistance exercises				■
Aquatic therapy		■	■	■
Cycling			■	■
Cryotherapy	■	■	■	■

It is recommended to follow the same pattern as in the protocol for partial meniscectomy, but to vary the timing to protect the suture or graft.

Variations

ROM:

In the first 2 weeks, mobility is limited to 90° of flexion. From the third week progression can be made in passive motion, as tolerated without causing pain. At 1 month, if tolerated by the patient, 120° flexion can be achieved; the upper grades (touching the buttock with the heel) should not be forced until 3 months [8–10].

Ambulation:

During the first 4 weeks, the patients walk in "shock" or what we call "proprioceptive walking," which is properly setting the foot on the floor and performing natural walking, but taking the full force on the hands, without putting the load on the operated leg. It helps the patient not to lose the feeling of walking.

In the fifth week progressive loading can begin, until the end of the sixth week when the total load weight could be taken [7, 8, 10].

Strengthening:

From the first day, the patient starts working the muscles with isometric exercise of different muscle groups, such as the quadriceps and gluteus. The hamstrings can wait until 4 weeks.

After 6 weeks, when the patient can take a full load, closed kinetic chain exercises are undertaken. Open kinetic chain exercises are not undertaken until 3 months [7–10].

Stretching:

The patient can begin to stretch 6 weeks after surgery. The patient is already supporting the weight on the leg and starts toning the muscles more. This will be easier to do because of the good joint mobility [7, 9].

Proprioception training:

Proprioceptive work is very important after any surgery, but especially for the lower extremity. It should start straightaway and the exercises progress depending on the weight load the patient is allowed to put. In the discharge phase, proprioceptive work includes manual exercises and exercises performed against a wall. Finally, proprioceptive work is completed with weight-loading training, which is executed first bilaterally and then unilaterally [6, 8–10].

28.5 Phase 3

The third phase is the same in both protocols. Return to sports has been met as the program objective.

The difference is that in the case of the partial meniscectomy protocol, the phase begins at around 8 weeks, and in the case of meniscal suturing or meniscal graft protocol, this would start at around 12 weeks [5, 7, 9].

Many authors agree on a test being performed to objectively assess the degree of muscular symmetry compared with the nonoperated side. The two most common tests are the hop test and the isokinetic test; there would have to be a score of at least 85 % symmetry [8–11].

At this stage it would be very important for the coordination team (physiotherapy) and fitness coach to perform a progressive process and adapt it to the patient and their sporting needs [9, 10].

Conclusion

Rehabilitation protocols in meniscal surgeries are often too aggressive to speed up recovery; however, caution and respect of the time lines should be exercised. Patients and physicians should be guided more frequently by the evolution and the objectives achieved than by temporality; thus, the phases should not be strictly adhered to. Some authors use a brace to immobilize the knee during the first few weeks. We do not use it in our patient. We believe that aquatic therapy is a necessary part of recovery for the elderly patient, as it improves the knee motion and it allows the return to the correct ambulation. The gait pattern should be restored as soon as possible to avoid muscle decompensation and delayed recovery in the elderly patient.

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29 Synthesis

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Contents

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29.1 Introduction

The surgical treatment of meniscal tears has evolved from open total meniscectomy for all lesions to arthroscopic meniscal preservation techniques. The better understanding of the function (shock absorption, stability, force transmission) [11], vascularity [5], as well as the knowledge of degenerative articular changes after meniscectomy [8, 16] led to various surgical procedures to manage a meniscus tear. Meniscectomy (as partial as possible), meniscus repair, meniscus tear left alone without treatment, and meniscal replacement are the therapeutic options available in the management of meniscus injuries, in order to leave the maximum of functional meniscus tissue in place [6, 18, 29].

The question for a surgeon is to decide whether to repair, remove, or leave the meniscus tear in situ [6, 12], in order to obtain durable clinical results and healing [23]. Before the surgical technique, the good indication for a good treatment remains the main important goal. But it is not easy to choose, sometimes.

29.2 Lesion Left In Situ

Many meniscus tears of questionable significance can be identified after acute ACL ruptures.

Among these mentioned procedures, a “non-operative treatment,” without repair or removal, of small and stable meniscus tears is commonly

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_29

used during an ACL replacement procedure. In an evidence-based review based on ten relevant studies [19], we found that the mean rate of bad results of small medial meniscus tears left in situ without treatment during ACL reconstruction remains high. So, repair of a medial meniscus tear, even if it is a stable peripheral tear, should always be considered first to decrease the risk of subsequent meniscectomy. "Let the lateral meniscus alone" for small stable lateral meniscus lesions during an ACL reconstruction is an acceptable proposal when the lesion stays posterior to the popliteus tendon [25].

29.3 Meniscus Repair

Saving the meniscus, especially in young patients, to decrease the risk of secondary osteoarthritis, is challenging. Meniscal repair techniques are well established and allow surgeons to address tears of different complexity and location. There exists no universal technique but rather several techniques that are adapted to different indications.

Even if all-inside fourth-generation devices are now the gold standard in the majority of cases [20], inside-out [24], outside-in [1], and even open techniques are still indicated in selected cases, and a combination of the techniques is often useful for treating one lesion [22]. The ultimate goal is to achieve a strong repair. For far posterior medial meniscal tears, vertical sutures are placed through a posteromedial portal with a suture hook [27].

29.4 Meniscectomy

The primary indication for arthroscopic partial meniscectomy remains symptoms of well-localized joint line pain with acute onset and mechanical symptoms such as catching or locking that have failed comprehensive nonoperative management [14].

Minimal tissue resection, which very often can be described as "adequate," e.g., leaving the meniscal rim, should be the rule [9]. Care should be taken to resect what has been torn and remove meniscal tissue only without creating chondral lesions. As Pierre Chambat always says: "During an arthroscopic meniscectomy, you must not damage the cartilage in only 10 minutes like mother nature make it in 50 to 70 years…." Although quick and frequent, arthroscopic meniscectomy is sometimes much more difficult than other arthroscopic procedures.

29.5 Meniscal Lesions in Children (Repair, Discoid Meniscus)

Isolated meniscal tears in the skeletally immature patient are rare but well-recognized injuries [10]. Meniscal tears are frequently seen in association with a ruptured ACL [4]. Meniscus repair should be considered first for almost all lesions in children, as meniscus in children have the highest vascular channels and therefore healing potential when compared to adults. Meniscal preservation is particularly desirable in the immature patient even for treating complex lesions [26], as early degenerative changes in this population have profound consequences in the long term. There are a variety of all-inside arthroscopic techniques that are relatively easy to master and that can be quick to perform as compared to the more technically demanding inside-out and outside-in methods.

Although uncommon, the discoid lateral meniscus is more prone to injury because of its increased thickness and lack of blood supply [7]. Because of the abnormal development, the peripheral attachments are frequently absent and instability often persists after a partial meniscectomy. If the instability is unrecognized during the initial treatment, a recurrence of pain and mechanical symptoms is likely and a subsequent subtotal meniscectomy may be the only treatment option [30]. With increased awareness, arthroscopic saucerization accompanied by arthroscopic meniscal repair if needed [2] is a preferable treatment option with an excellent outcome in the short term and in the long term [3].

29.6 Meniscal Cysts/Horizontal Cleavage of the Meniscus in the Young Athlete

It may be considered as an overuse lesion and should be differentiated from the well-known degenerate lesion in older patients. It appears as an intrameniscal (grade 2) or extra-meniscal (grade 3) horizontal cleavage often associated with a peripheral meniscal cyst [13]. Rather than an arthroscopic repair, an open repair technique can be performed [21]. It allows the debridement of the intrameniscal lesion close to the horizontal cleavage, direct removal of the cyst, and insertion of vertical strong bio-absorbable stitches.

29.7 Rehabilitation

There is little evidence to guide rehabilitation decisions such as range of motion, weight-bearing or return to sports. As a result, there is wide variability in meniscal rehabilitation protocols.

But there is a trend towards early and fast rehabilitation programs, as it seems to be not detrimental [17, 28]. The reduction in activity restriction will reduce morbidity associated with overprotective measures such as prolonged brace wear and limited weight-bearing [15] after meniscal repair or partial meniscectomy.

Conclusion

Surgical technique and indications are complementary. The best surgeon using the newest arthroscopic techniques will not obtain good results if his indications for surgery are wrong.

Meniscectomy, one of the most frequent orthopedic procedures, is probably too frequent. Meniscus repair is probably too rare. In France, meniscus repair only represents 4.5 % of the meniscectomies in stable knees in daily practice. We cannot exactly assess the rate of conservative treatment (since many of these cases do not come to the surgeon) so that it is not possible to compare the respective roles of conservative treatment, meniscectomy, and meniscus repair. But we can assume the rate of meniscectomies should decrease and the rate of repair or conservative treatment should increase in the future. Techniques evolved, indications are accurate; this contributes to current good clinical outcomes of meniscal repairs.

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Part V

Postoperative Evaluation

Functional and Objective Scores: Quality of Life

30

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30.1 Chapter Structure

Selecting an instrument that accurately measures the degree of disability following an injury or the outcomes of a surgical procedure is critical for performing accurate comparisons between surgical techniques and drawing conclusions regarding future treatment. Overall, outcome measures are divided in two types: those assessing general health or quality of life and those that are joint or disease specific [20]. Over the past decades, there has been a considerable increase in instruments and rating scales designed to evaluate knee function. Many of these instruments have been developed to be disease specific, with knee osteoarthritis and anterior cruciate ligament reconstruction being the focus of interest. Over 54 outcomes, measures have been described for the evaluation of ACL reconstruction alone [10]. Other instruments were developed to be specific for a particular subpopulation under study, such as athletes and the elderly. Apparently, a single universal instrument to measure across the spectrum of knee disorders and populations is still lacking today and may hardly be feasible.

Lately, there has been a shift towards the assessment of knee surgery outcomes based on patient-reported rather than clinician-based evaluation thus reflecting a shift of attention towards patient satisfaction in contrast to clinician satisfaction. This has led to a considerable growth in the number of knee instruments and rating scales designed to quantify surgical outcomes from the

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_30

perspective of the patient. Patient-reported outcome measures have been advocated to be superior in validity compared with objective knee tests, such as knee laxity, range of motion and physical examination tests [25]. There is also evidence to support that the systematic use of data from patient-reported outcome measures leads to improved doctor-patient communication and decision-making and increases patient satisfaction with care [14]. However, the implementation of patient reported outcomes into routine practice has revealed that numerous technical, social, cultural and even legal issues may ensue and impede successful adoption [5].

Outcome instruments are only useful in clinical trials provided that the critical properties of reliability, validity and responsiveness have been systematically tested [24]. Reliability describes the ability to score a measure without errors in a reproducible fashion [19]. Internal consistency and test-retest reliability are two measures of reliability. Validity is the ability to evaluate what the outcomes measure claims to measure with content, construct and criterion validity being different types of validity [18]. Responsiveness is the ability to detect a change in condition over time [17]. Previous studies have shown inconsistencies in results between similar instruments for the same patient group with a specific knee disorder [21, 26]. Being self-administered is also considered a significant advantage of outcome measures scales. In contrast, observer-dependent scores may introduce bias thus affecting the accuracy of data collection [8]. Despite the excess of outcome measures scales currently available to clinicians and researchers, only a few of these are both self-administered and validated.

Instruments assessing general health evaluate a wide range of parameters, both mental and physical. The advantage of a general health outcomes measure is that it can be used to compare diseases and conditions across the medical spectrum thus allowing comparisons of the relative impact of treatment despite completely different diagnoses. It may be believed that general health measures are less relevant to the disease condition under study. Therefore, such measures should be combined with disease-specific outcomes measures that have more content and validity for the specific condition. The Medical Outcomes Study 36-Item Short Form is the most commonly used general health measure in orthopaedics and has been widely used both in clinical research and in population surveys and health policy development [20, 28].

Although numerous outcome measures scales have been developed for the knee, there are very few that have originally been designed or validated for meniscal pathology. However, as meniscal surgery has progressed from partial meniscectomy to meniscal inserts and allograft transplantation, the need for meniscus-specific scores has increased. The major functional and quality-of-life scores that have been validated for meniscal pathology until recently are the Tegner activity level scale [2], the Lysholm knee scale [2], the Western Ontario meniscal evaluation tool (WOMET) [11], the International Knee Documentation Committee (IKDC) form [3], the Knee Injury and Osteoarthritis Outcome Score (KOOS) [23] and the visual analogue scale (VAS) for knee disorders [7]. Among these, the WOMET is the only instrument that has been specifically designed and validated to assess meniscal pathology and surgical outcomes [11]. Table 30.1 summarizes the most frequently used functional and quality-of-life scores that have been validated for knee joint pathology in general.

Selecting the appropriate outcome measures to evaluate specific parameters of knee function presents several challenges. Although a gold standard does not exist, researchers should select outcome measures scales based on their applicability on the patient population and disease characteristics they wish to study. In general, a general health outcomes measure scale, such as the SF-36, should be added to one or more disease-specific rating scales. To confirm the activity level of a particular population studied, such as professional athletes, or to study the effect of activity level as a confounding factor, an activity rating scale, such as the Marx or Tegner, should be included. In any case, the relevance of functional and quality-of-life scores used during a study should ideally be prospectively confirmed along the process of data collection.

Table 30.1 Synopsis of functional and quality-of-life scores used to assess knee function

Scoring scale	Introduced by	Type	Assessment parameter	Scale
Validated for the meniscus				
Tegner activity level scale	Tegner and Lysholm [27]	PR	Sport-specific activity level	0-10 point scale
Lysholm knee scale	Lysholm and Gillquist [12]	PR	Knee ligament surgery	Eight subscales: limp, support, stair climbing, squatting, instability, locking and catching, pain, swelling (0–100 scale)
Western Ontario meniscal evaluation tool (WOMET)	Kirkley et al. [11]	PR	Meniscal injury/ surgery	Three sections: physical symptoms, sports/recreation/work/lifestyle and emotions
International Knee Documentation Committee (IKDC) form	IKDC 1993	PR	Knee specific	18 questions (0–100 scale)
Knee Injury and Osteoarthritis Outcome Score (KOOS)	Roos and Lohmander [22]	PR	Sports injury	Five subscales: pain, symptoms, ADLs, sports and recreation function, knee-related QOL
Visual analogue scale (VAS) – knee disorders subjective history		PR	Knee function	10-cm scale. The ends of the line represent the extremes of pain
Not validated for the meniscus				
Cincinnati knee rating system	Marx et al. [15]	CB and PR	Ligament injury and reconstruction, HTO, meniscus repair and allograft transplant	Six subscales: symptoms, daily and sports functional activities, physical examination, knee stability testing, radiographic findings, functional testing
Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)	Bellamy [1]	PR	Condition specific for hip and knee osteoarthritis	Three subscales: pain, symptoms, function/daily living
Medical Outcomes Study 36-Item Short Form (SF-36)	Ware and Sherbourne [29]	PR	General health	Eight subscales (questions): physical functioning, role (physical/emotional), pain, general health, vitality, social functioning, emotional well-being
Medical Outcomes Study 12-Item Short Form (SF-12)	Ware et al. [30]	PR	General health	12 questions selected from SF-36
Flandry questionnaire	Flandry et al. [6]	PR	Knee specific (patellofemoral pain)	28 items (0–100 scale)
Activities of Daily Living Scale (ADLS) of the Knee Outcome Survey (KOS)	Irrgang et al. [9]	PR	Knee specific	17 items (0–100 scale)
Knee Assessment Scoring System (KASS)	Mahomed et al. [13]	CB and PR	Knee function	0-100 scale
Marx activity level scale	Marx et al. [16]	PR	Activity level	Four questions: running, cutting, decelerating, pivoting
American Academy of Orthopaedic Surgeons Sports Knee-Rating Scale	AAOS 1998	PR	Knee specific	Five parts; 23 questions in total
The Oxford Knee Score	Dawson et al. [4]	PR	Knee specific	12 multiple-choice questions, each with five answers

CB clinician based, *PR* patient reported

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31 Postoperative Imaging of the Meniscus

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31.1 Introduction

Radiographs are the first-line radiologically modality in the assessment of knee pain, irrespective of a potential previous knee surgery. Ossified joint bodies, osteonecrosis, and osteoarthritis can be evaluated on X-rays. Anteroposterior (ap) and lateral weight-bearing X-rays are standard projections of the knee joint. Additionally, the Rosenberg view, which is an ap projection in 45° flexion, can be obtained to assess joint space narrowing of the flexion facettes. Additionally to radiographs, magnetic resonance (MR) imaging is mandatory in the evaluation of soft tissues. Clinical identification of the meniscal origin of recurrent or residual symptoms may be confounded by the postoperative nature of the joint. Extrameniscal sources of pain are numerous and include cartilage damage, intra-articular fragments, ligamentous pathology, synovitis, osteonecrosis, and others [1]. MR can be challenging due to the postoperative changes simulating tears. A comparative preliminary MR investigation as well as description of the surgical site and technique provide valuable and necessary information for the evaluation of a potential recurrent tear [1]. MR arthrography with intra-articular administration of gadolinium can improve the accuracy in detecting a re-tear after meniscal surgery or non-integrity of a meniscal transplant [7, 13]. CT arthrography with intra-articular administration of iodine may be an alternative in patients who are unable to undergo MR or if MR is not available.

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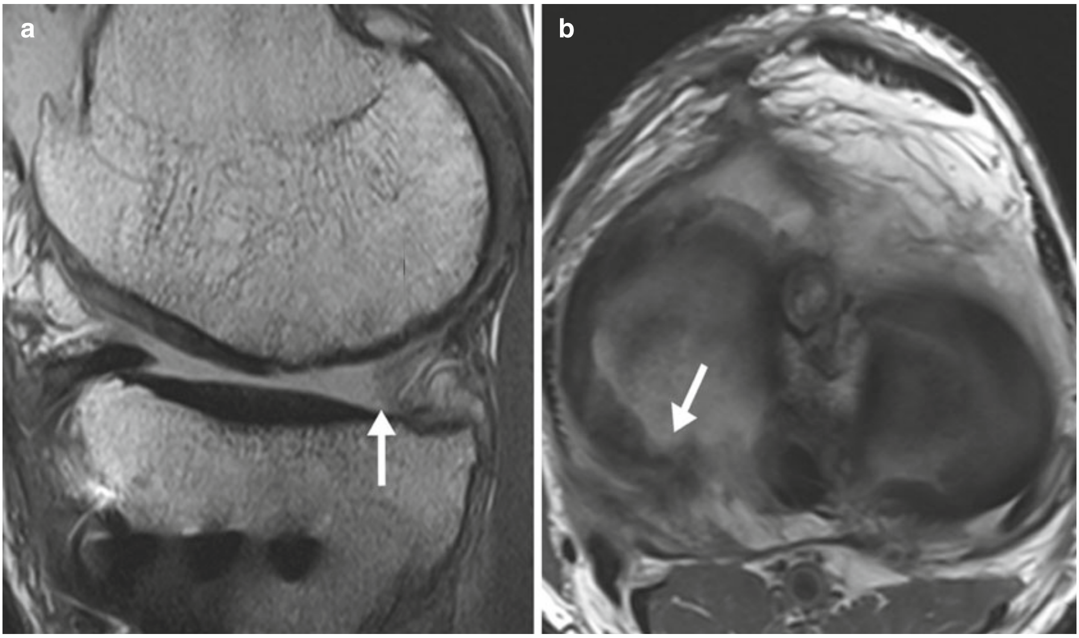

Fig. 31.1 Truncation of the meniscal remnant with fraying edges (*arrows* in **a**, **b**) is a normal finding after partial meniscectomy

31.2 Partial Meniscectomy and Meniscal Repair

After partial resection, the normal meniscal appearance is a truncated meniscal remnant with mild fraying of the free edge and adjacent signal intensities (Fig. 31.1). In the majority of cases, the MR appearance of a sutured meniscal tear is unchanged from the preoperative appearance long after the tear has healed [2, 3, 5, 9] (Fig. 31.2).

A recurrent tear can either present as high signal intensity in intermediate- or T2-weighted images extending to the meniscal surface or as a displaced meniscal fragment [1–3]. If contrast material after intra-articular administration is seen in the tear on coronal and sagittal T1-weighted fat-saturated sequences, a re-tear is obvious. In contrast, indirect MR arthrography with intravenous injection of gadolinium may show enhancement of a preexisting tear reflecting granulomatous tissue in the tear during the first year rather than reflecting a recurrent tear [14]. Extended partial meniscectomy particularly in patients with preexisting higher-graded cartilage defects are prone for an early development of osteoarthritis. Weight-bearing radiographs allow evaluation of the stage of osteoarthritis of the knee joint. In particular after wide resection of the meniscus joint, space narrowing may be evident on radiographs. Anchor dislocation may lead to an unstable meniscus or cartilage defects.

31.3 Meniscus Allograft Transplantation

Conventional MR sequences can be used in the evaluation of a meniscal transplant without the use of intra-articular or intravenous contrast administration. MR can provide information about the status of the meniscus allograft regarding its position,

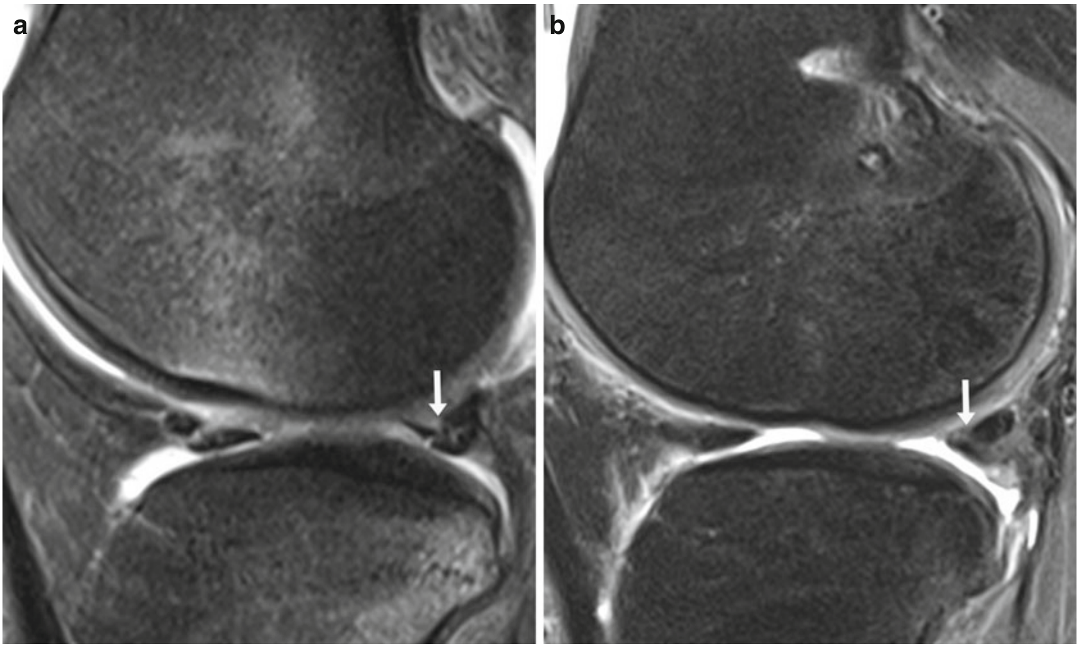

Fig. 31.2 Intermediate-weighted fat-saturated sagittal image of the left knee shows a complex tear of the posteromedial meniscus (**a**, *arrow*). Residual high signal intensity can be seen 2 years after sutured complex meniscal tear (**b**, *arrow*)

Fig. 31.3 Extrusion (*arrow*) of the meniscus after CMI is a common finding

the meniscal anchors, the capsular attachment, the detection of areas of meniscal degeneration, and the condition of the articular cartilage [8, 12]. Studies of MR evaluation of these transplants are few and have involved small numbers of patients [1, 3, 11]. In general, size of the meniscal transplant should be the same as the contralateral meniscus. Meniscal extrusion is a common finding [6] (Fig. 31.3). This is a risk factor for osteoarthritis, which can be diagnosed with weight-bearing radiographs. Morphology and signal intensity of collagen meniscal implants (CMI) are inconsistent in the literature [4, 6]. Although clinical outcome after CMI is satisfied, signal intensity of the transplant can vary as can the transplant be partially resorbed [6, 10–12] (Fig. 31.4). Therefore, morphological and signal changes of the CMI should be carefully interpreted. However, according to Verstraete et al., the clinical outcome appeared to be worse in patient with persistent joint effusion, full-thickness chondral loss, and peripheral displacement, fragmentation, degeneration, or frank extrusion of the allograft [12].

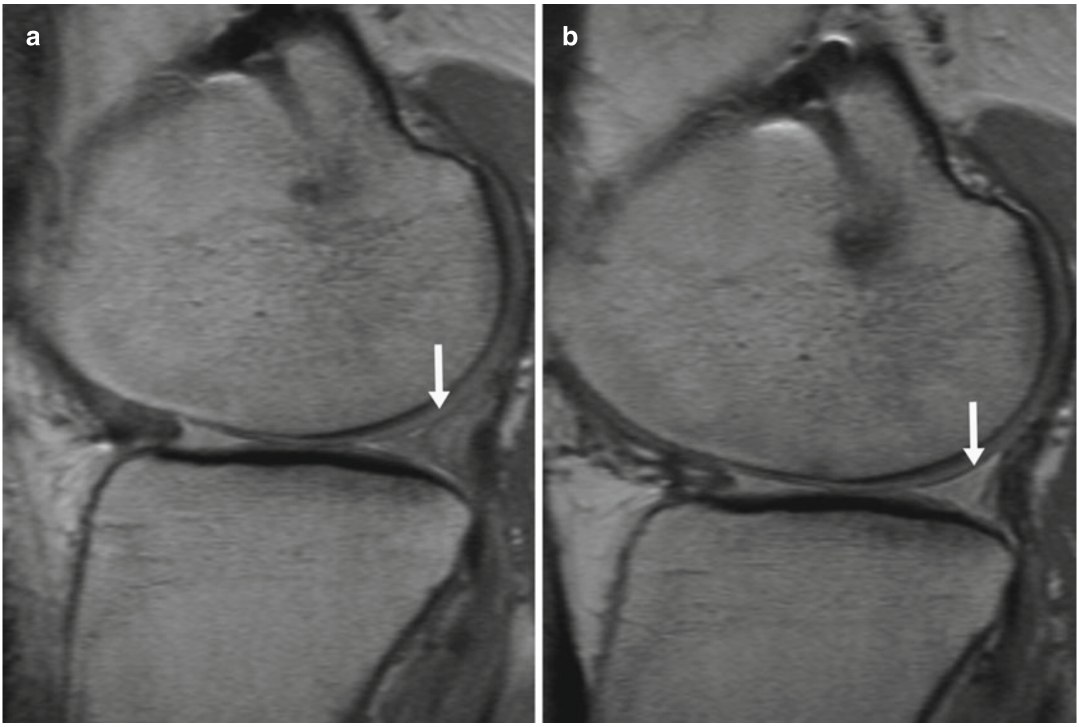

Fig. 31.4 Follow-up MR of the left knee 3 years after collagen meniscal implantation (CMI) shows a subtotal resorption of the CMI (**b**, *arrow*) compared to the previous MR (**a**, *arrow*). Note the high signal intensity of the CMI 2 years postoperatively (**a**)

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Synthesis

32

Giuseppe M. Peretti

Selecting a series of diagnostic exams for the pre- and postoperative evaluation of the status of the knee or any particular joint structure, like the meniscus, represents a crucial issue in the diagnosis and treatment of knee-related diseases. On the other hand, as the indication for surgeries and the evaluation of the outcome of a particular invasive or noninvasive procedure do not depend only on the imaging but also on the clinical status of the patient, it is similarly critical the identification of clinical instruments that accurately measure the degree of disability. This would allow for the performance of truthful comparisons between the different treatments and would be also fundamental for the planning of future treatments.

With regard to the functional and objective scores about quality of life related to the knee joint, these can be divided into those that assess general health or quality of life and those that are joint or disease specific. Generally, a single complete instrument to be applied to measure all knee disorders is still lacking today and may hardly be feasible in a concise form.

Some general health measures are available, which should be combined with disease-specific outcomes measures. On this regard, the Medical Outcomes Study 36-Item Short Form (SF-16) represents the most commonly used as general health measure in orthopaedics.

The major functional and quality-of-life scores validated for knee together with meniscal pathology are as follows: the Tegner activity level scale, the Lysholm knee scale, the Western Ontario meniscal evaluation tool (WOMET), the International Knee Documentation Committee (IKDC) form, the Knee Injury and Osteoarthritis Outcome Score (KOOS) and the visual analogue scale (VAS) for knee disorders. Among these, the only one really specifically designed and validated to assess meniscal pathology is the WOMET.

As previously stated, it is recommended that a general health outcomes measure scale, such as the SF-36, should be added to one or more disease-specific rating scales.

As far as it concerns the pre- and postoperative imaging of the meniscus, radiographs are the first modality in the assessment of knee pain. Ossified joint bodies, osteonecrosis and osteoarthritis can be easily evaluated on X-rays being the anteroposterior (ap) and lateral weight-bearing X-rays the standard projections and the Rosenberg view other additional projection. On the other hand, magnetic resonance (MR) imaging is mandatory in the evaluation of soft tissues, like the meniscus. On this regard, the importance of the MR in the evaluation of the intra-articular and extra-articular soft tissues but also hard structures is definite and, therefore, fundamental for a

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_32

differential diagnosis in the extrameniscal sources of pain. Among the different extrameniscal symptoms, we can list those derived from cartilage damages, from the presence of intra-articular fragments and from ligamentous pathologies, synovitis, osteonecrosis, bone marrow oedema and others. In the case of doubts about retears after meniscal surgery or non-integrity of a meniscal transplant, MR arthrography with intra-articular administration of gadolinium can provide a more definite imaging. As an alternative, in those patients who are unable to undergo MR or if MR is not available, CT arthrography with intra-articular administration of iodine could be employed.

In conclusion, the combination of a series of diagnostic exams, like X-rays and/or MR, together with dedicated scales for clinical assessment that measure the degree of disability is fundamental for the pre- and postoperative evaluation of the status of the knee or any particular joint structure, like the meniscus.

Part VI

Results

33 Posterior Horn Plus Pars Intermedia Bucket-Handle Tear Resection: Long-Term Outcome and Complications

Dimitris P. Giotis and Rainer Siebold

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33.1 Introduction

Historically the anatomical and functional role of menisci has been recognized through the extensive literature that had been performed the past decades. This crucial role is not only limited in load transmission and shock absorption by covering the contact area of the tibiofemoral joint but also expanded in contribution of accessory anteroposterior stabilization and proprioception of the knee joint and, additionally, nutrition and lubrication of the articular cartilage [1–17].

Anatomically, medial meniscus is C shaped and is anchored tightly to the tibial plateau, especially to the posterior part of the tibia. The lateral meniscus is more circular in shape, thicker at the periphery, and not so firmly attached to the area of the popliteal hiatus or lateral collateral ligament. This allows higher mobility to the lateral meniscus, as compared to the medial one [18]. In parallel, medial meniscus has a better blood supply [19].

This precious biological entity might be torn under several circumstances as sports activities, trauma, or discoid meniscus. During sports in young athletic population, the mechanism of injury might include twisting, turning, or squatting maneuver (pivoting), while in older patients, degenerative changes of the menisci might cause tear under even trivial activities. Meniscal tear is referred as the most common injury of the knee joint [20, 21] and might regard the medial, the lateral meniscus, or both menisci. Tears of the medial meniscus are relatively more common

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_33

than the lateral one, because lateral meniscus is more mobile, and therefore, medial meniscus receives greater biomechanical loads [22–26]. However, frequently, they might be accompanied by ligamentous injuries especially of the anterior cruciate ligament (ACL) [20, 27].

According to the localization of tears, they are classified to zones. Zones 0 and 1 are considered the menisco-synovial junction and outer third of meniscus (red-red zone) correspondingly, whereas zones 2 and 3 are regarded the central (red-white zone) and inner third (white-white zone) of the meniscus, respectively (Cooper et al.) [28]. The first two zones have better vascularization (vascular periphery) than the others, presenting higher success rate for meniscal repair [28, 29]. According to the morphology and the mechanism of injury, tears are also categorized as horizontal, vertical, radial, oblique, bucket-handle, or complex [18, 29, 30].

Operations regarding the meniscus are considered the most frequent orthopedic procedures, in particular concerning sports medicine [31]. The first meniscal surgeries were open procedures. However, from the1990s with the development of arthroscopy, they were substituted gradually but entirely with arthroscopic procedures [32]. Arthroscopy can provide easier access to the knee joint, reducing the operating time and avoiding the risk and complications of open procedures.

33.2 Bucket-Handle Tear

A bucket-handle tear is defined as a vertical longitudinal tear which usually extends from the anterior to the posterior horn including the middle part of the medial or lateral meniscus. These commonly long peripheral or near peripheral tears might involve large portions of meniscus when they include both horns. Sporadically they can be referred only to the medial peripheral avascular part of the meniscus which is known as pars intermedia, or they might include posterior or anterior horn plus pars intermedia. This torn part (fragment) might be displaced beyond the equator of the femoral condyle into the intercondylar notch, causing mechanical locking of the knee joint [30, 33]. Unlocking of the joint is associated with relocation of the displaced meniscal part, further extension of the tear mainly anteriorly, or rupture of the bucket-handle (free body) [30].

This type of meniscal tears represents nearly 10 % of meniscal tears. The ratio of medial to lateral bucket-handle meniscal tears is approximately 3:1 [30]. Moreover, it is more likely for patients with an ACL injury after acute knee trauma, to sustain a concurrent medial than lateral bucket-handle meniscal tear [30, 31]. It is a very common injury in young patients especially those who are dealing with sports, without having been proposed any clear mechanism of the damage so far. Except for acute traumatic bucket-handle tears, initially vertical longitudinal tears after continued giving-way episodes might lead to expansion of tears and development of bucket-handle tears. As it has also been reported, bucket-handle tears might occur in 15–20 % of patients without history of injury. In those cases, degenerative changes in the menisci might be involved with the pathology of the tear (degenerative tear) [30].

Clinically, apart from knee locking which is the most common characteristic of bucket-handle tear, insisting localized knee pain, effusion or haematoma, restriction of range of motion (especially extension), and positive McMurray test have been also reported [30]. In chronic cases, bucket-handle tear may be a scar into the intercondylar notch. Diagnostically, MRI in both sagittal and coronal plains is considered to have a sensitivity ranging from 50 to 100 %. This variation is attributed to difficulties in imaging of bucket-handle tears of the lateral meniscus as frequently they can reduce spontaneously [34–36]. There have been proposed six different MRI signs for bucket-handle tears: (a) fragment within the intercondylar notch sign, (b) absence of the bow tie sign, (c) disproportional posterior horn sign, (d) double posterior cruciate ligament sign, (e) double anterior horn sign, and (f) flipped meniscal sign [37]. However, the best diagnostic tool is considered the knee joint arthroscopy (nearly 100 % sensitivity).

33.3 Long-Term Outcome and Complications After Bucket-Handle Tear Resection (Posterior Horn Plus Pars Intermedia)

Total meniscectomy was historically a common procedure for meniscal tears. It was one of the oldest orthopedic procedures, first described in 1866 and popularized by Smilie in the 1970s. However, numerous studies demonstrated poor clinical and radiological long-term results after total meniscectomies [38–40]. Fairbank in 1948 [41] was the first who reported radiographic changes after total meniscectomy, alleging that meniscal resection can predispose to early degenerative osteoarthritic changes in the knee joint. Thus, to conserve this valuable tissue, arthroscopic meniscal repair or partial meniscectomy has become the gold standard for treating meniscal tears instead of total meniscectomy. Additionally, the unique role of meniscus in load transmission reveals the need of preserving as much meniscal mass as possible.

Theoretically, the success or failure after meniscal repair might be influenced by several factors as the type, length, and location of meniscal tear, the repair technique, concurrent ACL deficiency, concomitant ACL reconstruction, whether the tear is acute or chronic (injury to surgery time), or the rehabilitation protocol. Indications for bucket-handle tear repair may include tears in the vascularized area zone (red-red and red-white zones) without obvious additional complex tears or degeneration, isolated tears with concomitant ACL injuries, displayed tears when probing, relatively stable tear following reduction, or reducible inner fragment for chronic cases [42, 43]. It should never be ignored that a stable knee is important for successful meniscal repair and healing. Thus, associated ligamentous injuries must be always addressed.

On the other hand, when it is not possible to repair a bucket-handle tear, partial meniscectomy should be performed. Bucket-handle tears in the avascular zone (white-white zone), tears with degenerative changes, deformed torn fragments, or when there is inability to obtain anatomic reduction of the displaced fragment might be indications for partial meniscectomy [44].

33.3.1 Bucket-Handle Tears Resection: Surgical Technique

Various techniques have been proposed for resection of bucket-handle tears [45–50]. In all these procedures, the aim is focused on the removal of the mobile fragment leaving a stable and smoothly contoured meniscal rim. However, often additional portals or equipment such as suture punch or needle may be needed for better view of the posterior horn [45–50]. The most commonly executed is the classic one, where standard anterolateral and anteromedial portals are used to perform the arthroscopy of the knee joint. In this technique, the arthroscope is introduced via the anterolateral portal for a bucket-handle tear of the medial meniscus and via the anteromedial portal for a lateral bucket-handle tear. Through the ipsilateral portal, a probe is inserted to confirm the tear. If the fragment is displaced into the intercondylar notch and the visualization of the knee compartment is difficult, the surgeon should try to relocate the fragment to its original position to better delineate the extent of the tear with the use of the probe. After the repositioning of the bucket-handle, the resection of the tear follows according to the principles for longitudinal ruptures.

Afterward, the posterior horn is resected from a superior contralateral approach with the use of basket forceps or hooked scissors, taking care to leave a small portion of intact posterior attachment. For a medial meniscus, the view of the posteromedial compartment is facilitated by applying a valgus force in a 20° flexed and externally rotated knee, whereas for a lateral meniscus, the view of the posterolateral compartment is performed by applying a varus force in a figure four 80–90° flexed knee. Then an arthroscopic grasper is firmly clamped onto the displaced fragment, and with twisting manipulation and gentle traction, the meniscal remnants are detached by excising the anterior attachment of the tear with the use of hooked scissor or arthroscopic motorized shaver and the torn meniscal fragment is pulled out in one piece. In cases of bucket-handle tears regarding only the posterior horn and pars intermedia, which are the most common, a great effort should have been taken into account not to remove mistakenly any part of the anterior horn [51, 52]. Finally, an examination after resection follows, and smoothening of edges with the aid of shaver is performed.

After partial meniscectomy, patients can start full weight bearing from the first postoperative day and may advance to preoperative activities after 2–3 weeks. For athletes, return to sports varies between the 3rd and the 6th postoperative week, depending on the type of sport and whether full knee motion and strength before sports can be resumed. In cases of deficits in quadriceps function as compared to the contralateral side after the second postoperative week, physical therapy may be followed for up to 8–12 weeks.

33.3.2 Long-Term Outcome and Complications

As it was previously mentioned, meniscectomy is associated to early osteoarthritis in the knee joint [27, 38, 41, 53–55]. Kimura et al. [56] and Ohtoshi et al. [57] had also reported that subtotal meniscectomy had the potential to cause degenerative arthritic changes, whereas Roos et al. [58] reported that although arthroscopic partial meniscectomy alleviated pain, swelling, and other acute symptoms, patients' quality of life was deteriorated in terms of limitation of functional activities including running, jumping, kneeling, or squatting. These results can be justified, if it is taken into consideration that the degree of stress concentration in the contact area of tibiofemoral joint is increased accordingly to the amount of removed meniscal mass after meniscectomy [59]. Specifically it was reported that removal of 16 % of the meniscus increased the articular contact forces by 350 % [60]. Furthermore, Rangger et al. [61] and Macnicol and Thomas [62] associated also partial meniscectomy with an increased incidence of degenerative changes. Similar results were also observed in ACL-deficient knees after meniscectomy especially of the medial meniscus [63]. The fact that medial meniscus acts as a secondary stabilizer of the knee joint might have played a certain role on this result [10, 63].

On the other hand, Johnson et al. [40] demonstrated that knees after successful meniscal repair do not have a higher risk of radiographic osteoarthritic changes with a follow-up of more than 10 years. On the contrary, Majewski et al. [64] reported favorable functional results after meniscal repair in isolated longitudinal tears, but the effect on the risk of posttraumatic osteoarthritis was not clear. Specifically, an increased degree of osteoarthritic changes was reported in 24 % of knees after meniscal repair in comparison with the uninjured knee. However, in the literature, osteoarthritic rate after isolated partial meniscectomy may reach up to 53 % [38, 65].

Several comparative studies have shown that partial or subtotal meniscectomy results in more degenerative changes than meniscal repair [17, 66]. Stein et al. found better clinical results, in terms of return to sports activity and fewer osteoarthritic changes in young patients after meniscal repair (20 %) than in patients after partial meniscectomy (40 %), with a follow-up of 8 years [66]. Similarly, Paxton et al. presented higher Lysholm scores and less degeneration after meniscal repair as compared to partial meniscectomy [17]. Interestingly in the same study, it was found that despite the fact that meniscal repair was associated with better long-term outcomes, it had a higher reoperation rate than partial meniscectomy. This was observed in medial meniscal repairs and could be attributed to the higher biomechanical loads that are applied in the medial meniscus due to its tight attachment to the tibial plateau [18]. In the comparative meta-analysis study of Xu and Zhao [67], it was proposed that partial meniscectomy can be performed in cases of central lesions, in white zone of the meniscus, offering lower reoperation rate and satisfactory short-term outcome. However, it was also observed that meniscectomy was associated with poorer knee function, Lysholm scores, Tegner activity, and higher instability in the long term than meniscal repair.

Particularly, for bucket-handle tears, there are few large clinical comparative studies which correlate the outcome after meniscal repair versus partial meniscectomy [68–70]. In 2004, Shelbourne and Dersam [68] were the first who reported long-term (nearly 10-year follow-up) subjective and objective results of treatment for bucket-handle tears. They found abnormal IKDC rating in 40 % of the patients treated with meniscectomy of the bucket-handle tear and in 10 % of those treated with meniscal repair. They also demonstrated better sub-score for the pain in the meniscal repair group. They considered that these results may indicate the beginning of a degeneration process which would be presented in radiographs years later. On the other hand, Shelbourne and Carr [69] found that the outcomes after repair and resection of bucket-handle tears associated with ACL reconstruction were similar at 6–8-year follow-up time and only repaired degenerative tears had significantly lower subjective scores than those with non-degenerative tears. However, these results concerned a short term, and perhaps over the long term, they might be different.

Relatively good results after partial medial meniscectomy were reported by Chatain et al. [71]. They found that at a mean of 11 years postoperatively, 91 % of the patients were clinically normal or nearly normal but 22 % had radiographic degenerative changes. Specifically, concerning partial meniscectomy of bucket-handle medial meniscal tears, Shelbourne and Dickens in 2006 reported favorable subjective and radiographic results after a long-term follow-up of 12 years [72]. Higuchi et al. [38] observed also that 79 % of the patients at 12 years postoperatively had satisfactory subjective scores, but half had degenerative changes on x-rays. Jaureguito et al. [73] found that after partial meniscectomy, 72 % had none or one Fairbank's change on the side of the meniscectomy. On the contrary, Sheller et al. [74] demonstrated that at 5–15-year follow-up, only 66 % of lateral meniscectomies were good and excellent, whereas 78 % had degenerative changes. In addition, Hoser et al. [75] reported that 10 years after partial meniscectomy, only 29 % of the patients were normal or near normal in posteroanterior weight-bearing radiographs.

Conclusively, from the review of the literature, it was demonstrated that the long-term subjective results of meniscal resection especially after bucket-handle tear are not all that bad, compared to the objective results that indicated significant degenerative changes radiographically. Most of the studies conclude that partial meniscectomy of bucket-handle tears might progressively lead to early osteoarthritis, but it is not clear how much the osteoarthritic process is accelerated and through which mechanism. The recognition of the vital function of the meniscus is unquestionable. Loss of meniscal tissue leads to increased articular contact area in the tibiofemoral joint and abnormal distribution of load. Additionally, normal lubrication and synovial fluid nutrition of the articular hyaline cartilage is also impaired. It is believed that both of these functional disorders can lead to premature joint degeneration. In cases of unstable knees after ACL deficiency, the force transmission to the articular cartilage becomes even more anisomeric, predisposing to increased degeneration and finally to onset of early osteoarthritis.

Therefore, the emphasis must be given on leaving a stable remnant which may still provide some meniscal properties and function and to preserve as much meniscal tissue as possible. It is proposed by many authors that repair of a torn meniscus may restore the loading profiles of the joint and the ability of meniscus to absorb hoop stress and eliminate joint space narrowing, possibly decreasing the risk of degeneration [13, 76]. Even though, it is not strongly elucidated that meniscal repair of bucket-handle tears has much more satisfactory long-term results than resection, the general belief is that meniscal repairs are associated with better long-term outcomes than partial meniscectomies, despite their higher reoperation rate [17].

Although surgical repair is indicated for non-degenerative red-red or white-red zone bucket-handle tears, several authors demonstrated that even in the white-white zone, meniscal repair is not pointless in cases where there is a risk of loss of a large meniscal mass, especially in the lateral meniscus [27], offering functional meniscus for a certain period of time [77–79]. However, in case of failure, the choice of meniscectomy as a next step should always be addressed.

Furthermore, except early osteoarthritis which is of the greatest concern, other midterm complications might occur after partial meniscectomy. One of this regards especially athletes or those who are dealing with sport activities. Persistent symptoms such as pain, locking, and swelling, after a failure in the surgical procedure, may impair athletic or even daily activities, degrading the quality of life. Specifically for athletes, the subsequent inability to return to previous level of pre-injury activity might be dramatic leading to even the end of the career.

Intraoperative or early postoperative complications after arthroscopic partial meniscectomy range from 0.5 to 1.7 % [80, 81]. Iatrogenic articular damage due to limited visualization, especially when the meniscectomy concerns the posterior horn of medial or lateral meniscus, overresection of the meniscal remnants, and insufficient resection of the torn fragment are referred as the most common intra-operative complications. Vascular or nerve injuries, along with instrument failure and general anesthetic problems, are also mentioned as intraoperative complications after meniscectomy. Early postoperative complications should also be taken into consideration after partial meniscectomies. The most frequent complications include persistence of pain, or effusion which can be persistent especially after removal of big portion of meniscus, and might need a revision arthroscopy. The orthopedic surgeon should always be aware of the sterilization for the avoidance of possible postoperative infection which might need multiple arthroscopic lavages. Arthroscopic lavages might be also needed in cases of hemarthrosis. Stiffness and synovitis have been also referred as possible complications. The treatment for these cases might include physical therapy or even arthroscopic debridement of the synovial tissue. Finally thrombophlebitis might be another complication which might need special care.

Conclusion

Summarizing, partial meniscectomy after meniscal tear is a very common surgical procedure, and its results and complications have been extensively reported in the literature. However, there are few studies that investigate the outcome of partial meniscectomy after bucket-handle tear. The majority of them indicate that despite the fact the long-term results might be decent, it is proposed that the need of meniscal repair after a bucket-handle tear especially in cases of young active patients or athletes should be addressed always. The gold standard is to try to save as much meniscal mass as possible, even with a meniscal repair or a partial meniscectomy, as loss of meniscal tissue is associated with early osteoarthritis. The selection of patients in each case should be performed according to the advisable criteria. However, in cases of extensive meniscal resection, the orthopedic surgeon should always be aware of the solution that can be provided by human allograft meniscal transplantation, a relatively new procedure with very encouraging results. As clear indications and long-term results have not yet been established, further investigation should be performed to assess the efficacy of meniscal transplantation in restoring normal meniscal function and preventing from early osteoarthritis in the knee joint.

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34 Results of Lateral Meniscectomy

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34.1 Introduction

The menisci are fibrocartilage structures that increase the congruence of the knee joint thus contributing to the joint stability [1]. They transmit two to four times the body weight with each step, and they have a 5–11 mm excursion with knee flexion, being the lateral much more mobile. They have nerve endings in its peripheral third, particularly at both anterior and posterior horns, being an important source of proprioceptive information regarding the position, direction, velocity and acceleration and deceleration of the knee [2]. However, the most relevant meniscus properties are probably related to their ability to shock absorption and distribution of the load transmitted across the joint [3]. All these functions are intended to maintain the articular cartilage integrity and homeostasis.

The different surgical approaches to treat meniscal pathology were born by the end of the nineteenth century. Broadhurst is credited to have performed the first meniscal excision due to a symptomatic meniscal tear [4]. Practically at the same time, Annandale pioneered the idea of meniscal repair [5]. Some years later, Katzenstein reported the first clinical series of 7 patients, in whom a torn meniscus was sewed up with catgut stitches [6]. In spite of the good clinical results obtained, this work was ignored and meniscectomy became the most common procedure performed by orthopaedic surgeons.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_34

The deleterious effects for the knee of this previously supposed innocuous treatment were first suspected by King [7]. However, it was Fairbank [8], some years later, who described in detail the radiological changes the knee experimented after meniscectomy, thus introducing the concept of post-meniscectomized knee. Later on in the last century, the advent of arthroscopy made meniscectomy less aggressive, and partial meniscectomy turned out to be the gold standard approach for the injured meniscus. The benefits of arthroscopic meniscal partial resection included a rapid recovery, better objective and subjective outcomes and fewer complications [9]. This chapter is focused on the functional and radiologic results of arthroscopic lateral meniscectomy with especial reference to its long-term outcomes.

34.2 Effects of Meniscectomy

The removal of meniscal tissue led to increased contact stress, which in turn causes biomechanical wear, and permanent deformation of cartilage [10]. The lateral meniscus has a smaller contact area than the medial meniscus and so higher peak stresses are generated [11]. Furthermore, the lateral meniscus needs to resist both traction and shearing forces due to its greater mobility. This is particularly true in cases of ACL disruption, which is commonly associated with sudden transverse-plane rotary forces. In this situation, excessive lateral compartment compression and shear forces stressed the posterolateral tibiofemoral joint [12], thus making both radial and horizontal tears the most frequent injury patterns in the lateral meniscus [13].

Disruption of the circumferential arrangement of the meniscal ultrastructure caused by a tear or a meniscectomy may lead to marked increase in axial load at the articular surfaces, which lately increases the risk of knee osteoarthritis (OA) [14]. In fact, osteoarthritic changes are present at 8–16 years after arthroscopic partial meniscectomy, although clinical symptoms may not be significant [15]. Due to the particular anatomy and biomechanics of the lateral compartment, lateral meniscectomy results in a greater decrease in contact area (up to 50 %) and increase in local contact pressure (up to 335 %) resulting in worse outcomes than medial meniscectomy [16,17]. Consequently, meniscectomy should not be considered an innocuous procedure as it accelerates wear and permanent cartilage deterioration, and so, it should be cautiously indicated and skilfully performed particularly in the lateral meniscus [18].

In addition to removal of meniscal tissue, root tears or complete radial tears also effectively alter the meniscus function and increase contact pressures. Therefore, an anatomic reduction and robust fixation of the injured meniscal roots seems advisable, in order to prevent the development of OA [19].

34.3 Clinical and Radiographic Results of Arthroscopic Partial Lateral Meniscectomy

34.3.1 Short- to Mid-Term Follow-Up

Based on published data, arthroscopic partial lateral meniscectomy (APLM) gives excellent short and mid-term functional results with a significant tendency to deteriorate over time and a high incidence of degenerative changes.

In a retrospective review of APLM, Jaureguito et al. [20] encountered good or excellent functional results in 92 % of the cases, and 85 % of his patients were initially able to return to their preinjury activity level. However, the results worsen at 8 years follow-up, and only 62 % and 48 % of the patients were still good and were able to maintain the activity level, respectively [20].

Hoser et al. [21] evaluated the outcome of APLM of 31 knees that were otherwise normal. At a mean follow-up of 10.3 years, a mean Lysholm score of 80.5 points was found (14 excellent, 4 good, 5 fair and 8 poor). Radiological degenerative changes were seen in all but one lateral compartment. Interestingly, no significant correlation was found between the amount of tissue resected and the subjective, clinical and radiological outcome [21].

Bonneux and Vandekerckhove [22] conducted an 8-year follow-up retrospective case-control study on 31 knees having had APLM for isolated lesions of the lateral meniscus. Based on the IKDC score, 48 % of the patients were rated as excellent or good while 64.5 % do so according to the Lysholm score. With regard to the activity, the initial Tegner score of 7.2 (competitive sports) dropped to 5.7 (recreational sports). On the other hand, Fairbank degenerative radiological changes were noted in 92.9 % of the cases. The authors concluded that the extent of meniscal resection was a significant factor for the poor results [22].

Chatain et al. [18] retrospectively compared the results of arthroscopic partial medial meniscectomy with those of APLM in stable knees. The series included 362 medial and 109 lateral isolated arthroscopic meniscectomies with a minimum follow-up time of 10 years. They found 95 % of the patients very satisfied or satisfied with the results of the medial meniscectomy and 95.5 % with the results of the lateral meniscectomy. According to the IKDC form, 85.8 % of the medial meniscectomy group were free of any symptoms, as were 79.7 % of the lateral meniscectomy group. With respect to radiological changes, joint space narrowing was found in 21.5 % of the cases after medial meniscectomy and 37.5 % after lateral meniscectomy, respectively. Based on the obtained results, the authors concluded that partial meniscectomy, either medial or lateral, were well tolerated, and the clinical results in both sides were quite similar. However, the radiological results were significantly worse after lateral meniscectomy. An isolated medial meniscal tear with one or more of the following factors – age less than 35 years, a vertical tear, no cartilage damage and an intact meniscal rim at the end of the meniscectomy – were found to be prognostic or good results [18].

34.3.2 Long-Term Follow-Up

The available data after APLM on the long-term, meaning more than 10 years, is very limited. Burks et al. [23] followed up a series of 146 patients who had undergone arthroscopic partial meniscectomy at an average of 14.7 years. Twenty-seven of them had undergone APLM. At the latest follow-up, 88 % of patients with APLM were rated as good or excellent in anterior cruciate ligament-stable knees. The radiographic joint space side-to-side difference showed the operative knee to be only a 0.23 grade worse than the nonoperative knee. With respect to prognostic factors, the authors found that male patients had better radiographic results than female patients, but not better functional scores. Surprisingly, age at the time of meniscectomy was not found to be a relevant factor. The results were not significantly different in medial meniscus than in lateral meniscus. The knees with anatomic femoral-tibial alignment (more than 0° valgus) that had undergone medial meniscectomy had significantly better radiographic results. Finally, patients with anterior cruciate ligament deficient knees and meniscectomy did significantly poorer than those meniscectomized with stable knees in terms of radiographic changes and medial joint space narrowing, Lysholm score, satisfaction index and Tegner level [23].

Between 1982 and 1991, Scheller et al. [24] also conducted a retrospective case-control study to determine the clinical, functional and radiographic long-term results of patients who underwent APLM in an otherwise normal knee. The series was composed of 107 APLM, and 75 of these patients had an isolated lateral meniscal tear. The 77 % excellent and good Lysholm score results obtained at shortly after surgery decreased to 66 % at follow-up. Nevertheless, 43 % of patients were able to maintain their level of maximal improvement. One or more Fairbank changes were observed in 78 % of the patients at follow-up. Again deterioration of functional and especially radiographic results occurred with time, and the longer the follow-up, the more radiographic changes have to be expected. In spite of the high percentage of radiological changes, no significant correlation between subjective symptoms nor with functional outcome could be established [24].

Recently, a retrospective multicenter study was undertaken by the French Society of Arthroscopy [25]. The purpose was to evaluate the long-term effects of APLM and to identify those patients who are at the most risk of developing OA. Eighty-nine patients with a mean age of 35±13 years at the time of surgery and stable knees were included. The contralateral knee was used as a reference to calculate the prevalence and the incidence of OA.

At an average of 22±3 years, 48 % of the patients had an active lifestyle, with a KOOS score of 69 %, being 82 % before surgery. The prevalence of OA was 56 % in the affected knee, and the difference of prevalence between the operated and healthy knees was 44 %. In those patients presenting with OA of the operated knee and a normal contralateral knee, the incidence of OA was 53 %. Predictors of OA were an age superior to 38 years at the time of index surgery, obesity (defined as a BMI of 30 or greater), valgus malalignment as well as the presence of cartilage and degenerative meniscal lesions at the time of surgery. According to the findings, it was concluded that APLM in stable knees without initial cartilage lesions might yield good to excellent results in young patients in the long run. Conversely, patients who are at higher risk of developing symptomatic OA are those older (over 40), having a high BMI, with a valgus malalignment and with cartilage lesions at the time of surgery. However, the most important finding of this investigation was that the prevalence of osteoarthritis at 20 years follow-up was only slightly superior to the prevalence observed after 10 years follow-up in similar studies [25].

34.4 Failures

There is no consensus in the exact definition of what a failure of meniscectomy is. Regularly, failure is defined as the need for reintervention due to symptoms like residual pain and recurrent effusion. Due to the lesser congruence between the articulating surfaces, loss of meniscal tissue tends to produce poorer results and is more prone to develop postmeniscectomy syndrome in the lateral compartment. If merely degenerative changes were considered as a failure, the ratio in the lateral compartment would be higher.

In the series of Chatain et al. [18], 11.9 % of the patients having had APLM needed reintervention after 10 years of follow-up. Conversely, in the same period, only 6.4 % required reintervention in the medial meniscectomy group [18]. Hoser et al. [21] found a higher rate of reoperation (29 %) in their 10-year follow-up study. The Lysholm score for patients who had a further operation was significantly worse than for those who did not. Finally, Bonneux and Vandekerckhove [22] reported a 12.9 % reoperation rate at 8 years of follow-up.

There are also cases of a rare condition called rapid chondrolysis of the knee that may appear shortly after APLM. However, the causes of this complication have not been clearly identified [26]. It is likely that mechanical overloading causing chondrocyte necrosis and cartilage matrix damage might be implicated as suggested by [27]. It is also plausible that the increase in subchondral stresses caused by the loos of meniscal tissue might play a role [28].

All in all, the failure rate is superior in the lateral compartment when compared with the medial compartment [18], and further operations mainly include new arthroscopic procedures, varus osteotomies [21] and more recently allograft meniscal transplantation.

Conclusion

The good to excellent results obtained with APLM immediately after surgery deteriorate with time. However, according to the newest evidence, APLM in stable knees without initial degenerative cartilage lesions may yield good results in young patients in the long term. The factors that put patients at higher risk to develop symptomatic OA are well identified: (a) age, over 40 years; (b) overweight, BMI more than 30; (c) a valgus malalignment; and (c) cartilage lesions at the time of surgery. Therefore, even the lesser meniscal resection should be carefully considered in these cases.

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Meniscal Repair: Intra- and Postoperative Complications

35

Nicolas Graveleau, Romain Seil, Christophe Hulet, and Goulven Rochcongar

Contents

35.1 Introduction

Restoring and preserving meniscal status is one of the most challenging goals in the field of knee arthroscopic surgery. Meniscal preservation after the repair and healing process is necessary to avoid the early degenerative changes that frequently occur in totally or partially meniscectomized knees.

Arthroscopic techniques and implants for arthroscopic repair have continually improved in quality and popularity since the 1990s. Their ease of use, the minimally invasive/full arthroscopic approach, and the high quality of reconstructions obtained have led to a wide and frequent use of these products. Not only do they allow us to minimalize surgical incisions and neurovascular risks, but we are also able to

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_35

decrease operating time, while ensuring that the biomechanical properties of the repaired meniscus are as close as possible to those obtained with vertical sutures [1].

Complication rate after arthroscopic meniscal procedures was not very often subject to large surveys to determine its exact incidence, but it is generally considered as being relatively low. An analysis of large surveys of meniscal repair procedures performed by SFA in 2004 [2] showed that serious injury involving neurovascular structures was rarely encountered with a result of 5/278 operated patients for meniscal suture. The Arthroscopy Association of North America (AANA) in 1985, with a large retrospective study from De Lee [3], reported an overall complication rate of 0.6 %. In this survey, which focused on diagnostic arthroscopy and first-generation arthroscopic surgical procedures, some serious neurological and vascular complications were identified. Specific complications in meniscal repair procedures were not considered in this study. Variability in the reported overall complication rate of arthroscopic meniscal surgery depends on the criteria used to define a surgical complication. The French Arthroscopy Society (SFA) conducted a prospective study and reported an overall complication rate of 16 % in Coudane and Buisson [4]. In a prospective survey of 8,741 knee joint procedures, the AANA evaluated complications in arthroscopic surgery [5]: the overall complication rate was 1.8 %, and the incidence of complications was no higher for meniscal repair (1.2 %) than for partial meniscectomy (1.7 %), at the time when surgeons were regularly mixing open/arthroscopically assisted meniscal repair (outside-in and inside-out techniques) and arthroscopic all inside repair.

Intraoperative complications are mainly related to the approach of the meniscus with potential lesion of neurovascular structures surrounding the knee [6–8] and cartilage lesions due to sharp surgical devices used for the meniscal repair.

Postoperative complications (excluding rare nonspecific complications of arthroscopic knee surgeries [9, 10]) are cartilage damage mostly due to intra-articular shape of implants and failure of the healing process of the meniscus itself.

Making a decision in arthroscopic meniscal repair and receiving consent from our patients should take in account these potential complications.

35.2 Intraoperative Complications

These complications are mostly related to the approach of the knee, which is literally surrounded by different important anatomic structures. If major vascular injuries (popliteal arteries) are exceptional, neurologic damage during surgery is still a concern for surgeons. The two posteromedial and posterolateral neurologic structures, respectively, named "saphenous nerve" and "peroneal nerve" are the two structures that have been described as being susceptible to direct trauma due to surgical approach/instrumentation, passage/suture, and anchor stitching.

35.2.1 Neurologic Complications

35.2.1.1 Saphenous Nerve Injuries

The saphenous nerve is the medial structure which is most "at risk" of damage during medial meniscal suturing. The frequent injury of the saphenous nerve and its infrapatellar branches during medial meniscal refixation is explained by the fact that the nerve proceeds directly under the tendons of the sartorius and gracilis. At the level of the joint space, the saphenous nerve enters the subcutaneous tissue and runs with the great saphenous vein distally. The course is variable by (according to?) Morgan and Casscells [11]: the nerve can be both ventral and dorsal to the vein. At 0–20° of knee flexion where the meniscus is usually carried out, it is therefore either just ahead or just behind the posteromedial joint area and can be caught outside by the knot or inside by the loop of the stitch in the case of the outside-in technique. Because of this extremely variable anatomy, a secure zone cannot be described.

The nerve injury can be involved in the main trunk of the saphenous nerve or one of the infrapatellar branches. The complication rate is estimated to be up to 22 % according to Barber (1987) in the medial meniscal repair of 24 patients [12]. Usually saphenous neuropraxia results in clinical symptoms including pain with some degree of paresthesias and numbness. It is most often reversible after a period of 1–12 months, according to Stone [13]: from 43 % after surgery to 8 % at revision. This complication is very "classical" in inside-out arthroscopic-assisted repair with an additional posteromedial approach. Some surgeons have developed specific approaches or instrumentation (Henning's retractor, arthroscopic transillumination at the posteromedial corner) or used specific retractors (spoon) to protect the saphenous nerve at the time of passing suture and stitching knot.

Spindler et al. [14] reported a 13 % nerve injury rate when repairing the medial meniscus with a mini-open inside-out technique vs. 0 % when using arrows with an entirely arthroscopic technique. When an all-inside meniscal repair is performed, saphenous nerve irritation can be caused by implant failure and migration [15] or by a prominent meniscal arrow tip [16]. In any case, after skin incision, caution must be taken to dissect and retract soft tissue down to the joint capsule before penetrating the capsule with sharp instruments or tying a knot. In case of persistent saphenous nerve irritation, steroids or long-acting anesthetic drugs can be locally injected and usually lead to good functional recovery.

35.2.1.2 Peroneal Nerve Injuries

The peroneal nerve is the second and lateral neurological structure at risk in lateral meniscal repairs. In an anatomic cadaveric study, Jurist et al. [17] showed that inside-out needles placed into the posterior horn of the lateral meniscus are very close to the peroneal nerve. Location of this nerve is highly variable due to its anatomical variations in terms of proximal division. Henning [18] referred three different mechanisms of damage:

- Nerve puncture with needle (used to pass the suture)
- Nerve suturing (by tying the knots over the nerve)
- Nerve tethering (in surrounding scar tissue)

These injuries were described by Jurist (1989), Krivic (2003), and Casscells (1988) [17, 19, 20] and reported a rate of 3.4 % of incidence in an informal survey of AAOS [3]. The nerve injury usually occurs when a posterolateral approach is used to repair the meniscus (directly or by an inside-out or outside-in technique). Peroneal nerve injury can be caused by a surgical approach, instrumentation puncture, or sutures tied over the nerve. The quality of neural recovery after healing and functional recovery depends of the type of injury. An all-inside repair technique appears to be safer with regard to peroneal nerve injury as long as the depth of penetration of the meniscal device and implant is being controlled. When a posterolateral incision is used, the peroneal nerve must be protected by a retractor placed anterior to the biceps tendon, and the knee must be held in 60–90° of flexion at the time of suturing (while taking into consideration the anatomic variability in the course of the nerve). Peroneal nerve palsy after lateral meniscal repairs especially in the inside-outside technique requires early diagnosis and exploration of the potentially entrapped nerve.

35.2.2 Vascular Complication

Popliteal artery injury is exceptionally rare but could lead to pseudoaneurysms and arteriovenous fistulas resulting from laceration or penetration during meniscal surgery. Some reports of this complication have been made by Brasseur Carlin and Small during arthroscopic meniscectomy [5, 21, 22]. The origin of injury is usually a direct traumatism caused by an arthroscopic instrumentation such as an uncontrolled use (the misuse?) of a razor. Henning et al. in 1990 [23] reported a popliteal artery laceration after lateral meniscal repair using a posterior approach. From the proximal aspect of the popliteal fossa, the popliteal artery runs from a slightly medial position to the midline, in front of the popliteal vein and medial to the tibial nerve, to a more lateral position compared to the midline, at the level of the knee joint. Then at the joint line this popliteal artery lies in close proximity to the posterior region of the lateral meniscus. Because of its anatomic location, the popliteal artery is mainly exposed during lateral meniscal surgery and approach. In a cadaveric study, Cohen et al. [24] referred to the proximity of the popliteal artery with two all-inside repair devices inserted in the posterior horn of the lateral meniscus.

Choosing the correct position of the needle or meniscal implant is mandatory and is better obtained by introducing the sharp device through the contralateral portal (anteromedial portal). Inside-out repair technique for posterior part of the lateral meniscus requires the use of a posterolateral approach: insertion of needles/implant and tying of the suture is then greatly secured.

Any clinical doubt regarding potential vascular violation during meniscal repair would indicate angiography (computed tomographic or catheter-based angiography) rather than ultrasonography, prior to any revision surgery.

35.2.3 Medial Collateral Ligament Sprain and Cartilage Lesion

Arthroscopic medial meniscal suture in the middle and posterior parts of the medial meniscus can be difficult when the medial tibiofemoral compartment is tight. Passage of the instruments may damage the cartilage. Medial collateral ligament rupture has been reported during medial meniscal procedures [2, 25] when excessive valgus(?) forces are applied to a tight medial compartment. When visualization or instrumentation access to the posterior part of the medial meniscus is difficult, it is, however, possible to partially release [26] the tight medial ligament by means of several needle punctures. This technical artifice is named "medial pie crusting" of the medial collateral ligament and has been shown to be safe and efficient in addressing the posterior part of the medial meniscus in tight knees. Healing is usually achieved with no residual laxity or local pain [27].

35.3 Postoperative Complications

As for all other meniscal arthroscopic procedures, meniscal repair can result in surgical complications: both nonspecific and specific complications.

35.3.1 Nonspecific Complications

Despite nonspecific complications being rare and equally prevalent after any type of arthroscopic meniscal surgery, some may be responsible for severe morbidity. Deep vein thrombosis (DVT), subsequent pulmonary embolism, and septic arthritis sometimes lead to serious consequences.

35.3.1.1 Deep Venous Thrombosis (DVT)

Deep venous thrombosis (DVT) following knee arthroscopy is a consistent finding in studies of unprophylaxed patients when routine screening using venography or ultrasonography is performed. Demers et al. [28] found that 17.9 % of 184 patients showed DVT, documented by venography. None of them were clinically suspected of pulmonary embolism, 5 % of them had proximal DVT, and 39.4 % of patients with documented DVT were clinically asymptomatic. Delis et al. [29] and Hoppener et al. [30] reported a 5.7 % incidence of DVT, as Delis reported a rate of 7.8 %, using routine ultrasonographic detection and found the risk to be significantly higher with tourniquet times of more than 60 per min or more than two risk factors for thromboembolism. Prophylaxis with low molecular weight heparin significantly reduced the rate of postoperative DVT [31] but increased the risk of minor bleeding and transient variations in platelet count in a minority of patients, although major bleeding was rare.

Pharmacological thromboprophylaxis seems justified after both knee arthroscopy and meniscal repair, especially in the DVT high-risk population, and a consensus on the duration of treatment is lacking.

35.3.1.2 Arthrofibrosis and Type 1 Complex Regional Pain Syndrome

For Kline and Miller [32], arthrofibrosis occasionally appears to be associated with meniscal repair. The hypothesis is that tissues have been overtightened, especially posterior capsular, limiting the extension of the knee. Morgan and Casscells [11] recommend to tie the sutures with the knee in full extension to prevent both excessive posterior capsular tensioning and high-intensity pain during the postoperative period. He also recommends using an adequate mix of long-acting anesthetic drugs (via intra-articular injection) and intravenous morphine, despite the real effect on reducing the incidence of RSD not having been proven.

Type 1 complex regional pain syndrome or reflex sympathetic dystrophy (RSD) is a multisymptom syndrome, usually affecting all extremities. Associated symptoms include vasomotor disturbances and unusually prolonged pain and night pain, in addition to trophic changes in the soft tissues and skin. O'Brien et al. [37] advocated arthroscopic procedures as the most common (event precipitating) RSD of the knee. Because RSD remains poorly understood and often difficult to treat, neural blockage is helpful in obtaining resolution of symptoms. Complete functional recovery is usually obtained after a period of 6–24 months. The prognosis appears to be closely related to the presence or absence of a remaining anatomic lesion or a persistent painful stimulus. In the postoperative period, pain can be relieved by intra-articular injection of long-acting anesthetic drugs or morphine, but the effect on reducing the incidence of RSD has not yet been proven. Patellar tendon contracture and loss of patellar height are both less common in RSD [33], but can be involved in the mechanical limitation of knee flexion. If patella infera persists after the resolution of all RSD symptoms, surgical lengthening of the patellar tendon can be suggested, as described by Dejour et al. [34].

35.3.1.3 Infection

Infections after arthroscopic procedures are rare events. Specific relationships between arthroscopic meniscal implants for repair and postoperative infections have not been well established. However, diagnostic arthroscopy without additional interventions has a very low infection rate, which is reported in the literature from 0.04 to 3.40 % [32, 35, 36]. Small [5] reported a 0.21 % rate in 8,791 arthroscopic knee procedures. The infection rate after surgery increases according to operating time, number of previous interventions, the extent of the surgical procedure, and particularly following a former steroid injection. Even after meniscal sutures, infection can occasionally occur. The most commonly identified germs in septic arthritis after arthroscopic knee surgery are the Staphylococcus and Streptococcus species. Long operating times, intra-articular steroid injections, and inadequate sterilization of arthroscopic instruments (in particular cannulas) all increase the risk of septic arthritis, as reported by Blevins et al. [35]. Early diagnosis, immediate arthroscopic lavage, combined with prolonged antibiotics adapted to the germ are crucial in achieving recovery.

35.3.2 Specific Complication Related to the Meniscal Repair

Some meniscal implants will be reabsorbed over time, which could affect their biomechanical properties and lead to possible fragmentation and migration, potentially risking further specific complications [38–60]. Many meniscal repair implants were made of polylactic acid or its derivatives and were subject to the reduction of tensile strength after a period of 6–12 weeks. The structural integrity of these implants declines with time, leading to a decrease in the molecular weight and eventual fragmentation of the implant in the joint [38] or a nonspecific foreign-body reaction, induced by a lower molecular weight polymer. Developing a foreign-body reaction induced by the degradation of the implant can cause aseptic synovitis in the joint [39] or cystic subcutaneous reaction out of it [40–46].

35.3.2.1 Mechanical Symptoms Related to the Fixation Devices

Some mechanical complications are related to the use of bioabsorbable meniscal implants, i.e., local irritation at the site of repair usually resolving within 3–12 months [47], implant breakage [47, 55, 57], subcutaneous migration [58], articular migration [57], foreign-body reaction [39, 59], cystic hematoma formation [42], and synovial cyst formation [40, 41]. Mechanical irritation of the knee has been previously the only complication in reparation as reported by Petsche [47] in 2002. Oliverson [58] and Ganko [43] reported a subcutaneous foreign body in 5 cases: a migrated arrow appeared under the skin of the knee. Because all-inside meniscal repair techniques remain technically demanding procedures, some complications are particularly encountered during the learning curve period: intra-articular loosening of the implant, articular deployment of the implant, failure or sectioning of suture during tensioning, and finally intraoperative meniscal and chondral damage [48–57]. It must be known that the final static (probe) and dynamic (flexion-extension) stability of the repair should be addressed as a final step of the surgical procedure.

35.3.2.2 Meniscal Cyst Formation

The meniscal cyst formation is also well documented in the literature relating to irritation of the surrounding structures by stitches or anchors in the soft tissues [40]. Symptoms such as painless mass are usually described, with free intervals related to the index surgery.

Subcutaneous migrations of meniscal fixation devices are also described by Hutchinson (1999), Hechtman (1999), and Ganko (2000). This complication was described by Jones (2002) in as many as 32 % of the 38 patients involved, where the arrow technique repair for the meniscus was performed. It is usually spontaneously resolute but should sometimes be addressed with a surgical approach when symptomatic.

35.3.2.3 Aseptic Synovitis

References were made by Blevins (1999), Ganko (2000), Song (2001), and Asik (2002) [35, 39, 43, 47]. The exact mechanism of so-called “aseptic” synovitis is not well understood. The shape of the implant which could be prominent in its intra-articular portion and the crystallinity of the implant as well as some other mechanical factors seem to influence the degradation and release of degradation products. A foreign-body reaction is called an immune system response to corpuscular structures which are either crystalline or metallic or made of polymers that may be poorly tolerated.

35.3.2.4 Cartilage Damage

Cartilage damage due to mechanical irritations is a major concern in the future of the knee. Many descriptions of iatrogenic cartilage damage due to some implant designs are reported in the related literature. Chondral injury is of particular concern and occurs when the tip of the arrow is not fully inserted in the meniscal tissue. Chondral damage is located in the posterior area of the femoral condyle, overlying the arrow during knee motion. The depth of the chondral rail defect created by the head of the arrow can vary from partial to full thickness. Several cases of chondral grooving have been reported [47–57].

Mensche in 1999 and Seil in 2000 advocated chondral lesion related to PLA particles responsible for foreign-body giant-cell chronic reactions with no inflammatory cell. The description is referred to rail-shaped lesions on the femoral condyle in relation to the contact between the intra-articular part of the meniscal arrows and the cartilage. Ross in 2000 and La Prade in 2004 [46, 50, 54] reported a symptomatic swollen and painful knee after meniscal repair. These persistent symptoms were related to kissing cartilage lesion, caused by bioabsorbable meniscal arrow repair device to cartilage. It has been shown by Kumar (2001) [52] with bioabsorbable screws repairs, by Menetrey et al. in 2002 [51] with anchors, and by Gliatis et al. [56] that after migration of the suture, it leads to some damages on the cartilage.

These results are in contrast to the near 0 % rate of chondral injury with meniscal repairs using traditional vertical sutures or all-inside fast-fix suturing devices [21].

Some other complications are not related to the surgical technique and surgical approach itself, but more to the anchors, sutures, or fixation devices used to fix the meniscal lesion. To ensure adequate passage of stitches around and in the meniscal lesion, sharp and sometimes quite voluminous instrumentation needs to be manipulated in the knee in contact with the cartilage surfaces.

35.4 Discussion

Complication rate after knee arthroscopy procedures like meniscal repair has become low over time especially due to technological and industrial progress.

Because many implants have some potential disadvantages and could be risky especially for the cartilage, all potential meniscal repairs should be considered not only as an opportunity to protect the cartilage in the future but also as a procedure which requires follow-up of the patients after surgery to depict any possible side effects from the procedure. Persistent pain, residual swellings, or abnormal tumefaction around the knee in the area of the suture should be closely examined and monitored. Migration or side effects of the implanted devices should also be checked.

Simple to complex meniscal repair with intra-articular implants represent an interesting and safe alternative to the classic meniscal suture in reconstructive meniscal surgery. The different operating principles and elaborate tools enable the adequate treatment of most meniscal lesions to form and reach many locations in the knee via arthroscopic approaches.

The development of modern hybrid implants has significantly reduced the morbidity rate as well as the number of specific complications due to the technique and the implant itself. Since it is a more standardized procedure, the actual number of complications remains a concern for surgeons and patients.

The last real "complication" surgeons are now facing is the average rate of 20 % of nonmeniscal healing following healing repair [61]. Altogether, it is probably an acceptable and comprehensive rate in relation to the potential evolution of arthritis in young patients after early meniscectomy in an active population.

Conclusion

Meniscal repair surgeries with dedicated 3rd-generation hybrid meniscal implants are mainly full arthroscopic procedures with a relatively low morbidity, comparable to regular arthroscopic meniscectomy. Surgeons are able to provide patients with valuable techniques; for rare complications among which, neurovascular damages are the most serious because they could lead to permanent consequences. Complications related to the surgical approach and repair technique can mainly be avoided with correct and proven surgical techniques and approaches, combined with a thorough understanding of the posteromedial and posterolateral neurovascular anatomy of the knee. Appropriate training of orthopedic surgeons is required to master the method of repair and to avoid specific pitfalls and complications of all-inside meniscal devices in well-selected indications for repair.

Today the most prevalent "complication" is the nonhealing of the meniscus itself, exposing the knee to further cartilage degeneration and late development of knee arthritis.

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Meniscal Repair: Results

36

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Contents

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36.1 Meniscal Repair: Short-Term Results (Clinical Outcomes and Imaging)

36.1.1 Introduction

The concept of meniscal healing and preservation has risen since the end of the 1980s [8, 28], even though the first open meniscal repair was performed by Sir Thomas Annandale in 1885 [5, 6]. With the growing trends toward meniscal repair in order to decrease degenerative changes and osteoarthritis in young patients, there have been many advances in repair techniques since the introduction of the arthroscopy. This chapter will summarize the current results of meniscal repair for longitudinal traumatic lesions in the short term (clinical outcomes, healing, failures). Furthermore, the repair of horizontal meniscal cleavages will also be discussed.

36.1.2 Meniscus Repair: Short-Term Clinical Outcomes

Clinical outcomes, including reoperation rates and subjective outcomes, of recent studies using modern repairing techniques at short- to midterm follow-up are summarized in Table 36.1 (literature review up to March 2015). Old open techniques and all-inside techniques with arrows have been excluded from this review because these techniques are not recommended anymore

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_36

nowadays. In all the studies, there was a large heterogeneity, including tear pattern, location, and patient demographics, and the authors stated that nonsignificant differences may be due to underpowered studies. In this population of patients (Table 36.1), the mean age was 28.3 years, the ACL was shown at 80.2 %, the ratio between medial and lateral repaired meniscus was 2/1, the mean failure rate was 17 %, and the Lysholm score was on average 92.5 % at follow-up.

36.1.2.1 Difference Between Techniques

Despite an increase in the number of published series that evaluated meniscal repair, there is no consensus on the ideal technique. Grant et al. (2012) [24] published a systematic literature review of inside-out versus all-inside meniscal repair in isolated peripheral, longitudinal, unstable meniscal tears. This demonstrated that there was no clear benefit of 1 technique over the other with regard to structural healing, perioperative complications, clinical outcomes, nor reoperation rate.

36.1.2.2 Medial Versus Lateral Meniscus

Barber-Westin et al. reviewed 23 relevant papers about the clinical results and healing rates after meniscal repair in the red-white zone [10]. Patient age, chronicity of injury, lateral or medial side, gender, and concurrent ACL reconstruction did not adversely affect the results.

36.1.2.3 Time from Injury to Surgery

Recent tears (less than 12 weeks) may have a better prognosis. Chronic bucket-handle tears may be difficult to reduce (plastic deformity) and to repair properly without over-tensioning the sutures to the capsule. Nevertheless, Popescu [46] and Espejo-Reina [21] reported good functional results and low reoperation rates after repairing chronic meniscal tears when compared to repairs done in the acute phase. So a chronic meniscal lesion can be repaired if the tissue quality is good enough and the decision should be taken during the surgical procedure.

36.1.2.4 ACL Reconstruction

The meniscal repair is frequently associated with ACL reconstruction. Lyman et al. [42] reported good clinical outcomes in their day surgery database (9529 patients) with 8.9 % reoperation rate and a decreased risk if a concomitant ACL reconstruction was performed. For Wasserstein et al. [59], a meniscal repair performed in conjunction with ACL reconstruction carries a 7 % absolute and 42 % relative risk reduction of reoperation after 2 years compared with isolated meniscal repair.

36.1.2.5 High-Level Sports

Alvarez-Diaz et al. [4] reported a case series of 29 competitive football players. Twenty-six (89.6 %) patients returned initially to the same level of competition. Five years after surgery, 45 % were still able to continue playing football at any level.

36.1.3 Failures

Subsequent meniscectomy should be considered as the main clinical failure after meniscal repair. Johnson et al. [32] reported a secondary meniscectomy rate of 24 % 10 years after open meniscal repair. In Rockborn and Messner's [54] study, this rate was 29 % at a mean follow-up of 13 years. However, the failures included lack of healing in one third of cases and re-tears after healing in two thirds. At the French Arthroscopic Society symposium in 2003 [19], 203 cases were retrospectively reviewed. Secondary meniscectomy was performed in 23 % of cases at a mean follow-up of 45 months. Twenty-four percent of medial meniscal repairs and 11 % of lateral meniscal repairs were converted into secondary meniscectomy, which was performed within the first 2 years in 79 % of cases. Moreover, Arnoczky et al. [7] showed that meniscal healing takes place over a period of at least 18 months. Nonetheless, instability of the repair early in this period may result in unsuccessful healing of the tear.

Early failures (6 months) should be considered as technical failures or as resulting from improper patient selection. Failures are most

Table 36.1 Bucket-handle meniscal tear 3 years after meniscal repair: new location into the avascular zone (the first lesion at the meniscosynovial junction completely healed)

Author	Nb of patients	Mean age (years) at time of surgery	Mean follow-up (months)	Concomitant treatment of ACL injury (*n*)	Medial/lateral meniscus	All-inside implant or other techniques used	Failure rate (secondary meniscectomy or re-repair)	Mean functional outcome
Kotsovolos et al. [36]	58	32.6	18	36	34/27	Fast-Fix	9.8 %	Lysholm = 87.5
Barber et al. [12]	41	28	30.7	29	26/15	Fast-Fix	17 %	Lysholm = 87.4
Konan and Haddad [35]	288	32	18	138	171/141	Fast-Fix (258 cases)	10.3 %	–
Dehaan et al. [20]	27	31	38	27	22/5	Fast-Fix	22 %	Lysholm = 90
Gallacher et al. [23]	148	28	64.8	148	110/38	Clearfix/Fast-Fix	28 %	–
Logan et al. [40]	45	23.2	102	37	30/15	Outside-in	24 %	Lysholm = 89.6 IKCD = 85.4
Popescu et al. [46]	25	31	20	11	20/5	Fast-Fix	16 %	Lysholm = 95
Westermann et al. [60]	235	21	72	235	154/72/9 bimeniscal	210 all-inside 19 in-out 6 out-in	14 %	IKDC = 87.4
Hoffelner et al. [29]	27	31	54	17	19/8	Fast-Fix		Lysholm = 85
Haas et al. [25]	42	27	24.3	21	23/9/5 bimeniscal	Fast-Fix	13.5 %	Lysholm = 94 IKDC = 92
Kalliakmanis et al. [33]	265		24.5	265	181/99	T-Fix, Fast-Fix, RapidLoc	10 %	
Billante et al. [16]	38		30.4	38		RapidLoc		
Barber et al. [11]	32		31	23	25/7	RapidLoc	12.5 %	Lysholm = 93.6
Quinby et al. [53]	54		34.8	54		RapidLoc	9.3 %	
Espejo-Reina et al. [21]	24		46	16			17 %	Lysholm = 95
Hacklar [26]	112	29	49.3	89	112 M	Inside-out	10.6 %	Lysholm 89.5
Pujol and Beaufils [48]	54	25	12	31	36/17	Fast-Fix	6 %	IKDC = 78.9

frequent between 6 and 24–36 months [47]. They represent real healing failures and should be evaluated separately. After 24–36 months, a failure mainly occurs on meniscal scar tissue (Fig. 36.1) and might be called a true re-tear (Table 36.1). Moreover, a systematic review of clinical results of all-inside meniscal repairs was published in 2007 [41]. The clinical failure rate varied from 0 to 43.5 %, with a mean failure rate of 15 %. In Table 36.1, the reoperation rate of the recent literature for failure after meniscal repair using modern techniques is stable (mean 17 %).

36.1.4 Trends in Meniscal Repair Practice

In 2013, Abrams et al. [1] published a review in the trends of knee arthroscopic procedures performed in the USA between 2005 and 2011 using a national database compiled from a collection of private insurance records. There were 387,833 meniscectomies and 23,640 meniscal repairs performed, as well as a doubling of meniscal repair performed over that time, although the meniscal repair represented only 6 % of the meniscal procedures. Moreover, there was no significant change in the number of meniscus repairs performed at the same time or ACL reconstruction during the study time frame. Likewise, the most concerning part remained to be the high rate of meniscectomy (65 %) performed during ACL reconstruction when there is a meniscal tear, when compared to meniscal repair (25 %) and tears left in situ (9 %) [45]. Similarly, Wyatt et al. [61] reviewed 5712 patients with meniscal tears and an ACL reconstruction. They found significant factors which determined if the meniscus was repaired, such as younger patient age, lower BMI, higher surgical volume, and if the surgeon was sports fellowship trained. Subsequently, it has been shown that trends in meniscal practice are in favor of a slight increase toward meniscal repair, although it must be improved. Additionally, scientific societies have a crucial teaching role in promoting meniscal repair in the future.

36.1.5 Short-Term Imaging

36.1.5.1 Short-Term Imaging Features

Some objective methods to assess meniscal healing, such as arthrography and second-look arthroscopy, are invasive and therefore ethically questionable if the patient has no complaint. Hence, conventional MRI had been proposed as an alternative to assess the healing status of meniscus after repair. With conventional MRI, a nonspecific hypersignal persists at the repair site more than 6 months after surgery. Farley and al. [22] compared arthrography and MRI in the assessment of the meniscal healing after repair, which demonstrated that T2 fat sat MRI sequences had a sensitivity of only 60 % and a specificity of 90 %.

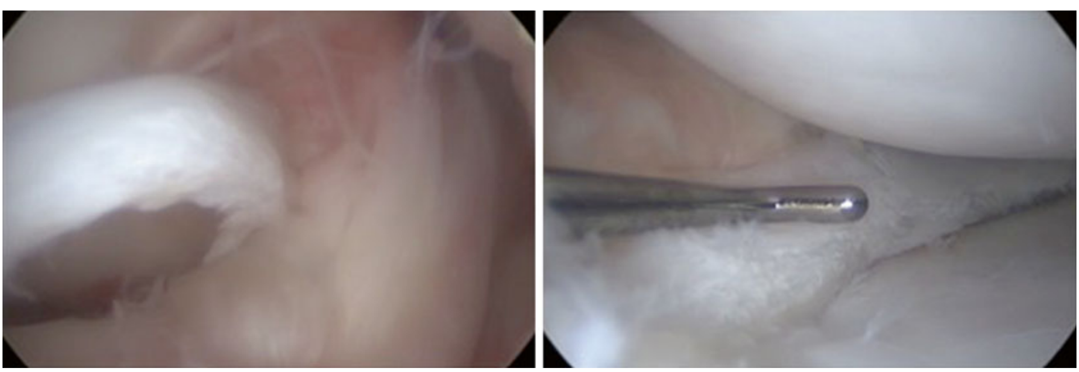

Fig. 36.1 Partial meniscectomy 2 years after repair of a complete bucket handle meniscal lesion in red red zone: it's a re-tear in white-white zone

Hantes et al. [27] assessed the healing process of the meniscal repair by indirect MRI at 3, 6, and 12 months after the operation. Through this, a postoperative hypersignal was found in each of the 20 patients involved in this study at 3 months. Moreover, a significant reduction (but not total disappearance) of this hypersignal occurred from 3 to 12 months, which suggested that the meniscal healing process lasted for at least 12 months. Miao et al. [44] evaluated the MRI signal characteristics and MRI diagnostic accuracy in identifying completely healed repaired menisci. Likewise, a second-look arthroscopy confirmed complete healing, and a T2 hypersignal was found in 63 % of the 38 cases at a mean follow-up of 16 months. Furthermore, MRI diagnostic accuracy correlated positively with the follow-up time. Nevertheless, other authors found that conventional 1.5 T MRI was unsuitable and unreliable for diagnosis of the healing process of a repaired meniscus [17, 39, 52] (Fig. 36.2).

Hoffelner et al. assessed meniscal repair in 27 patients with a 3-T MRI. They found good, but no definitive reliability on meniscus healing, and therefore with no additional advantage compared to 1.5-T MRI for patients with adequate clinical outcomes [29]. By adding MR arthrography to a 3-T MRI, sensitivity, specificity, and accuracy raised to 80, 100, and 84.6 %, respectively [34, 43]. Moreover, conventional arthrography had a sensitivity and a specificity rating of 90 % [22].

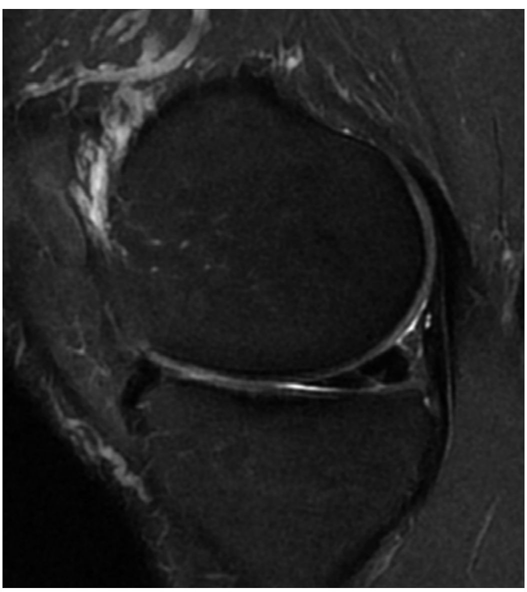

Fig. 36.2 Persisting hypersignal in the repaired area 10 years after meniscsu repair

A few studies have compared MR arthrography with CT arthrography. For example, Toms et al. [57] compared indirect MR arthrography with CT arthrography for imaging of the postoperative meniscus. They found that CT arthrography had the advantage of being quick and less susceptible to a variety of artifacts and concluded that it would likely be the investigation of choice if the clinical picture is clearly one of a recurrent tear.

36.1.5.2 Short-Term Imaging Outcomes and Second-Look Arthroscopy

The researcher conducted a literature review (PubMed search from 1982 to March 2015) of the different healing rates observed by second-look arthroscopy, arthrography, arthro-MRI, and arthro-CT scan. For the reasons mentioned above, MRI has not been considered in this review (Table 36.2). The results are different according to the measurement method, which works toward a better healing with second-look arthroscopy. This is possibly due to the subjectivity of the arthroscopy when compared to imaging. However, healing after meniscal repair was not better in the most recent studies when compared to the other studies, despite technical improvements and increasing knowledge of the pathology in the last decades. Hence, this represented a major challenge for the future, which would technically be by the use of biological enhancers. Also, there is no indication for a routine assessment of meniscal healing. If the patient has clinical symptoms at least 6 months after a meniscal repair, conventional MRI is difficult to interpret. Therefore, arthro-CT scan or MR arthrography should be considered first in these cases.

Table 36.2 MRI 2 years after meniscal repair: note the presence of a hypersignal in the repaired zone, without any significance if the patient has no complaint

Anatomical control of meniscal repair	Author	Year	*N*	Results (%)		
				Complete healing	Partial healing	Lack of healing
Arthroscopy	Horibe et al. [31]	1995	132	73 %	17 %	10 %
	Asahina et al. [9]	1996	98	74 %	13 %	12 %
	Horibe et al. [30]	1996	36	75 %	11 %	14 %
	Kurosaka et al. [37]	2002	114	79 %		21 %
	Ahn et al. [3]	2004	32	82 %		18 %
Arthrography	Henning et al. [28]	1987	81	71 %	20 %	9 %
Arthroscopy or arthrography	Scott et al. [55]	1986	178	73 %	13.5 %	13.5 %
				59 %	18 %	23 %
	Cannon and Vittori [18]	1992	69	88 %		12 %
			21	62 %		38 %
Arthroscopy (15) Arthrography (41)	Van Trommel et al. [58]	1998	56	45 %	32 %	23 %
Arthro-CT scan	Beaufils, and Cassard [13]	2003	62	42 %	31 %	27 %
	Pujol et al. [50]	2008	54	58 %	24 %	18 %
Second-look arthroscopy	Ahn et al. [2]	2010	140	84.3 %	12.1 %	3.6 %
	Tachibana et al. [56]	2010	62	74 %	15 %	11 %
Arthro-MRI	Popescu et al. [46]	2015	28	53.6 %	35.7 %	10.7 %
	Kececi et al. [34]	2015	26	38.5 %	61.5 %	

36.1.6 Outcomes of Meniscal Repair of Horizontal Cleavage Tears

Meniscal tears can have either traumatic or degenerative causes. In younger patients, traumatic tears frequently occur during sports injuries. These tears often result in pain localized to the joint line. In contrast, degenerative tears, which are typically associated with aging and osteoarthritis, often occur without an inciting episode. Moreover, in between, horizontal cleavages that occur in young patients are a specific entity [14]. These lesions extend from the capsular junction to the avascular zone of the meniscus, so a meniscectomy of such lesions would be a subtotal meniscectomy. This is result is unacceptable in young patients unless the lesion is reparable, because of the risk of deterioration and flattening of the articular cartilage surfaces and subchondral bone sclerosis with time. Consequently, meniscal repairs have been proposed to treat such horizontal cleavages.

Biedert was the first to describe four different treatments for such lesions (no operative treatment, partial meniscectomy, trephination, meniscal repair) [15]. The researcher previously reported a retrospective series of 30 cases operated on using an open meniscal repair technique at a mean follow-up of 4 years. The clinical outcomes were good (median subjective IKDC score at 89 ± 14, 15 % reoperation rate), and the functional results decreased significantly with age after 30 [49]. In addition, another case-control series was published recently and supported the use of PRP (platelet rich plasma) to enhance meniscal healing [51] in this specific entity. Kurzweil et al. published a literature review regarding meniscal repair of horizontal meniscus tears. Among nine eligible articles (a total of 98 repairs), the overall success rate without subsequent surgery was 77.8 % [38]. Subsequently, the conclusions demonstrated that literature does not support the hypothesis that surgically repaired horizontal cleavage tears have an unacceptably low rate of success. Indeed, the results of the present study show that existing studies of repaired horizontal cleavage tears show a comparable success rate to repairs of other types of meniscal tears. Therefore, if the indication is correct (no osteoarthritis) and the patient is young, meniscal repair of horizontal cleavages is a valuable meniscal sparing option.

36.1.7 Summary

Clinical results of meniscal repairs are good to excellent in more than 80 % of cases, depending on multiple factors such as on the type of tear or zone of the rupture which outlines the importance of proper patient selection.

Recent tears seem to have a better prognosis. However, even in chronic tears, good functional results with low healing rates are described. Concomitant ACL reconstruction may further enhance healing of the meniscus.

Failures of meniscus repairs consist of technical failures, inadequate patient selection, as well as failed biological healing. However, there is a discrepancy of anatomical healing and clinical results as even partial healing of the meniscus may lead to a successful clinical outcome.

36.2 Meniscal Repair: Long-Term Results (Clinical Outcomes and Imaging)

36.2.1 Introduction

Meniscectomy is described with good to excellent clinical outcomes in the short term [69, 75]. However, in the long term, subsequent osteoarthritis is developed as a consequence of the meniscal loss especially in the lateral compartment [68, 82].

Therefore, the fundamental principle of preserving the meniscus, if possible, becomes even more important concerning the long-term results.

Clinical results comparing meniscectomy versus meniscus repair have shown superior results for those patients where the meniscus was preserved [73, 78, 84, 86].

Xu et al. [86] performed as meta-analysis comparing meniscal repair versus meniscectomy in the treatment of meniscal tears. In their results, seven studies were included. They could demonstrate a statistically significant difference in favor of meniscal repair for the Lysholm score as well as Tegner score. Besides, meniscal repair had a lower failure rate than meniscectomy as well. Melton et al. [73] compared three subgroups of patients having either meniscal repair, an intact meniscus or meniscectomy during ACL reconstruction, at a median follow-up of 10 years. Patients with meniscal repair showed significantly higher IKDC scores compared to the patients undergoing meniscectomy. Stein et al. [84] compared arthroscopic partial meniscectomy and meniscal repair at 3 and 8 years. They could show better clinical results and fewer osteoarthritic changes in the repaired group, especially in young patients. These findings were confirmed by Paxton et al. [78] who published a literature review comparing meniscal repair and partial meniscectomy. In the long term, meniscal repair was associated with higher Lysholm scores and less degeneration than partial meniscectomy.

36.2.2 Meniscus Repair Long-Term Results

Pujol et al. [80] investigated the long-term results of 27 meniscus repairs in stable or stabilized knee at a mean follow-up of 114 months. They could report on a mean Lysholm score of 95 and a mean IKDC score of 90. These results were not statistically different from the reported results of the same patient cohort at 1-year follow-up [79] indicating that clinically successful repaired menisci exhibited good results even in the long term.

These good to excellent long-term results were confirmed by several other papers [60, 66, 67, 73, 81, 83, 84].

A systematic review performed by Nepple et al. [74] analyzed the outcomes of meniscal repair at a minimum follow-up of 5 years. Thirteen studies with a total of 566 knees were enrolled in the study. After a mean follow-up period of 7.4 years (5–12), the overall failure rate, defined as the clinical failure rate according to the criteria of the individual study, was 23 %. Very similar failure rates were found for outside-in, inside-out, as well as all-inside repairs (22.3–24.3 %). In contrast to the results of Pujol et al. [60, 66, 67, 73, 81, 83, 84], only approximately 30 % of the failures occurred two years postoperatively indicating that failure rates increased at midterm follow-up compared to previously reported short-term results [41].

Even in meniscus ruptures in the red-white zone according to Anderson et al. [62], a repair of the meniscus may lead to satisfactory long-term outcomes. In a systematic review, Barber-Westin and Noyes [10] could demonstrate an overall success rate of clinically healed menisci of 83 %. However, only a few studies reported on the long-term results in this review [76].

Noyes et al. [76] reported on the long-term (mean 17 years) results in 22 patients who were aged 20 years or younger when the inside-out R/W meniscus repair was performed. Eighteen (62 %) of the meniscal repairs had normal or nearly normal characteristics in all of the parameters assessed. Only six repairs (21 %) required partial arthroscopic resection; 13 patients had decreased their sports level for reasons unrelated to their knee condition and had no limitations or symptoms. No patient had given up sports because of knee problems. Moreover, a chondroprotective joint effect was demonstrated in the healed menisci repairs as there was no significant difference in the mean articular cartilage T2 scores in the healed menisci between the involved and contralateral tibiofemoral compartments in the same knee.

36.2.3 Radiological Long-Term Results

Brucker et al. [66] investigated the clinical and radiological outcomes of open meniscus repair in stable knees. 8 patients were excluded due to a re-rupture of the meniscus. In the 18 remaining patients after mean follow-up of 20 (16–25) years, the mean Lysholm score was 98 and 17 patients rated their outcome as excellent (13) or good (4). Radiological evaluation demonstrated comparable osteoarthritic changes to the contralateral side reflecting natural history. The authors concluded that meniscus repair in stable knees leads to excellent clinical long-term results with only mild osteoarthritic changes comparable to the contralateral healthy side.

Paxton et al. [78] performed a systematic review comparing the clinical outcomes and reoperation rates of meniscal repair versus partial meniscectomy. Radiographic and magnetic resonance imaging were included in 66 % (4 of 6) of long-term meniscal repair studies and 100 % (12 of 12) of long-term partial meniscectomy studies. 78 % of meniscal repairs (85 of 109) had no radiographic degenerative changes compared with 64 % of partial meniscectomies (66 of 104). Moreover, one grade change or less was found in 97 % of meniscal repairs (106 of 109) compared with 88 % of partial meniscectomies (91 of 104). The authors concluded that meniscal repair was associated with less radiological degeneration than partial meniscectomy.

Rockborn and Gillquist [81] followed for 13 years a consecutive series of patients who underwent open meniscus repair. In their results, 80 % of their patients had normal knee function for daily activities. The incidence of radiological changes did not differ between the group with meniscal repair and the control group even if knee function was reduced. The authors concluded that meniscus repair in stable knees led to good long-term outcomes with nearly normal knee function and a low incidence of low-grade radiological changes.

36.2.4 Meniscus Repair in the Elite Athlete

Logan et al. [40] investigated the clinical outcomes of meniscal repairs in the elite athlete. After a mean follow-up of 8.5 years, average Lysholm score was 89.6 and IKDC score was 85.4. The traumatic failure rate was described with 11 %. However, 11 patients required revision surgery with another patient with a possible failure leading to an overall failure rate of almost 27 %. Medial meniscus repairs were significantly more likely to fail than lateral meniscus repairs with a failure rate of 36.4 % and 5.6 %, respectively.

Although the authors concluded from the results that meniscus repair and healing are possible in this selected group and most athletes can return to their pre-injury level of activity, the potential failure of more than one third especially in the medial meniscus has to be discussed in detail with the athlete prior to surgery.

36.2.5 Meniscus Repair and Concomitant ACL Reconstruction

Ruptures of the meniscus are frequently associated with concomitant ruptures of the ACL [65, 70]. In patients with concomitant ACL ruptures, however, preservation of the meniscus may be even more important, as additional rupture of the meniscus showed a significant increase in knee stability [71]. Additionally, the meniscus may have a positive effect on graft protection as well as a total resection of the medial meniscus increased the force on the ACL by about 33–50 % [77].

Furthermore, there are a few numbers of papers in the literature indicating that concomitant ACL reconstruction may have a protective effect on the meniscal repair [55, 59, 63, 76, 85].

Wasserstein et al. [59] compared the failure rates of meniscal repair with or without concomitant ACL reconstruction and reported clinical failures in 10 % in the ACL reconstruction and meniscus repair group, whereas the meniscus repair group without concomitant ACL reconstruction had a failure rate of 17 %. In another study, Noyes and Barber-Westin [76] found a clinical failure rate of 9 % in the ACLR and meniscus repair group. In the meniscus repair group without concomitant ACLR, however, the reported failure rate was 25 %.

There are different possible explanations for the lower failure rate in patients undergoing concomitant ACLR with meniscal repair compared to those who don't. One fundamental factor may be the slower rehabilitation in patients with additional ACL reconstruction, producing a low-force environment for meniscal healing [60]. As second possible explanation, drilling of the bone tunnels in ACL reconstruction may produce an improved biological environment for meniscus healing [59]. Moreover, different rupture patterns of the meniscus in patients and an ACL rupture with additional meniscus rupture which are more amendable for repair [64, 74] compared to patients with isolated meniscus ruptures commonly degenerative in nature [67, 72] may have a significant impact on healing rates as well.

The clinical long-term results in patients with meniscus repair and additional ACL reconstruction are promising. Westermann et al. [60] investigated the operative success and patient outcomes after ACLR and meniscus repair at a 6-year follow-up. 286 patients were enrolled in the study. Of those, 235 patients could be followed at 6 years with 254 medial meniscus repairs and 72 lateral meniscus repairs.

The overall failure rate leading to subsequent arthroscopy was 14 % (33/235 failures). Even if medial meniscus repairs tend to fail earlier than lateral meniscus repairs, there was no significant difference in the failure rates between medial and lateral repairs of the meniscus. Importantly, no significant differences were found in comparison of the clinical results of the investigated cohort after 2 years follow-up compared to 6 years follow-up in the KOOS, IKDC, and WOMAC scores.

Although more failures occurred in the all-inside meniscus repairs compared to the outside-in and inside-out techniques, the study was not able to show a clear difference between the failure rates based on the repair technique due to the low number of outside-in and inside-out techniques. However, these results may suggest that an adequate all-inside repair may be technically more demanding compared to the open techniques. Moreover, due to the increased costs of all-inside implants, a lower number of sutures may be used for the repairs, which may have a negative impact on the biomechanical properties of the repairs as well.

36.2.6 Summary

Clinical investigations of meniscus repairs indicate that good to excellent results can be maintained even in the long term with a success rate ranging from 14 to 25 %. Even in meniscus tears in the red-white zone, the results were satisfactory which warrants the procedure in select patients as well.

Moreover, a chondroprotective joint effect was found in the healed meniscus repairs with comparable radiological findings to the healthy contralateral knee. Therefore, preservation of the meniscus is recommended, whenever possible.

In the elite athlete with highest functional demands, however, repair of the medial meniscus seems to be associated with a higher failure rate (Fig. 36.2).

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Discoid Meniscus. Meniscus Lesions in Children: Indications and Results

37

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37.1 Introduction

The discoid meniscus (DM) is an infrequent anatomical variant first reported by Young [62] in the ninetieth century that usually affects the lateral compartment of the knee. However, the first case of a symptomatic DM was reported 40 years after Young's finding in a medial meniscus [57]. The youngest case of a symptomatic discoid meniscus was reported in a child aged 4 months [41]. The prevalence of this variant is difficult to calculate, as it is asymptomatic in most cases. Nevertheless, the estimated prevalence of lateral DM ranges from 0.4 to 17 % [23, 26, 40], and the higher rates have been observed in the Asian population [26, 32]. However, as mentioned earlier on, its actual frequency may be even higher as has been described in some cadaveric studies in which it surpasses 30 % [30, 47]. The incidence of medial DM does not exceed 0.3 % and the finding is anecdotal [10, 28].

The aim of this chapter is to review the current concepts on the origin of DM, its diagnosis and treatment and the results drawn from the available literature as well as from the experience of the authors.

37.2 Origin and Ultrastructure

Different theories have been postulated as to the origin of the DM. Smillie [51] theorized that a discoid shape is normal during foetal development,

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_37

Table 37.1 Classification of lateral and medial discoid meniscus

Lateral meniscus	Medial meniscus
Type I or complete	Complete
Type II or incomplete	Incomplete
Type III or Wrisberg type	
Type IV or ring shaped	Ring shaped

Modified from Watanabe et al.

and having a discoid shape after birth results from arrested meniscal growth during the embryological period. However, more recent embryological studies do not support this theory [11]. Kaplan [29] proposed that a repetitive movement of the meniscus due to insufficient posterior meniscal attachment caused the DM as continuous micromotion would ultimately change the meniscal shape. This theory was also refuted later on due to the fact that normal posterior attachment was observed during arthroscopic evaluations in most of the DM. Contrary to these “developmental” and “biomechanical” theories, a “congenital” theory has also been postulated. It is based on a familial series that showed several cases of DM, either lateral or medial, within families [2, 37].

Grounded in its arthroscopic appearance, Watanabe et al. [56] first classified the DM into three types. There is the type I or complete DM that covers the entire articular surface of the tibial plateau, while type II or the incomplete DM covers a great part of the tibial plateau. Therefore, the main difference between these two types is only quantitative. Type III, or the Wrisberg ligament type, is a meniscus without posterior meniscotibial attachment otherwise normal in shape. This fact increases its mobility so as to produce the classical “snapping knee” syndrome. Watanabe’s classification was expanded later on by including a type IV. It consists of a ring-shaped meniscus with a normal posterior tibial attachment [39]. Variants similar to types I, II and IV have been also described for the medial DM [2, 10, 21] (Table 37.1).

However, the DM is not only wider than a normal meniscus but is also thicker. In addition, its ultrastructure significantly differs from that of a normal meniscus. According to Atay et al. [8], the DM collagen network is altered both in the number of fibrils, which appear decreased, and in the way they are aligned. The altered collagen network weakens its architecture and may contribute to its increased tendency to tearing.

37.3 Diagnosis

Most of the discoid menisci are either asymptomatic or incidental arthroscopic findings [40, 58]. However, in symptomatic cases, the symptoms are highly variable depending on the type of DM, its location, the presence or not of a tear and rim stability [40, 59]. The onset of symptoms might not be preceded by a clear trauma and is present since childhood in some cases [59]. Conversely, symptoms appear later in adulthood in a number of knees with DM. Wong and Wang [58] retrospectively reviewed a series of 32 lateral discoid menisci. In 38 % of those patients, the onset of symptoms began at 25 years of age or older.

While a degenerative horizontal cleavage is the tear pattern most commonly found in some DM series [7, 9, 44], longitudinal or bucket handle tear patterns were present in a higher percentage of cases in some others [10, 19, 49, 53]. Nevertheless, most of the discoid menisci are asymptomatic if they do not have a tear [47].

The “snapping knee” syndrome has been considered the classical clinical sign of a DM. However, this syndrome seems to be mostly related to the uncommon hypermobile type III, the so-called Wrisberg ligament type, and is otherwise infrequently seen in the rest of the discoid menisci. When a DM is torn, the common symptoms are quite similar to those encountered in a regular meniscal tear, namely, swelling, effusion, joint line pain or locking. A history of knee popping, a clunk or a positive “giving way” as well as classical meniscal manoeuvres like the Mc Murray test may also be found. Ahn et al. [6] reported the two most frequent preoperative clinical manifestations were pain and extension block with 39 lateral DM in children. They also suggested the extension block was significantly more common in patients with the thickened anterior type than in the thickened posterior type.

With regard to the imaging, in recent years, conventional X-rays and ultrasounds have lost importance in the diagnosis of this abnormality. However, a simple radiological study can still provide some useful information [46]. Choi et al. [12] quantitatively compared radiographic findings of symptomatic lateral DM in children with those of matched controls. Significant differences in the mean height of the lateral tibial spine, the lateral joint space distance, fibular head height and obliquity of the lateral tibial plateau between the two groups were observed. Those authors suggested these findings would be helpful as a screening tool for lateral DM in children.

MRI is currently considered the "gold standard" for imaging in the diagnosis of a meniscal abnormality. Samoto et al. [48] conducted a study aimed at establishing the quantitative MR diagnostic criteria for lateral DM. MR imaging of 60 knees with arthroscopically confirmed lateral DM, and 134 knees with normal semilunar lateral menisci were analysed. They found that a ratio of the minimal meniscus width to maximal tibial width superior to 20 % on the coronal plane or a ratio of the sum of the width of both lateral horns to the meniscal diameter of more than 75 % on the sagittal plane suggested the presence of a DM. Furthermore, the presence of a "bow tie sign" in three or more consecutive sagittal MRI slices is considered pathognomonic of DM as usually this sign can only be seen on two consecutive adjacent sagittal slices. Some other MRI parameters have also been described to define a DM [13, 25, 38]. In order to provide more information to surgeons in choosing the appropriate treatment methods, Ahn et al. [4] further analysed the sensitivity, specificity and accuracy of a shift in preoperative MRI depending on the existence of peripheral tear when corroborated with arthroscopy. Finally, Choi et al. [13] has recently published a diagnostic criterion to distinguish between complete and incomplete lateral DM based on MR images.

However, the exact role MR imaging may play has been a matter of controversy. Kocher et al. [34] suggested that clinical examination was more sensitive for lateral DM, while selective MRI was more specific for medial meniscal tears. For this reason, the authors stated that an MRI was not necessary for the diagnosis of a lateral DM as it does not provide enhanced diagnostic utility over clinical examination. Yoo et al. [60] observed that preoperative MRI evaluations based on signal intensities do not accurately predict the presence of a lateral DM tear in children, except when these menisci show grade 3 signal changes.

While meniscal deformation may be correctly assessed with MRI, meniscus instability would be much more difficult to predict. For that reason, some authors highlighted the difficulty in establishing a decision-making protocol when dealing with DM, particularly in the case of the unstable but otherwise apparently healthy Wrisberg type and the key role of arthroscopy as an adjunct. In that sense, Good et al. [22] proposed an arthroscopic classification of DM based on the presence or not of meniscus instability and on the location of the absent capsular attachment.

To sum up, the conclusion is that the diagnosis of a lateral DM should be suspected as the first option in a paediatric population with knee symptoms or pain suggesting a lateral meniscal tear [49]. Moreover, an MRI evaluation is currently indispensable to confirm the diagnosis and rule out other knee conditions such as an osteochondral lesion of the lateral femoral condyle [52]. Finally, a standard radiological study should also be performed in these patients due to the complementary information provided. However, the final judgement and decision making should be done during the arthroscopic procedure, and the surgeon must be prepared to deal with a meniscus tear and/or instability.

37.4 Treatment

Patients with no symptoms, in which the MRI details the presence of a DM, should be followed up and only treated if they become symptomatic. However, a surgical procedure should be considered regardless of whether it is torn or not when a DM is symptomatic.

The treatment described in most of the first published series was total or subtotal meniscectomy through an arthrotomy [14, 45]. Although the best surgical treatment for a symptomatic DM is still controversial, the current approach is arthroscopically assisted since the advent of this less invasive technology. Over recent decades, a better understanding of the meniscus' complex function as load distributor and shock absorber has led to a diminishment in the amount of meniscal tissue removed. In cases of a symptomatic but otherwise stable DM, either complete or incomplete with no tears associated, saucerization is accepted as the treatment of choice. This procedure consists of a partial meniscectomy to reshape the DM into a normal semi-lunar form.

When the meniscus is torn and repair is not feasible, saucerization should again be performed, preserving as much meniscal tissue as possible. In some cases, particularly in peripheral longitudinal tears, the damaged tissue can be repaired by suturing in accordance with standard techniques. Again, it might be difficult to predict the reparability of the meniscus preoperatively and so the surgeon should be prepared to manage the situation [33, 34, 50].

The uncommon hypermobile Wrisberg type is more problematic. As this variant typically exhibits a posterior horn-deficient attachment, the treatment should be oriented to reattaching the posterior horn to the capsule. Some of the new techniques recently described to treat injuries of the posterior meniscal root may also be applied or associated with conventional suture repair [17, 18]. If reattachment is not possible, this type of DM may be condemned to a complete meniscectomy. Postoperative management will vary depending on the surgical procedure performed.

Ahn et al. [4] have advocated for the lateral DM being classified based on the location of a peripheral tear and that the repair be undertaken by applying a technical guide to arthroscopic techniques. They conjectured that the technical guide to arthroscopic partial meniscectomy in conjunction with the meniscal repair of the peripheral tear is an effective method in children with a symptomatic DM.

37.5 Results

Since Fairbank's [15] pioneering work, the detrimental effects of a complete removal of the meniscus from the involved knee compartment is well recognized. Particularly in paediatric knees, long-term poor results have been reported after lateral meniscectomy for non-discoid meniscus tears [27].

Surprisingly, the oldest series of open total meniscectomies to treat the DM showed reasonably good clinical results. Aichroth et al. [7] retrospectively reviewed 62 lateral discoid menisci operated on at an average age of 10.5 years, most of them with an open meniscectomy. On Ikeuchi's grading system [26], 37 % of the knees had excellent results, 47 % had good results and 16 % had fair results. Early degenerative changes were only observed in three knees, at an average follow-up of 5.5 years. More recently, Räber et al. [45] retrospectively reviewed the long-term results of total meniscectomy in 17 paediatric knees with asymptomatic lateral DM. After a mean follow-up of almost 20 years, 10 out of 17 knees showed clinical symptoms of osteoarthritis. Ten knees also had radiological signs of osteoarthritis. These results, similar to those obtained by some other authors [14, 55], again confirmed the long-term deleterious effects of lateral total meniscectomy for the DM.

Aglietti et al. [1] published one of the first series of lateral DM exclusively treated arthroscopically. Seventeen adolescents who underwent arthroscopic lateral meniscectomy were followed up for 10 years. The clinical results were considered excellent or good in all but one patient. However, the radiological examination revealed the presence of osteophytes in 8 knees and joint space narrowing in the lateral compartment in 11 knees. It is worth noting that there was no relationship between the type of meniscectomy and the clinical or radiological results obtained.

The long-term efficacy of the arthroscopic treatment of symptomatic lateral DM has been described in some other series. Stilli et al. [53] retrospectively reviewed a large cohort of children treated arthroscopically for a symptomatic lateral DM. They found that subtotal meniscectomy was preferable in younger patients when meniscal tissue was degenerated. However, the preservation of as much meniscal tissue as possible was recommended in older children. Good et al. [22] also showed the short-term efficacy of arthroscopic saucerization and meniscal repair in selected cases of symptomatic DM. They emphasized the importance of improving DM classification to further locate the area of instability.

Due to its frequency and the higher healing potential in children, the significance of preserving peripheral stability and the DM attachments by combining peripheral repair and saucerization has been proposed in different studies [5, 33].

Several authors [24, 31, 42, 43, 58] have focused on the results of lateral DM surgery in adults aged 25 years or older. Again these studies have suggested that the development of degenerative knee changes negatively influences outcomes. Kim et al. [31] compared the long-term radiologic outcomes of the partial meniscectomy and total meniscectomy for torn lateral DM. They observed that partial meniscectomies led to better results than total meniscectomies at a minimum follow-up of 5 years. In addition, the prognosis for the procedure was related to the amount of tissue removed. These results were in agreement with those obtained by Ahn et al. [3] in a series with a much longer follow-up. It turned out that arthroscopic reshaping for the symptomatic lateral DM in children led to satisfactory clinical outcomes after a mean 10.1 years. However, progressive degenerative changes appeared in 40 % (819 in 38 knees) of the patients. In their series, 40 knees (83 %) underwent meniscal reshaping through partial meniscectomy with or without repair. Therefore, they suggested that the lateral DM in children should be treated with arthroscopic partial meniscectomy with or without meniscal repair depending on the presence or absence of peripheral tears (Fig. 37.1). Wong and Wang [58] conducted a functional analysis of the treatment of torn lateral DM at different ages. They compared the results in paediatric patients of less than 11 years old (24 %), in young adults under 25 years (38 %) and in people older than 25 years (38 %). The results were satisfactory at up to 6 years of follow-up with both the age of symptom onset and the time of operation correlated with the functional outcomes.

As DM often presents in skeletally immature patients, the potential relationship to lower limb axial alignment is a matter of concern. Wang et al. [54] recently evaluated the influence of arthroscopic meniscectomy of a lateral DM on the axial alignment of the lower limb in adolescents. It was observed that varus deformity was significantly reduced and valgus inclination was instead developed in some of these patients. Furthermore, the valgus deviation was more pronounced in patients with a torn lateral DM compared with those with a torn non-discoid lateral meniscus. This very same fact was previously suggested by Habata et al. [24] in a series of 37 lateral DM, in patients in an age range from 9 to 52 years. They observed moderate or severe narrowing of the lateral joint line in 11 % of the knees after saucerization. Furthermore, a significant postoperative lateral shift of mechanical axis was observed in patients operated on at an age of 20 years or older at a mean follow-up of 14.5 years.

However, axial alignment is not the only parameter that might be altered after lateral meniscectomy in a knee with a DM. Fan et al. [16] investigated the effect of arthroscopic partial meniscectomy for a lateral DM on patellar tracking. They found the postoperative bisect offset index to be significantly increased in comparison to the preoperative value. These results suggested the patella translates more laterally to the femoral trochlear groove and so maltracking may appear. In a recent publication, Kwon et al. [36] also observed that those patients with a lateral DM that had undergone an open-wedge high tibial osteotomy for a varus knee can see acceleration in lateral DM degeneration, and it might affect the clinical outcomes of the procedure. Notably, the study conducted by Yoon et al. [61], assessing the outcomes of meniscal allograft transplantation after total meniscectomy in torn lateral DM, observed similar good results in patients with or without a previous lateral DM.

Finally, Fu et al. [20] investigated the relationship between isolated lateral DM tears and the presence of articular cartilage damage. The study showed that there was no difference in the incidence of articular cartilage lesions among patients with different types of DM tears. Female patients as well as patients with a body mass index greater than 23 kg/m^2 or patients with a time course superior to 6 months presented articular cartilage lesions much more frequently. Lastly, most of these cartilage lesions were observed in the lateral compartment and secondarily in the patellofemoral joint.

The results of some of the last published series are summarized in Table 37.2.

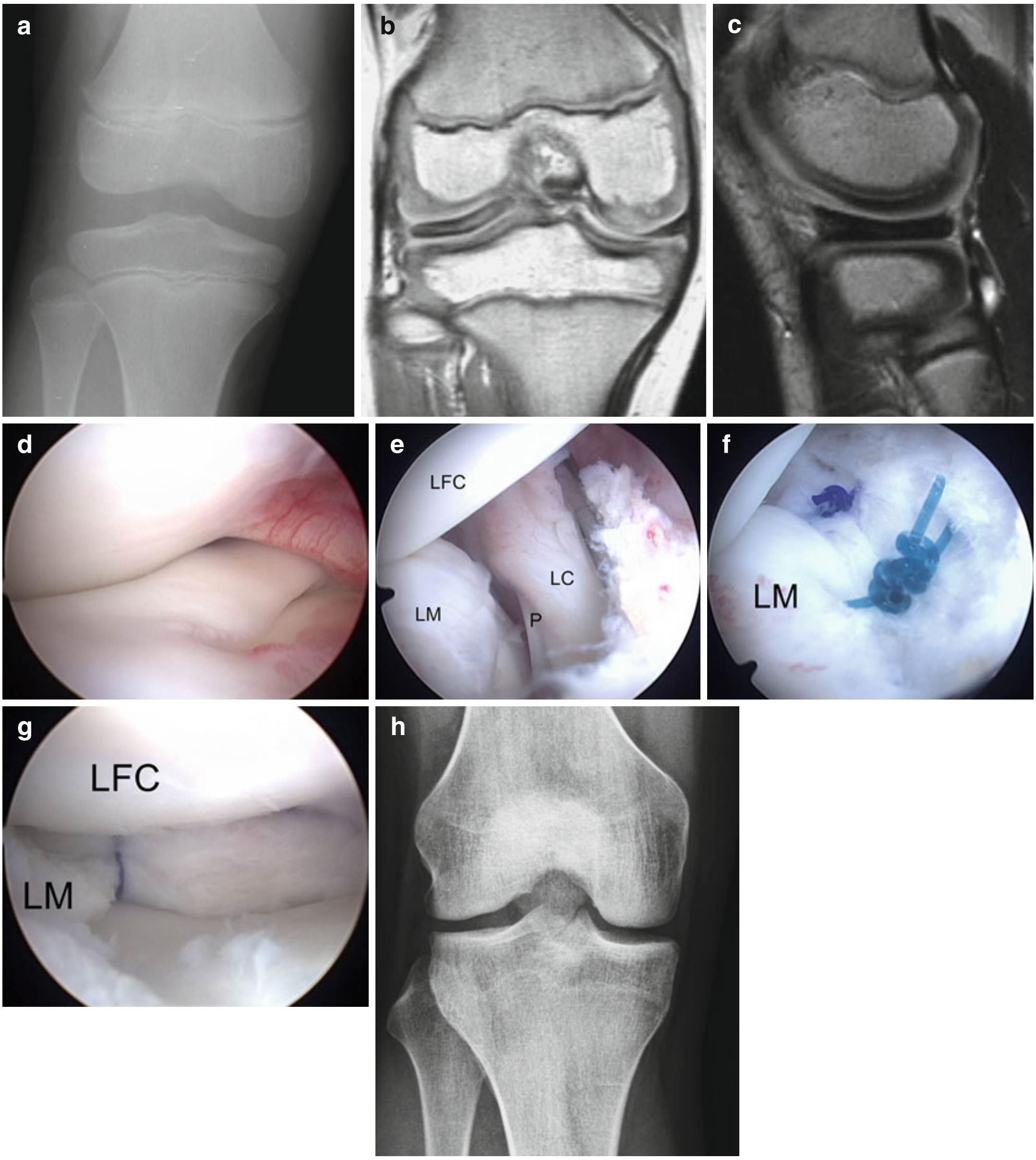

Fig. 37.1 (**a**) A 10-year-old boy; anteroposterior X-ray view of the right knee showing no significant abnormalities. (**b**) Coronal MRI shows a type I or complete discoid lateral meniscus. (**c**) Sagittal MRI shows an anterocentral shift type of the discoid lateral meniscus. (**d**) Arthroscopic view of the same case confirms a complete-type discoid lateral meniscus. (**e**) Arthroscopic view of the posterolateral compartment obtained with a 70° arthroscope inserted from the anteromedial portal. A tear of the posterior horn of the lateral meniscus at the meniscocapsular junction around the popliteus tendon can be seen. (**f**) The tear was repaired with vertical mattress modified all-inside sutures. (**g**) Arthroscopic partial central meniscectomy was performed along with repair using PDS sutures. (**h**) Anteroposterior X-ray view shows minimal lateral joint space narrowing without marginal osteophyte, which was classified grade I, at 10 years follow-up (*LFC* lateral femoral condyle, *LM* lateral meniscus, *P* popliteus tendon, *LC* lateral capsule)

Table 37.2 Functional results found in prior studies

Author	Year of publication	Number of cases	Surgery mean age (year old)	Type of treatment[a]	Follow-up (months)	Functional results	Radiological results
Wong et al.	2013	32	31.3	18 saucer+PM 8 Rep 6 STM	64.5	27 exc/good 5 fair	–
Ahn et al.	2015	48	9.9	22 PM 18 PM+Rep. 8 STM	122	31 exc 14 good 3 fair	29 no changes 19 radiological changes
Good et al.	2007	30	10.1	28 saucer. 2 TM	29.8	–	30 no changes
Aglietti et al.	1999	17	13.6	11 PM 6 TM	10	12 exc 4 good 1 fair	6 no changes 11 radiological changes
Habata et al.	2006	37	31.2	37 TM	14.5	17 exc 14 good 5 fair 1 poor	0 no changes 37 radiological changes
Kim et al.	2007	125	26.1	72 TM 53 PM	2 groups; <5 years; ±90 months >years; ±50 months	13 exc 19 good 13 fair 1 poor	7 no changes 39 radiological changes
Stilli et al.	2011	104	8	68 STM 20 PM 16 PPM	102	65 exc 30 good 6 fair 3 poor	–
Atay et al.	2003	34	19.8	33 PM 1 TM	66	13 exc 16 good 5 fair	No changes (only condylar femoral flattening in comparison with contralateral knee)
Papadopoulos et al.	2009	39	31.7	33 PM 1 STM 5 conserv.	±110	Lysholm 91.8 intact DLM vs. 82.9 torn DLM	–

[a]*TM* total meniscectomy, *PM* partial meniscectomy, *STM* subtotal meniscectomy, *Rep* meniscal repair, *saucer* saucerization, *PPM* partial posterior horn body meniscectomy, *conser* conservative, *LDM* lateral discoid meniscus

37.6 Summary

- A discoid variant mainly affects the lateral meniscus with prevalence around 30 % in cadaveric studies. However, the prevalence ranges from 0.4 to 17 % in the clinical setting, the prevalence being higher in the Asian population.
- The classification of DM includes four types for the lateral meniscus and three types for the medial meniscus.
- The condition should be suspected in patients with lateral meniscal symptoms during childhood.
- MR imaging as well as radiological examination should be performed to correctly diagnose the condition. Several MRI parameters have been described to help in the diagnostic process.
- In types I and II, a partial meniscectomy (saucerization) should be attempted. However, reattachment of the posterior horn of the meniscus is the treatment of choice in the hypermobile type III.
- Functional outcomes seem to be better in patients operated on at younger ages. However, a meniscal loss during childhood might produce an overload on the involved compartment. Although these patients may have excellent clinical and radiological results for up to 20 years, the loss of meniscal tissue at such a young age may have deleterious effects on the joint in the long run.

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38 Synthesis

Christophe Hulet

In daily clinical practice, treatment of symptomatic meniscal lesion regardless of the status of other intra-articular structures is based on two options: the complete or partial resection of the meniscal tissue with meniscectomy or the notion of meniscal preservation with the concept of meniscal economy. Initially, with the fabulous development of arthroscopy, subtotal meniscectomy was the most frequently used treatment.

Advances in knowledge of the LCA biomechanics and the high occurrence of ACL injuries as well as the development of new arthroscopic meniscal repair techniques have changed this attitude.

The treatment of a meniscal lesion depends on many parameters: the type of injury (traumatic or degenerative), intra-articular lesions (associated ACL intact or deficient), age, level of sports, and patient's motivation.

Both treatment options are:

- The partial or total meniscectomy arthroscopic surgery which is widely practiced but is definitive and irreversible for the knee with important biomechanical consequences.
- Meniscal preservation of meniscal lesions with either retained (left in place) or meniscal repair. The last attitude is more technically demanding and subject to the risk of recurrence. The failure rate is 20 % but essentially occurs during the first 2 years.

Let us stereotypically define how these parameters interact with each decision, in order to define several profiles that match the clinical situations we generally encounter.

- Meniscal tear on stable knee. Most often, traumatic tear is the common situation.

Facing a MM tear, the recovery is faster after meniscectomy, but in these young patients, osteoarthritis degradation is far from zero. Overall, results for meniscectomies are functionally good in the short term. However in the long term, arthroscopic meniscectomy is definitively not a benign procedure. The results are more favorable for the medial meniscus. After lateral meniscectomy, the risk of rapid chondrolysis is a major issue. With 10 years of follow-up, the incidence of OA is 38 % for the ML (53 % at 20 years) and 22 % for the medial meniscus.

Facing a LM tear, left alone or repaired if the subject is young, is an alternative to meniscectomy. It must be discussed each time and balanced with partial or subtotal meniscectomy.

These results emphasized the need for extreme caution because a patient of 18 years at the time of surgery can still actively practiced sports 20 years later. Therefore, Meniscal repair must be encouraged and performed each time it is a

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_38

vertical lateral meniscus tear. Take the time to explain to the patient the advantages and disadvantages of each approach, and do not forget information is crucial.

On the contrary, a meniscal degenerative tear on stable knee for an active patient of 45 years is very challenging. This is a specific situation, and before performing surgery, X-ray evaluation with schuss view and medical treatment for at least 3 months are required. An MRI evaluation is mandatory for searching bone edema and meniscal extrusion which were critical in the decision-making attitude.

After analyzing all of these parameters, medical treatment is an interesting alternative with often providing pain relief. However in the specific situation of a meniscal degenrative lesoin grade III open in the knee joint with no joint space narrowing and no subchondral bone modifications, resisting to the medical treatment is a reasonable indication of arthroscopic partial meniscectomy.

- Meniscal tear treatment with ACL-deficient knee.

It is in this situation that we must know how to search for all meniscal lesions. Recent studies have shown the importance of posterior roots lesions and also meniscofemoral synovial lesions which are accessible and highlighted after completion of a posteromedial approach. A diligent search and arthroscopy expertise is mandatory. The meniscal tear incidence is very high just after the injury, typically having a high potential of healing then decreased incidence followed by a recurrent instability episode. The rate is currently increasing up to 60 %.

For ML, small lesions (<10 mm) could be left in place if they are stable under the probe in the posterior part of the LM. Recent publications highlight the fate of meniscus when left in place in such situation particularly in the case of LM.

For the MM, the failure rate is higher and meniscus suture is the best option. The indications for meniscectomy with ACL reconstruction are mostly reserved in particular circumstances where there is an ACl-deficient knee with instability in a nondemanding patient.

For MM, we need to push the indications and take the risk of a suture. Failure rate for meniscal suture is about 20 % and occurs mainly during the first 2 years after surgery. The results are very encouraging for meniscal repairs on reconstructed knees, with 75 % good results at 5 years

In all cases, the reconstruction of the ACL is necessary. Meniscectomy must remain a potential treatment when all other possibilities have been conservatively eliminated.

Meniscal repair requires technical knowledge because it is time-consuming and requires a different rehabilitation process and the use of specific instrumentation, and it should be anticipated preoperatively based on the preop MRI analysis.

We must give the meniscus a chance and explain the risk of failure to the patient.

In the very particular case of discoid meniscus pathology, we must appreciate two things: the anatomy of lateral meniscus but also the stability of the remaining meniscal tissue. Again progress in sutures has changed our attitude. We now need to both preserve the maximum amount of meniscus tissue possible and fix it to the peripheral rim for joint stability.

Part VII

Indications: Adults

Traumatic Lesions in a Stable Knee: Masterly Neglect - Meniscectomy - Repair

39

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39.1 Introduction

Lesions of the menisci are the most common injuries of the knee joint. Although tears of the menisci are mostly based on degenerative changes, they might also be caused by a traumatic incident. Treatment options have evolved greatly over the last decades and are based on different factors such as patient age and activity, tear pattern, quality of the tissue and concomitant injuries (e.g. ligaments and cartilage). After thorough history taking, patient examination and MRI evaluation, the final selection of the best strategy depends on the arthroscopic examination. Treatment options are numerous and range from conservative therapy ("masterly neglect") to partial or subtotal meniscectomy and repair of the meniscus.

39.2 Basic Science

In order to choose the treatment option that is most suitable for the patient and the tear pattern, extensive knowledge of the function and healing potential of the menisci and the knee joint is essential.

Since in adults the blood supply only reaches the basis of the meniscus (outer third, zone III, Figs. 39.1 and 39.2), the inner parts (zone I) are not capable of producing a healing response [2, 3, 11, 14, 22, 24, 49]. Thus small flap tears or radial tears (Fig. 39.3) are not suitable for repair and are treated by resection of instable tissue.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_39

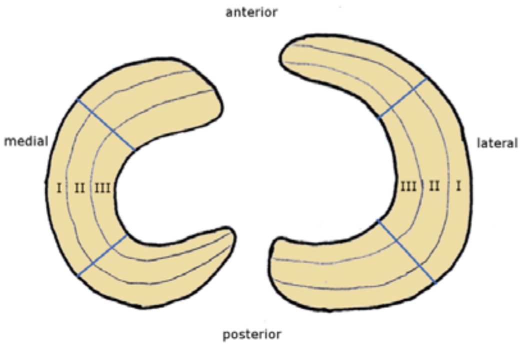

Fig. 39.1 Zone classification of the meniscus. *I* represents the outer third (red-red zone), *II* the middle third (red-white zone) and *III* the inner third (white-white zone) of each meniscus

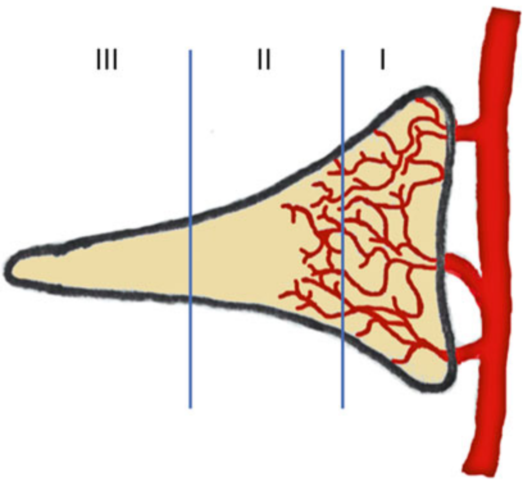

Fig. 39.2 Schematic drawing of meniscal blood supply. *I* represents the outer third (red-red zone), *II* the middle third (red-white zone) and *III* the inner third (white-white zone) of each meniscus. Tears of zone I have a high healing capacity, whereas tears of zone III usually do not heal

Longitudinal tears close to the outer third, reducable bucket-handle tears or some radial tears extending to the synovia (Fig. 39.3) have a high healing potential and are usually repaired [1, 7, 9, 17, 23, 26, 32–34, 40, 41].

Unfortunately, large radial tears lead to a loss of function of the meniscus and have biomechanical unfavourable properties [29, 34].

Due to the biomechanical importance of the menisci, a quick and thorough diagnosis of traumatic tears is essential. The typical loss of chondroprotective function can lead to further degenerative lesions. Especially the diagnosis of traumatic tears is made by a combination of patient history including the mechanism of trauma, clinical examination and imaging studies, especially MRI [28].

39.3 Patient History

Although traumatic meniscus tears are often associated with ACL injuries, they might also occur in stable knees. Rotational forces in deep flexion and a combination of flexion and external rotation can lead to a rupture of the meniscus. Rising from squatting or kneeling might cause a dislocation of a longitudinal tear leading to a bucket-handle tear (Fig. 39.3). In some cases, the patient reports an initial trauma followed by pain at the joint line that progressed with blocking and swelling after a second (minor) trauma that lead to a dislocation of meniscus tissue (e.g. in flap tears or bucket-handle tears, Fig. 39.3).

Typically the patient reports swelling and pain over the medial or lateral joint line sometimes accompanied by blocking of the knee in extension and/or flexion.

39.4 Physical Examination

Meniscal tears can present with different symptoms. Typically pain reported by the patient aggravates when rotational forces are applied, which can be reproduced by specific clinical tests [45]. With a ratio of 10 to 1, the medial meniscus is more frequently affected than the lateral. Typically there is tenderness over the joint line; in some cases joint effusion can be palpated. In dislocated bucket-handle tears, there might be loss of extension and/or flexion. Tests described to detect meniscal tears are numerous and usually are positive when the typical pain can be reproduced by compression and shear stress of the torn meniscus [28, 45].

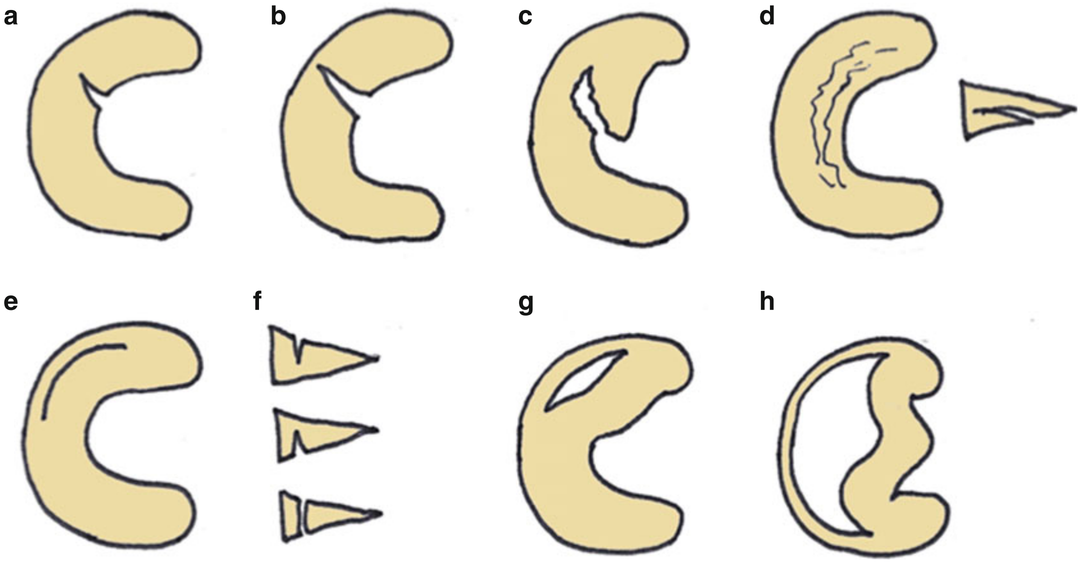

Fig. 39.3 Overview of different types of meniscal tears. (**a**) small radial tear, (**b**) large radial tear involving the red-red zone, (**c**) flap tear, (**d**) horizontal tear, (**e**) stable longitudinal (*vertical*) tear (incomplete of complete) (**f**), unstable longitudinal tear (**g**) and bucket handle tear (**h**). Flap tears (**c**) and horizontal tears (**d**) are usually degenerative

39.5 Imaging

Former imaging techniques such as computed tomography (CT) or arthrography have been replaced by magnetic resonance imaging (MRI), which nowadays is the method of choice with an accuracy of more than 90 % for diagnosing meniscal tears [18, 31, 39]. Especially in traumatic meniscal tears, an MRI is recommended to confirm the positive findings in patient history and examination [28].

39.6 Arthroscopy

Due to the high accuracy of the clinical examination combined with MRI, a mere diagnostic arthroscopy is usually not necessary. However, the arthroscopic evaluation and probe examination are essential to decide which strategy (e.g. resect or repair) is most suitable for the individual case. Exact size and location of the meniscal tear and concomitant injuries can be easily diagnosed.

Because a minor trauma often leads to a progression of pre-existing degenerative changes in many cases, a definite differentiation between mere traumatic or mere degenerative tears is not possible. However degenerative causes typically result in horizontal tears, flap tears or complex tears, whereas traumatic causes more often lead to longitudinal tears or radial tears that might progress to a flap tear (Fig. 39.3). Longitudinal tears have to be divided into complete vs. incomplete and stable vs. unstable and bucket-handle tears (Fig. 39.3).

In general, whenever possible the meniscus should be repaired and as much viable tissue as possible should be preserved. Besides the tear pattern, other factors such as tear location, stability of the tear, quality of the tissue, integrity of the meniscus body, patient age and time period between trauma and surgery have to be considered [15]. Additionally treatment options, potential consequences of meniscus loss and the protracted rehabilitation after refixation have to be discussed with the patient. In some cases, e.g. professional athletes, a refixation of the meniscus with a long drop out of sports and a high likelihood of re-tearing might not be the right choice.

Taking into account these previous parameters, the final decision of the best treatment option is based on the intraoperative findings at arthroscopy [45].

39.7 Treatment Strategies

After the diagnosis of a meniscal tear has been confirmed by clinical examination and MRI, the physician has to decide whether surgery is necessary or conservative treatment is sufficient. This choice largely depends on clinical symptoms. Although meniscal tears usually do not heal on their own, not all tears become symptomatic [13].

39.7.1 Conservative Treatment

Non-surgical treatment typically means leaving alone the meniscal tear ("masterly neglect"). Depending on the symptoms reported by the patient, this might be considered for partial-thickness split tears and short (less than 5 mm) vertical or oblique complete or radial tears (Fig. 39.3). Although meniscal tears usually do not heal, especially in patients not performing strenuous physical activities, they may be asymptomatic [16, 45, 47]. This especially counts for stable tears of less than 1 cm in length, which means that the central portion cannot be displaced more than 3 mm [9, 48]. Therefore, arthroscopic probe examination is necessary. The same applies for longitudinal tears of the peripheral part with a length of less than 5 mm, as well as partial-thickness tears (Fig. 39.3) [16, 45]. Conservative treatment might be more effective in tears of the lateral meniscus [37].

39.7.2 Surgical Treatment

In symptomatic meniscal tears, or if conservative treatment is not feasible, different surgical procedures ranging from open meniscectomy to arthroscopic repair have been described. Nowadays the treatment of choice is arthroscopy and whenever possible repair of the torn tissue. In cases of irreparable tears, cautious partial resection is recommended. Although meniscal repair has a higher reoperation rate than meniscectomy, it offers significantly improved long-term results in osteoarthritis prophylaxis and sports activity compared to partial meniscectomy [36, 43].

39.7.2.1 Meniscectomy

Cautious partial meniscectomy should be performed for lesions of the avascular zone of the meniscus (Figs. 39.1 and 39.2) [45]. Decades ago, little attention was paid to the important biomechanical properties of meniscal tissue and open meniscectomy was commonly performed. Since the first description of typical radiological changes (flattening of the femoral condyles, peripheral ridges, joint space narrowing) by Fairbank in 1948, the awareness of the function of the meniscus has risen [19]. Further studies confirmed the correlation of early osteoarthritic changes and meniscectomy. Roos et al. followed 123 patients with open total meniscectomy for 21 years, compared them to normal knees of matched controls and found that the likelihood of degenerative changes was 14 times higher in meniscectomized knees than in uninjured knees [32]. Since then plenty of studies have proven the superiority of partial resection over total meniscectomy [20, 21, 30, 35, 44]. Nowadays surgeons aim to preserve as much viable meniscal tissue as possible and only resect instable parts [25].

39.7.2.2 Repair

Due to the advances in arthroscopic techniques, open procedures for meniscus repair are rarely necessary. Numerous techniques and implants have been developed to achieve a stable refixation of the torn tissue. Mainly three different strategies that may be combined are available: outside-in, inside-out and all-inside techniques. Absorbable and non-absorbable sutures may be used. The orientation of the suture material can be horizontal or vertical, the latter achieving a higher biomechanical stability and superior pull-out strength [4–6, 8, 10, 38, 42].

39.7.2.3 Evaluation of the Lesion and Decision Making

If the meniscal tear is suitable for repair, it has to be evaluated by a thorough diagnostic revision of the joint and a probe examination of the meniscus. Additionally patient factors such as age, duration of the tear, location of the tear, degenerative changes and activity level have to be included in the decision making.

Due to its vascularization, only the peripheral third (3–5 mm) of the meniscus has good healing potential [15] (Figs. 39.1 and 39.2). The "classic" indication for a meniscus suture is a longitudinal tear of the vascular zone of more than 1 cm [46] (Fig. 39.3). These longitudinal (vertical) tears are most suitable for repair (Fig. 39.4) and have a high healing potential [7, 9, 34] especially if the circumferential hoop fibres are still intact [34]. Radial tears can involve only the avascular zone or extend into the vascular basis of the meniscus (Fig. 39.3). In small radial tears, repair usually is not an option, and cautious partial resection is recommended. When the tear extents to the basis of the meniscus, repair should be considered (Fig. 39.5). Typically a side-to-side suture of the basis is combined with a resection of the avascular part. Especially chronic cases may present with complex tears, e.g. bucket-handle tears with radial components [12, 24]. These have a lower healing potential and are usually treated by a combination of repair of viable parts and resection [9]. Oblique or horizontal tears (Fig. 39.3) are rarely suitable for repair and sometimes associated with meniscal cysts [27]. In these complex tears, the structural integrity of the meniscus often is damaged and vascularity may be impaired [15].

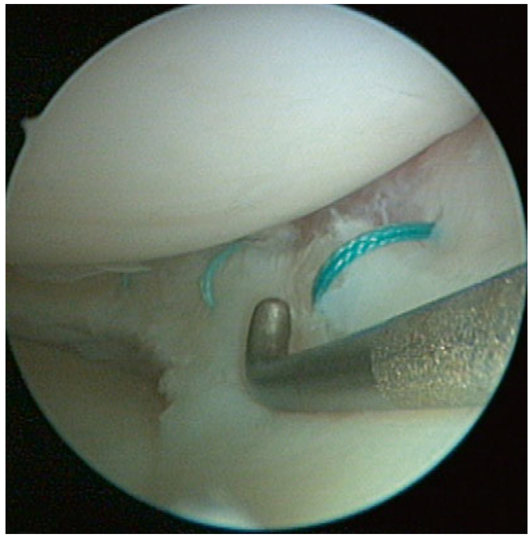

Fig. 39.4 Arthroscopic refixation of longitudinal tear. Result of outside-in refixation of the medial meniscus (probe examination)

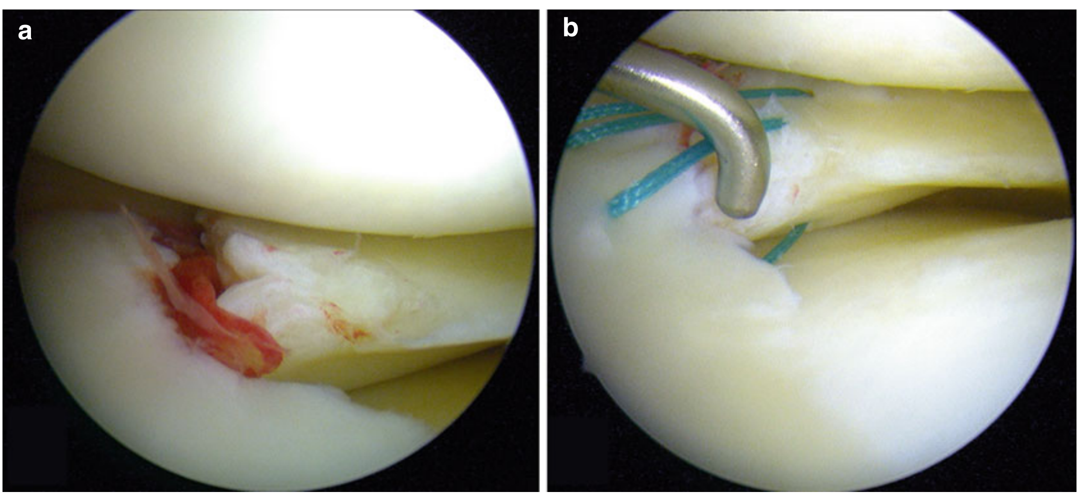

Fig. 39.5 Arthroscopic refixation of radial tear. Arthroscopic repair of a large traumatic radial tear of the lateral meniscus, before (**a**) and after (**b**) side-to-side suture

Conclusion

Traumatic meniscal tears are primarily diagnosed by the patient history and thorough clinical examination usually supplemented by MRI. The treatment regimen ranges from masterly neglecting the lesion to arthroscopic partial meniscectomy or meniscal repair. Which treatment modality best suits the needs of the individual patient is dependent on different factors: Patient age, activity level and duration of the tear are as important as location and size of the lesion and quality of the tissue. Asymptomatic tears may be treated conservatively, whereas symptomatic tears require surgical treatment. Whenever possible, the meniscus should be repaired, which is usually feasible for tears of the red-red zone. If repair is not an option, cautious partial resection is the treatment of choice.

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Meniscal Traumatic Lesions in ACL-Deficient Knee: Masterly Neglect, Repair, or Meniscectomy

40

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40.1 Introduction

Meniscal tears are frequently associated with anterior cruciate ligament (ACL) injuries. In acute ACL ruptures, the incidence of meniscal tears ranges from 25 to 45 % medially and 31 to 65 % laterally [19, 35, 36, 55, 79]. In chronic ACL-deficient knees, the incidence of meniscal tears increases with time, from 86 % at 2 years [17], to 96 % at 4 years [25], to 100 % at 10 years according to some studies [39]. Surgeons treating patients with acute or chronic ACL injuries must be prepared to address concomitant meniscal injuries.

Injury to either the ACL or the meniscus will increase the risk of osteoarthritis (OA) in the affected knee and the risk is even higher in combined ACL-meniscal injuries. Even after successful ACL reconstruction, damage to the medial meniscus increases the risk of osteoarthritis. At 10 years after ACL reconstruction, Neyret found a 20 % incidence of OA in knees that required a partial meniscectomy and 30 % for those that underwent a total meniscectomy [53]. Similarly, at 8 years after ACL reconstruction, Shelbourne et al. described a 9 % incidence of OA in knees that required a partial lateral meniscectomy, 23 % after partial medial meniscectomy, and 25 % after both partial lateral and medial meniscectomy [75]. Dejour et al. demonstrated the importance of the intact meniscus to decrease the risk of OA after ACL reconstruction. At more than 10 years follow-up, osteoarthritis was present in only

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_40

7.6 % of their ACL reconstructions with intact menisci. Conversely, the rate of OA in their ACL reconstructions with partial of total meniscectomy was 42 % [22, 23]. The menisci are also known to contribute to knee stability. The posterior horn of the medial meniscus acts as a wedge, which resists anterior tibial translation. In an ACL-deficient knee, the loss of a meniscus increases measurable joint laxity [12, 42–44]. A partial meniscectomy performed in a previously "stable" ACL-deficient knee may lead to functional instability. Clearly, preserving the meniscus should be a primary goal when treating the ACL-injured knee.

The treatment options for meniscal tears include leaving the tear alone (masterly neglect), meniscal repair, partial meniscectomy, and meniscal replacement. While meniscectomy is still commonly performed, the approach to the treatment of meniscal tears has evolved over the past 30 years with more of a focus on meniscal preservation. The status of the ACL also greatly affects the treatment of meniscal tears. Meniscal preservation is even more important in knees with ACL injuries but has a much higher success rate in stabilized knees. The treatment of meniscal tears in the ACL-deficient knee will vary based on meniscal tear pattern, the ability to achieve functional knee stability, and patient characteristics. In this chapter, we will discuss these factors to help guide the surgeon in deciding on the best treatment for each individual patient.

40.2 Masterly Neglect

In 1983, Lynch et al. showed that some meniscal injuries left in situ after ACL reconstruction can heal without formal treatment. "Neglecting" such tears allowed for retention of all meniscal tissue without the difficulties and time required for meniscal repair [45]. Leaving a tear in situ avoids the complications that can occur with other forms of treatment. Multiple other studies have shown high healing rates and good outcomes of stable meniscal tears that are left untreated [29, 45, 57, 64, 76, 90, 91, 93]. Depending on the series, this therapeutic option represents between 6 and 54 % of meniscal tears encountered during ACL reconstruction. It is critical to note that in these studies all patients had stable knees or were undergoing ACL reconstruction. In unstable knees, it is likely that these stable tears will fail to heal or will increase in size and symptoms over time. Thus, in the setting of an ACL injury, we can only recommend "masterly neglect" in treating stable meniscal tears in patients who are undergoing ACL reconstruction.

The surgeon should adhere strictly to the indications for which meniscal tears can be "neglected." With the development of all-inside techniques, meniscal repair for smaller tears is now a fast and safe procedure. Neglecting a meniscal tear carries the risk that the tear may progress, may become symptomatic, and could eventually require a partial meniscectomy. This would have a dramatic negative impact on knee joint long term.

The meniscal tears with the greatest potential for healing with nonoperative treatment are longitudinal, stable, short, and asymptomatic (Fig. 40.1). The definition of stable remains subjective. If the patient has mechanical symptoms of locking, the tear should be considered unstable and should be treated. Most authors advocate "masterly neglect" if a full-thickness

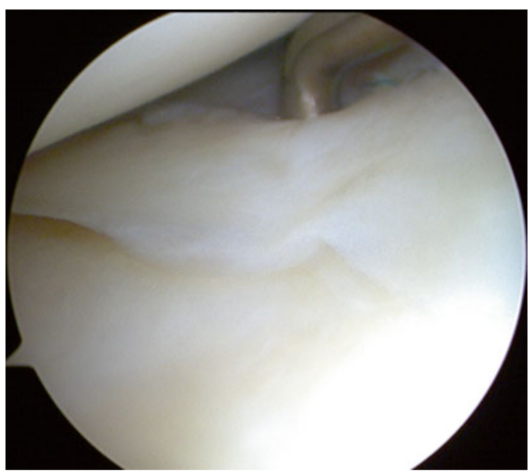

Fig. 40.1 A longitudinal, stable, and short lateral meniscal tear, which was left in situ after ACL reconstruction

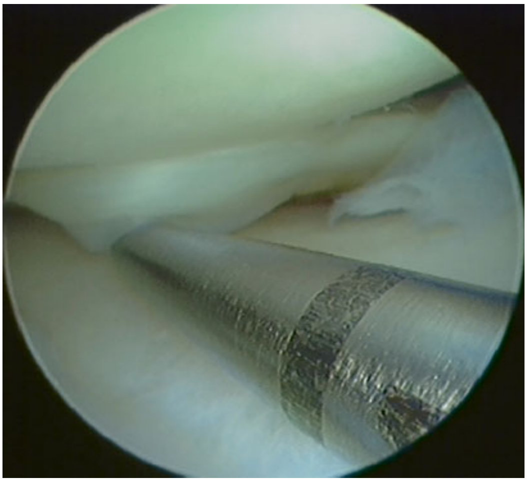

Fig. 40.2 This meniscus is able to be displaced under the central part of the femoral condyle. This meniscal tear is considered unstable

longitudinal tear has a length and is less than 10 mm and, when probed, the meniscus is unable to be displaced under the central part of the femoral condyle [78] (Fig. 40.2). Tears longer than 10 mm may extend in size and become unstable bucket-handle tears [20, 89]. However, some authors advocate leaving lateral meniscal tears in situ if they are unable to be displaced under the condyle, irrespective of length of the tear [8, 62, 71]. Partial-thickness tears are rarely a cause of mechanical symptoms. They have a high likelihood of spontaneous healing, particularly after a recent injury [12]. Zemanovic et al. found no failures in 31 partial-thickness tears "neglected" at the time of ACL reconstruction [93].

When treated with "masterly neglect," lateral meniscal tears have been shown to have greater healing potential than medial meniscal tears. Yagishita et al. described that 79 % of stable lateral tears healed without treatment vs. 61 % of medial tears [91]. Medial meniscal tears left in situ extend into bucket handle two to four times more often than lateral tears [24, 86, 91]. In a review, Pujol and Beaufils found that medial meniscal tears left in situ had a failure rate of 14.8 % (range 10–66 %) whereas lateral tears had a failure rate of 4.8 % (range 4–22 %). Failure was defined as residual pain or the need for a subsequent meniscectomy [64]. Several studies have found higher rates of arthroscopic revision for nontreatment of medial meniscus tears compared to lateral tears, particularly for tears greater than 10 mm in length [62, 86]. The criteria for which meniscal tears can be treated without treatment must be stricter for the medial meniscus than for lateral menisci [8, 62].

In a recent systematic review, Rothermich et al. also found a higher rate of reoperation for medial meniscal tears left in situ (9.5 %) compared with lateral tears left in situ (3.0 %) [67]. Lateral meniscal tears are more commonly encountered during acute ACL reconstructions and are often peripheral vertical tears. In contrast, chronic ACL reconstructions are more frequently associated with medial meniscus injury and there may be secondary degenerative changes occurring in the meniscus. Therefore, the medial meniscus tear may represent a more chronic injury, with lower healing potential than an acute lateral meniscal tear. These differences in tear characteristics may explain the higher failure rates seen with "masterly neglect" of medial meniscal tears. The surgeon must keep in mind these differences when deciding on which meniscal tears can be left untreated.

The treatment of small radial tears is more controversial. Whereas most small longitudinal tears occur in the peripheral, vascular region of the meniscus, radial tears start at the avascular inner edge of the meniscus. Many authors advocate nonoperative treatment for radial tears less than 5 mm in length. However, Weiss et al. showed on second-look arthroscopy that these short radial tears left alone did not heal and recommended partial meniscectomy [90]. They theorized that since the outer rim of the meniscus remained intact, the function of the meniscus would not be greatly disturbed. Other authors have found satisfactory results for radial meniscal tears left in situ if they are asymptomatic and less than 5 mm in length [29, 83].

When treating meniscal tears in ACL-deficient knees, we only recommend "masterly neglect" in knees that are undergoing ACL reconstruction. We advocate this treatment for stable full-thickness, peripheral, vertical, longitudinal tears

<10 mm in length or for partial-thickness tears. Our approach to short (<5 mm) radial tears is to perform a small partial meniscectomy to prevent tear propagation, which should have minimal effect on joint biomechanics. By strictly following these therapeutic indications for meniscal tears left in situ, it appears that there is no difference on subjective and objective outcomes between tears treated by meniscal repair or benign neglect [67].

40.3 Meniscal Repair

While the first meniscal suture was performed in 1863 by Annandale [5], this treatment did not gain wide acceptance until the 1990s. Improvements in instrumentation and techniques have allowed meniscal repair to become more commonly performed. Meniscal repair has two main objectives in ACL-deficient knee: (1) prevent the occurrence of osteoarthritis and (2) increase the stability of the knee. When making decisions about which meniscal tears should be repaired, the surgeon must consider both the characteristics of the tear (size, tear pattern, acuity, location) and more general factors (age, activity level, stability of the knee, alignment).

The ideal tear for meniscal repair is an unstable, vertical longitudinal tear in the peripheral region of the meniscus (Fig. 40.3). The unstable tear is a good indication for performing a meniscal repair (Fig. 40.4). These unstable tears cannot be left in situ and a partial meniscectomy would remove a significant portion of meniscal tissue with the likely development of osteoarthritis. If

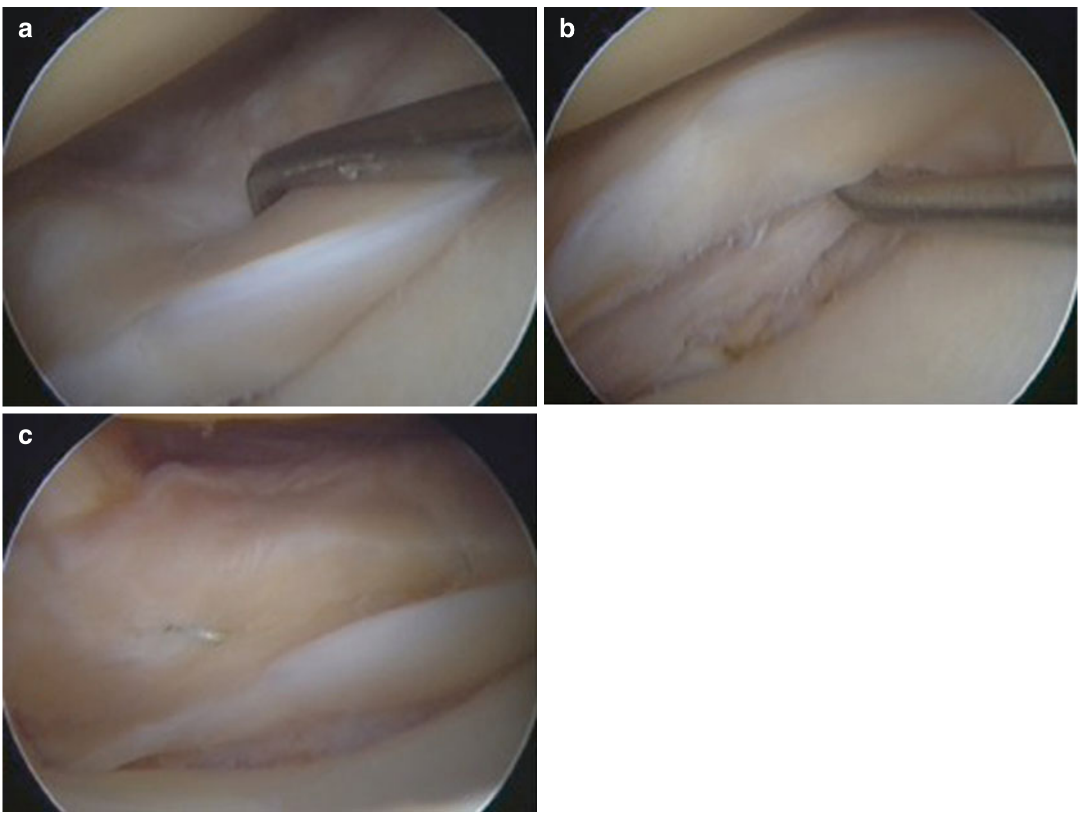

Fig. 40.3 (**a**, **b**) Posterior horn medial meniscal tear which is painful, peripherally located, >10 mm, and unstable. These are ideal indications for a meniscal repair. (**c**) After rasping the torn surfaces of the meniscus to promote bleeding, sutures have been placed to stabilize the tear

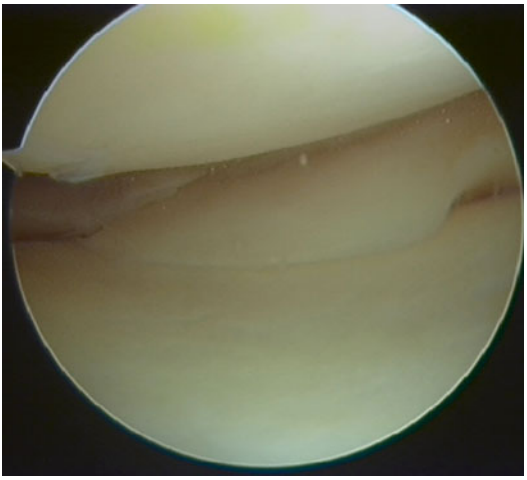

Fig. 40.4 An unstable medial meniscus tear, which underwent meniscal repair

the meniscal tissue quality allows, meniscal repair is recommended to stabilize the tear [10]. Vertical longitudinal tears are easy to reduce and are well suited for the placement of vertical mattress sutures. Biomechanical studies have shown that vertical mattress sutures are the strongest configuration and these should be used whenever possible [63, 65, 72]. Radial tears which extend to the periphery disrupt the meniscus' ability to contain hoop stresses, similar to a complete meniscectomy. Although technically difficult to reduce and repair, the surgeon should attempt to repair these lesions [56, 92]. If large radial tears are treated with meniscectomy or neglect, weight bearing will result in extrusion of the meniscus and result in markedly altered contact stresses and probable early osteoarthritis [83]. Complex meniscal tears, defined as a tear in two or more planes, are generally characterized as not repairable and are treated with partial meniscectomy. Yet in certain clinical situations, such as a pediatric patient, the surgeon may elect to attempt to repair the tear with the knowledge that a meniscectomy can be performed in the event of failure.

The acuity of the meniscal tear may have a role in predicting healing. Most authors have shown that acute tears (<12 weeks) have a better prognosis [21, 26]. Beaufils et al. described a healing rate of 84 % for meniscal repairs performed in the 12 weeks following ACL rupture, compared to 63 % after 3 months [9]. However, other authors have not noted any difference in healing between acute and chronic tears [38, 48].

The lateral meniscus is frequently involved at the time of ACL injury. These tears are generally shorter and located in the vascular zone. On the other hand, the medial meniscus tears occur more frequently in chronic ACL injuries and are often longer, more unstable, or complex [16, 80]. These differences may account for the higher healing rates for lateral meniscus tears [9, 14, 34, 68].

Location of the tear is another critical factor. The meniscus has been divided into three equal circumferential zones based on vascularity termed the red-red, red-white, and white-white zones [18]. Only the peripheral 10–25 % of the meniscus is vascularized in adults [6]. Meniscal healing requires local bleeding to provide cellular elements and biochemical mediators. Therefore meniscal tears in the peripheral (red-red) zone have the best potential for healing. However, it has been shown in animal explant culture models that meniscal tissue is capable of a repair response in the absence of vascularity [33]. Several clinical studies have demonstrated good long-term survivorship of meniscal repair in red-white zone and even in white-white zone of meniscus [48, 73]. In a clinical study of 198 meniscal repairs that extended into the avascular zone, 80 % remained asymptomatic at mean follow-up of 42 months [68]. O'Shea and Shelbourne found similar results in a study on bucket-handle repairs, with 36 of 43 (83.7 %) meniscus repairs in the white-white zone remaining asymptomatic at a mean follow-up of 4 years [58]. Kalliakmanis et al. did not find significantly different outcomes between tears located in the red-red zone and tears in the red-white zone [38]. Thus an extension of the tear into the avascular area is not an exclusion criterion for meniscal repair, particularly in young patients or for highly competitive athletes.

Bucket-handle tears are large unstable vertical longitudinal tears and are commonly seen in ACL-deficient knees. Meniscectomy for these lesions involves removing a large amount of meniscal tissue and should be avoided (Fig. 40.5). Feng et al. found an 89.6 % success rate (completely healed or incompletely healed but asymptomatic) for 67

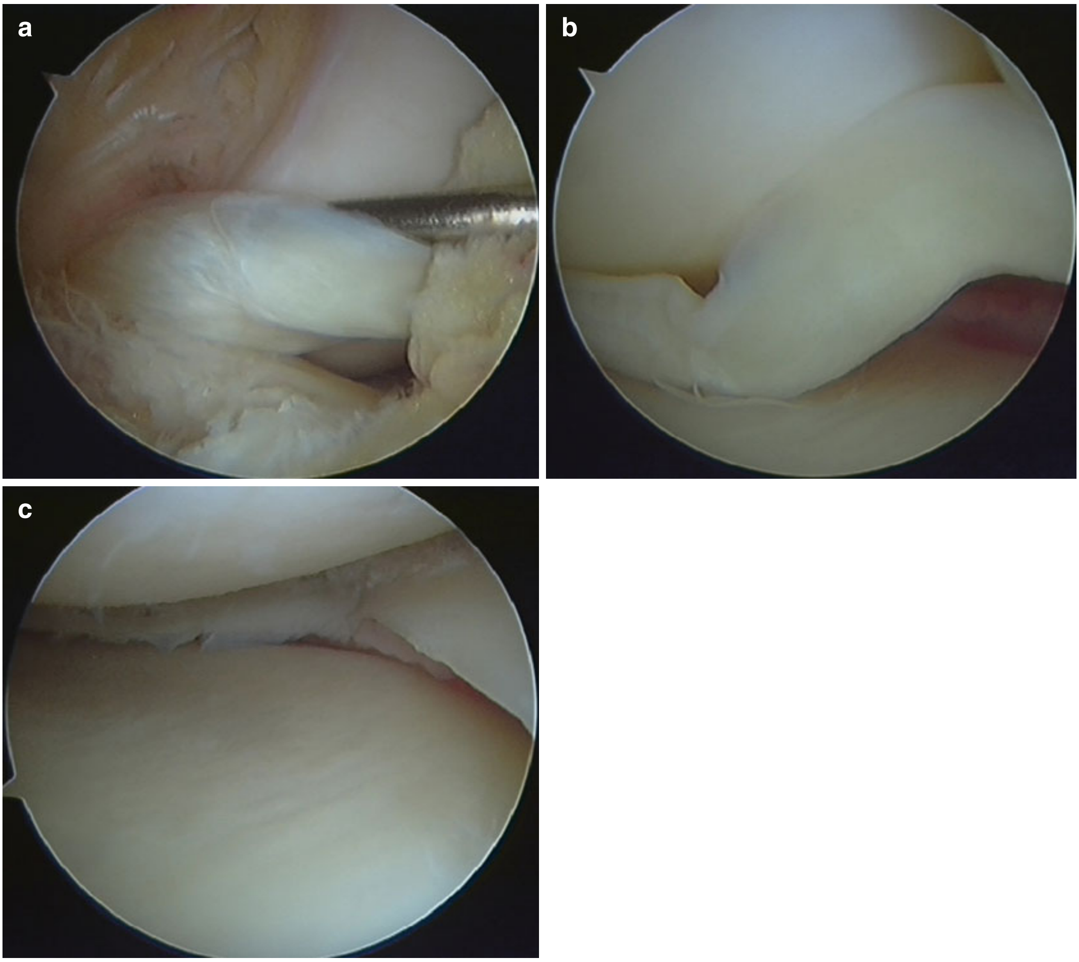

Fig. 40.5 (**a**, **b**) A displaced bucket-handle tear of the medial meniscus of a right knee. (**c**) The meniscus has been reduced and sutured

bucket-handle meniscus repairs, during a second-look arthroscopic evaluation, at a mean follow-up of 26 months [28]. However, some bucket-handle tears will have secondary degeneration defined as having an additional horizontal cleavage tear or instar-substance delamination. Tears with degenerative changes should be treated with meniscectomy. Shelbourne and Carr treated 155 medial bucket-handle tears at the time of ACL reconstruction, with either repair or partial meniscectomy according to tissue quality. Using these criteria, only 9 % of meniscal repairs failed. Surprisingly, no significant difference of subjective and objective scores was seen between meniscal repairs compared with partial meniscectomy [73].

However, a similar study on lateral bucket-handle tears showed that patients in the partial meniscectomy group had more pain than those in the repair group [74]. For bucket-handle tears, if the meniscus does not show degenerative changes, meniscal repair should be attempted, even in the white-white zone.

General factors also play a role in determining the optimum treatment for a given meniscal tear. The role of age in meniscal healing is controversial. Several studies have compared the outcomes of meniscal repair in younger or older populations. Eggli et al. found that patients over 30 years of age undergoing meniscal repair had a greater risk of re-tear than younger patients [26]. Conversely, in a study on 280 meniscal repairs with a mean follow-up of 24.5 months, Kalliakmanis et al. found no significant difference on failure rates between patients over or under 35 years of age [38].

Similarly, in patients over 40 years of age, Noyes et al. found 87 % of patients were asymptomatic 33 months after meniscal repair and ACL reconstruction [56]. While aging plays a role in the occurrence of degenerative changes in the meniscus, the quality of meniscal tissue is more critical than the patient's chronological age when deciding on which meniscal tears to repair. A longitudinal peripheral tear without degeneration should be repaired whether the patient is 20 or 50 years old. In athletically active patients (even aged 40 and over), the preservation of meniscal tissue is preferable, wherever possible.

The status of the ACL is critical when deciding whether or not to repair a meniscal tear. An ACL-deficient knee has a high risk of new meniscal injuries or extension of preexisting tears [30]. There is a higher failure rate of meniscal repair in unstable knees. Warren described failure rate of 30–40 % of meniscal repairs if the knee remains unstable [89]. Similarly, failure of ACL reconstruction is associated with failure of meniscal repair. Feng et al. have described that 57 % of failed bucket-handle repairs were associated with a failure of ACL reconstruction [28]. When a repairable meniscal tear is expected in an ACL-deficient knee, this should give even greater importance to performing a simultaneous ACL reconstruction. Even in low-demand patients, the ACL reconstruction will improve the chance of a healed meniscus and decrease the long-term risk of osteoarthritis.

A stable knee provides the optimum environment for meniscal tear healing. Many authors have observed improved healing rate for meniscal repairs in knees that undergo simultaneous ACL reconstruction [21, 49, 89]. In fact, Cannon et al. demonstrated higher success rates for meniscal repairs with concomitant ACL reconstruction than in knees with an intact ACL. In addition to the improved stability, the hemarthrosis resulting from the ACL reconstruction may provide additional factors that promote healing of the meniscal repair.

While most of the time an ACL reconstruction should be performed at the time of the meniscal repair, one possible exception is a knee with a locked bucket-handle tear that lacks full extension. In such instances, Shelbourne advocates a two-stage approach in order to minimize the risk of arthrofibrosis [77]. During the first stage, the meniscus is reduced and repaired but the ACL is not reconstructed. An ACL reconstruction was not performed until the patient had regained full motion, on average 72 days after the meniscal repair. Only one of the 16 patients treated in this fashion had failure of the meniscal tear. The decision of whether to perform a simultaneous or staged ACL reconstruction in locked knees must be individualized to each patient.

Some authors even advocate for meniscal repair in ACL-deficient knees even when a patient has decided against ACL reconstruction [10, 21]. Acceptable results for isolated meniscal repair have been reported in ACL-deficient knees in low-demand patients [31]. However, the surgeon and patient must be cognizant that meniscal repair in such situations has a higher failure rate and that a partial meniscectomy may be necessary in the future.

Finally, other parameters must be evaluated to help determine the appropriate meniscal treatment. Factors such as alignment (e.g., a varus knee with a medial meniscus tear) or ipsilateral chondral damage increase the risk of osteoarthritis in the ACL-deficient knee with a meniscal tear. In such situations, even more consideration should be given to meniscal-preserving surgery, even in less than ideal conditions for meniscal healing.

40.4 Meniscectomy

For many years, total meniscectomy was the preferred treatment for symptomatic meniscal tears. Since Tapper and Hoover highlighted the high rates of osteoarthritis following total meniscectomy [87], partial meniscectomy has been the most common treatment for meniscal tears. Partial meniscectomy relieves the pain and removes the mechanical symptoms associated with a damaged meniscus. Some of the benefits of a partial meniscectomy are that it is a minimally invasive procedure, the risk of complications is low, and it allows a rapid return to activity. However, if a patient is undergoing a simultaneous ACL reconstruction in order to allow return to sport, these advantages lose their importance.

Although partial meniscectomy has excellent short-term outcomes, there are long-term negative sequelae to removing meniscal tissues particularly in patients with associated ACL tears. Baratz et al.

theorized that in the absence of a functional meniscus, a worse outcome from ACL reconstruction might be expected [7]. Several studies have confirmed that in patients undergoing ACL reconstruction, those that have a concomitant meniscectomy have more long-term pain and episodes of swelling [22, 47]. Biomechanical study has demonstrated that the medial meniscus is a secondary stabilizer to anterior translation, particularly in the ACL-deficient knee [44]. Meniscectomy may increase instability symptoms in the ACL-deficient knee. Finally, meniscectomy has been shown to alter loading patterns and increase focal contact pressures. The removal the inner third of the meniscus increased peak local contact stress by 65 % [7]. Another study showed that removal of 50 % of the meniscus doubled contact pressures [60]. These alterations in loading patterns may predispose to early osteoarthritis (Fig. 40.6). Many clinical studies have documented premature knee osteoarthritis following meniscectomy [11, 32, 45, 51], even in ACL-reconstructed knees [2, 3, 45, 51]. In a review of 100 ACL-reconstructed knees, Pernin et al. found that the risk of developing osteoarthritis at 24.5 years follow-up increased threefold when the medial meniscus was removed. Among the patients with a healthy medial meniscus at the time of ACL reconstruction, 61.4 % had a normal or nearly normal radiographic rating at 24.5 years follow-up vs. 31.3 % with a total medial meniscectomy. The incidence of severe osteoarthritis was 41 % if a medial meniscectomy was performed [61]. The negative effect of meniscectomy is even more pronounced in ACL-deficient knees. Neyret et al. found a pre-osteoarthritis or osteoarthritis incidence of 100 % at 10 years of meniscectomy in ACL-deficient knee [52]. Clearly, meniscectomy has negative effects on the knee joint that are magnified in ACL-deficient knees.

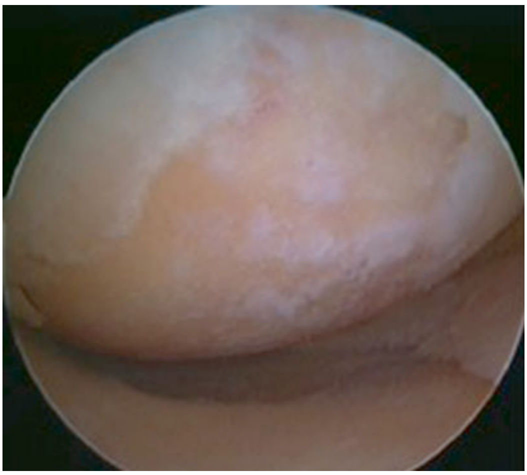

Fig. 40.6 Medial femoral-tibial osteoarthritis that occurred after a subtotal medial meniscectomy

Since most combined ACL/meniscal tears occur in young, active patients, minimizing the long-term risk of osteoarthritis should be a primary goal of treatment. Toward that goal, the role for partial meniscectomy has diminished as repair techniques have improved. Currently, the primary indication for partial meniscectomy in association with an

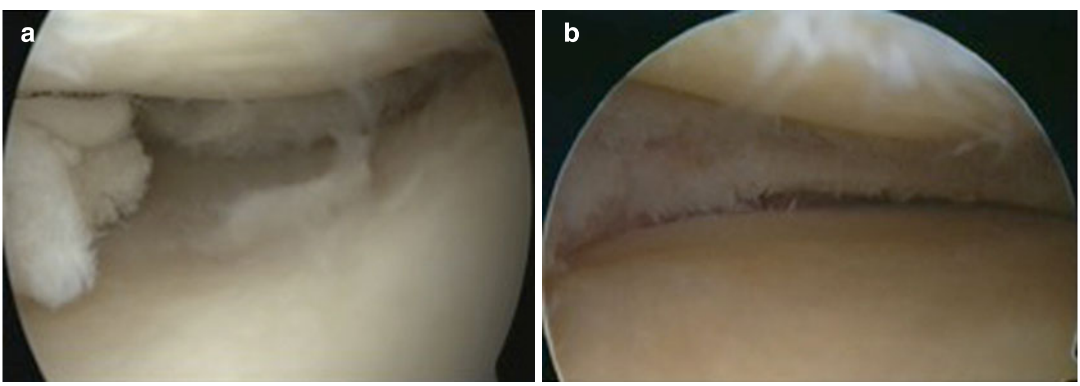

Fig. 40.7 (**a**) Complex tear of the lateral meniscus. This tear was not amenable to repair and required a partial meniscectomy. (**b**) Appearance of the lateral meniscus after partial meniscectomy

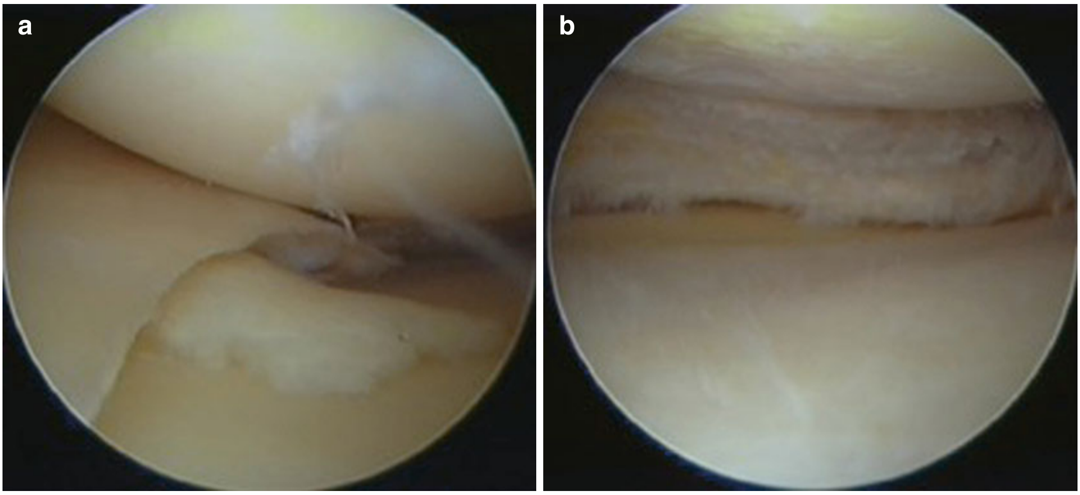

Fig. 40.8 (**a**) A displaced flap of the posterior horn of the medial meniscus with associated degenerative changes in a middle-aged patient. This tear was treated with partial meniscectomy. (**b**) The appearance of the meniscus after partial meniscectomy

ACL reconstruction is a meniscal tear where the other treatment options (masterly neglect or meniscal repair) have a low chance of success [10]. Tears that meet these criteria include degenerative meniscal tears, complex tear patterns (Fig. 40.7), chronic displaced tears with plastic deformation (Fig. 40.8), and tears in the white-white region of the meniscus (rim width greater than 8 mm). An argument can also be made for performing a partial meniscectomy in less active patients over 50 years of age since the deleterious effects of meniscectomy are diminished and, should OA develop, the reconstruction options are better suited for older patients. Meniscectomy without ACL reconstruction should only be proposed if all the four following criteria are met: (1) a symptomatic meniscal lesion, (2) an irreparable meniscal lesion, (3) no knee laxity on clinical examination, and (4) an inactive or elderly patient [10].

40.5 Meniscus Replacement

While a thorough discussion of meniscal replacement is beyond the scope of this chapter, mention must be made of the role of the ACL in meniscal replacement. Meniscal allograft transplantation has been developed as an option to treat symptomatic knees after total or subtotal meniscectomy. The results of meniscal transplantation have continued to improve over the past 30 years but there is still a 10–29 % failure rate [27, 66, 69, 81]. Successful meniscal transplantation requires a stable ACL. ACL-deficient knees with post-meniscectomy syndrome should have an ACL reconstruction performed prior to or at the time of meniscal transplantation [66].

Conclusion

Treatment of meniscal tears in ACL-deficient knees must be individualized to each tear and to the individual patient (Table 40.1). In general, the goal of the surgeon should be to preserve as much functioning meniscus as possible in order to reduce the risk of future osteoarthritis and to improve stability of the knee. In most cases, the knee will also benefit from simultaneous ACL reconstruction. Short stable tears are often best treated with “masterly neglect.” Unstable vertical longitudinal peripheral tears without degenerative changes can usually be successfully repaired with current techniques. Unfortunately, many meniscal tears in ACL-deficient knees

Table 40.1 Indications of the different treatment options for meniscal tears

Masterly neglect	Meniscal repair	Meniscectomy
Asymptomatic	Symptomatic	Symptomatic
Stable knee	Stable knee	Unstable knee
Stable tear	Unstable tear	Chronic displaced tear
No degenerative changes	No degenerative changes	Degenerative meniscal tear
Peripheral meniscal zone	Peripheral meniscal zone	White-white region
Acute tear	Acute tear	Chronic tear
<10 mm	>10 mm	Complex tear
Vertical longitudinal	Vertical longitudinal	Radial
Active patient	Active patient	Inactive or elderly patient

still require partial meniscectomy. We hope that as techniques improve and as we gain greater understanding of biologic factors that enhance meniscal healing, that in the future, more and more menisci can be retained.

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41 Degenerative Meniscal Lesions: Indications

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A degenerative meniscal lesion (DML) is a meniscal tear, commonly involving a horizontal cleavage in the knee of a middle-aged or older person. It is characterized by linear intrameniscal signal (including a component with horizontal pattern) typically communicating with the inferior meniscal surface.

It is a slowly (over several years) developing process likely involving progressive mucoid degeneration and weakening of the meniscus ultrastructure. There is often no clear history of an acute injury [8]. Overloading, coupled with degenerative meniscal matrix changes possibly related to early-stage osteoarthritis, could thus lead to meniscal fatigue, rupture, and extrusion [7, 20, 25]. 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 loss [2]. Partial loss of meniscal function may thus negatively affect the knee in the long term. Therefore, in many persons, a degenerative meniscal lesion is a feature indicative of a knee joint with (or at high risk of) developing osteoarthritis.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_41

41.1 Classification

Arthroscopic classification was first proposed in 1983 by Dorfmann et al. [8] and Boyer et al. [3] (Fig. 41.1):

- Type I represents an alteration of the meniscus without interruption of its continuity: it is flat and yellow, and its inner edge is frayed.
- Type II is characterized by the presence of calcium deposits (meniscocalcinosis).
- Type III indicates the presence of a horizontal cleavage.
- Type IV refers to the presence of a radial tear (IVa). Association with a horizontal tear can lead to a flap (IVb).
- Type V is a complex lesion which cannot be precisely described.

The classification of Crues et al. [5] serves as a reference standard for MRI:

- Grade 1 is a high-intensity intrameniscal signal which is round and occupies a variable volume of the meniscus.
- Grade 2 is a high-intensity intrameniscal signal which is linear. It does not involve the surface (Fig. 41.2a).
- Grade 3 is high-intensity signal extending to the surface of the meniscus. It indicates a true meniscal tear (Fig. 41.2b). The application of the two-slice-touch rule [6]), i.e. grade 3 signal intensity seen on at least two consecutive MR images, increases the specificity for the diagnosis of a meniscal tear.

41.2 Frequency

Degenerative meniscal lesions are tremendously common – the prevalence of degenerative meniscal lesions in the general population increases with age, ranging from 16 % in knees of 50–59-year-old women to over 50 % in the knees of men aged 70–90 years (Fig. 41.3) [11, 12, 22].

41.3 Assessing a DML

Due to this high frequency, there is limited evidence that pain in the degenerative knee is attributable to a degenerative meniscus lesion. Health-care professionals seeing patients with knee pain need to be aware of the fact that a meniscal lesion may be asymptomatic per se in a patient with knee pain. Just because there is a degenerative meniscal lesion, visible on knee

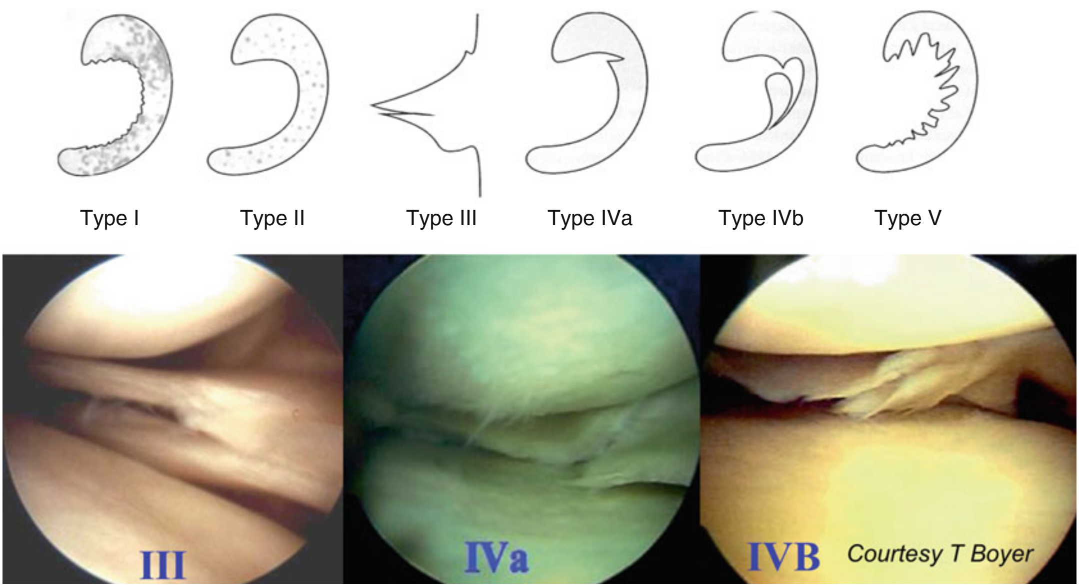

Fig. 41.1 Arthroscopic classification of degenerative meniscal lesions according to Dorfmann and Boyer [10]

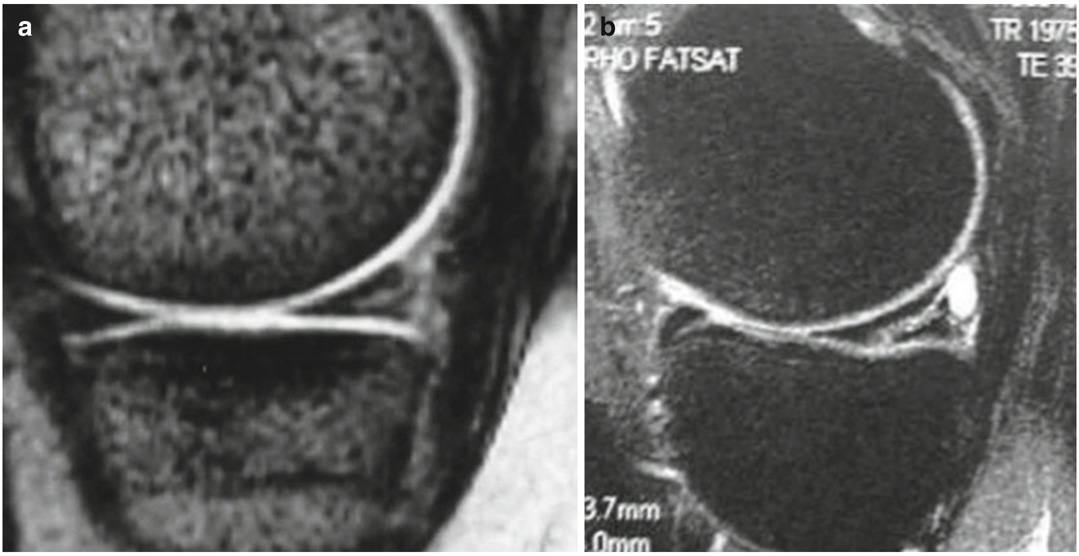

Fig. 41.2 (**a**) Grade 2 intrameniscal hypersignal. (**b**) Grade 3 hypersignal of the posterior horn (medial meniscus) associated with a parameniscal cyst

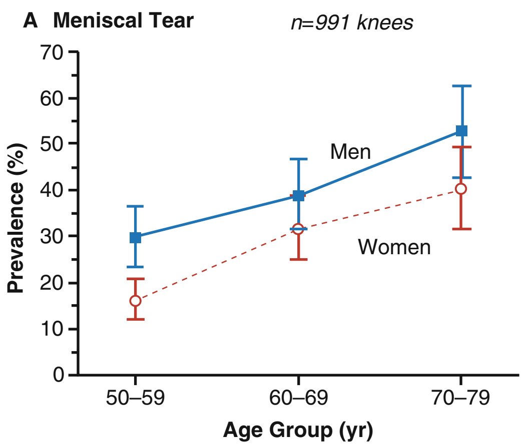

Fig. 41.3 Prevalence of meniscal lesions according to age and gender (Englund [8])

MRI or at arthroscopy, it does not necessarily imply the torn meniscal tissue is actually painful, so that surgical resection will resolve the patient's pain or aid the patient in the long term [19].

Knee radiography may be used to support a diagnosis of osteoarthritis or detect certain more rare conditions of the knee. Therefore, in the specialized orthopaedic clinic setting, bilateral weight-bearing semi-flexed knee radiography may be included in the workup of the middle-aged or older patient with knee pain. Typical features of osteoarthritis on radiography such as osteophytes and joint space narrowing support the clinical diagnosis of osteoarthritis. On the medial side, partial or subtotal meniscectomy itself is not associated with joint narrowing [16, 25]. On the lateral side, there is no evidence of the relationship between meniscectomy and joint line narrowing.

Knee MRI is typically *not* indicated in the workup of the middle-aged or older patients with knee joint symptoms, except if arthroscopic surgery is considered (failure of functional treatment) in order to:

- Assess the meniscus tear itself: localization, grade, extent, and evidence of a dislocated or unstable tear (Fig. 41.4).
- Assess the knee for other early osteoarthritic changes: cartilage defects, bone marrow lesions in the subchondral bone, meniscal extrusion, or differential diagnoses such as osteonecrosis or tumours.

41.4 Treatment

41.4.1 Functional Treatment or Arthroscopic Meniscectomy?

The primary choice in the treatment of a patient with knee pain and findings of a DML is nonsurgical therapy including weight management (if overweight or obese patient) and functional treatment irrespective if there are other evidences of osteoarthritis or not.

There are seven RCTs comparing functional and arthroscopic treatment of DML [13–15, 17, 20, 28, 32]. Two of them concern patients with moderate to severe knee osteoarthritis [18, 20]; five are associated with mild or no osteoarthritis [13–15, 17, 28, 32]. All series demonstrate a substantial improvement after functional treatment or APM. Except the study by Gauffin et al [13], no study concludes APM is better than functional treatment in DML (Table 41.1).

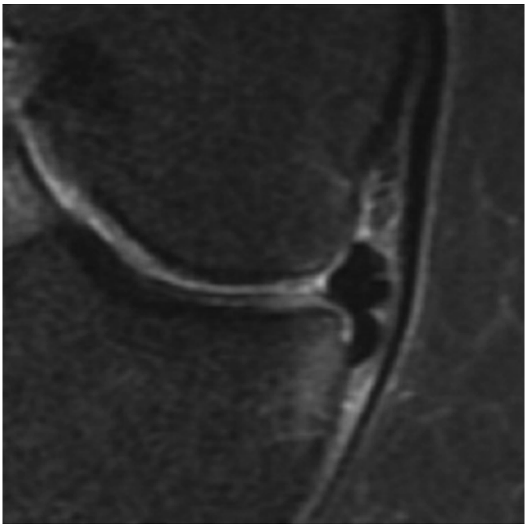

Fig. 41.4 Displaced flap in the tibial gutter responsible for pain and clicking knee. Note the tibial subchondral bone edema due to the impingement. Typical pattern of "painful unstable meniscus" indicating a meniscectomy

There are no differences in terms of outcomes whatever the severity of other osteoarthritis changes [26]. The indication for arthroscopic partial meniscectomy should not depend on status of the joint cartilage.

However, Yim et al. [32] and Herrlin et al. [14] do not report crossovers from the functional arm to the surgical arm, but Herrlin et al. [15] with a longer follow-up, report 27 %, Katz et al. [17] 30 %, Vermesan et al. [31] 17 %, and Sihvonen et al. [28] 7 %. Rimington et al. [27] proposed in their prospective study surgery or functional treatment after a standardized 4-week rehabilitation protocol: 46 % of the patients declined surgical procedure. Gauffin's study [13], based on selected group of DMLs – sudden onset, daily joint catching, and joint locking for more than 2 s over the past month – suggests APM might result in better clinical results (KOOS/EuroQOL 5D/VAS) at 3 and 12 months. In a recent randomized control study, the Fidelity group didn't demonstrate any supplementary efficacy of arthroscopic partial meniscectomy in a specific group of catching and occasional locking symptoms in patients with DML Sihvonen et al. (in Press).

Table 41.1 Outcomes reported in seven RCTs, according to the degree of arthritis

Study	Patients' age	Inclusion criteria (arthritis)	Conclusion
Moseley et al. [20]	51 ± 11	$>6 months KL ≤ 4	Debridement = Sham
Kirkley et al. [18]	59 ± 10 years	$>3 months KL 2–4	Debridement = PT
Herrlin et al. [14, 15]	45–64 years	$>2 months Al ≤1 Medial tear MRI	APM = PT
MeTeOR Katz et al. [17]	45–64 years	$>2 months Al ≤1 Medial tear MRI	APM = PT
Yim et al. [32]	43–62	$>1month KL ≤1 Medial Tear MRI	APM = PT
Sihvonen et al. [28]	35–65	$>3 months KL < 1 Medial tear MRI	APM = Sham
Gauffin et al. [13]	45–64	$>3 months Al < 1 Mechanical symptoms	APM + PT > PT

KL Kellgren-Lawrence classification

41.4.2 Functional Treatment: What Does It Mean?

It usually consists of a short phase of analgesics and sometimes NSAIDs and a structured rehabilitation programme.

For Stensrud et al. [30], the exercise therapy programme consisted of progressive neuromuscular and strength exercises over 12 weeks, performed during a minimum of two and a maximum of three sessions per week. Neuromuscular exercises were aimed to improve the position of the trunk and lower limbs relative to one another, as well as quality of movement performance, while dynamically and functionally strengthening the lower limb muscles.

In Yim's trial [32], the nonoperative treatment included analgesics, nonsteroidal anti-inflammatory drugs (NSAIDs), or muscle relaxants, depending on clinical symptoms for the first 2 weeks. In addition, patients underwent supervised physical exercise to improve muscle strength, endurance, and flexibility for 60 min per session, 3 times weekly, for 3 weeks. After that, patients were provided with a home exercise programme, which they conducted unsupervised for 8 weeks.

The duration of programme varies from 4 weeks [24] to 12–16 weeks [23] (Table 41.2).

41.4.3 Partial or Subtotal Meniscectomy: Which Outcomes?

Which type of meniscectomy: as partial as possible resecting the only unstable part of the meniscus or more extended to resect the pathological meniscal tissue (meniscal disease)? There is no evidence-based answer.

Table 41.2 Duration of functional treatment according to the literature

Study	Duration
Østerås et al. [23]	12–16 weeks
Stensrud et al. [30]	12 weeks
Herrlin et al [14]	8 weeks
Yim et al. [32]	8 weeks
Neogi et al. [21]	12 weeks + home exercises
Rimington et al. [27]	4 weeks AINS ± rehab long term

Whatever the type of meniscectomy, one can often expect the patient will improve. According to Chatain et al. [4] who reported the results of a large multicentric studies conducted by the French Arthroscopy Society, factors of poor results, however, are associated with the presence of degenerative cartilage lesions (OR 2.8), resection of the meniscal wall (OR 2.2), and age >35 (OR 5.0).

In case of parameniscal cyst, typically associated with a horizontal meniscal lesion, and when a surgical treatment is indicated, it is very important not only to treat the meniscal lesion but also to evacuate the content of the cyst into the joint. It is therefore often necessary to resect a sufficient amount of the meniscus to the meniscosynovial junction at least at the level of the cyst and to enlarge the tract of the cyst. Open excision of the cyst, in conjunction with arthroscopic meniscectomy, is only needed in case of very large subcutaneous cyst.

41.4.3.1 What Is the Risk of Osteoarthritis After APM?

The rate of surgical complication is low (1–2 %)

There are several observational studies that have examined the long-term outcome of meniscectomy [9, 10, 24]. As opposed to RCTs, which have primarily focused on pain as the primary outcome, these cohort studies have focused on the development of incident radiographic knee osteoarthritis as the outcome of interest. For example, importantly partial meniscectomy has been reported to be associated with *less* radiographic osteoarthritis than total meniscectomy [9]. Further a DML 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) [9]. The data support the important distinction between a DML and a traumatic meniscal tear, where a patient with a traumatic meniscal tear has a better long-term prognosis after meniscal resection than patients with a DML. Further, a DML may be suggestive with incipient generalized osteoarthritis as a DML has been reported to be linked with a higher frequency of osteoarthritis also in finger joints [7, 10].

41.5 Algorithm

- Outcomes are similar after conservative treatment and arthroscopic partial meniscectomy.
- There are no differences in outcome regardless of the severity of other osteoarthritic changes in the joint or absence of such changes.
- Arthroscopic meniscectomy may be associated with increased risk of osteoarthritis progression if functional meniscus tissue is removed.
- In event of failure of non-surgical treatment, APM may be considered as an alternative treatment option.

According to these principles, algorithm has been proposed as guidelines to the French orthopaedic community in 2009 [1] (Fig. 41.5).

This algorithm remains globally valuable, in the light of recent publications. Conservative treatment is always the first line (Fig. 41.6). If it fails, arthroscopic treatment can be considered. Information to the patient is crucial.

At what time should surgery be proposed? This important question remains uncertain and has no evidence-based answer. According to expert opinion:

Surgery may be considered for patients with considerable mechanical symptoms such as daily substantial joint catching or joint locking for more than 2 weeks over the past 2 months (2 months correspond to mean period between symptom onset and inclusion in RCT(s)).

After 3–6 months of persistent pain/mechanical symptoms: for a degenerative meniscus with normal X-rays/abnormal MRI signal (grade 3) suggestive of an unstable lesion, surgery can be proposed as a symptomatic treatment (3–6 months correspond to the mean period between functional treatment and conversion to APM in RCT(s)).

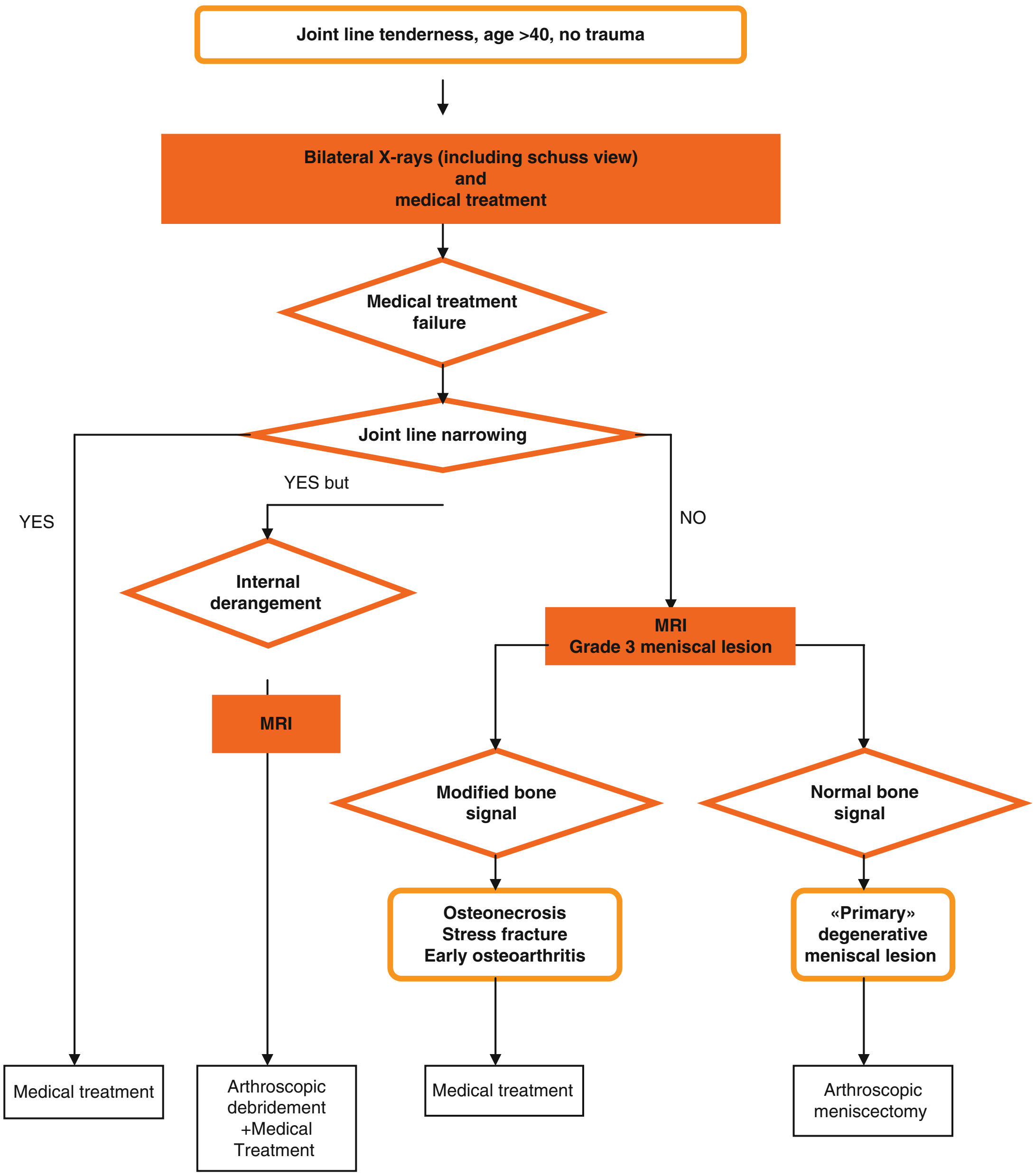

Fig. 41.5 Algorithm for the management of knee pain in middle-aged patients according to the Haute Autorité de Santé guidelines [1]

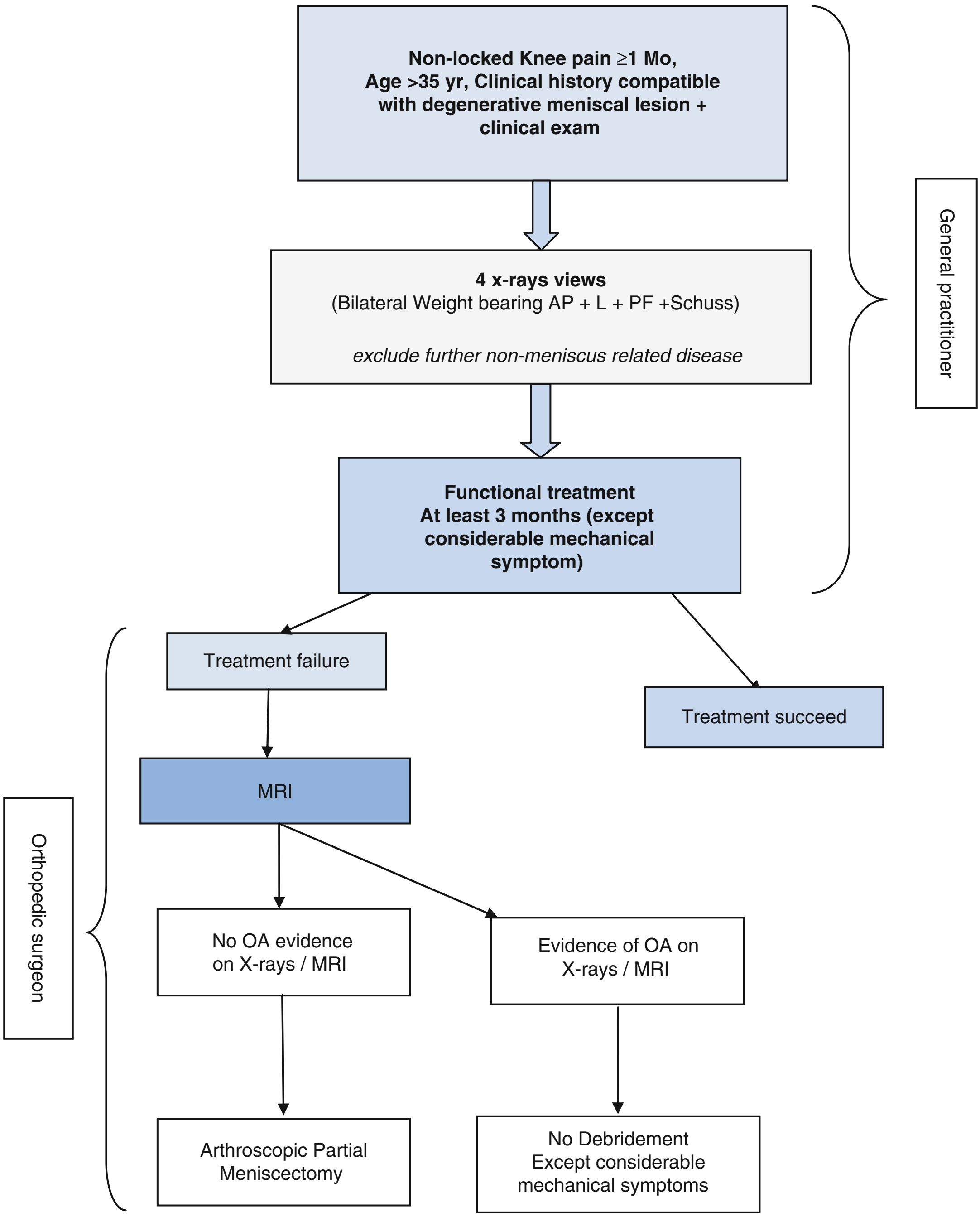

Fig. 41.6 Algorithm for the management of knee pain in patients after 35 years old according to the recent publications

Conclusion

Meniscectomy, one of the most frequent orthopaedic procedures, is probably too frequent. It is not possible to exactly assess the rate of conservative treatment (since many of these cases do not come to the surgeon) so that it is challenging to compare the respective parts of non-surgical treatment and surgical treatment. But one can assume the rate of meniscectomy should decrease and the rate of non-surgical treatment should increase.

Based on a precise diagnosis, treatment principles become clear. In the DML, waiting before any potential surgical procedure is never considered a mistake. Arthroscopic partial meniscectomy can be considered when conservative treatment fails.

Acknowledgements The authors would like to thank the other steering group members of the ESSKA Meniscus Consensus Project: N Darabos, A Gokeler, M Hirschmann, C Hulet, T Järvela, H Mayr, P Ntagiopoulos, H Pereira, and R Verdonk.

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42 Arthroscopic and Supplementation Therapy in Osteoarthritis of the Knee

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42.1 Introduction

Osteoarthritis is a progredient, noninflammatory, degenerative alteration of the knee leading to progressive destruction of cartilage and surrounding joint structures. Concomitant meniscus tears are found in 35 % of patients older than 50 years of age, two thirds of which are asymptomatic [14]. Meniscal lesions are commonly treated by arthroscopic partial meniscectomy [48]. Due to the frequently asymptomatic meniscus lesions in patients with osteoarthritis of the knee, it is difficult for surgeons to determine whether symptoms are caused by the meniscus tear, osteoarthritis, or both. Arthroscopic therapy in osteoarthritis is popular due to the relatively limited invasiveness. The patient and surgeon often desire to exhaust every possible therapeutic option to postpone or avoid endoprosthetic joint replacement. Pain reduction, improvement and retainment of joint function, improvement of prognosis, and inactivation of osteoarthritis are the sought therapy goals. Conservative options stretch from oral and intra-articular drug administration over dietary supplementation and weight reduction to physiotherapy and technical orthopedics. Operative options in osteoarthritis are arthroscopic surgery, leg axis correcting osteotomies, and, ultimately, endoprosthetic joint replacement [11].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_42

42.2 Arthroscopic Therapy

Arthroscopy is a cost-effective outpatient procedure with low complication rates (between 0.27 and 5 %) [16]. But the role of arthroscopy in osteoarthritis is controversially discussed at present. Satisfactory results following arthroscopic debridement are quoted with varying percentages between 0 % and 66 %. The prospective randomized study published by Moseley et al. [36] showed no significant difference between arthroscopic lavage and sham procedure. Yet, inhomogeneous study population and the fact that null hypothesis and statistics were adapted post hoc must be critically mentioned [36]. Further studies could not show any advantages of arthroscopy concerning function, pain, and quality of life compared to intensive physiotherapy, either [27, 42]. Although the outcome regarding symptomatic meniscus lesions was not specifically addressed [18]. On this behalf the METEOR trial was initiated to assess outcomes following arthroscopic partial meniscectomy in patients with mild to moderate knee osteoarthritis and symptomatic meniscal tears compared to standardized physical therapy [23].

In the United States, less arthroscopies for osteoarthritis were registered during the last years [39]. Arthroscopic treatment for symptomatic osteoarthritis is no longer recommended by the AAOS according to their 2013 consensus [23]. Still, a present meta-analysis showed substantial disparity between AAOS recommendations and actual clinical practice patterns in the United States [9].

Other studies have shown that certain patient subgroups may profit from arthroscopic treatment [45]. A recent survey among ESSKA members – all experienced knee surgeons – showed that there are indeed indications for arthroscopic treatment of knee osteoarthritis [35]. In the absence of universal guidelines and RCTs, the application of this type of treatment has actually increased in Europe during the past 10 years. Arthroscopic debridement for knee osteoarthritis seems to be a sufficient treatment option within a time interval of 5 years, resulting in excellent or good outcome in approximately 60 % of patients [49].

In the United Kingdom, the number of arthroscopic procedures performed in a patient age group 60 years and older has decreased between 2000 and 2012, whereas the number of arthroscopic meniscal resections has increased [33].

42.2.1 Lavage

Arthroscopic treatment options for knee osteoarthritis are lavage, debridement, abrasion arthroplasty, and microfracturing. Theoretically, microscopic and macroscopic intra-articular debris as well as inflammatory intra-articular cytokines responsible for synovitis and pain can be washed out of the joint. A 2014 Cochrane review exhibited substantial trial heterogeneity [8]. No improvement of pain or function could be shown after mere joint lavage in knee osteoarthritis [8, 20, 41]. Mere lavage only moderates symptoms for a limited time span [1]. Thus, stand-alone joint lavage cannot be recommended.

42.2.2 Debridement

Synovectomy; resection of non-stable meniscus tears and scar tissue; removal of loose bodies, osteophytes, and chondral flaps; and notchplasty comprise arthroscopic debridement options for knee osteoarthritis. Preoperative planning must consider the desired effectiveness of arthroscopic treatment and whether anticipated symptom relief can account for possible risks and complications for the patient as well as economic factors. Appropriate patient selection is the true challenge for the surgeon.

In cases of knee osteoarthritis combined with mechanical symptoms, arthroscopic debridement could improve function and pain with good patient satisfaction [22]. Further, patients with non-stable cartilage or meniscus lesions seem to benefit most from arthroscopic treatment in a short- to middle-term interval [15]. A level 2 clinical study published in 2006 showed that the preoperative grade of osteoarthritis predicts the postoperative result [1]. In advanced osteoarthri-

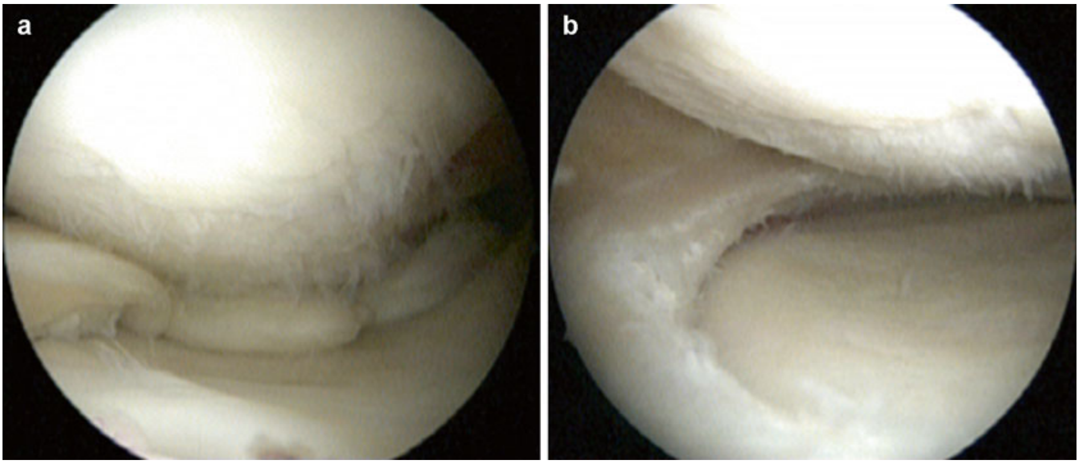

Fig. 42.1 (**a**) Non-stable bucket-handle medial meniscus tear in presence of osteoarthritis grade II of the medial femoral condyle. (**b**) Medial compartment after partial meniscectomy and cartilage smoothing

tis grades III and IV according to the Kellgren/Lawrence classification [26], pain symptoms cannot be improved by arthroscopic debridement. 40 % of the questioned ESSKA members saw no indication for arthroscopy in osteoarthritis grades III and IV [35]. In patients 60 years and older and in fixed varus/valgus deformities, results are rather unsatisfactory. The progression of osteoarthritis could be slowed down by arthroscopic debridement for 3–5 years [29]. Another study showed significant pain relief after resection of non-stable meniscus tears in osteoarthritis patients (Fig. 42.1), with the most benefit when clinically certain meniscus symptoms were present [10]. 75 % of the consulted ESSKA members reported excellent or, at least, positive experience with results after arthroscopic partial meniscectomy in knee osteoarthritis. Other study results indicated that arthroscopic debridement of nontraumatic medial meniscus tears in combination with postoperative exercise therapy was not superior to physiotherapy alone at 2- and 5-year follow-up [18]. Therefore they recommended physiotherapy as initial treatment. Patients with persistent knee symptoms improved after arthroscopic surgery with partial meniscectomy [18]. Katz et al. also reported no advantage of arthroscopic meniscus debridement compared to stand-alone physiotherapy after 6 months. Yet, 30 % of patients with physiotherapy alone in

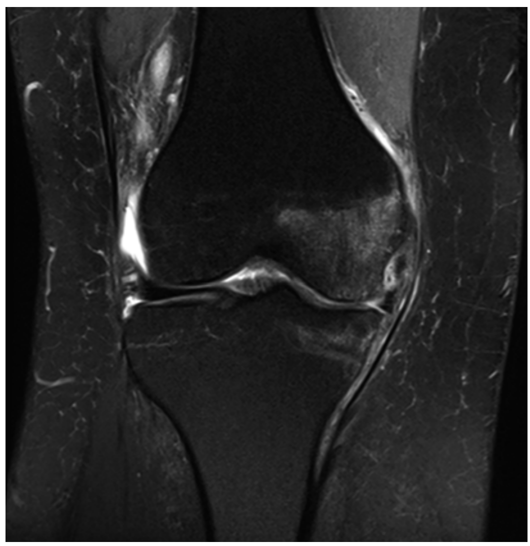

Fig. 42.2 T2-weighted MRI scan of the right knee in frontal plane with extensive bone edema of the medial femoral condyle and medial tibial head

their study underwent surgery within 6 months [25]. Short symptom duration of less than 6 months seems to have a positive influence on postoperative results after arthroscopic debridement [9]. A current meta-analysis declared overweight, obesity, female gender, and previous knee injury as main risk factors for development of symptomatic knee osteoarthritis in adults [46]. Preoperative bone edema in MRI (Fig. 42.2)

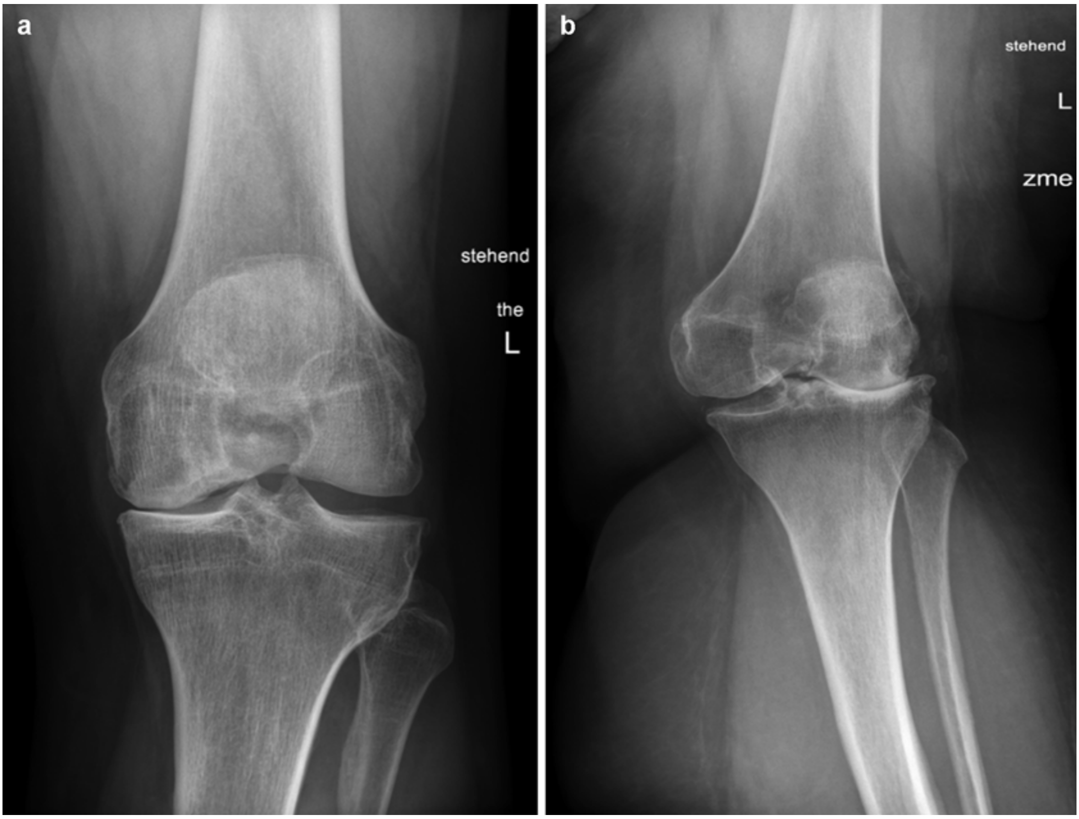

Fig. 42.3 (**a**) p.a. X-ray left knee in Rosenberg technique: varus malalignment with medial compartment osteoarthritis grade III according to the Kellgren/Lawrence classification. (**b**) p.a. X-ray left knee in Rosenberg technique: valgus malalignment with osteoarthritis grades III–IV according to the Kellgren/Lawrence classification

was clearly associated with poor postoperative outcome [54]. Further, according to Mayr et al., persisting extension deficit can be connected to the development of osteoarthritis [34]. Prognosis and functional outcome can be improved by resection of scar tissue and osteophytes as well as notchplasty in order to regain extension [50]. Still, the postoperative outcome is worse if preoperative extension deficit is more than 10°. Clinical results in patients with mechanical axis deviations (Fig. 42.3) are described as significantly worse compared to patients with a neutral mechanical axis [1, 17].

Abrasion of osteoarthritic joint surfaces is widely considered obsolete. Johnson et al. already recorded no improvement after abrasion compared to arthroscopic debridement in 1986 [24]. Contrarily, pain often actually increased due to disturbance of the body's own adaptation mechanisms to the osteoarthritic changes.

Arthroscopic debridement in patients with chondrocalcinosis may activate recumbent osteoarthritis; calcifications must be taken into account when evaluating radiographic images [37].

Microfractures (Fig. 42.4) are a viable therapy option for localized Outerbridge grade IV cartilage defects with survival rates of 89 % after 5 years and 68 % after 10 years; outcome was better in patients with defects smaller than 2 cm^2 [3].

42.3 Supplementation

The indications for nonoperative treatment of knee osteoarthritis are various. Patients and physicians may simply want to postpone or avoid

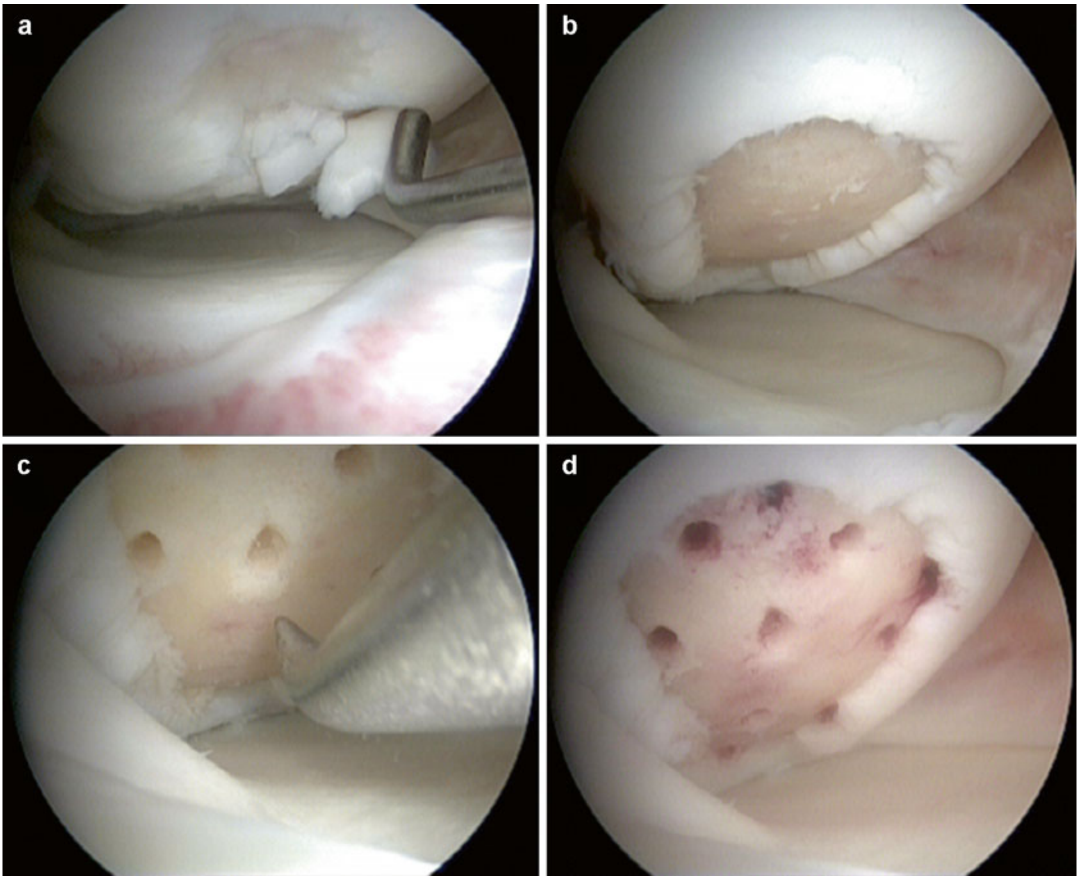

Fig. 42.4 (**a**) Non-stable chondral flap of the medial femoral condyle. (**b**) Medial compartment after cartilage debridement. (**c**) Medial femoral condyle after microfracturing. (**d**) Control of perfusion under reduced water pressure

operative treatment; in some cases surgery may not be possible due to patient preconditions or other limiting factors. Also, osteoarthritic pain may persist even after arthroscopic debridement and/or partial meniscectomy. Well-established treatment options such as oral NSAIDs and intra-articular corticosteroid and/or local anesthetic injections have been successfully applied for years. Dietary supplements such as glucosamine and chondroitin as well as intra-articular injections with hyaluronic acid (HA) or platelet-rich plasma (PRP) are increasingly being requested and used. Still, these treatment options are controversially discussed in current literature. Although several systematic reviews have been conducted, increasingly suggesting positive effects, there is an allover lack of high-quality trials with long-term follow-up.

42.3.1 Intra-articular Viscosupplementation

Intra-articular injection options are corticosteroids, local anesthetics, hyaluronic acid, and blood cell derivatives. Risk of joint infection must always be taken into account as a potentially devastating complication [44]. Sterile application is a must.

Corticosteroid injections provide short-term reduction of moderate to severe pain in osteoarthritis patients, whereas the stated duration varies between 4 and 26 weeks. Side effects are rare; predictors for response to intra-articular corticosteroids are poorly studied [2]. Although the American College of Rheumatology subcommittee on osteoarthritis recommends intra-articular corticosteroids for pain reduction [19], the AAOS was unable to recommend for or against their use due to inconclusive evidence [23].

Patients with degenerative medial meniscus tears and present osteoarthritis seem to only marginally profit from arthroscopic debridement compared to intra-articular steroid injection [51].

Intra-articular application of local anesthetics, commonly used in combination with corticosteroids, has recently been critically discussed. Cytotoxic effects of local anesthetics on chondrocytes have been demonstrated in several studies [7, 40]. The chondrotoxic effect is time-, concentration-, and drug-dependent. Cartilage with signs of osteoarthritis showed higher cellular death rates than healthy cartilage [7]. So far, there was no measurable toxic effect published after single postoperative use of lidocaine [40]. In comparison, even multiple applications of intra-articular corticosteroids showed no signs of increased cartilage destruction in several studies [2].

To date there is no clear recommendation for the use of viscosupplementation in the treatment of knee osteoarthritis. A benefit is suggested for high molecular mass preparations compared to low molecular mass preparations [21]. Some authors, though, conclude this benefit to be small and clinically irrelevant given the increased risk for serious adverse events [43]. Further, viscosupplementation is not supported as treatment for osteoarthritis of the knee in the 2013 AAOS guidelines, although better research is needed concerning the treatment of knee osteoarthritis according to the work group [23]. Some benefits in the knee could be found in literature, especially for pain improvement [38, 52]. Hyaluronic acid may have a positive effect on pain up to 24 weeks after injection, yet cost-effectiveness must be considered [2].

Bannuru et al. conducted several studies on the topic, comparing common treatments of knee osteoarthritis. Intra-articular corticosteroids seemed to be relatively more effective for pain regulation than intra-articular hyaluronic acid up to 4 weeks after treatment, whereas the differences seemed to level up between weeks 4 and 8, yet showing greater efficacy of hyaluronic acid beyond week 8 [4]. Small but robust differences could be detected in favor of intra-articular treatments compared to oral NSAIDs. In a 2014 meta-analysis, Bannuru et al. pointed out a possible placebo effect of intra-articular hyaluronic acid [6]. In addition no significant difference of intra-articular hyaluronic acid and continuous oral NSAID therapy could be detected. Also, there were no safety concerns. Still, the included studies all had short follow-up duration. It seems to have positive effects when given postoperatively after an arthroscopic debridement (Fig. 42.5) [53]. In conclusion, intra-articular hyaluronic acid may be a viable alternative to NSAIDs for knee osteoarthritis, especially for older patients at greater risk for systemic adverse events [5].

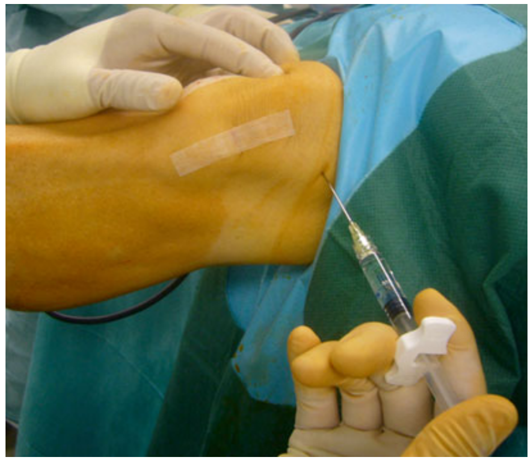

Fig. 42.5 Sterile application of hyaluronic acid into superior recessus of the left knee from the lateral side

The use of platelet-rich plasma (PRP) for intra-articular knee injections in osteoarthritis seems to be an alternative. Current studies are inconclusive concerning the efficacy of PRP injections, though [31]. Again, there is no clear recommendation for or against the use of intra-articular PRP injections in the AAOS guidelines [23]. PRP injections seem to have a positive effect on pain and function compared to placebo or hyaluronic acid [32]. The median duration of symptom relief in osteoarthritis is stated at 9 months. Though there is no data supporting cartilage or meniscus regeneration in patients with substantial defects, younger patients with mild osteoarthritis seem to profit most. Still, extensive high-quality evidence for clinical advantages of PRP use is missing. Simple preparation, low cost, and safety are leading to increasing acceptance among physicians and patients [2].

42.3.2 Oral Supplements and Medication

Conservative medical treatment is the first-line therapy in early to mild osteoarthritis without severe structural damage. Pharmaceuticals and dietary supplements are the main therapeutic options. Since 80 % of patients with knee osteoarthritis regularly report persisting pain symptoms compromising activities of daily living, pain-modifying therapy is a cornerstone in conservative osteoarthritis treatment [28].

Paracetamol is judged to be the first choice concerning safety and cost [28]. Adverse effects in patients with hepatic diseases, alcohol abuse, and interactions with warfarin must be taken into account. Nonsteroidal anti-inflammatory drugs (NSAIDs) are most commonly used in the treatment of knee osteoarthritis, moreover when paracetamol fails effectiveness. Most NSAIDs are nonselective inhibitors of cyclo-oxygenase (COX-1 and COX-2), whereas there are also selective COX-2 inhibitors. Adverse events are upper GI hemorrhages for nonselective NSAIDs. Different NSAIDs should never be applied in combination since analgesic effects, in contrast to adverse effects, are not exponentiated. COX-2 inhibitors have less GI side effects; cardiovascular thrombotic events are possible, though [28].

Patients with severe pain not eligible for surgery can receive opioids. The most common adverse events are nausea, vomiting, and constipation, limiting patient compliance.

Study findings suggest conventional NSAIDs may increase progression of osteoarthritis, whereas selective COX-2 inhibitors seem to have positive effects on knee cartilage [12].

NSAIDs and selective cyclooxygenase-2 (COX-2) inhibitors lead to an inhibition of osteoblasts [52]. This should be considered in patients with poor bone healing.

In general, using these types of medications, sensitivity of medications, drug to drug interactions, and comorbidities must be acknowledged concerning cost-benefit calculation.

Slow-acting drugs such as glucosamine, chondroitin sulfate, and diacerein can be used in the early stages of osteoarthritis [38]. They aim at slowing down degenerative progression, improving joint function and pain reduction. Adverse reactions are rare.

Glucosamine and chondroitin sulfate are main parts of the extracellular cartilage matrix. Diacerein is an interleukin-1 inhibitor; symptomatic and structural effects on cartilage are suggested, but it is presently not approved in many European countries. Literature concerning oral supplement efficacy is heterogeneous.

Recommendations for osteoarthritis treatment by the Osteoarthritis Research Society International (OARSI) saw possible symptomatic benefit of glucosamine and/or chondroitin sulfate for patients with knee osteoarthritis. Treatment should be discontinued, though, if there is no apparent response within 6 months of initiation [55].

A Cochrane review of 43 randomized controlled trials comparing chondroitin to placebo or active control found a slight but clinically meaningful advantage concerning pain in osteoarthritis. Two studies even showed significantly slower joint space reduction. Critically mentioned must be that many of the included trials were flawed by small sample size, short follow-up, or pharmaceutical funding [47]. Also, another short-term study did not show structural benefits, such as improvements in MRI cartilage morphology, from oral glucosamine supplementation in patients with chronic knee pain [30].

Another systematic review analyzed a variety of supplements and found that glucosamine hydrochloride did not have an effect on pain management unless the sulfate formulation was used; diacerein relieved pain compared to placebo [38].

Recently, positive effects of sesame on clinical symptoms in knee osteoarthritis patients could be shown, indicating that sesame might be a viable adjunctive osteoarthritis treatment [13].

Several other nutritional supplements such as S-adenosylmethionine (SAMe), avocado soybean unsaponifiables, vitamin E, green-lipped mussel, dimethyl sulfoxide, and methylsulfonylmethane have been studied and partially used to treat moderate/severe knee osteoarthritis. Currently there is no clear recommendation due to lack of sufficient clinical evidence [56].

Conclusion

Following highly differentiated indications according to accurate diagnostic analysis (Table 42.1), patients with early stages of knee osteoarthritis can benefit from arthroscopic debridement with resection of non-stable meniscus tears, cartilage flaps, scar tissue, loose bodies, and inflammatory synovia. An age of less than 60 years, neutral mechanical axis, and symptom duration of less than 6 months are positive predictors. Arthrofibrosis, bone marrow edema in MRI, chondrocalcinosis, and mechanical axis deviations as well as higher osteoarthritis grades are associated with poor outcome. Adequate patient selection is fundamental.

Oral pain medications, especially NSAIDs, play an important supportive role in all stages of osteoarthritis, whereas other oral supplements at best have mild influence on pain modulation. Although there is no general recommendation for intra-articular injection therapy with corticosteroids, hyaluronic acid, or PRP, current literature confirms good short-term effects of corticosteroids and long-term effects of hyaluronic acid and PRP in osteoarthritis of the knee. With their respective safety profiles, intra-articular hyaluronic acid or PRP may be beneficial alternatives to surgery and/or NSAIDs for patients with multiple comorbidities.

Table 42.1 Important indication criteria for arthroscopic debridement in knee osteoarthritis

Relative indications:
Osteoarthritis grades I–II according to the Kellgren/Lawrence classification
Mechanical obstruction by cartilage/meniscus flaps, scar tissue
Close to neutral mechanical axis
Short symptom duration
Less than 10° extension deficit with stenosis of the intercondylar fossa
Contraindications:
Osteoarthritis grades III–IV according to the Kellgren/Lawrence classification
Mechanical axis deviation
Relevant bone edema in MRI

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Indications in Meniscus Surgery: Synthesis

43

Philippe Beaufils and Nicolas Pujol

Contents

Take-Home Messages

- Be sure the meniscal lesion is responsible for the symptomatology.
- Save the meniscus as possible.
- Traumatic lesions:
  - Stable knee: vertical peripheral longitudinal tears MUST be repaired, especially on the lateral side.
  - ACL tears REQUIRE a concomitant RECONSTRUCTION.
  - ACL tears: medial meniscal tears MUST be repaired; lateral ones may be left alone if stable. Do not forget posterior hind meniscal tears.
  - Indications of meniscus repair can be pushed in certain conditions: root tears, radial tears and horizontal cleavage in young athletes.
  - Meniscectomy is proposed when no conservative solution is possible.
- Degenerative meniscal lesions:
  - DML are related with early osteoarthritis.
  - Conservative treatment (physiotherapy, etc.) is always the first choice.
  - Wait at least 6 months before considering arthroscopic meniscectomy, except in case of internal derangement (clicking, catching, etc.).

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_43

The development of arthroscopic knee surgery in the 1970s brought about a substantial advance in meniscal surgery. The use of diagnostic arthroscopy and the emergence of the MRI as a diagnostic tool have contributed a great deal to the analysis of meniscal lesions, quality of lesion diagnosis and management. Arthroscopic meniscectomy became a great success, based on three pillars: rapidity of the arthroscopic procedure, low morbidity and good short-term results. Because of these reasons, arthroscopic meniscectomy has rapidly become the most frequent surgical procedure in numerous countries.

There is not one but many meniscal lesions.

There is not one but many methods of treatment.

When an orthopaedic surgeon is faced with a meniscal lesion which is assumed to be the source of the patients' symptoms, he needs to answer two fundamental questions:

- Is it necessary to treat this lesion surgically? Abstention from operative treatment must be thoroughly considered.
- If there is a need for surgical treatment, is either meniscectomy or meniscal repair indicated?

Apart from this, the treatment is also clearly dependent on other factors:

- Epidemiologic criteria, e.g. patient's age, activity level, time since injury or coexistent lesions, particularly to ligaments and joint cartilage
- Anatomical criteria, e.g. medial or lateral meniscus, type of lesion, its localization and extension

Anatomic, biomechanical, animal and clinical studies have clearly demonstrated the important role of the meniscus and thus the importance of its preservation. The concept of meniscal preservation was therefore born and is based on three treatment options:

- Meniscal repair
- Conservative treatment of the meniscus lesion (masterly neglect or let the meniscus alone)
- The most partial meniscectomy possible if no other options exist

There are two principal situations that appear in clinical practice: traumatic meniscal lesion (stable knee or ACL-deficient knee) and degenerative meniscal lesion (with or without obvious osteoarthritis)

43.1 Traumatic Lesions

Meniscus repair outcomes (with or without ACL tear) are now well established. For vertical peripheral longitudinal tears which are located in a vascular zone, the rate of failure is acceptable (4–28 %). Long-term comparative studies and meta-analyses with the arthroscopic meniscectomy demonstrate superiority of meniscus repair in terms of function, return to sports and cartilage protection [19, 20, 24, 28].

In case of ACL tear, meniscus preservation (repair or abstention) in combination with ACL reconstruction protects the cartilage. According to a commonly shared opinion, unstable or symptomatic meniscal tears need to be surgically repaired during ACL reconstruction, while stable asymptomatic tears could be left untreated. However, the exact definition of instability of a lesion has not been clearly defined, and the problem of finding correct criteria (e.g. size of lesion and abnormal mobility of the meniscus) remains unsolved. In reality, regarding the risk of secondary meniscectomy, indications for surgical repair can be widened for the medial meniscus (increased risk of secondary meniscectomy after abstention), whereas in case of the lateral meniscus, abstention can be the favoured choice (low risk of subsequent meniscectomy) [21].

New indications of meniscus repair appeared in the last years:

Horizontal cleavage in young athletes is a rare specific condition which can be regarded as an overuse lesion on stable knees. When functional treatment fails, meniscus repair can be considered. Pujol and Beaufils et al. [22] propose an open approach. Meniscal repair is performed with vertical sutures. In the Kurzweil et al. [14] literature review (a total of 98 repairs), the overall success rate without subsequent surgery is 77.8 % [25].

Pujol et al. [23] propose to add injection of PRP to enhance the healing process in the avascular zone of the lesion.

Preliminary results are encouraging.

- Posterior menisco-capsular 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 [17] and popularized by Ahn [1].
- Root tears are frequent when far posterior degenerate meniscal lesions are included in this group. True traumatic root avulsions are rare, frequently associated with ACL tears. These meniscal tears correspond to a total functional meniscectomy and must so be repaired by a transosseous tibial reinsertion [29].

In traumatic tears, meniscectomy, as partial as possible, should only be considered when a conservative treatment is not possible. In reality, meniscus repair and meniscectomy are not alternative procedures for the same tear, but complementary techniques whose indications are different.

If so, how can we explain the infrequent use of the meniscal repair in our daily practice? 6.5 % in Germany in 2012 and 5.6 % in France in 2013 (ATIH (Agence Technique de l'Information sur l'Hospitalisation) data) compared with meniscectomies. These percentages have certainly evolved in the right direction (2.7 % in France in 2008) but still remain low and greatly under the optimal values of 15–25 % according to the type of lesion considered. The meniscectomy remains overused in regard to meniscal repair. How can we explain this gap?

The adoption of a surgical procedure by the majority of the surgical community cannot be merely due to the quality of the scientific articles (evidence-based medicine). Other non-scientific criteria pay a very important role:

- Meniscal repair is technically more demanding.
- Meniscal repair requires more time to perform.
- Meniscal repair demands a longer rehabilitation protocol which can cause problems in cases of professional athletes.
- Finally and probably the most important reason is related to the variable economic constraints from one country to another that can influence the surgical decision in regard to meniscal repair (expensive implants, surgeon fees that are similar to that received after meniscectomy for a more difficult surgery).

It is convenient not to underestimate the hurdles that demonstrate to us the importance of surgical skill teaching, patient information and collaboration with public authorities.

43.2 Degenerative Meniscal Lesions

The question of a meniscectomy in case of a degenerative meniscal lesion still remains controversial and is still debated [2], Beaufils et al. [3], [6, 15, 25]. The definition of the degenerative meniscal lesion and its relationship with the osteoarthritic process is now well defined [7]. The frequency of asymptomatic meniscal lesions in the elderly population should be underlined. It should be stressed that the presence of an MRI meniscal lesion does not have to be responsible for the symptomatology.

What is the place of the meniscectomy in this context? The debate is open. Numerous publications showed the functional improvement after meniscectomy but also the increased risk of osteoarthritis at the mid- and long term. Six randomized studies have questioned the legitimacy of arthroscopy in the degenerative joint or in isolated torn menisci [8–13, 18, 27].

In 2002, Moseley et al. [18] were the first to perform a randomized study comparing meniscectomy versus sham surgery in cases of knee osteoarthritis. The results obtained were not better in meniscectomy in comparison to placebo surgery. Kirkley [13] in 2008 arrived at the same conclusion, comparing arthroscopic surgery and physiotherapy in osteoarthritic knees.

Recently, Katz et al. [12], Herrlin et al. [10, 11] and Shivonnen et al. [27] have questioned the efficacy of the arthroscopic meniscectomy in degenerative meniscal lesions even in the absence of macroscopic signs of osteoarthritis. The first three studies compared partial meniscectomy with physiotherapy, while the third compared it to sham surgery.

However these articles should be read with great care. For example in the Katz study [12], there is no difference between physiotherapy and meniscectomy. However, there is a crossover from the physiotherapy group to the arthroscopy group in 35 % of the patients.

Shivonnen et al. [27] studied patients suffering from isolated degenerative meniscal tear but without having presenting cartilage degeneration. They compared arthroscopic meniscectomy with what they call sham surgery which is in reality arthroscopic lavage. They did not find any difference. But this design, which is interesting for scientific purpose, does not correspond to the daily practice.

The important and common find of these studies might be the fact that surgeons should rather wait for a while before arthroscopy should be performed. We all are sure that there are a number of patients who may only require conservative treatment. Taking these facts into consideration arthroscopy can be considered as a successful therapy in patients suffering on meniscal tears and mild or moderate osteoarthritis when conservative treatment failed after a period of about 6 months.

At the same time, Gauffin et al. [8] performed a randomized study that demonstrated better results in the meniscectomy group in comparison to the physiotherapy group at 1-year follow-up whether the design was "intent to treat analysis" or "as treated".

Two major lessons should be drawn from this apparent contradiction:

1. A well-designed randomized study alone cannot be considered as the absolute truth. Numerous elements or biases can contribute on the identical subject therefore altering the results: conditions of the cohort recruitment, definition of the selection criteria (what is a degenerative meniscal lesion?) and role of the time between the onset of symptoms and the date of study inclusion (numerous symptomatic meniscal lesions become spontaneously asymptomatic in the first months). Data "beautification or embellishment" that enhances positive outcomes must not be forgotten as well [26]. These biases have been repeatedly studied in the medical literature and consist of selective choice of statistically significant results, inversion between the main and second objective, use of composite judgement criteria, false double-blind RCTs, false intent to treat methodology, subgroups which are not in the initial protocol and non-supported conclusions [5, 9, 26]. To sum it all up, in the Chess' study [4] including 232 randomized studies in orthopaedic surgery, the authors conclude that "very few studies meet all … criteria. Thus, many of these studies likely have biased estimates of treatment effects".
2. These studies, however solid they may appear, should be read and interpreted with a critical scientific mind. They should not be taken as a fact but should contribute to the scientific debate with an ultimate objective of improving our practice [16].

The necessity of a consensual process is thus necessary [3], founded on independence and participation of all interested parties to produce the most exhaustive critical analysis of the literature possible. Such work permits probable reduction of the number of arthroscopic meniscectomies in our countries in favour of abstention and meniscal repair and the better nosological definition of the meniscectomy rendering it pertinent and efficient.

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Part VIII

Post-meniscectomized Knee

Postoperative Osteonecrosis of the Knee: Incidence, Diagnosis, Management and Results

44

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Contents

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44.1 Introduction

Osteonecrosis (ON) of the knee comprises three separate disorders. The first one is called *primary spontaneous osteonecrosis* of the knee (SPONK), which was first described as a distinct entity by Ahlback and colleagues in 1968 [2]. Two main theories of the aetiology of osteonecrosis have been identified, a vascular arterial insult and trauma, but neither has been definitely proven. Classically described as a focal lesion occurring in the medial femoral condyle of a patient in their fifth or sixth decade of life, females are affected almost three to five times more commonly than males (Table 44.1) [1, 2, 4, 25, 37].

The second entity of osteonecrosis of the knee is called *secondary osteonecrosis*, which is associated with risk factors and a poor prognosis. Frequently, this secondary ON is a sequela of prolonged steroid therapy used for many medical conditions such as rheumatoid arthritis, SLE, following renal transplantation, chronic bronchial asthma, skin lesions, etc. In patients with

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_44

Table 44.1 A modified classification system by Soucacos et al. [44] combines findings on various imaging methods to find the one most appropriate method to diagnose each of the four stages of his classification of SPONK

Stage	Characteristic findings on imaging/clinical	Imaging method most likely to establish diagnosis	Additional indicative imaging	Time interval since onset of symptoms [months]	Progression to further stages	Treatment recommended
I	Incipient	MRI/bone scan	Bone scan/ MRI	1–2	Likely but potentially reversible	Conservatively
II	Flattening of condyle	MRI	Bone scan Plain X-rays	2–4	Likely but potentially reversible	Depending on size
III	Crescent sign	Plain radiography	–	3–6	Irreversible	Surgically
IV	Collapse of subchondral bone and articular cartilage	Plain radiography	–	9–12	Irreversible	Surgically

secondary ON, 50 % of the cases are bilateral and 60 % affect the lateral femoral condyle. Multiple sites (such as humeral head, hip, lateral humeral condyle, talus, etc.) may be involved but the symptoms are often minor compared with primary osteonecrotic lesions that involve an entire condyle. Secondary ON may be multifocal (e.g. involving both femoral condyles and the tibial plateau).

Lately, a potential third entity of ON of the knee has been described by Brahme et al. [10] in 1991. He was the first to describe the occurrence of osteonecrosis of the knee evolving after routine arthroscopic meniscectomy. Since then, osteonecrosis in the postoperative knee has been noticed as a complication of arthroscopic meniscectomy [14, 30] and has been referred to as “postarthroscopic” [20] or “postmeniscectomy” osteonecrosis of the knee [14, 22, 34].

Since osteonecrosis has also been noted after other arthroscopic interventions, such as cartilage debridement [18] and ACL reconstruction [6], it might be advisable to refer to this entity as ONPK: osteonecrosis in the postoperative knee (Table 44.1). This term helps in avoiding possible medicolegal implications, which has been explained previously [37].

So far, 49 ONPK cases have been reported in the literature [3, 10, 13, 14, 20, 23, 29, 30, 39, 42]. Compared to the high number of arthroscopic knee procedures performed worldwide, the prevalence of ONPK is very low. Several aetiological factors for ONPK have been discussed but the exact cause remains unknown. In contrast to the patient population typically affected by spontaneous osteonecrosis of the knee (SPONK), ONPK tends to affect younger patients (mean, 58 years; range, 21 to 82 years) with an equal gender distribution (23 females and 24 males) [4, 8].

The purpose of this paper is to review the incidence, the pathophysiology and the clinical and radiographic features as well as the pitfalls in diagnosing ONPK. Studies reporting associated use of radiofrequency devices or laser techniques for arthroscopic meniscectomy are not considered in this review, because the suspected principal aetiology for such cases is the thermal and/or photoacoustic effect rather than routine arthroscopic meniscectomy performed with hand instruments or mechanical shavers [27, 38]. Studies reporting associated trauma or other risk factors for secondary osteonecrosis are also not considered.

44.2 Incidence and Epidemiology in ONPK

The exact prevalence of ONPK has never been evaluated but seems to be very low considering the large number of arthroscopic meniscectomies [20]. Ten clinical studies with a total of 49 patients have reported ONPK after arthroscopic meniscectomy [3, 10, 13, 14, 20, 23, 29, 30, 39, 42]. In all cases, meniscectomy was performed prior to the evolution of ONPK. In all 49 patients, postoperative MRI showed signs which were consistent with ONPK (Table 44.2). Both genders were equally affected (25 male, 24 female patients) with a mean age of 58 years (21–82 years, Table 44.2).

There is a clear association between ONPK and medial meniscal tears. Of the 49 patients diagnosed with a meniscus lesion prior to the initial arthroscopy, 43 had a medial meniscus tear (87 %) and 7 had a lateral meniscus tear (13 %). The medial femoral condyle was predominantly affected in 82 % ($n=41$) of cases followed by the lateral femoral condyle in 8.5 % ($n=5$), the lateral tibial plateau in 2.1 % ($n=2$) and the medial tibial plateau in 2.1 % ($n=1$).

The location of osteonecrosis correlated geographically with the pre-existing pathology and arthroscopic procedures in all studies. In cases of a medial meniscal tear, MRI signal changes were usually restricted to the medial femoral condyle. No patient developed osteonecrosis in the opposite compartment to the meniscectomy site. Of the seven patients with a lateral meniscal tear, four developed osteonecrosis of the lateral femoral condyle and the other two developed osteonecrosis of the lateral tibial plateau. 65 % of patients were diagnosed with a concomitant chondral lesion of varying degree. The medial compartment was affected in 33 patients (26 patients with a chondromalacia of the medial femoral condyle, 7 patients with medial tibial plateau; Table 44.2). ONPK does not differ from SPONK with regard to location of the lesions. The simultaneous involvement of the medial femoral condyle with either the adjacent tibia or the lateral compartment seems to be very rare in both ONPK and SPONK [10, 44]. However, single lesions other than in the medial femoral condyle can appear in both SPONK and ONPK [3, 26, 27, 31, 35, 38, 39, 42, 43].

Musculo et al. [30] reported on a series of five patients over 60 years of age who were followed with serial MRIs; each had a symptomatic medial meniscal tear and developed SPONK; arthroscopy was not performed. In all cited studies, meniscectomy was performed prior to the evolution of ONPK. Still, it remains unclear if SPONK and ONPK have different aetiologies.

44.3 Physiopathology

The physiopathology of postarthroscopy osteonecrosis remains conjectural. The main theory for the aetiology of osteonecrosis has been identified as a vascular arterial insult. According to Prues-Latour et al. [39], increased permeability of damaged cartilage leads to arthroscopic fluid leaking into subchondral bone, leading to subchondral bone oedema and subsequent osteonecrosis. Fukuda et al. [15] cited altered knee mechanics following meniscectomy, leading to subchondral stress fractures and intraosseous synovial fluid penetration as the cause of osteonecrosis.

Arthroscopy itself is suggested as a non-degenerative cause for osteonecrosis [22, 39] although the initial reason for arthroscopy is the meniscal tear. Other non-degenerative causes, such as the use of an irrigation pump or tourniquet during surgery and the preoperative intra-articular administration of local anaesthetic, have not been associated with subsequent osteonecrosis [14, 20, 30].

In the majority of studies, degenerative changes of both cartilage and meniscus at the time of arthroscopy were thought to be responsible for the development of osteonecrosis [14, 20, 39, 40, 43]. The meniscal tear itself however seems to have an association with ON even before surgery has been performed [7, 31].

Altered knee biomechanics after meniscectomy were also considered to be a predisposing factor for osteonecrosis [45]. In these cases an increased tibiofemoral contact pressure is thought to result in insufficiency fracture of the cartilage and subchondral bone with intraosseous leak of synovial fluid and subsequent osteonecrosis [15, 21].

Other authors hypothesized whether the pathologic cartilage has increased permeability for the arthroscopy fluid, which might lead to subchondral oedema and consequent osteonecrosis [29, 40]. Whether an aetiologic relationship

Table 44.2 Epidemiological data of reviewed studies reporting about evolving osteonecrosis (ON) on postoperative MRI after conventional arthroscopic meniscectomy of the knee

Author	Total number of patients with ONPK	Type of study	Male/female	Mean age [years] (range)	Number of patients with meniscal tears and its location at initial arthroscopy *N* Medial/lateral	Number of patients with chondromalacia at initial arthroscopy	Location of chondromalacia at the femoral condyle at initial arthroscopy	Location of chondromalacia at the tibial plateau at initial arthroscopy	Type of treatment for cartilaginous lesion	Location of osteonecrosis on MRI following arthroscopic meniscectomy
Brahme [10]	7	Retrospective, case reports	4/3	60.5 (42–72)	7 6 med/1 lat	7	7 med/1 lat	1 med/0 lat	Chondroplasty in 7 patients	6 MFC/1 LFC and LTP
Johnson [20]	7	Retrospective, case reports	3/4	60 (41–79)	7 4 med/3 lat	6	7 med/2 lat	3 med/4 lat	Chondroplasty in 6	4 MFC/1 LFC/1 MTP/1 LTP
Prues-latour [39]	9	Retrospective, case series	4/5	69 (58–82)	9 8 med/1 lat	7	4 med/2 lat	3 med/1 lat	Chondroplasty in 1 patient	8MFC/1 LFC
Santori [42]	2	Retrospective, case reports	1/1	34 (21–47)	2 2 med/0 lat	0	0	0	–	2 MFC
DeFalco [13]	1	Case report	1/0	48	1 1 med/0 lat	0	0	0	–	1 MFC
Kusayama [23]	2	Retrospective, case reports	2/0	52	2 2 med/0 lat	0	0	0	–	2 MFC
Al-Kaar [3]	10	Retrospective, case reports	5/5	69 (55–81)	10 9 med/1 lat	7	4 med/1 lat	0	Chondroplasty in 1	9 MFC/1 LFC
Faletti [14]	1	Retrospective, case reports	1/0	66	1 1 med/0 lat	0	0	0	–	1 MFC
Musculo [30]	8	Retrospective, case series	3/5	65 (54–75)	8 8 med/0 lat	4	4 med/0 lat	0	–	8 MFC
Moynot et al. [29]	2	Retrospective, case series	1/1	64 (57–70)	2 2 med/0 lat	2	2 med/0 lat	0	–	2 MFC
Average				53						
Total	49		25/24		49 43 med/6 lat	33 (67.3 %)	28 med/6 lat	7 med/5 lat	15 Chondroplasty	43 MFC (82 %) 4 LFC (8.5 %) 1 MTP (2.1 %) 2 LTP (4.2 %)

The location of ON correlated geographically with pre-existing pathology and arthroscopic procedures in all studies. In cases of medial meniscal tear, MRI signal changes were usually restricted to the medial femoral condyle. No patients developed ON in the contralateral compartment to the meniscectomy site. Of the six patients with a lateral meniscal tear, four developed an ON of the LFC and the other two developed ON of the lateral tibial plateau.

Abbreviations: *MFC* medial femoral condyle, *LFC* lateral femoral condyle, *MTP* medial tibial plateau, *LTP* lateral tibial plateau: non-weight bearing for at least 4 weeks with NSAIDS exists between degenerative meniscal and cartilage damage and arthroscopy or is mere coincidence without causative relationship is unclear because of the high prevalence of degenerative meniscal tears in elderly patients in whom osteonecrosis is more frequently seen.

Several authors suggested that the lesions described as subchondral osteonecrosis following meniscectomy actually represent subchondral insufficiency or stress fractures [17]. This was suggested by Yamamoto and Bullough [46] on the basis of a careful histologic evaluation of patients with osteonecrosis of the hip and knee.

44.4 Patient History, Physical Examination and Differential Diagnosis

Elderly patients have a high incidence of degenerative meniscal tears [12]. They often present with medial knee pain of sudden onset. Some patients complain about locking and catching. On clinical examination, a mild effusion together with a tender medial joint line can be found. Standard X-rays of the knee frequently show a preserved joint space and no signs of osteonecrosis [36]. MRI shows degenerative meniscal lesions and chondral damage. Sometimes, bone marrow oedema can be found in the tibial plateau. If conservative treatment with injections, NSAIDs and physical therapy fails, arthroscopic surgery is often the next therapeutic step to be considered. At initial arthroscopy, the cartilage of the femoral condyle and the tibial plateau is usually intact or shows only mild degenerative changes. The degenerative meniscus tear is resected.

Symptoms usually resolve. In some patients, however, symptoms may persist or even occasionally worsen [14, 20, 22, 30, 42]. These patients have similar clinical and imaging findings, which can be indicative for evolving osteonecrosis:

- A tender joint line together with effusion on postoperative exam consistent with a potential (re-)tear of the operated meniscus
- A bone marrow oedema pattern (BMO) in the meniscectomised compartment on postoperative MRI [10, 14, 19, 20, 22, 30, 34, 42]

The clinical significance of these findings is difficult to interpret since SPONK, ONPK and chondromalacia can mimic meniscus symptoms and postoperative BMO is frequently transient [19, 22].

In patients with persistent or worsening symptoms following knee arthroscopy, one must distinguish between a missed diagnosis of early-stage osteonecrosis of the knee (SPONK) [2], an osteonecrosis in the postoperative knee (ONPK) [10, 14], a transient lesion that shares the bone marrow oedema pattern on MRI with the former two [25] and a recurrent meniscal tear [30].

It can be difficult to establish a correct diagnosis due to these pitfalls:

1. The medial knee pain can be caused by the degenerative meniscal tear, bone marrow oedema or both.
2. There seems to be an association between degenerative medial meniscal tears and the evolution of SPONK [31].
3. Signs, symptoms, imaging findings and the potential to progress are similar for ONPK and SPONK [14], but additional arthroscopy in the presence of undiagnosed SPONK can accelerate joint destruction [25].
4. BMO on MRI is a frequent but non-specific signal pattern that can be related to ischaemia (i.e. osteonecrosis, bone marrow oedema syndrome, OCD), mechanical (bone bruise, microfracture) or reactive (osteoarthritis, postoperative BMO) causes [19].
5. An undefined time interval between the onset of osteonecrosis symptoms and MRI findings has been noted ("window period" of the MRI method to detect SPONK) [22, 28, 30].

With consistent BMO changes on pre- and postoperative MRI, the diagnosis of a pre-existing SPONK is reasonable. Without BMO changes on preoperative MRI, ONPK must be suspected, but as above, SPONK cannot be ruled out. Without a preoperative MRI, SPONK, ONPK and transient lesions must be included in the differential diagnosis, and definitive diagnosis may only be possible in retrospect.

44.5 Diagnosis of ONPK and Imaging Findings

To diagnose evolving osteonecrosis, MRI is mandatory to detect bone marrow oedema (BMO). Since only bone marrow structures are initially affected, plain radiography, CT or arthroscopy is unable to demonstrate these early changes. Although a bone scan is highly sensitive to detect early changes in vascularisation by increased tracer accumulation, its spatial resolution is poor and differentiation from other disorders with increased uptake is impossible [19, 25, 28, 41].

According to the literature, the following two prerequisites have to be fulfilled simultaneously to establish the diagnosis of evolving ONPK and will be reviewed in detail below [19, 20, 24, 25, 28, 31, 35, 41]:

- Absence of osteonecrosis on preoperative MRI obtained 4–6 weeks after the onset of preoperative symptoms
- A timely association between knee arthroscopy and a suspicious BMO pattern on postoperative MRI

To establish the diagnosis of advanced and irreversible ONPK, preoperative MRI must mitigate against a diagnosis of missed SPONK, and one of the following two findings – which will also be detailed below – has to be present:

- Pathognomonic imaging findings of advanced osteonecrosis on plain radiographs (Fig. 44.1), MRI or CT such as crescent sign or collapse of subchondral bone and articular cartilage
- Histologic findings consistent with osteonecrosis of the resected lesion during a salvage surgery

44.5.1 Absence of Osteonecrosis on Preoperative Imaging

Normal findings on preoperative MRI are mandatory to distinguish ONPK from SPONK. However, in the early stage of SPONK, findings on MRI might be normal, as a so-called window period

Fig. 44.1 Anteroposterior conventional radiograph of a 67-year-old women with a 4-months history of spontaneous knee pain shows a radiolucent lesion of the medial condyle (crescent sign) indicating stage III osteonecrosis according to Soucacos et al. [44]

has been noted between the onset of symptoms and the appearance of signal changes on MRI [9, 20, 32, 34, 47]. In the ten clinical studies reporting cases of osteonecrosis in the postoperative knee, the mean time between arthroscopy and MRI establishing the diagnosis of ONPK was 18 weeks (range: 3–176 weeks).

Johnson et al. [20] have arbitrarily chosen 6 weeks as the minimal time interval between the onset of knee symptoms and MRI examination as an inclusion criterion for his knee patients. This decision was based on a laboratory model by Nakamura et al. [32] who surgically induced ON of the femoral head in a canine model and demonstrated that it may take up to 4 weeks after surgery for the MRI to become positive.

In a clinical MRI study, Lecouvet et al. [24] have described a mean interval of 10 weeks

Table 44.3 Survey of timely relationship between diagnostic imaging and the suspected evolution of postarthroscopic osteonecrosis (ONPK)

Author	Total number of patients with ONPK	Number of patients with preop MRI	Mean duration between onset of symptoms and diagnostic MRI prior to initial arthroscopy [weeks] (range)	Number of patients potentially examined within diagnostic window of MRI (4–6 weeks after onset of symptoms) or without a preop MRI at all	Mean duration between initial arthroscopy and MRI establishing the diagnosis of ONPK [weeks] (range)
Brahme [10]	**7**	7	Unclear	up to 7	32 (8–56)
Johnson [20]	**7**	7	42 (6–144)	0	16 (12–24)
Prues-Latour [39]	**9**	9	26 (0.4–72)	2	24 (5–48)
Santori [42]	**2**	1	Unclear	1	4
DeFalco [13]	1	1	3	1	9
Kusayama [23]	2	2	2.5 in 1 case	Up to 2	16
Al-Kaar [3]	10	9	Unclear	Up to 10	27.5 (3–176)
Faletti [14]	1	0	Unclear	1	16
Musculo [30]	8	8	Unclear	4	18 (6–36)
Moynot et al. [29]	2	2	Unclear	4	18 (6–36)
Average			18.3	1	12
Total	49	46 (93.6 %)		28 (59.5 %)	

In total, up to 30 of the 49 ONPK cases (59.5 %) might actually represent pre-existing, undiagnosed early-stage SPONK due to the diagnostic window of the MRI method to detect SPONK

between the onset of symptoms and subsequent MRI changes. Musculo et al. [30] reported on a series of five patients with symptomatic degenerative medial meniscal tear followed up with MRI who developed osteonecrosis without arthroscopic meniscectomy performed. The mean interval between initial MRI and onset of symptoms was 2.2 months.

Although the exact length of the diagnostic MRI window to detect SPONK has not yet been well defined, it appears that MRI findings might be considered normal only if the examination was obtained at least 6 weeks after the onset of symptoms. Otherwise it may not be possible to distinguish between early SPONK and ONPK.

44.5.2 Timely Association Between MRI Signal Changes Following Arthroscopy

Ten clinical studies with a total of 49 patients have reported ONPK after arthroscopic meniscectomy (Table 44.3). In all studies, MRI was the initial diagnostic imaging method [3, 10, 13, 14, 20, 23, 29, 30, 39, 42].

A timely association between ON and the occurrence of postoperative MRI signal changes after knee arthroscopy was the sole basis for a diagnosis of ONPK in the majority of studies (Table 44.3) [3, 10, 13, 14, 20, 23, 29, 30, 39, 42].

In the cited studies, a preoperative MRI was obtained in 46 of 49 patients (93.6 %). In five of nine studies, the exact onset of clinical symptoms prior to the preoperative MRI was not mentioned. In total, up to 28 of the 47 ONPK cases (59.5 %) might actually represent pre-existing, undiagnosed early-stage SPONK (diagnostic window, Table 44.3). In addition, BMO on MRI was a common and non-specific pattern found in several diseases [19]. Postoperative BMO is frequently present after arthroscopic meniscectomies [22, 30, 42] or ligament reconstructions [6]. In ONPK, MRI findings seem inconsistent, may resemble SPONK [10, 30, 39] or may even be transient [22, 39, 42] or reactive in nature [11, 18] (Table 44.4). Kobayashi et al. [22] found postoperative BMO on MRI in 34 % of patients after partial meniscectomy within 8 months after surgery. No signal changes were seen prior to arthroscopy (Fig. 44.2). Postoperative changes

Table 44.4 Surgical data of reviewed studies

Author	Total number of patients with ONPK	Number of conventional arthroscopic meniscectomies per formed with shaver/ punch (cases/study)	Number of arthroscopic meniscectomies per study performed with laser/radiofrequency energy (cases/study)	Number of patients with open revision surgery due to progression of disease (cases/study) Prosthesis/HTO	Number of patients with arthroscopic revision surgery due to ongoing symptoms	Number of patients with resolving signal changes on Second FU MRI after arthroscopy	Number of Patients treated medically after ONPK diagnosis is established
Brahme [10]	7	7	0		5	0	2
Johnson [20]	7	7	0	3/2	–	Second FU performed in 1 of 7, MRI changes resolved	2 patients lost to FU
Prues-Latour [39]	9	8	1	3/0	–	0	1
Santori [42]	2	2	0	–	–	2 of 2	2, no NSAIDS
DeFalco [13]	1	1	0	–	1	0	0
Kusayama [23]	2	2	0	–	–	0	2
Al-Kaar [3]	10	8	2	3/0	–	0	7
Faletti [14]	1	1	0	Prosthesis scheduled	–	0	1
Musculo [30]	8	8	0	–	–	0	?
Moynot et al. [29]	2	2	0	1/1	0	0	O
Average							
Total	49	46 (93 %)	3	10/3	6	Resolving MRI changes in 3	

were restricted to the meniscectomised compartment, both on the proximal tibia and the distal femur. The extent of the meniscectomy correlated with the incidence of bone marrow changes. There was no correlation between incidence and extent of BMO and age, gender or degree of chondromalacia. In addition, Kobayashi did not observe progression of the disease in his rather young patients. Muscolo et al. [30] and Prues-Latour et al. [39] suspected that the chance of progression to ONPK after partial meniscectomy seems to increase in patients older than 50 years.

In summary, there seems to be an association between arthroscopic surgery and postoperative bone marrow changes on MRI. To assume the presence of ONPK, early-stage SPONK has to be excluded prior to arthroscopy. In addition, postoperative BMO on MRI is common and generally does not lead to ONPK [19, 22].

Fig. 44.2 Bone marrow oedema pattern (BME) on MRI (low-signal changes on T1-weighted images and high-signal on T2-weighted or STIR sequences). Coronal T2-weighted MRI (2000/80 [TR/TE]) shows a subchondral area of low signal intensity. The medial condyle shows a moderate increase in signal intensity suggestive of oedema

44.5.3 Imaging Findings and Classification

There is no classification system for ONPK. However, clinical presentation, imaging findings and the frequent progression to irreversible stages are similar for ONPK and SPONK [14, 30]. Thus, the current classification systems for spontaneous osteonecrosis of the knee (SPONK) seem to be suitable for use in ONPK. Aglietti et al. [1] proposed a radiographic classification system which is only helpful in the diagnosis of advanced SPONK since early bone marrow changes of evolving osteonecrosis are not visible on plain radiographs (Table 44.5).

Soucacos et al. [43] reported a modified classification system of SPONK which pairs diagnostic findings with treatment recommendations

Table 44.5 Five radiographic stages of SPONK have been described by AGLIETTI [1]

	Findings on plain radiography	Time interval since onset of symptoms
Stage 1	Normal	Several months
Stage 2	Flattening of the affected weight-bearing portion of the femoral condyle	Several months
Stage 3	Pathognomonic lesion consisting of an area of radiolucency of variable size and depth and surrounded proximally and distally by some sclerosis, frequently found as the "earliest" radiologic sign of SPONK	Up to 1 year
Stage 4	Radiolucent area surrounded by sclerotic halo, subchondral bone has collapsed and is visible as a calcified plate	Up to 1 year
Stage 5	Secondary degenerative changes of the medial compartment with joint space narrowing, subchondral sclerosis and osteophyte formation associated with some erosion	More than 2 years

Stages 3–5 have a pathognomonic appearance on plain radiographs and can be easily recognized. However, the diagnosis may be difficult at early-stage SPONK since radiographs can be normal or at least inconclusive through the entire course of the disease

(Table 44.1). In his classification, stages I and II have the potential to resolve with conservative therapy. However, the majority of SPONK patients seem to progress to further, irreversible stages (Fig. 44.3a, b). It seems that reversible stages (stages I and II) can frequently be diagnosed only in retrospect, since radiographic findings are generally normal or inconclusive and MRI may or may not show bone marrow oedema. This likely depends on whether the diagnostic window of the MRI method to detect osteonecrosis has been considered. Moreover, BMO cannot be considered pathognomonic for ONPK since it is frequently seen as a transient lesion following knee arthroscopy [19, 32]. If BMO is present in the preoperative knee, abnormalities in T2-weighted images have been related to a further progression of the disease (Fig. 44.2) [9, 32]. Lecouvet et al. [24] described MRI characteristics that seem to allow for a differentiation between transient lesions and early irreversible SPONK. These MRI criteria are (a) a subchondral area of low signal intensity on T2-weighted images, (b) a focal epiphyseal contour depression and (c) lines of low signal intensity located deep in the affected condyle. The prognostic value of these MRI criteria has been confirmed in just one clinical study [35], and further research is needed (Fig. 44.3a, b). BMO in the postoperative knee is reported to be a "normal" and transient finding in 34 % of patients after a knee arthroscopy [22]. None of these patients have progressed to osteonecrosis, and of course no progression has been seen in the remaining 66 % of patients without signs of BMO in the postoperative knee. If BMO is absent in the preoperative knee, there is either no osteonecrosis or evolving osteonecrosis is not yet demonstrable with MRI (diagnostic window) [31]. However, if evolving osteonecrosis is suspected, three-phase bone scintigraphy (bone scan) is a reliable tool to diagnose evolving osteonecrosis since there is no diagnostic window for this imaging method to detect early

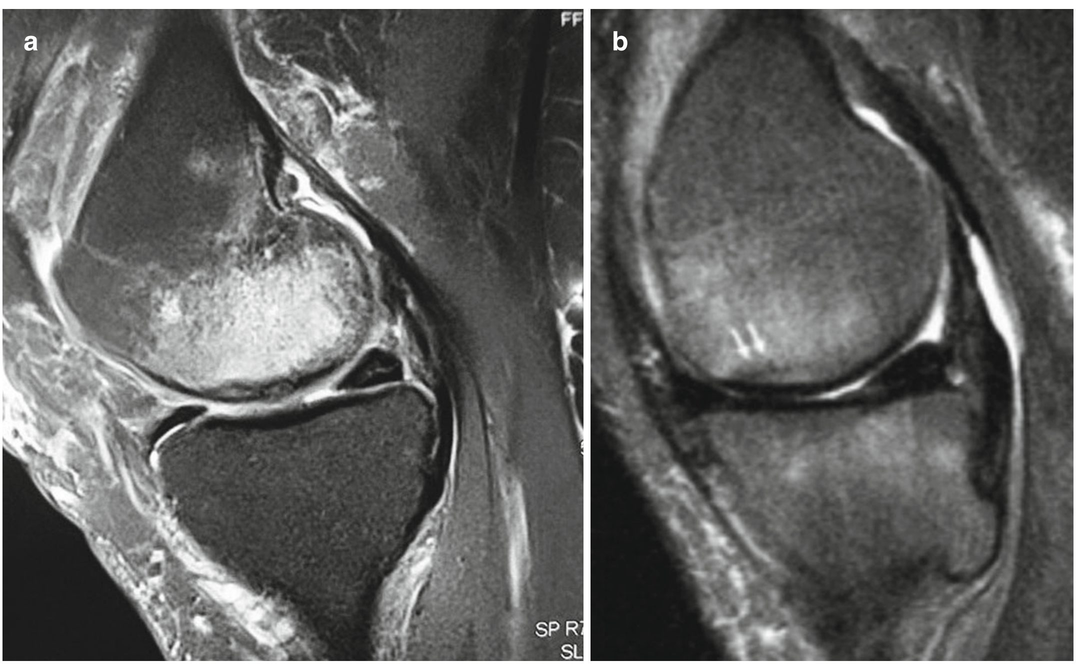

Fig. 44.3 (**a**, **b**) On MRI, spontaneous osteonecrosis of the knee (SONK) shows bone marrow oedema and subtle subchondral bone changes. Recently, Lecouvet [24] described MRI characteristics that allow for a differentiation between transient epiphyseal lesions and early irreversible SONK. These MRI criteria for early irreversible SONK comprised a subchondral area of low signal intensity on T2-weighted images and (**a**, *black arrow*) a focal epiphyseal contour depression (**a**, *white arrow*) and lines of low signal intensity located deeply in the affected condyle (**b**, *white arrows*)

changes. Radionuclide uptake over the lesion is increased up to 15-fold [43] which can be indicative of subchondral bone necrosis [5, 16]. Unfortunately, bone scan is not a pathognomonic or specific imaging modality, and other differential diagnosis, such as chondromalacia or transient BMO changes, cannot be ruled out (Fig. 44.4).

According to Soucacos et al. [43], stage III and IV osteonecroses are frequently associated

Fig. 44.4 Three-phase bone scintigraphy (^{99m}TC-MDP) at 4 weeks after onset of symptoms in an elderly patient with early-stage spontaneous osteonecrosis of the knee (SONK) (incipient stage) showing a typical distribution pattern of radionuclide uptake in the right medial femoral condyle several hour post injection of a radionuclide demonstrating increased metabolic activity in the entire femoral condyle

with irreversible destruction of the subchondral bone and articular cartilage, and surgery is the treatment of choice. In stage III, a radiolucent lesion can be detected on plain radiographs, which is referred to as the so-called crescent sign. This is pathognomonic for segmental necrosis of the subchondral bone with articular cartilage destruction. Other imaging methods, although positive, are not necessary to diagnose a stage III osteonecrosis. In stage IV, additional destruction of articular cartilage and subchondral bone is present on plain radiographs, which can extend over the transverse diameter of the medial femoral condyle. Again, additional imaging methods are not necessary for diagnosis.

44.6 Histologic Findings

Contradictory reports exist about histologic findings in ONPK. All cases that have been examined histologically required knee arthroplasty. Johnson et al. [20] found clear evidence of osteonecrosis. Yet Nakamura et al. [33] report that MRI findings of osteonecrosis can be present in the absence of histologic osteonecrosis and describe an "osteonecrosis-like lesion". Yamamoto and Bullough [46] report similar findings in SPONK patients and conclude that the primary pathology is a subchondral insufficiency fracture and that associated osteonecrotic changes are secondary to the fracture. It remains unclear whether SPONK and ONPK are of different pathogenesis.

44.7 Blood Markers

Different markers of bone turnover were investigated in order to facilitate the diagnosis of osteonecrosis [8]. Currently, no reliable serum marker has been found. Nevertheless, joint fluid levels of chondroitin-6-sulphate and C-telopeptide cross (ICTP metabolite of type 1 collagen) were significantly higher in cases of osteonecrosis of the knee in case of osteoarthritis.

44.8 Natural History and Prognostic Factors of ONPK

Of the 49 patients diagnosed with ONPK, 46 patients (93.8 %) have had either permanent MRI lesions or have shown a progression to irreversible stages. In 19 of these 49 patients (38.7 %), further surgery was needed. A knee arthroplasty has been performed in ten, a high tibial osteotomy in three and a repeat arthroscopy in six patients (Table 44.4).

The prognosis when ONPK develops in a compromised knee after arthroscopy is unclear [20]. So far, Al-Kaar et al. [3] is the only author who has correlated MRI changes to different stages of ONPK. In his series of ten patients, he observed at the beginning of the disease a large area of non-specific intramedullary oedema with low signal intensity on T1-weighted images and with heterogeneous high signal intensity on T2-weighted images. Approximately 3 months after surgery, the oedema decreased and a clearly defined central area of necrosis appeared. This area showed a very high signal intensity on T2-weighted images and a subchondral band with low signal intensity on both T1- and T2-weighted images, related to a variable portion of impacted and necrotic medullary bone. During the following stages, bone sequestration occurred (low signal intensity on T1- and T2-weighted images with a complete rim of very high signal intensities) and the development of either loose bodies or a residual flattening of the articular surface was observed. Al-Kaar believed that the subchondral band of osteosclerotic bone has a prognostic significance and that its thickness is proportional to the risk of bone sequestration [3]. However, these findings depend mainly on the quality of MRI resolution and may vary between different MRI setups. Moreover, the above-mentioned signal changes in ONPK do not substantially differ from MRI findings in patients diagnosed with SPONK [10, 19, 22, 24].

It is well documented that the size of the lesion in SPONK is a prognostic factor and guides the treatment [25]. The size of the lesion can be measured on T1-weighted images as the area of low signal intensity, evaluated according to Lotke's method and referred to as a percentage of the diameter of the medial femoral condyle [4, 9, 25]. Large lesions with a diameter greater than 50 % carry a poor prognosis, do not respond to conservative therapy and need to be treated surgically prior to the development of a fixed deformity [10, 25].

In ONPK patients, the size of the lesion has rarely been correlated with outcome. Johnson et al. [20] reported about five of their seven patients with ONPK who deteriorated rapidly and required subsequent surgery at an average of 7.6 months after arthroscopy (range: 5–9 months). In all five patients, the size of the lesion was greater than 40 % of the area of the medial femoral condyle on postarthroscopy MRI. Musculo et al. [30] reported about five patients with ONPK with an average size of the lesion of 24 % (range: 12–30 %). In a different study on medically treated patients with a degenerative meniscal tear and de novo BMO lesions (not associated with arthroscopy), Musculo described nearly the same size of bone marrow changes in the femoral condyle (21 % on average, range 17–26 %) [31]. However, the author did not comment whether the relatively small size of lesions in both of his SPONK and ONPK patients has been correlated with a benign course of the disease.

These findings on lesion size in ONPK do not confirm the prognostic value of the size of the lesion known from SPONK. It seems that even relatively small bone marrow changes on postoperative MRI frequently lead to osteonecrosis. Further studies correlating potentially prognostic factors with outcome are needed.

44.9 Treatment Options

Recognition of osteonecrosis is essential for appropriate therapy. If diagnosed early, a benign course of osteonecrosis with satisfactory knee function can be achieved with conservative therapy [34]. In the 49 patients mentioned above, the abnormal BMO pattern on the first postoperative MRI was diagnosed 18 weeks on average after initial surgery (range 3–176 weeks Table 44.3). In three [20, 42] of these patients (6.4 %), signal changes resolved completely after a 6-week period of non-weight bearing.

Although different stages of ONPK on MRI have been reported, there is no clear treatment algorithm for each stage [3]. Once the diagnosis is established, nonoperative treatment with partial weight bearing for 6 weeks, anti-inflammatory medication and analgesic is frequently used [14, 30, 39, 42]. A second postoperative MRI for follow-up evaluation of the BMO pattern has generally been recommended. It showed a persistent or progressive lesion in the majority of cited studies except for 3 out of 47 patients [20, 42] (Table 44.4).

A variety of surgical treatments for advanced or irreversible lesions have been proposed such as arthroscopic debridement, osteotomy, drilling and total knee arthroplasty [3–5, 12, 14, 15, 33]. Of the 49 patients diagnosed with ONPK, 19 patients were treated with revision surgery (36 %). Of these 19 patients, 13 (64 %) were treated with open surgery (10 arthroplasties, 2 high tibial osteotomies) and 6 (36 %) patients had an arthroscopic revision surgery (Table 44.4).

Conclusion

Little is known about the aetiology of postarthroscopic osteonecrosis of the knee (ONPK). Its prevalence is probably very rare. The most important differential diagnosis is a pre-existing and undiagnosed early-stage spontaneous osteonecrosis of the knee (SPONK) [2, 3, 6, 13, 14, 23, 37]. From the medicolegal point of view, orthopaedic surgeons need to be aware of the diagnostic pitfalls in differentiating between ONPK and SPONK and must understand that both may be non-preventable conditions.

If pain persists after an arthroscopic operation such as meniscus resection, cartilage debridement or other intra-articular procedures, MRI is recommended to evaluate for a bone marrow oedema pattern. We would recommend non-weight bearing for 6 weeks, which may be more preferable to quickly performing another surgical intervention with the potential of accelerated joint destruction.

In addition, elderly patients with meniscal tears and chondral lesions should be alerted that there is a small risk of developing osteonecrosis following knee arthroscopy [30].

At this stage, surgeons can neither predict nor prevent this condition. Even if arthroscopy is associated with the evolution of osteonecrosis and adequate preoperative imaging has ruled out pre-existing SPONK, ONPK should be considered to be a non-preventable complication.

We thus have suggested the descriptive term "osteonecrosis in the postoperative knee" rather than the more nebulous term "postarthroscopic osteonecrosis" be used.

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Concepts in Managing the Patient with Post-meniscectomy Knee Pain

45

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45.1 Introduction

The menisci are important structures within the knee. Their primary functions are to increase the congruency of the tibio-femoral joint and to act as the major load-bearing tissues within the knee. Consequently, the lateral and medial menisci transmit 70 and 50 % of the load through their respective compartments of the knee [36]. Further functions of the menisci include secondary anteroposterior stabilisation of the knee [21] and joint proprioception, lubrication and nutrition of the articular cartilage [26].

Removal of the meniscus has long been known to have serious consequences for the knee. Meniscectomy decreases the contact area by up to 75 % and increase contact pressures by up to 300 % [20, 25]. Meniscectomy increases the long-term risk of osteoarthritis of the knee [24], with lateral meniscectomy resulting in worse outcomes than medial meniscectomy [16]. In the long term, only 47 % of patients undergoing lateral meniscectomy have a good outcome [27]. In addition to removal of meniscal tissue, root tears or complete radial tears also effectively defunction the meniscus and increase contact pressures.

Symptomatic unicompartmental pain in the meniscus-deficient knee without significant articular cartilage wear is known as 'post-meniscectomy syndrome'. Once symptomatic, several factors need to be taken into account when formulating a management strategy for the post-meniscectomy syndrome patient.

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_45

45.2 Aim

This chapter outlines the options and factors to consider in the complex decision-making process of treating the symptomatic meniscus-deficient knee.

45.3 Patient Assessment

Several factors need to be taken into account when formulating a management strategy when evaluating the symptomatic post-meniscectomy patient. It is essential to determine that their symptoms are related to the lack of functional meniscus and/or concomitant pathology. One must also gauge the character of the patient and establish their associated expectations from any treatment intervention. Sports and activity levels and type of employment are essential factors in determining the most appropriate course of management. The sedentary office worker represents a completely different therapeutic challenge to the competitive football player who works in construction.

Physiological age and body mass index (BMI) are also important to consider. As a general rule of thumb, patients over the age of 40 years old may not respond as favourably to biological treatments than those younger. Obesity is associated with greater joint loading, accelerated joint surface wear and higher complication rates after surgery.

The knee is evaluated for malalignment, instability and chondral injuries, whilst other potential causes of knee pain are excluded. A functional assessment of the whole limb is undertaken to evaluate the dynamic muscle control and to quantify the strength and gait deficits. Poor core stability, in particularly weak hip abductors and gluteals, can result in poor knee kinematics and increased joint loading.

Radiological imaging assists with the underlying diagnosis, associated pathology and the development of a suitable treatment plan.

Long leg alignment films and standard plain radiographs including a PA flexed weight-bearing view are essential for the assessment of the limb's mechanical axis and any underlying osteoarthritic change. MRI provides useful information regarding the remaining volume of the meniscus, the condition of the articular cartilage and the status of the cruciate ligaments. CT imaging may be required for evaluation of previous cruciate ligament reconstruction tunnels if revision surgery is indicated. Finally, it is useful to obtain previous arthroscopy notes, pictures and, if possible, videos.

45.4 Nonoperative Treatment

Although the mainstay of this chapter is on the surgical management of these complex problems, any discussion on treatment would be incomplete without first mentioning the nonoperative options. There are multiple ways that patients can be helped without resorting to surgery. Some of these are also useful adjuncts to eventual operations and can help with both diagnosis and prognosis.

Physiotherapy, weight loss, analgesia and nutritional supplements can all be used in the post-meniscectomy knee as in any other knee condition. These have low morbidity and do not burn any bridges in terms of future treatment. Likewise, off-loader braces are useful both as a treatment and also as a diagnostic tool, mimicking the effect of a corrective osteotomy and giving the patient an expectation of the likely benefits of surgery.

Injections, either of local anaesthetic and cortisone or of viscosupplementation, can be useful in confirming the diagnosis as well as a temporising measure. Finally, activity modification, both in terms of employment and sporting activity, may well reduce symptoms to acceptable levels and remove the need for surgery.

45.5 'A la carte' Surgical Approach

We favour the approach popularised by Arnold et al. [5] and others [13], outlining a hierarchy of 'a la carte' strategies to bring the damaged knee into its comfort zone. Such a 'comfort zone' is based on the concept of joint homeostasis as popularised by Scott Dye [9]. The result is an orthobiologic approach to address limb alignment, knee stability, meniscal deficiency and articular cartilage damage whilst providing appropriate rehabilitation to achieve the optimum outcome.

45.5.1 Arthroscopy

It is our opinion that there is no role for repeat arthroscopy as treatment in these cases. Whilst it may occasionally be necessary to perform a diagnostic arthroscopy for planning a further surgical approach, this is not part of our routine treatment protocol. Most patients will have had recent arthroscopic surgery and the information needed can usually be obtained from standard investigations and examination of the records.

45.5.2 Alignment

It is well accepted that it is inappropriate to attempt any surgery to correct meniscal deficiency or chondral injury without first correcting limb alignment. The malaligned meniscus-deficient knee results in more rapid articular cartilage wear than the well-aligned knee [4], with varus malalignment carrying a worse outcome than valgus [8]. A recent systematic review of articular cartilage surgery in over 4500 patients showed that the tibial osteotomy was the most important factor in obtaining a good outcome [15].

Similarly, Linke et al. [22] showed that there was no measurable short-term difference in outcome between those patients who had an isolated high tibial osteotomy (HTO) and those who had an HTO combined with a collagen meniscal implant (CMI). In this study, CMI implantation without correction of varus was not performed and it is considered inappropriate to attempt to rebuild a compartment in the knee where there is significant malalignment.

Osteotomy aims to unload the damaged overloaded compartment and controversy exists regarding the optimal point of correction. To unload the medial compartment in a varus knee, traditionally surgeons have aimed to correct the weight-bearing line to the ‘Fujisawa point’ – 62.5 % of the distance from medial to lateral tibial plateau. The rationale for this point is unclear and is based on a small study of 54 osteoarthritic knees [11]. More recently, Agneskirchner et al. [1] have considered tailoring the correction depending on the joint surface wear to between 50 and 62.5 % of the medial to lateral tibial plateau distance. Other researchers suggest that a femoral-tibial angle of 3° valgus gives the best outcomes [40]. To unload the lateral compartment in a valgus knee, overcorrection is avoided and the aim is to achieve a weight-bearing line passing through the 50 % point.

Osteotomy is a versatile procedure that can be performed on the femoral or tibial side with either an opening or closing wedge technique. It can be combined with ligament reconstruction, meniscal reconstruction (synthetic scaffolds or allograft transplantation) and articular cartilage repair procedures. Osteotomy alone may also confer knee stability in the ligament-deficient knee. Adjusting the sagittal tibial plateau slope during the coronal plane correction may be utilised with a decrease or an increase in slope for ACL and PCL deficiency, respectively. Coronal plane correction may also address varus or valgus thrust thereby reducing the effect of lateral or medial collateral ligamentous deficiency, respectively. Figure 45.1 outlines the decision-making pathway when considering combined meniscal reconstruction and osteotomy.

Surgery can be combined in one event or performed in a staged fashion. If possible, the authors favour combining all procedures at a single surgery to help minimise the overall recovery time for a patient. Additionally, patients may be reluctant to undergo a second staged surgery and instead choose to accept a potentially lesser quality result.

It could be considered that osteotomy alone may be responsible for the improvement of symptoms in combined MAT and osteotomy. This has been addressed in two studies which demonstrate that patient-reported outcomes

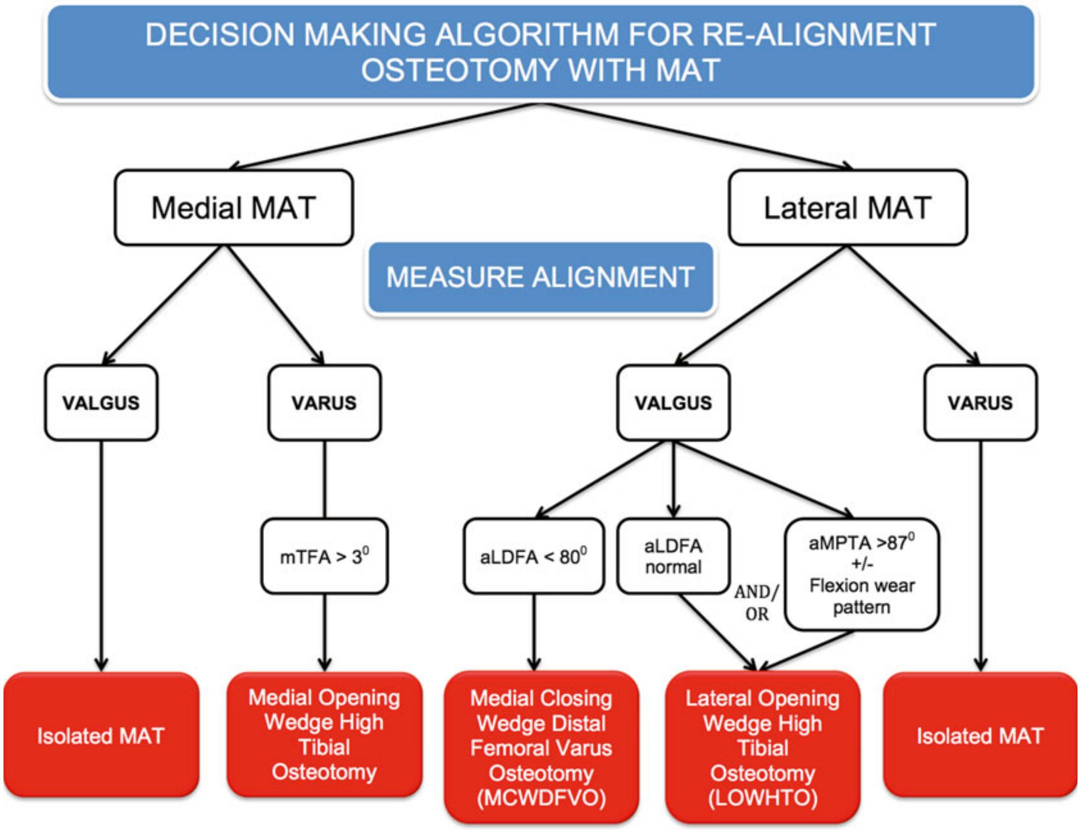

Fig. 45.1 Decision-making algorithm for realignment osteotomy with meniscal transplantation

following MAT were improved by the addition of an HTO, compared to isolated MAT [35, 45].

Surgical Pearl #1
When combining medial opening wedge tibial osteotomy with medial meniscal transplant, our preferred technique is to mark the intended osteotomy site and plate position on the tibia prior to arthroscopic insertion of the meniscus. The anterior and posterior horn bone tunnels are made proximal to the osteotomy level and the lead sutures are protected with a reversed 4.2 mm cannulated drill to avoid inadvertently cutting them when applying the HTO plate.

45.5.3 Stability

It is well understood that the combination of meniscectomy and ligament insufficiency leads to accelerated degeneration of the articular cartilage [37] and that this degeneration is more rapid than following isolated meniscectomy [6]. More recently, simultaneous ACL reconstruction and meniscal repair have been shown to improve survivorship at 6 years compared with meniscal repair alone [47]. It is not surprising that recurrent episodes of instability are likely to adversely affect the meniscus and articular cartilage. Although the meniscus is protected by ACL reconstruction, it is also noted that an intact medial meniscus is important for the protection of the ACL, and this interdependence is of relevance when patients present with a failed ACL reconstruction and an absent medial meniscus [2, 31].

Meniscus reconstruction should therefore only be performed in a stable or stabilised knee to prevent secondary meniscal injury due to altered knee kinematics. MAT has been shown to have a higher failure rate in the ACL-deficient knee [43] and the combination of ACL reconstruction with MAT has been shown to have good medium- and long-term outcomes [12, 48].

When combining primary ACL reconstruction with meniscal reconstruction, there is little need for surgeons to change from their normal graft choice, tunnel placement and fixation techniques. Revision ACL reconstruction raises additional challenges to each of the areas mentioned above and may require a two-stage operative technique [17].

Surgical Pearl #2

Specific detail is outside of the scope of this chapter, but primary and revision ACL reconstruction can readily be combined with meniscal surgery and osteotomy to improve outcomes. When combined with meniscal transplantation (± osteotomy), the ACL tunnels should be drilled first, in the optimal position. The bone tunnels for the meniscus are then positioned to avoid conflict with the ACL tibial tunnel. The meniscus is inserted and, if necessary, the osteotomy is then performed below the level of the tunnels. The HTO plate is applied and fixed with a reversed 4.2 mm cannulated drill bit protecting the posterior root sutures in the tibial tunnel. Finally, the ACL graft is passed and fixed in the usual manner. It is often necessary to remove or shorten the length of one of the HTO plate fixation screws to avoid conflict with the tibial tunnel of the ACL reconstruction.

45.5.4 Meniscus Deficiency

It may seem odd at first glance to address meniscus deficiency in third place in the list of priorities when considering post-meniscectomy syndrome; however, as previously determined, meniscus reconstruction is contraindicated in the malaligned and unstable knee.

When considering the meniscus, one should first establish if there is any viable meniscus left that is amenable to repair. Spontaneous osteonecrosis of the knee (SONK) has been linked with medial meniscus posterior root tears [32]. It is possible that a previous partial meniscectomy has been performed that has failed to address the underlying diagnosis. Therefore, every attempt should be made to preserve the meniscus where possible, using advanced repair techniques including the all-inside meniscal fixation systems, inside-out and outside-in techniques and newer root repair procedures [19].

Once it is established that the meniscus is deficient, the amount of viable tissue present and the continuity or lack thereof of circumferential fibres will help dictate whether a partial or complete replacement of the meniscus is indicated.

(a) Meniscal scaffolds

Where there is only partial loss of the meniscus, it may be possible to augment the remaining native meniscus using a meniscus implant. The two current products in use are the collagen meniscal implant (CMI from Ivy Sports Medicine, Gräfelfing, Germany), consisting of a collagen scaffold, and Actifit (Orteq, London UK), which is composed of polyurethane. Insertion is by an arthroscopic technique but recovery is slow and prolonged over a 9- to 12-month period.

The ideal patient for a meniscus implant is one who has an intact meniscal rim, with sufficient anterior and posterior horns to allow for secure fixation, in a well-aligned and stable knee. BMI should be less than 35 kg/m^2 and chondral surface damage should be of no more than ICRS grade 3a [30].

Rodkey et al. [33] have demonstrated using second-look arthroscopy that meniscus-like tissue grows into the collagen meniscus implant at 1 year and that chronic meniscus-deficient patients have improved clinical outcomes. The authors did not show improved outcomes when performing meniscal reconstruction in the acute meniscal injury setting. Another study by Monllau et al. in 22 patients treated with CMI showed no or minimal joint space narrowing at 11 years [29]. Further studies utilising MRI evaluation reported relatively poor amounts of regenerate tissue with normal appearances in only approximately 20 % of patients [29, 49]. Whilst the Actifit has only published short-term results, patient-reported outcome scores are significantly improved from baseline and follow-up MRI scans have shown stable ICRS cartilage grading [46].

Surgical Pearl #3
Meniscal scaffolds are implanted for short-segment defects up to 45 mm, combining surgery as appropriate with osteotomy or ligament reconstruction. Special consideration is given in the presence of bare bone surface damage, but in general, such amount of wear precludes use of scaffolds in the authors practice.

(b) Meniscal Allograft Transplantation (MAT)

Where a larger amount of the meniscus has been lost or there is complete transection of the peripheral meniscal rim with a radial tear, i.e. no functional meniscal tissue present, meniscal implants are no longer a viable option. A meniscal allograft transplant (MAT) is therefore an option to reconstruct the mechanical meniscal properties. It has been shown in cadaveric studies that MAT significantly reduces the contact pressures within the knee compared with those after meniscectomy [3].

The first meniscal transplant was performed in 1984 [28], and over the last 30 years, the surgical technique has evolved from an open procedure to an arthroscopic procedure. The three commonly used techniques for graft fixation are bone plugs in tunnels, a bridge slot technique or free grafts sutured through bone tunnels. Clinical outcomes are similar with all techniques [38]. A recent systematic review documenting 1,374 transplants reported significant clinical improvements and a failure rate of 10.6 % at 4.8 years [38].

Due to the length of time MAT has been used in clinical practice and the number of outcome studies detailing satisfactory long-term results, it is the author's opinion that the concept of MAT is no longer experimental. However, we anticipate that there is much to be learnt to improve techniques and to optimise survivorship and sustainability of patient outcome into the future.

Surgical Pearl #4
Meniscal allografts are implanted and fixed using a free graft technique with sutures passed trans-osseous and tied over the tibial cortex. Peripheral fixation uses a combination of all-inside devices and inside-out sutures tied over the capsule. The optimal indication for MAT in the presence of articular cartilage damage is the absence of bare bone. Patients are counselled as to a higher risk of failure in the presence of chondral lesions ICRS grade 3b on one or both surfaces.

45.5.5 Articular Cartilage Lesions

Fourth in line, after considering alignment, stability and meniscal deficiency, is reconstruction of articular cartilage. The presence of bare bone has been shown to compromise the survival of a MAT [18], whilst successful repair of articular cartilage is unlikely if the first three factors have not been addressed.

MAT has been shown to be chondroprotective on animal and clinical studies [2, 39, 42]. The presence of ICRS grade 3b or greater changes would traditionally have been a relative contraindication for MAT. However, with the advancement of articular cartilage repair techniques, MAT and articular cartilage repair have been shown to work synergistically, with this combination of procedures not being shown to increase the complication rate compared to MAT alone [14].

Although some authors have published reasonable results treating advanced degenerative changes with MAT in combination with cartilage repair [41], patients should be counselled about the potentially higher risk of failure.

There are a variety of chondral regeneration techniques described, from microfracture, autologous chondrocyte implantation (ACI) and osteochondral autograft or allograft. All of these can be combined with a MAT, and good outcomes have been described for both ACI + MAT [10] and MAT + osteochondral grafts [34].

Surgical Pearl #5
Small chondral lesions less than 2 cm^2 can be repaired with microfracture or osteochondral autograft techniques and larger defects can be treated with autologous chondrocyte implantation (ChondroCelect, SOBI, Sweden) or by augmented microfracture techniques involving one of several different commercially available products.

45.6 Rehabilitation

The most important step in the patient's rehabilitation begins before the operation in assessing the patient's goals and managing their expectations appropriately. Patients presenting to tertiary referral centres will often have undertaken their own online research, but the quality of information published online can be variable and confusing. Patients should be clearly informed of the risks and benefits of embarking on a surgical strategy to biologically rebuild their knee. Whilst the above-mentioned combinations of procedures can provide significant functional benefits, they cannot restore the knee to its original native state. Patients need to understand this important point, so their expectations and goals of the treatment are realistic.

Before embarking on the surgical path involving complex surgery and a prolonged period of rehabilitation, it is necessary to ensure that the patient is engaged and committed to the whole process. It may well take a few months to source an appropriately sized meniscal allograft, and as such, information on the rehabilitation process should be provided, along with clinical review of the patient to ensure that they are fully engaged. Patients also need to be aware that this surgery is not necessarily the end of the road for their treatment and they need to be aware of the complication and reoperation rate that can be as high as 30 % [44].

During post-operative rehabilitation, it is vital for physiotherapy to address all aspects of the lower limb biomechanics – including gait, range of motion and proprioception. A personalised and sports-specific training programme will need to be developed between the patient, sports physician, physiotherapist and surgeon to obtain the optimum outcome.

Most patients have a desire to return to their sporting activities. In the early days of MAT, patients were usually restricted in their post-operative exercise but, as the technique has become more widespread surgeons, have been more liberal at allowing return to sport. It is our practice to advise patients not to return to any twisting sports for at least 1 year following surgery.

Results of return to sporting activity in the literature are mixed. In high-level athletes, 77 % returned to their desired level of play following MAT [7]. In professional football players, 92 % were able to return to football post-operatively, but only 75 % were still playing professionally, with the remainder playing at the semi-professional level [23].

45.7 Decision Making: Putting It All Together

Bearing all the described factors in mind, our approach to the meniscus-deficient knee is a patient-centred one, starting with the patient's history, activity levels and expectations.

We consider all the issues that we have outlined and then discuss the treatment options and plan our approach. Our approach focuses first on the limb alignment, then on stability and only then on the meniscus itself, before finally considering whether there are any articular cartilage defects that need to be addressed (Fig. 45.2).

Further decisions concern whether treatments are being staged or carried out all at the same time, and there are arguments for and against these strategies. Staging the surgery has the advantage of being simpler, and there is also the possibility that the patient's symptoms may be improved to such a degree that the subsequent operations may not be required. However, the disadvantages include the prolonged total treatment time and repeated rehabilitation periods and the patient may opt not to continue treatment due to the inconvenience of multiple operations. In this scenario, the patient may not reach the potential outcome that might have been possible had all stages been carried out.

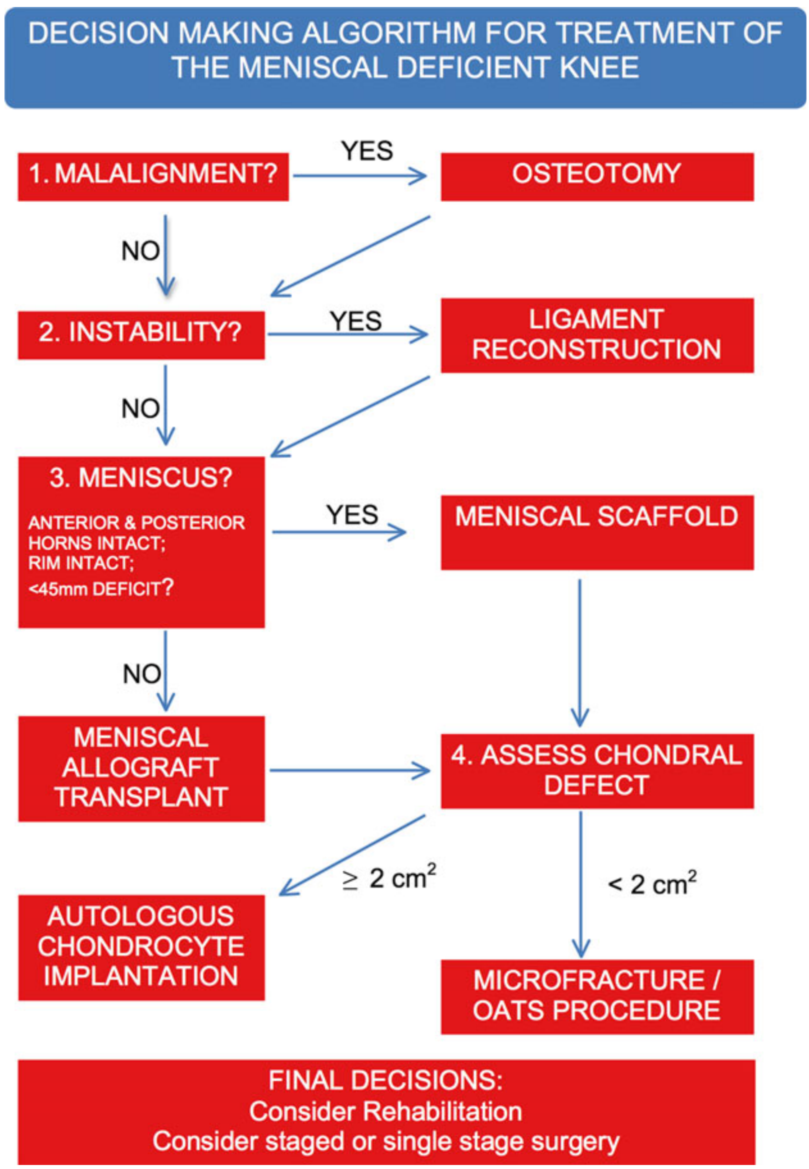

Fig. 45.2 Decision-making algorithm for treatment of the meniscus-deficient knee

Ultimately, the decision to stage treatment or not depends on the wishes of the patient but also on the surgeon and in particular their skill and ability to perform all elements of the surgery at a single stage. The theatre staff and physiotherapists must also be used to these combination surgeries to make the operation as technically easy as possible and ensure a successful rehabilitation outcome.

45.8 Summary

The natural history of the meniscus-deficient knee is well known with early degenerative changes as a direct consequence. In the event of failed nonoperative treatment of the meniscectomised knee, it is our philosophy that surgical treatment is best performed as an ‘a la carte’ combination of procedures addressing in priority order: lower limb alignment, knee stability, meniscus function and the articular cartilage. Surgery and rehabilitation are personalised and it is crucial to ensure patients remain engaged in the treatment process.

Surgery can be staged or performed in a single operation depending on the surgeon’s confidence and ability. Our preferred approach is to combine the procedures to allow for a shorter total rehabilitation time and quicker return to work and sports.

Good long-term outcomes, survivorship and return to sporting activity have been described with this approach.

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Part IX

Meniscal Reconstruction: Allograft

Basic Science on the Meniscus

46

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46.1 Embryology

Normal synovial joint formation consists of two phases. First, the developing mesenchymal blastema differentiates into a cartilaginous model of the future long bone. Adjacent skeletal elements are separated by thin bands of mesenchymal cells known as interzones. Although the biology of the interzone is poorly understood, it is believed that these structures differentiate into three layers: two outer chondrogenic layers that will cover the cartilage anlage and an intermediate layer that contributes to the formation of intra-articular structures such as ligaments, menisci and the synovium. Subsequent to the formation of the interzone is joint cavitation, the process by which adjacent cartilaginous elements separate to form two distinct articulating joint surfaces (Fig. 46.1).

Only if both of these developmental processes proceed undisturbed will normal formation and

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_46

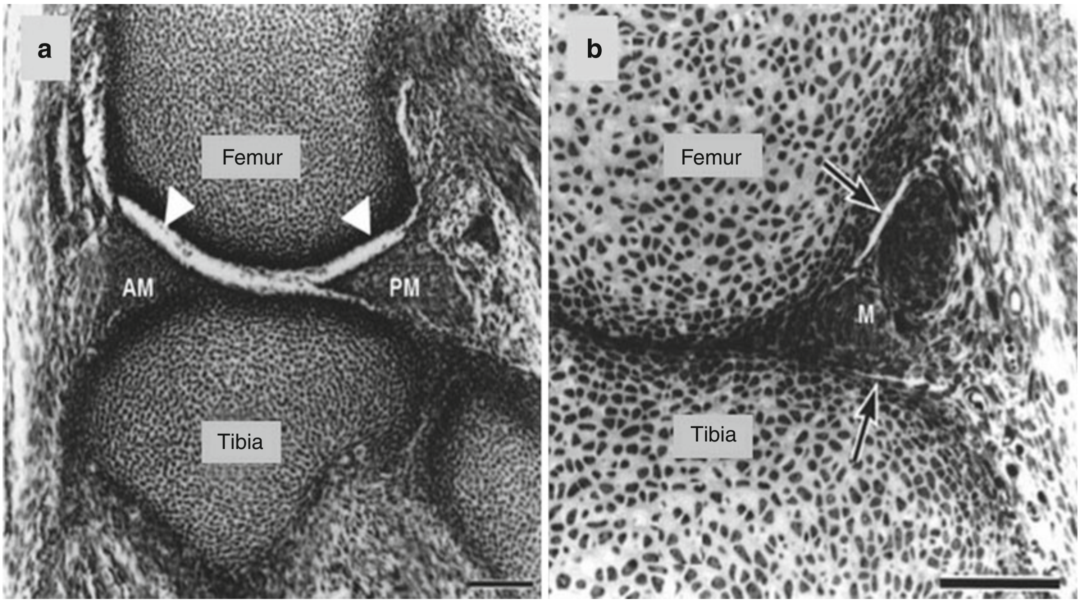

Fig. 46.1 (**a**) Progress of cavitation in a paraffin section at E17 ± 5 of a rat. Cavitation has advanced at the femoro-meniscal junction (*arrowhead*) and has started between the tibia and the posterior horn of the lateral meniscus (*PM*) in this sagittal section. No cavitation is seen between the tibia and the anterior horn of meniscus (*AM*). Azan staining. Bar, 100 μm. (**b**) Initial appearance of cavitation in a coronal epoxy section at E18 ± 5. Cavitation (*arrows*) has begun in the peripheral part of the intermediate zone, both between the femur and the meniscus (*M*) and between the tibia and the meniscus (*M*). Toluidine blue staining. Bar, 100μm (Pictures courtesy of Ito and Kida [28])

maintenance of synovial joints be observed [28]. Mechanical stimulation during the embryogenesis is essential for the maintenance of the meniscus. In the absence of functional muscle contractions, the early meniscus condensations initially form but degenerate and disappear quickly thereafter [39].

In the developmental progression of matrix gene expression in the mouse meniscus, four distinct stages of meniscal morphogenesis have been identified: stage 1, mesenchymal cell condensation between the articular surfaces of the femur and tibia; stage 2, differentiation of meniscal fibrochondroblasts within the rudimentary meniscus; stage 3, meniscal ECM synthesis and deposition; and stage 4, meniscal ECM maturation [44]. The appearance of discrete meniscal condensations during stage 1 correlates with the expression of BMP-4 and GDF5 by mesenchymal cells that aggregate to form the meniscal rudiment [44]. Once this condensation is complete, mesenchymal cells differentiate into fibrochondroblasts. Acquisition of a chondrocyte-like phenotype by meniscal cells is coincident with the loss of expression of BMP-4 and GDF-5 (stage 2) [44]. Meniscal cells now begin matrix synthesis, producing an extracellular matrix of type I and type III collagen and aggrecan (stage 3) [44]. Type II collagen expression by meniscal cells occurs late in meniscal morphogenesis (stage 4) [44]. These results suggest that the meniscus is a unique connective tissue with a distinct developmental profile.

46.2 Chemical Composition and Organisation of Normal Meniscal Tissue

Normal human meniscal proteoglycans contain approx. 40% chondroitin 6 sulphate, 10–20 % chondroitin 4 sulphate, 20–30 % dermatan sulphate and 15 % keratan sulphate, the proportions of which are maintained under tissue culture conditions by a corresponding glycosaminoglycan production [26, 56]. In dry weight, the inner third of the meniscal body contains

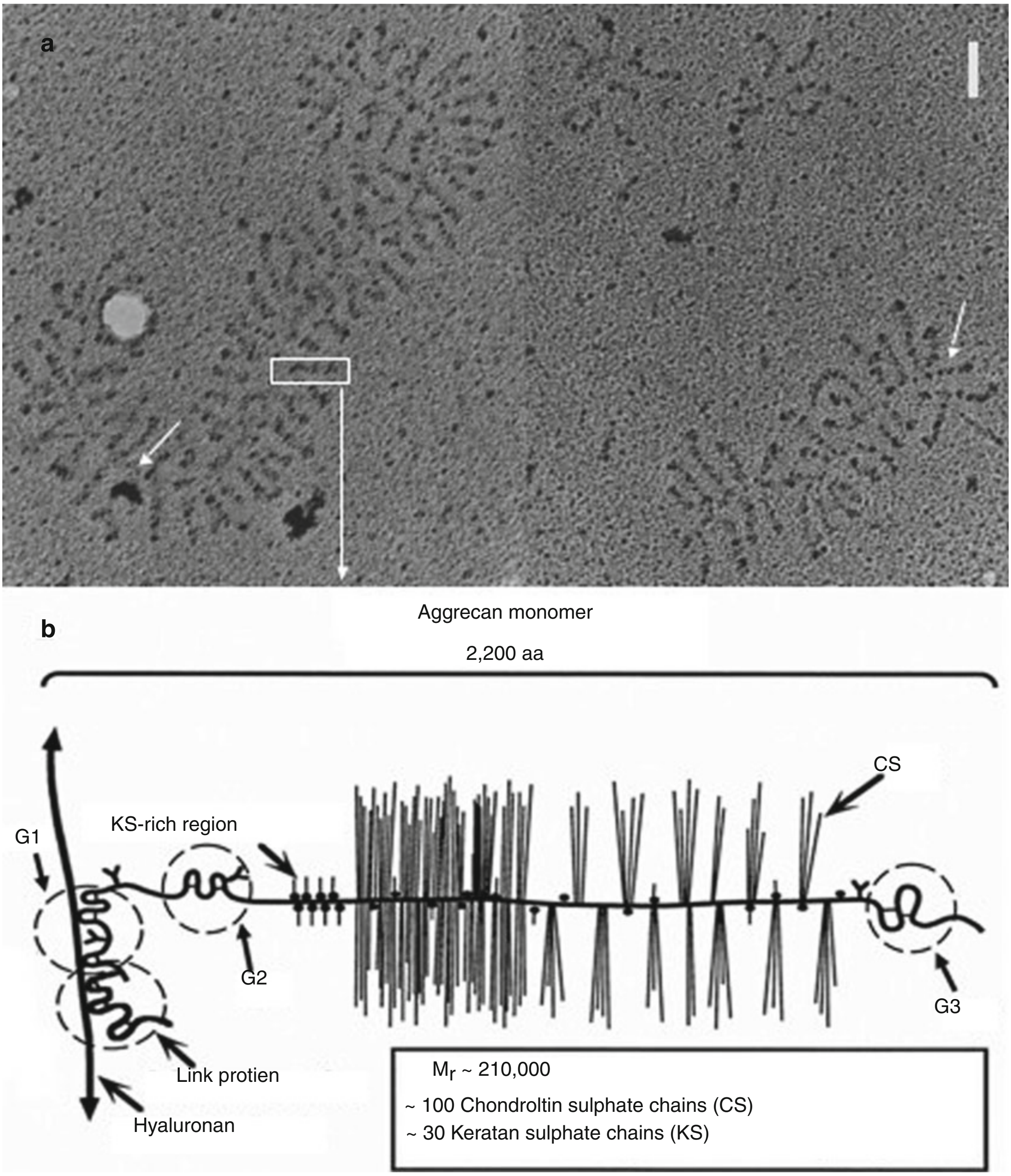

Fig. 46.2 (**a**) The structure of aggrecan aggregate. Aggrecan monomers (*square*) are attached on a hyaluronan backbone (*arrow*) to form aggregates of different sizes. (**b**) In the aggrecan monomer, the three globular domains (*G1,G2 and G3*) are separated by two extended segments which carry the glycosaminoglycans chondroitin sulphate and keratan sulphate. The link protein stabilises the aggregate structure between hyaluronan and the aggrecan monomer. Up to 200 aggrecan monomer may bind to one hyaluronan

8 % glycosaminoglycans, and its peripheral third only contains 2 % glycosaminoglycans. Aggrecan has been found to be a major proteoglycan in adult bovine and canine menisci (Fig. 46.2).

Its biosynthesis and accumulation begins in meniscal tissue and insertional ligaments during foetal development [37]. Meniscal tissue explants from inner and middle zones produce predominantly aggrecan-like proteoglycans under culture condition, but also smaller proteoglycans. Explants from peripheral zones produce in general less proteoglycan and, preferentially, smaller ones [11]. Aggrecan is not produced in the outer region of the canine meniscus [55]. In general the concentration of aggrecan produced in the meniscus averages 1/8th to 1/10th of the concentration in articular cartilage [27]. Biglycan and fibromodulin were found in higher amounts in the inner and middle than the peripheral zones of pig menisci. Decorin, on the other hand, is found more extensively in the peripheral zone [50]. The apparent regional distribution of proteoglycans certainly reflects the tissue adaption to local loads, which is even maintained under tissue culture conditions. Specific proteoglycans (aggrecan, biglycan, fibromodulin) seem to accumulate in the inner compressed region of the meniscus.

46.3 Cellular Composition of Meniscal Tissue

The meniscus is defined as a fibrocartilage, because of the rounded or oval shape of most of the cells and the partly fibrous appearance of the extracellular matrix in the light microscope [16].

Ghadially et al. classified cells in the meniscus as chondrocytes, fibroblasts, or cells of intermediate morphology, based on their shape and the presence or absence of a territorial matrix [16]. The work of Eyre and Muir in the 1970s established that type I collagen is the major fibrillar collagen in the meniscus, in contrast to articular cartilage where the major fibrillar collagen is type II [14]. This difference in expression can be used as a molecular criterion in the distinction of fibrocartilage (type I collagen) and hyaline cartilage (type II collagen) and of meniscus cells and chondrocytes. There are, however, small amounts of type II collagen in the meniscus. Given that most of the collagen is type I collagen in the meniscus and the amounts of type II collagen are reportedly small, it is clear that the cell in the meniscus with its round/oval, chondrocyte-like morphology is not a true, hyaline cartilage chondrocyte. McDevitt et al. were the first to refer to these oval-shaped cells as fibrochondrocytes [38]. There appear to be three and possibly four distinct cell populations in the meniscus: (a) the fibrochondrocytes, located predominantly in the inner half of the meniscus where the forces are predominantly compressive; (b) fibroblast-like cells that occupy the outer, more fibrous portion of the meniscus that influences tensile forces; and (c) superficial zone cells, located in the surface zone of the meniscus that interfaces with the synovial fluid (Fig. 46.3).

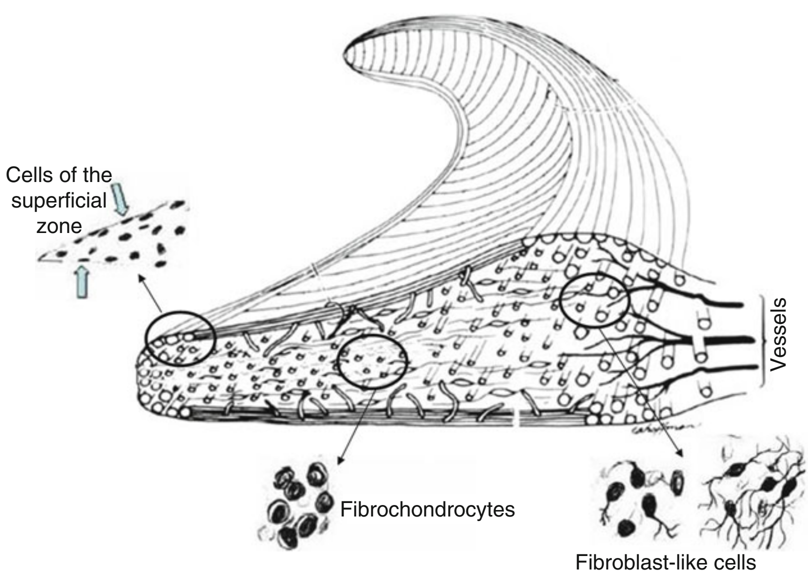

Fig. 46.3 Schematic representation of the human meniscus showing the distinct cell type populations and their regional distribution. Fibrochondrocytes are round cells with no cellular projections, located in the avascular portion of the meniscus, while fibroblast-like cells are located in the vascular portion and reveal thin cytoplasmic projections. Cells from the superficial area are fusiform

Cells of intermediate morphology between that of a fibrochondrocyte and fibroblast are located in the outer portion of the tissue.

46.3.1 Fibrochondrocyte

A fibrochondrocyte is defined as a round or oval-shaped cell that synthesises type I collagen as its major fibrillar collagen and that has a territorial, pericellular matrix. The pericellular matrix appears in the transmission electron microscope as fine filamentous material with a distinct transition to the fibrous interterritorial matrix.

The interterritorial matrix synthesised by the fibrochondrocyte contains relatively small amounts of type II collagen and type III collagen. Type VI collagen is a distinctive component of the pericellular matrix of the fibrochondrocyte, as it is for the articular chondrocyte.

The fibrochondrocyte is the main cell in the body of the middle and inner meniscus. The location, shape and properties of the fibrochondrocyte are consistent with this cell functioning in that portion of the meniscus that predominantly experiences compressive forces.

46.3.2 Fibroblast-Like Cells

These cells lack a pericellular matrix and are located in the outer portion of the meniscus. Staining with the anti-vimentin antibody revealed the presence of cells with several long, thin cytoplasmic projections that extend out from the main body of the cell to make contact with other cells (via gap junctions, connexion 43 staining) and different regions of the matrix [22]. Moreover, these cells contained two centrosomes, one associated with a primary cilium whose structure suggested a sensory rather than motile function. The location of the cells with extended projections in the outer portion of the meniscus led the authors to conclude that these cellular structures enable the cells to respond to different types of mechanical loading (circumferential or compressive) [22]. The presence of cells with long extensions that make contact with other cells enables these cells to maintain homeostasis by sensing both the immediate and more distant environment.

46.3.3 Cells of the Superficial Zone

These cells have a characteristic fusiform shape, have no cytoplasmic projections and reside in the superficial zone just below the surface of the tissue [16, 22]. These cells have long been recognised as having a different shape to the main body of cells in the interior of the tissue. In an in vivo canine model for wound healing, it was noted by Kambic et al. that the superficial zone cells expressed alpha SMA and appeared to migrate into the wound. SMA-positive cells were also concentrated at the interface of the wound and adjacent meniscus [31]. The intriguing possibility arises that the superficial zone contains specialised cells, perhaps progenitor cells, which initiate the wound healing process.

The significance of cells outside a wound site staining positively for alpha SMA is unclear. Ahluwalia et al. noted that about 25 % of the non-vascular cells in menisci from total knee arthroplasties of older humans (average age 66 years) expressed alpha SMA, suggesting it may be part of a remodelling response in the tissue [1]. Hu et al. concluded from a scanning electron microscope study of the rabbit meniscus surface (i.e. the superficial zone) that the progressive change in shape of the cells of the superficial zone towards a more flattened morphology was consistent with the idea that these cells originated in the synovium and moved out into the surface zone of the tissue [27].

46.4 Healing Response in the Injured Meniscus

The capability of a meniscus to heal has been illustrated in three models of meniscus injury: (1) transection of the anterior cruciate ligament, (2) the devitalized plug model and (3) the meniscus tear.

46.4.1 Model I: Transection of the Anterior Cruciate

Transection of anterior cruciate ligament is known to induce increased mechanical stresses on the menisci, especially the medial meniscus. This injury pattern has been used in multiple animal models to evaluate histologically and functionally the response of the meniscus cells in an in vivo situation [7, 8, 21, 23, 24, 60]. In general, histological observations showed a progressive destruction of both the meniscus and the articular cartilage after ACL transection [23, 24]. There is also evidence of meniscus cell cluster formation following ACL transection. Immunohistochemistry demonstrated increased staining for type I and type III and particularly for type II collagen, in the pathologic specimens compared with controls [23]. Specific proteoglycan staining indicated an increased expression of these molecules in the pathological meniscus [23]. Functional analysis reveals that catabolic enzymes such as MMP-1, MMP-3 and particularly MMP-13 mRNA levels were higher in the pathologic meniscus compared with controls (Table 46.1) [60].

In the medial meniscus, significant increases in the mRNA levels for type I, II and VI collagen, TIMP-1, aggrecan, biglycan and iNOS were noted in the pathologic specimens compared with controls. Type VI collagen is a protein whose expression is increased in wound healing and remodelling scenarios in different connective tissues, so the increased levels of col6a3 mRNA are presumably a vigorous attempt at repair [60]. In summary, the meniscus responds to injury by increased expression of genes for matrix protein and enzymes.

46.4.2 Model II: Plug Model

In this interesting canine model, a plug was removed from a non-vascularised portion of the meniscus, rendered acellular by repeated freeze-thawing cycles and then reimplanted into the defect [31]. This model was used to observe cellular migration upon injury. One year after the injury, the plug was repopulated by cells with a variety of shapes. Cells from the superficial region appeared to play a crucial role in the repair response. They expressed SMA and appeared to migrate into the wound.

Table 46.1 Overview of the matrix-metalloproteinases (MMPs)

MMP	Alternative name	Substrates
MMP-1	Collagenase (type I, interstitial)	Collagens (I, II, III, VII, VIII, and X); gelatin; aggrecan; L-selection; IL-1beta; proteoglycans; entactin; ovostatin; MMP-2; MMO-9
MMP-3	Stromelysin-1, proteoglycanase	Collagens (III, IV, V, and IX) gelatin; aggrecan; perlecan, decorin; laminin; elastin; caesin; osteonectin; ovostatin; entactin; plasminogen; MBP; IL-1beta; MMP-2/TIMP-2; MMP-7, MMP-8; MMP-9; MMP-13
MMP-8	Neutrophil collagenase	Collagens (I, II, III, V, VII, VIII, and X); gelatin; aggrecan; fibronectin
MMP-10	Stromelysin-2	Collagens (III-V); gelatin; casein; aggrecan; elastin; MMP-1; MMP-8
MMP-12	Macrophage metalloelastase	Collagen IV; gelatin; elastin; casein; fibronectin; vitronectin; laminin; entactin; MBP; fibrinogen; fibrin; plasminogen
MMP-13	Collagenase-3	Collagens (I, II, III, IV, IX, X, and XIV); gelatin; plasminogen; aggrecan; perlecan; fibronectin; osteonectin; MMP-9
MMP-18	Xenopus collagenase-4	Type I collagen
MMP-19	RASI	Type I collagen
MMP-20	Enamelysin	Amelogenin; aggrecan, and cartilage oligomeric matrix protein (COMP)
MMP-22	Chicken MMP (C-MMP)	Unknown
MMP-27		Unknown
MMP-28	Epilysin	Unknown

46.4.3 Model III: Tear Model

Tears in the vascularised zone in the peripheral third of the meniscus body heal similarly as for other vascular tissues [4, 20, 33]. The initial formation of a haematoma and fibrin clot in the gap acts as a scaffold for ingrowth of vessels from the perimeniscal capillary plexus. The vascular ingrowth is accompanied by migration and proliferation of undifferentiated mesenchymal cells, possibly originating from the synovium. Eventually, the lesion becomes filled with a highly cellular fibrovascular scar tissue. Final remodelling of this scar tissue required several months until it acquired a meniscus tissue-like shape and biomechanical properties [6, 41]. The clinical experience with this type of tear is usually good. Repair of peripheral, longitudinal tears show a high frequency of healing and good functional results [12, 13, 52]. It also seems that a once healed meniscal tear remains as stable as an initially intact meniscus [52, 53].

In contrast to tears located in the vascularised zone, the more frequently encountered ruptures in the avascular zone heal poorly [25, 33]. Because of the obvious advantages of meniscal repair, many efforts have been made to improve the healing of tears in these regions. Longitudinal incisions in the non-vascularised portion of the meniscus were successfully induced to heal by connecting the lesion to peripheral vasculature by 'vascular access channels', which resulted in a similar healing process as described for tears in the vascular region [4, 61]. For this procedure, a major radial split through the peripheral third of the meniscus to create the channel should be avoided to minimise damage of the circumferential collagen framework, which is a prerequisite for normal meniscal function. Another possibility for improving healing in avascular tears is the use of free synovium or a synovial pedicle flap which is sutured directly or through a tunnel into the lesion [17, 30, 35, 51, 58]. The use of fibrin clot alone or together with endothelial cell growth factor or autogenous precultivated stem cells and even implantation of porous polymers did improve the healing response of experimentally created lesions in the avascular region of the meniscus [5, 19, 34, 46, 54]. However, the strength of the scar tissue which was measured after the use of fibrin clot and stem cells only achieved 40 % of normal within 4 months after implantation [46]. Thus, there is no doubt that tears in the avascular lesion can be made to heal with various methods, although the healing frequency for this type of lesion is clinically lower than after repair of more peripherally located tears [25]. However, it is also doubtful whether repair of these tears re-establishes normal meniscal function. Thus, there is no evidence for now that repair of a tear in the avascular region is better than partial meniscectomy.

46.5 Rationale for Meniscal Replacement

Substantial research has already been performed to substitute the resected meniscus in case of a total or partial meniscectomy, in order to prevent or delay cartilage degeneration, improve biomechanics and relieve pain. The importance of the meniscus for the protection of the articular cartilage is highlighted by the fact that the articular cartilage in the periphery of the tibial plateau (covered by the meniscus) is severalfold thinner than in the central region of the tibial plateau [62, 63]. Possible surgical approaches include the use of autologous or allogenic tissues: e.g. tendon, pediculated Hoffa fat pad, periosteal tissue, perichondral tissue, small intestine submucosa, meniscal allografts, meniscus scaffolds based on native polymers (collagen and hyaluronic acid) or purely synthetic scaffolds such as poly-lactic acid, poly-glucuronic acid and poly-urethane [9, 10, 15, 36, 40, 42, 45, 49, 57, 59]. Other than meniscal allografts and a collagen type I-based meniscus scaffold (CMI®, Regen Biologics, Franklin Lakes, NJ, USA), none of these materials have advanced to human clinical use. These surgical approaches are based on the concept of a timely colonisation of the acellular scaffold or allograft tissue by host cells which are probably derived from the synovium and joint capsule (Fig. 46.4) [3, 29, 48].

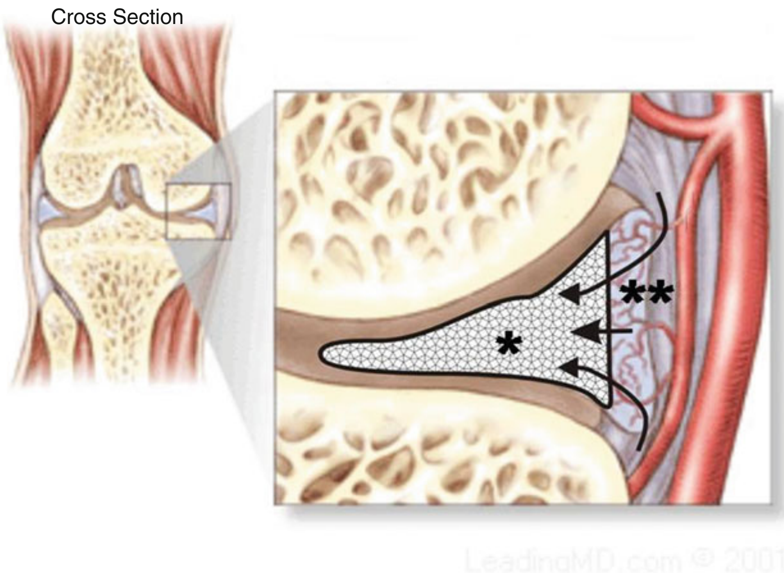

Fig. 46.4 Acellular meniscus grafts or scaffolds (*) are colonised by host cells (*arrow*) which are probably derived from the synovium and the joint capsule (**)

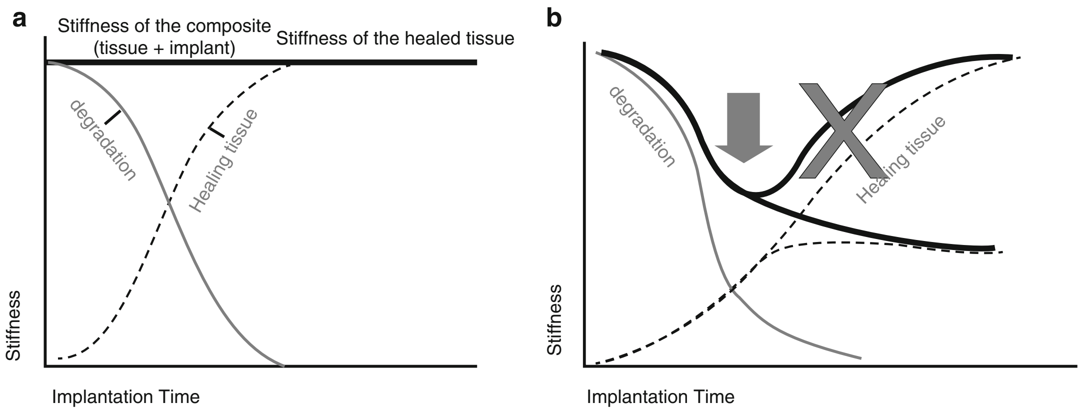

Fig. 46.5 (**a**) Idealistic degradation kinetic of resorbable scaffolds (*grey line*) related to tissue healing (*dashed grey line*). The sum of these processes (*black line*) guarantees the stiffness of the construct. (**b**) In the human model, tissue healing is considered much slower than the resorption of many grafts and scaffolds, resulting in reduced stiffness (*arrow*) and early failure of the construct

The phenotype of these host-derived scaffold-colonising cells ultimately determines the biochemical composition and biomechanical behaviour of these repopulated scaffolds or tissues.

Another critical variable in this approach is the time needed for colonisation of the scaffold or tissue: since these scaffolds or tissues are biodegradable, the colonisation and healing by host cells should be faster than the degradation process, for the regeneration or healing of the meniscus substitute to be successful (Fig. 46.5).

Previous animal studies have provided evidence that fresh meniscus allografts are quickly invaded by host cells within 1 month after transplantation [3, 29]. In the human model, however, only limited data is available. A previous study performed at our institution has provided evidence that this process of colonisation is considerably slower in the human model: DNA fingerprint analysis, performed on human viable meniscal allograft biopsies taken up to 36 months after transplan-

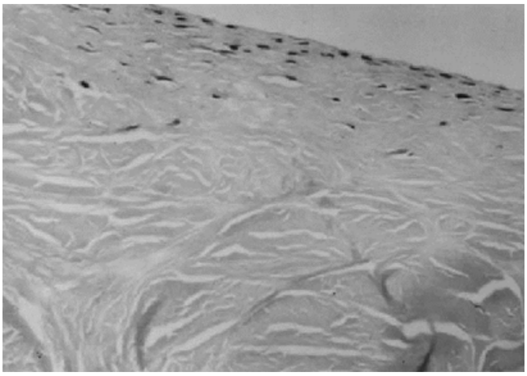

Fig. 46.6 Histological section of a deep-frozen meniscal allograft 6 months post-transplantation in a human demonstrating only superficial cell repopulation. The central core of the grafts remains acellular (Picture reproduced from Rodeo et al. [48])

tation, showed that these allografts contained only donor-derived cells in a number of cases. These data substantiate observations published elsewhere on transplanted human deep-frozen meniscal allografts and collagen scaffolds. Histological sections on these specimens showed a decreased cellularity after transplantation, indicating insufficient repopulation of the graft or scaffold (Fig. 46.6) [29, 47].

Hence, an increase of the initial cell number at the defect site and thereby a decrease of the time needed for colonisation can be accomplished by (1) transplantation of an in vitro cultured 'viable' meniscal allograft or (2) seeding autologous cells with a proven meniscus repair potential on or in a biodegradable scaffold prior to implantation.

46.6 Immunological Aspects of Meniscal Transplantation

In transplant surgery immune response is of special interest because of rejection of the graft. Little is known of immune responses after meniscal transplantation.

Histological analysis of meniscal transplants showed repopulation, although insufficiently, of cells in the grafts [29]. Potentially, this could evoke an immune response.

Ochi et al. investigated both cellular and humeral immune response in mice. Their results indicated that in mice a fresh meniscus is not sufficiently immunogenic to induce a systemic reaction [43].

Khoury et al. were the first to show a generalised expression of class 1 and class 2 human leukocyte antigens (HLA) which were found in the endothelial and synovial cells of fresh and frozen human meniscal tissue [32]. Because of this generalised expression of HLA antigens, whether meniscal allografts are able to sensitise the host and elicit an immune response is of interest. Van Arkel et al. compared blood samples from the meniscus transplant recipients to determine the HLA antigens and antibodies directed against these antigens. Serological HLA typing was performed by standard microcytotoxicity assays for both class 1 and class 2 antigens. A control group comprised healthy male volunteers with no history of prior blood transplantation or blood transfusion. Exclusion criteria were a previous transplantation, prior blood transfusion and previous pregnancies. The conclusion was that recipients of a cryopreserved meniscal transplants can become sensitised [2]. These results were confirmed by Rodeo et al. They concluded that the presence of HLA on the meniscal surface at time of transplantation, even after freezing, indicates the potential for an immune response against the transplant [48].

To our knowledge Hamlet et al. reported the only case of meniscal graft rejection [18].

Due to the absence of a frank immunological reaction, meniscal tissue is an immune-privileged tissue to transplant. The subtle immune response may affect the healing, incorporation and revascularization of the graft.

Conclusion

The meniscus is a fibrocartilage which only receives vascularisation in the peripheral third of the meniscus body. Three types of cells can be found: fibrochondrocytes, fibroblast-like cells and cells of the superficial zone. These cells are responsible of the formation of proteins such as collagen I (the major fibrillar collagen in the meniscus). The latest investigation on meniscal replacement has focused on scaffolds which can be colonised by host cells derived from the synovium and the joint capsule. However, fresh meniscus allografts are still very commonly used since meniscal graft rejection is very rarely reported.

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Organization: Type of Grafts, Conservation, Regulation

47

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Contents

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The demand for meniscal allografts has recently increased due to the extended indications for meniscus allografting. It is still a matter of debate the more appropriate technique to preserve menisci allografts in an acceptable condition until transplantation. When looking for a graft to be transplanted, one must wonder which properties the preserved tissue should possess if it is going to work for the patient. Does it have to contain metabolizing cells that are capable of cell division or not? Does it have to maintain its architectural indemnity to function properly or not? The meniscus is mainly an avascular structure. Its mid-substance nutrition is fed by solute diffusion from the periphery through the interfibrillar space. It was demonstrated that an abnormally higher interfibrillar space leads to a decrease in solute diffusion [27]. Subsequently, it seems logical to look for a storage technique that produces no change or minimal changes in the menisci's collagen architecture.

In this chapter, each meniscal preservation technique is described with its particular advantages and disadvantages.

47.1 Tissue Banks and Control

Tissue banks have arisen from small to medium enterprises, whereof some initially were organized under or affiliated to hospital departments and university units. The organization of complex procedures like procurement, harvesting,

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_47

processing, storage, donor screening, testing, and distribution has led the development of tissue banks from smaller units into larger units. Also, regulatory mechanisms and authorization requirements have turned the development in direction of large regional tissue banks [38].

The European tissue banks are regulated by directives from the European Commission on human tissue, which set the standards of quality and safety for the donation, procurement, testing, processing, preservation, storage, and distribution of human tissues and cells [11]. The directives from the EU describe a development of the last decade from general standards to more centralized retail regulation.

The directive from 2004 was the first large political move, in which the European Parliament and Council took the lead in regulation of musculoskeletal grafts and tissue banks in Europe [14]. The directive stipulates that member countries shall endeavor to ensure that the procurement of tissues and cells as such is carried out on a non-profit basis. In the two following directives, the Commission went into technical retail management by setting up more specific requirements for the donation, procurement, testing, coding, processing, preservation, storage, and distribution of human tissues and cells [15]. More requirements to traceability and notification of serious adverse reactions were added later the same year [16].

Tissue banks associations including the European Association of Tissue Banks (EATB) have been involved in the development of standards and guidelines for meniscus transplantation. EATB is a scientific organization that stimulates science and development and offers updates in the field of tissue transplantation. The American Association of Tissue Banks (AATB) and the Asia Pacific Association of Surgical Tissue Banks (APASTB) are similar associations and cooperation exists between these sister tissue banking associations, who are connected by formalized worldwide congress activity arranged by the World Union of Tissue and Cell Banking Associations (WUTBA).

Increased tissue transplantation activity demonstrated a further need for more and better control with allografts and tissue banks as it has been emphasized by professionals: Proper regulation and control as exemplified by the European Community rules will most often be more efficacious than business directives even if supervised by state regulators. And furthermore, instructions for recognitions and empowerment for allowing tissue institutes in order to organize, manage, document, and register quality controls are required [40].

In 2010, the European Commission took the next step with a directive on inspection and control, where the obligations of the health authorities of member countries were stipulated [17]. Member countries must designate the competent authorities responsible for implementing the directive. All tissue establishments should be accredited, designated, or authorized by a competent authority. Together with the directive, the Commission published an operational manual of inspection to be used by the competent authorities. The aim of this manual was to support EU member countries in implementing a series of regulatory tasks with respect to inspection of tissue and cell procurement and tissue establishments.

In 2012, the Commission published a directive for technical requirements, where the member countries must ensure that tissue and cell procurement and testing are carried out by persons with appropriate training and experience and that they take place in conditions approved by the competent authorities. The European Commission has continued their focus on the area of tissue and cell transplantation. In 2015, two new directives with more detailed regulation have been published from the Commission. This confirms the development in direction of retail regulation in the area of meniscal transplantation.

47.2 Donor and Recipient Protection

Donor selection and screening in terms of medical reports and microbiologic and serologic testing are essential when regarding recipient protection. The risk of transmission of infectious diseases in meniscus transplantation is very low and even lesser for processed menisci such as deep-frozen or cryopreserved. Donor suitability is determined in compliance with the national standards and the guidelines given by European associations, either the European Association of Musculoskeletal Transplantation (EAMST) or the European Association of Tissue Banks (EATB). The American Association of Tissue Banks (AATB) also provides guidelines that influence standards on donation, procurement, testing, processing, preservation, storage, and distribution of meniscus allografts [2, 3, 38].

Meniscus allografts are procured from young adult organ donors. Consent for tissue retrieval is obtained according to the national law and European regulations. In Belgium, the consent is based on donor-presumed consent. Tissue harvesting is allowed only if the potential donor is not registered with a national registry. Nevertheless, informed consent from the next of kin will always be sought [11].

Anonymity between donor and recipient is a basic principle in transplantation, but traceability of the graft by coding number is essential to investigate adverse reactions. Traceability of human tissues after implantation is a prerequisite regarding general health and health quality [16, 40].

Donor protection is executed through regulation of the organs and tissue markets. Limited availability of meniscus allograft forces surgeons to select recipients carefully, choosing patients with the highest needs and patients with the expected best outcome based on current knowledge. This requires systematically data collection on the outcome as recommended by the WHO [45].

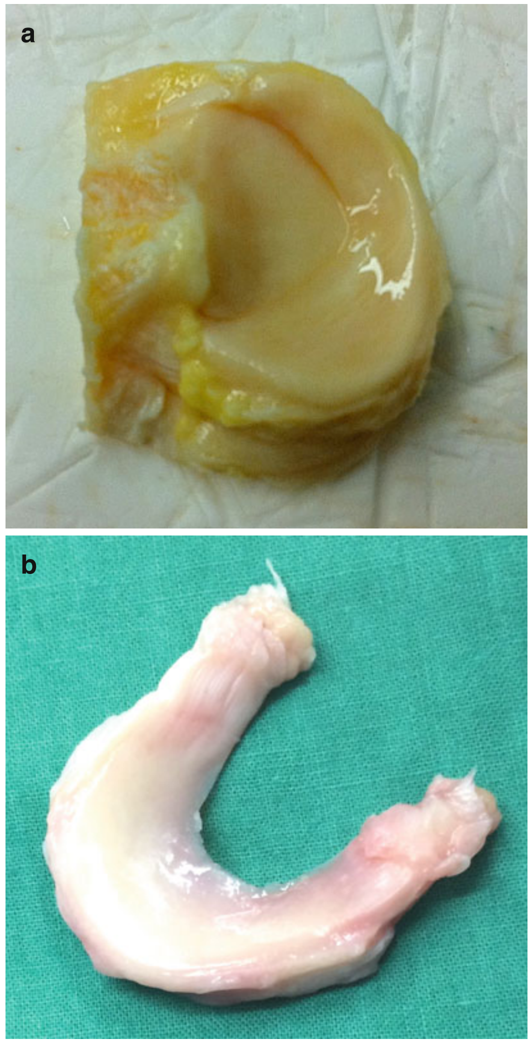

Fig. 47.1 Meniscus harvesting. (**a**) The meniscus is ideally taken with a 1–2 cm-thick bone block of its corresponding tibial plateau. (**b**) Some tissue banks prefer to provide the meniscus without bone tissue

47.3 Harvesting

Donor menisci are removed under sterile conditions in the operating room by a team of trained individuals after the procurement of other organs from heart-beating or non-heart-beating donors. The donor should preferably be under 45 years of age. However, in daily practice, age is not the main critical factor. In fact, posttraumatic or degenerative changes may already be present in younger patients, whereas a suitable meniscus might sometimes be found in donors older than 45 years. The menisci are inspected for macroscopic tears or degenerative changes. Ideally, each meniscus is harvested including a 1–2 cm-thick bone block section of the corresponding tibial plateau (Fig. 47.1a). Unfortunately, some tissue banks provide menisci without bone blocks (Fig. 47.1b), which precludes performing a bone tissue fixation technique of the meniscal transplantation. The menisci can then be transported in a sterile physiological solution to the tissue bank.

47.4 Risk and Recommendations

The risk of viral disease transmission through tissue is very low, provided that the guidelines for donor selection have been strictly followed and that the donor has been screened by medical history taking and blood testing. The theoretical risk of transmission has been evaluated to be less than one in a million for HIV and one in 200,000 for HCV [7].

ABO blood group typing is not required prior to bone or soft tissue allografting. On the other hand, the Rhesus factor has to be determined if the recipient is a female with a potential of becoming pregnant. It has been shown that 0.5 ml of bone marrow is sufficient to induce Rhesus immunity in a Rhesus-negative patient [23]. Soft tissue as meniscus does not carry this risk. Thus, an only-soft-tissue fixation technique should not carry such risk.

47.5 Regulation

The European Union (EU) frames the legislative regulation of meniscal allografting in Europe by a set of standards on quality and safety in regard to donation, procurement, testing, processing, preservation, storage, and distribution of human tissues and cells [14–16]. The member nations of the EU are required to translate the European directives into national laws or directives. Each nation remains free to enact their rules equally or expansively to the European directives. The EU directives and guidelines have a major impact on all aspects of tissue banking and transplantation. In particular, the EU directives secure that local tissue banks operate inside national laws [29].

Every member nation in the EU formulates laws and rules of their own. In this manner, there are both a professional obligation and a political responsibility for procurement of grafts and donor and recipient protection. Furthermore, national rules should be harmonized both within the EU and worldwide, in order to reduce insecurity among providers and recipients of meniscal allografts [32, 40]. Transplantation often includes transnational exchange of organs, tissues, and cells. The exchange of tissues is facilitated by an international harmonization of rules and standards on quality and safety.

Regulative rules and directives for transplantation are made to secure graft procurement and to protect donors and recipients in terms of ethical and health aspects such as anonymity, transparency, reduce risk of disease transmission, registration of adverse reactions, etc.

The tissue banks provide meniscal allografts. It is the task of the competent authorities in each member country to inspect and control the tissue banks. Same national institutions license and accredit the local tissue banks. The organization of the national controlling institutions differs from nation to nation within the EU.

The World Health Organization (WHO) has provided a set of guiding principles for cell, tissue, and organ transplantation [45]. Also, a number of national and international associations of tissue banks conduct scientific, nonlegislative regulation in terms of professional guidelines and ethical rules. These organizations facilitate research and knowledge through education, courses, and congresses.

47.5.1 Development

During the last five decades, there has been a rapid development of transplant medicine and thus an increasing demand for regulation. Today, allografts are utilized in almost all surgical disciplines including orthopedics, neurosurgery, gynecology, cardiac surgery, burn care, and many others. In the field of orthopedic surgery, bone and soft tissues have successfully been used as allografts. The transplantation activity in orthopedic has increased, reasons being that physicians realized and reported the benefits of using allograft tissues, extended indications, and increased patient demand.

The development in meniscus allograft transplantation began in the eighties and has developed ever since. A survey on the meniscus allograft activity in Europe demonstrates the development in the period 1997–2007 [1]. Sixty-seven surgeons from 51 hospitals and clinics with

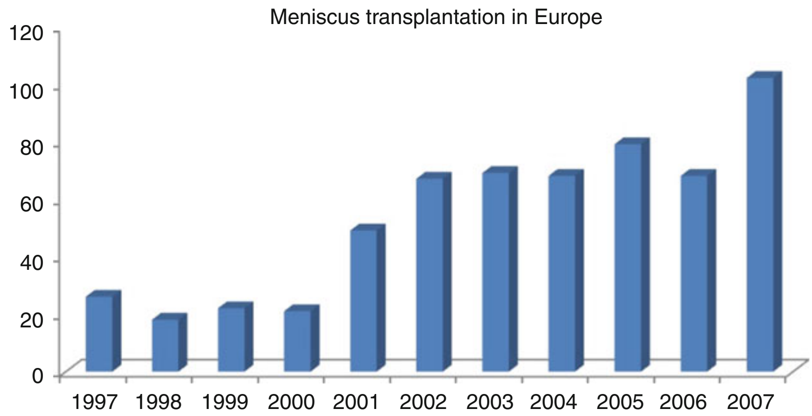

Fig. 47.2 Development of meniscal allograft transplantation in Europe 1997–2007 (N per year). A questionnaire-based survey [1]

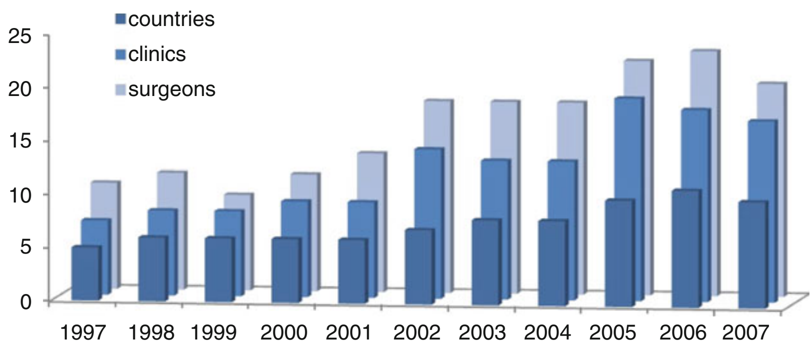

Fig. 47.3 Meniscus transplanting countries, clinics, and surgeons in Europe 1997–2007 (N per year) [1]

presumed implanting activity in 16 European countries were asked every second year to report their meniscus allograft in this period. Even though not comprehensive nor exhaustive, the survey gives a reflection of the development in meniscus allograft transplantation in Europe in this 10-year period (Figs. 47.2 and 47.3).

47.5.2 Ethics

Organ and tissue transplantations raise some ethical questions. Who has the legitimate rights to the harvested meniscal allograft? Is it the harvesting hospital, the tissue bank, the donor, or the national or local health authorities? Who and how should recipients be selected? Is it the patients who suffer the most or those who pay the most? How are the donor and the recipient protected? In addition, stories about illegal markets of organs and tissues may stress the decision-making in meniscal transplantation. Probably all can most likely agree to the fact that selling organs and tissues to potential donors may never be an option. However, these ethical dilemmas are not solved easily, but they point out the need for regulation and control.

The WHO has formulated 11 ethical guiding principles that influence legislation and procedures of meniscus transplantation [45]. Extracts from the WHO guiding principles state that allocation of organs, cells, and tissues should be guided by clinical criteria and ethical norms, not by financial situation or other considerations. Following consent, allografts should be donated freely without any payment or other kinds of reward. The long-term outcomes of donation and transplantation should be assessed for the living donor as well as the recipient in order to document benefit and harm. Organization and execution of donation and transplantation activities, as well as their clinical results, must be transparent, while the personal anonymity and privacy of donors and recipients always remain protected. Physicians determining that a potential donor has died should not be involved in graft removal or subsequent transplantation procedures. Health professionals involved in transplantation should be prohibited from receiving any payment that exceeds the justifiable fee for the services rendered.

The ethical guiding principles from WHO influence professional guidelines and national rules. The directives from the European Commission [18] are also adapted to the WHO guidelines, e.g., the European Directive reaffirms the general principles of voluntary and unpaid donation and the anonymity of donors and recipients [14].

47.6 Types of Grafts

47.6.1 Lyophilization

Lyophilization or freeze-drying, which consists in drying tissue under vacuum and freezing conditions, is an appropriate method to preserve viability of cells if cryoprotective solutions are used. Lyophilization without cryoprotection makes the tissue nonviable and dried. Allografts are thawed and rehydrated before transplantation. Although this method allows for unlimited storage, it also produces changes in the biomechanical properties and size of allografts, which may cause problems with graft sizing during transplantation [46]. Freeze-drying is just a preservation method and cannot be treated as a kind of sterilization. Lyophilization is probably the most convenient method as regards storage because dried tissue can be kept at room temperature, but at the same time, it is the least common among preservation techniques. Sterilization of lyophilized tissues is troublesome; therefore, irradiation at 25 kGy (2.5 Mrad) is usually associated [12]. According to the data collected by some authors in a clinical setting, dried tissue is also irradiated for final sterilization. This combined process of lyophilization and irradiation appears to be detrimental to the tissue, because it results in deep changes in the architectural structure of the extracellular matrix [10]. Despite many logistical advantages of lyophilization, this method is not currently applied due to some serious weaknesses including reduction of tensile strength, poor rehydration, and graft shrinkage as well as increased risk of meniscal size reduction [25, 46].

47.6.2 Freezing

Freezing, deep-frozen or fresh frozen, is one of the most common conservation methods used in orthopedics. This method is technically simple and minimally immunogenic. The menisci harvested under sterile conditions are put into physiologic saline with an antibiotic agent (usually rifampicin) and stored in a deep-frozen state

Deep-frozen allografts are easy to store, but during the freezing process, donor cells are destroyed. It may result in denaturation of histocompatibility antigens, which may in turn decrease immunogenicity [6]. They are packaged in sterile plastic bags and stored in a mechanical freezer at −80 °C. In the operating room, deep-frozen menisci are again soaked in an antibiotic solution (usually vancomycin), which will be gradually released from the implant for at least 3 weeks after the operation [34].

Despite the ease of the technique, there are differences in the description of this graft conservation method as seen in various studies. Some of them described the deep-freezing process as a sudden temperature drop, brought down within in 1 min with the help of liquid nitrogen either to −80° [4] or to −196 °C [44]. Others simply freeze the samples without processing either at −70 °C [24] or at −80 °C [13, 35, 42].

Freezing was once accepted as a simple and reliable way of preserving those tissues that only have to retain mechanical and some biochemical properties. It had been suggested in an animal model that this technique kept the ultrastructure of the collagen net intact. Some other investigations compared, in animal models, the effect of cryopreservation and direct freezing at −80 °C. The menisci allografts were analyzed under light and polarized light microscopy [13] or TEM [31]. Their authors affirmed that although deep-freezing completely destroys the cell components during the freezing process, the collagen net was kept intact. Some other researchers were in agreement with this observation [10]. Interestingly enough, there was a lack of ultrastructural studies on the effect of these aforementioned procedures on the collagen network. The ultrastructural findings observed in a more recent study [19] refuted this affirmation showing that, when ultrastructurally studied, the freezing process led to severe architectural disarray.

In addition, it was demonstrated that menisci that underwent a single freeze–thaw cycle have a significantly higher Young's modulus than those undergoing multiple freeze–thaw cycles [37], which might compromise the allograft's ability to resist compression. According to Arnoczky et al. [4], this architectural disarray might make the menisci more susceptible to injury.

In conclusion, although the fresh frozen preservation technique is a simple and low-cost method, it should not be considered the most appropriate method to maintain the allografts.

47.6.3 Cryopreservation

Cryopreservation is another widely used meniscal allograft preservation technique. In this technique, the harvested graft is submerged in a solution with a cryoprotective agent, a culture medium, and an antiseptic agent. When the impregnation is completed, the graft is slowly cooled at 1 °C/min in liquid nitrogen to minimize cellular tears generated during the freezing process. This type of grafts is stored at −196 °C. Theoretically, cryopreservation may protect viable donor cells due to the use of a cryoprotectant such as glycerol or dimethyl sulfoxide that avoids formation of intracellular ice crystals. However, even if the cryopreserved graft still contains living cells after thawing, their long-term survival and its actual metabolic viability remain controversial [13, 42]. The main usually accepted advantage of cryopreservation over freezing and lyophilization had been that it does not destroy cells. This ability is particularly true in cultured or isolated cells [36]. Tissues are obviously more complex than cell suspensions. Cumulative evidence suggests that cryopreserved menisci suffer various tissue and metabolic changes as well as some loss of structural details of the cells [28, 43]. According to recent data, the percentage of cell survival after cryopreservation has been established between 4 and 54 % [20, 22]. In addition, due to the fact that some time after transplantation the allograft nearly has solely host DNA [4], the advocated advantage of being a cell preservation technique might then seem to be a secondary issue.

In terms of biomechanics, this technique does not seem to alter the ultrastructure of the collagen architecture of the meniscus [20]. Although cryopreservation allows for a more prolonged allograft storage than the fresh frozen technique, it is a considerably more demanding, difficult, and costly technique. In addition, it may theoretically increase the risk of transmission of infectious diseases [13]. In conclusion, keeping the collagen net architecture intact might be the main advantage of cryopreservation over the freezing procedure.

47.6.4 Fresh Allograft

Fresh menisci are used for viable meniscal allografting. This type of graft is supported by the viable cells theory, which says that fresh tissue contains a large number of these cells, which may have influence on the maintenance of extra-cellular matrix properties [26]. Thus, fresh allografts may be advantageous as not only does it not destroy cells but it also keeps them viable by producing proteoglycans and collagen fiber structures. This is a crucial difference from the cryopreservation technique. In fact, a normal or nearly normal cellular function can be expected from the moment of implantation [5, 8, 42]. In order to keep the best possible fresh meniscal allograft properties, a few restrictions must be respected. To maintain the maximal viability and metabolic activity of the meniscal cells, procurement should take place as soon as possible and not longer than 12 h after death [41].

The procedure of donation should be performed as follows: After harvesting under sterile conditions, the graft must be kept at 4 °C in sterile saline solution. In the next step, the graft has to be placed in a culture medium containing 20 % of the recipient's serum and stored at 37 °C in continuously controlled environmental conditions. The graft can be safely kept for up to 15 days without a remarkable loss of cell viability [42].

It has been demonstrated that cellular repopulation occurs in the meniscal allograft after transplantation even if there are no viable cells in the time of surgery [5, 30, 33, 47]. However, donor DNA in the viable human meniscal allograft has been detected for as long as 64 months after transplantation, indicating that donor cells survive for a long period of time [39]. Thus, the replacement process by host cells is probably slower in the human model, suggesting the superiority of a preserving system that is able to maintain the cell viability. In this controversial debate, other authors [9] have shown that sometime after transplantation, the allograft meniscus nearly has only host DNA. Therefore, it suggests that cell viability is not as important as preservation of the collagen net architecture.

Fresh meniscus allograft has been shown to remain viable after 2 weeks in the Dulbecco modified Eagle's medium (DMEM; Gibco Invitrogen, Merelbeke, Belgium) supplemented with 20 % of autologous serum [41, 42]. Although this recommended 2-week window for safe transplantation after harvesting appears to work well according to previous studies [41, 42], it might not contribute to the widespread use of this technique for obvious time-relative and logistic limitations. The technique requires host serum to supplement the medium of the menisci. It is difficult to set up fresh menisci banks because there is only a 2-week window to transplant the meniscus. In addition, the host patient must be determined in advance in order to obtain his/her serum. A recent study showed that this time period might be prolonged at least up to 4 weeks from harvesting if the Insulin-Transferrin-Selenium is used to maintain meniscal tissue instead of the host donor [21]. Both characteristics might make viable meniscal transplantation less complicated logistically to perform.

It is finally worth remembering that the use of fresh tissue as a transplant is always associated with a higher risk of disease transmission.

Conclusion

Each of the meniscal preservation and sterilization methods presented in this work has its pros and cons (Table 47.1).

The two most commonly implanted menisci are either deep-frozen or cryopreserved, but fresh meniscal allograft transplantations have also grown in popularity. However, no clinical superiority of any of the conservation techniques over the others has still been proven.

Legislative regulation on tissue transplantation in Europe is framed by the European Commission by a set of standards on quality and safety on donation, procurement, testing, processing, preservation, storage, and distribution. The EU member nations control their own transplantation activity and tissue banks and need to enact national rules and laws that as minimum equal the European directives.

Table 47.1 Main characteristics of each meniscal preservation technique

Type of graft	Preparation and logistic	Risk of disease transmission	Collagen net quality	Cost	Usage
Lyophilized	++	+	−	++	−
Fresh frozen	+	+	+	+	+++
Cryopreserved	++	+	++	++	++
Fresh	+++	++	+++	+++	+

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Meniscus Allograft: Organization and Regulation in Europe and USA

48

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48.1 Organization in Europe

Two options exist for the use of meniscus allografts in Europe. One option is the acquisition of a meniscus allograft through a tissue supplier, such as a tissue bank or a nonprofit organization that has been accredited to distribute allografts. If such a supplier is not available, an individual surgeon could potentially procure and implant the meniscus allograft. However, all the responsibilities of tissue safety and adherence to the European standards would lie with this person. Therefore, a thorough knowledge of the required regulations must be obtained before considering such a practice.

The European Parliament has outlined guidelines for the handling and distribution of allografts through directives that are binding for every country belonging to the European Union. These standards had to be implemented into national laws by 01/09/2008 and were defined in the directives 2004/23/EC, 2006/17/EC, and 2006/86/EC. Here, all details on donation, distribution, procurement, testing, processing, preservation, and storage of allografts are outlined. The directives can be downloaded from http://eur-lex.europa.eu/homepage.html. Further, implementation of these guidelines into national laws had to be carried out by a national authority, assigned by each European country for regulating the use of human tissue and cells. Their respective names and contact information for all European countries can be found at http://www.eurocet.org

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_48

under the link “competent authorities.” These authorities shall ensure authorization or licensing of all tissue establishments where activities of testing, processing, preservation, storage, or distribution of human tissues and cells intended for human applications are undertaken. Donated tissue must be traceable during tissue procurement, processing, storage, and distribution on national territory. It is crucial for a surgeon who plans to undertake meniscus transplantations to be familiar with the requirements of the local national authority, because the implementation of European directives into national law has varied substantially, with some national authorities requiring regulations beyond the European Commission (EC) directives. As a result, nonsterilized meniscus allografts cannot be procured and distributed in some European countries, whereas in others, such activity is possible.

The following paragraphs briefly describe the requirements for allograft use as outlined by the EC; these standards must be met when considering the procurement and implantation of a meniscus allograft by individual surgeons.

Directive 2004/23/EC was the first to outline the basic requirements for donation, procurement, testing, processing, preservation, storage, and distribution of human tissues and cells intended for human applications. It also regulates the import of allografts from third-party countries. This is of special importance because certain tissue types, such as nonsterilized meniscus allografts, might not be available in certain European countries and must therefore be imported from abroad. It is required that an import be carried out by tissue establishments that are accredited, designated, authorized, or licensed for the purpose of those activities. In most European countries, such institutions are local tissue banks and pharmacies. Before using the allografts, the physician must inquire who these local authorities are and whether they meet the standards laid out by the EC. Member States and tissue establishments that receive such imports from the third-party countries shall ensure that they meet standards of quality and safety equivalent to those laid down in the European directives. Local tissue establishments must be registered and record their activities, including the types and quantities of tissues and/or cells procured, tested, preserved, processed, stored, and distributed, or otherwise disposed of, in addition to the origin and destination of the tissues and cells intended for human applications. Any serious adverse events and reactions must be noted.

Tissue donation must proceed in European Member States through nonprofit organizations, which must ensure voluntary and unpaid donations of tissues and cells. Donors may receive compensation, which is strictly limited to rewarding expenses related to and inconvenience caused by the tissue donation.

To ensure the quality and safety of allograft tissue and cells, a quality management system must be established. This requires the documentation of standard operating procedures, guidelines, training and reference manuals, reporting forms, donor records, and information on the final destination of tissues or cells. Trained personnel assigned must possess a diploma, certificate, or other evidence of formal qualifications in the field of medical or biological sciences awarded upon completion of a university course of study or a course recognized as equivalent by the Member State, with at least 2 years’ practical experience in the relevant fields.

While directive 2004/23/EC already calls for general regulatory measures for tissue and cell processing and testing, tissue storage conditions, and distribution, directive 2006/17/EC defines the more specific requirements that must be met with regard to allograft donation, procurement, and testing of human tissues and cells.

Tissue procurement shall be carried out by persons who have successfully completed a training program specified by a medical team, trained in the procurement of allografts, or a tissue establishment authorized for procurement. Procurement must take place in the appropriate facilities, following procedures that minimize bacterial or other contamination of the tissues and cells procured. The procurement procedures must protect those properties of the tissue/cells that are required for their ultimate clinical use and, at the same time, minimize the risk of microbiological contamination during the process, particularly when tissues and cells cannot subsequently be sterilized. Appropriate facilities must exist that allow for sterile tissue harvest and transport to the facilities that further process, store, and distribute the tissue. Time between the death of the donor and tissue removal must not exceed 24 h.

European directive 2006/86/EC provides details on laboratory requirements, especially when the sterilization of allogenic tissue is not possible (Annex 1, D). These requirements must comply with the current European Guide to Good Manufacturing Practice (GMP). The GMP directive is constantly updated based on the current medical knowledge in the field of disease prevention. Therefore, national authorities are required to ensure that local facilities or institutions meet these standards if they are to work with allogenic tissue. The GMP guidelines can be found at http://www.ema.europa.eu.

As a consequence of today's medical standards, highly developed laboratory infrastructure and equipment are required to safely facilitate tissue processing without the risk of disease transmission. These requirements have limited the processing of meniscus allografts in Europe to a small number of institutions that are able to finance and operate such an infrastructure. Also, several laboratory tests must be carried out to minimize and prevent the transmission of pathogens from the donor to the recipient of the allografts. All donor plasma or serum must be screened for human immunodeficiency virus (HIV) I/II, hepatitis B and C, and syphilis (Annex II, 2006/17/EC). In deceased donors, blood sampling must occur within 24 h of death. Further testing may be required, depending on the regulations of the respective national authorities.

Directives 2006/17/EC and 2006/86/EC recommend the sterilization of all allogenic tissue and cells. However, it is not required, considering the fact that the sterilization of certain tissue types, such as meniscus allografts, may not be possible without compromising tissue function and integrity. It is, therefore, left to the national authorities to decide whether terminal sterilization of allografts is mandatory. In Europe, legal regulations vary significantly. For example, meniscus allografts must undergo sterilization by either high-dose irradiation or peracetic acid ethanol sterilization, when harvested, procured, and distributed in Germany, whereas no sterilization procedure is obligatory in Spain. Therefore, it is very important to contact national authorities to obtain detailed information on the requirements of meniscus tissue processing before surgical implantation. As current sterilization procedures have adverse effects on the biomechanical and biological properties of meniscus allografts [1], fresh-frozen nonsterilized allografts are considered the golden standard in meniscus transplantation. Therefore, in some European countries (e.g., Spain, Belgium, Switzerland), it is currently possible to harvest, process, and distribute nonsterilized meniscus allografts, whereas in others, it is not possible because of the required sterilization procedures.

The importance of obtaining meniscus allografts from accredited institutions is that all legal liabilities with respect to tissue safety lie with the distributing institution.

In the countries of the European Union, where the production of nonsterilized meniscus tissue is not possible, the alternative is to import meniscus allografts from abroad. In Germany, for example, it is permitted to import nonsterilized meniscus allografts, when no other alternative treatment exists for a particular patient. The lack of alternative treatments must be stated in writing based on current medical knowledge. Only in these special cases can nonsterilized meniscus allografts be imported from abroad. However, authorized institutions for medical devices and drugs, such as a pharmacy, must be contacted to carry out the imports. These institutions are legally required to confirm that the harvest, procurement, processing, storage, and distribution of the imported meniscus allograft are in accordance with regulations laid out by the European Commission (European Medicines Agency, EMA). As the regulations of the American Association of Tissue Banks (AATB) are in accordance with these regulations, it is currently possible in Europe to import fresh-frozen meniscus allografts from tissue banks in the USA that have been accredited by the

AATB. The local allograft importing institution is legally liable for any issues related to tissue safety.

Another option for most European countries with no availability of nonsterilized meniscus allografts is the execution of ex- and implantation in the same person. The process of meniscus procurement, processing, and possibly storage must take place under the guidance of the same physician. All liabilities regarding tissue safety remain with the surgeon. Therefore, this option is rarely executed and not feasible for regular meniscus implantation.

In summary, current practice for using meniscus allografts varies substantially among European countries. If a surgeon aims to perform meniscus transplantation in Europe, the national authority accredited by the EMA in the handling of meniscus allografts must first be identified and consulted. Second, it must be acknowledged whether the sterilization of meniscus allografts is required. Third, national institutions must be identified that have been accredited according to the standards of the EMA to produce meniscus allografts. Then, the implantation of meniscus allografts from within the national country is legally possible. If the national production of meniscus allografts is not legally possible, then the national regulations of the accredited authorities must be analyzed for alternatives, such as the importation of meniscus allografts from abroad.

48.2 Organization in the USA

The majority of musculoskeletal (MSK) allografts and meniscus transplants in the world are performed in the USA. A nationwide network of large and smaller institutional tissue banks, organized as nonprofit organizations, exists that supply meniscus allografts on demand to the orthopedic community. All tissue suppliers in the USA must be accredited and licensed to do so. Because availability is greater compared with Europe, meniscus transplantation has become a standard surgical procedure in the USA.

State and federal laws mandate the requirements for the accreditation of tissue processors, such as tissue banks. Human tissues and cells intended for another human recipient, such as a meniscus allograft, are classified as “human cell, tissue, and cellular and tissue-based products” (HCT/Ps). Federal law decreed in 2004 that the FDA Center for Biologics Evaluation and Research (CBER) was responsible for regulating HCT/Ps (http://www.fda.gov/cber/tiss.htm). The CBER regulates HCT/Ps under the Code of Federal Regulations Title 21 Parts 1270 and 1271 [2]. In these codes, mandatory procedures are described for the registration and listing of institutions that handle allografts, such as menisci, donor eligibility (screening and testing of donor and transplanted tissue), current good tissue practices (including requirements for personnel, facilities, documentation, procedures for sterile tissue procurement and processing, labeling, storage, tracking), and the inspection of tissue establishments. The aim of these regulations is to minimize the risk of disease transmission.

An important accreditation institution of tissue banks is the Joint Commission (JC), which is a nonprofit organization that is independent of the FDA. It has accredited more than 20,000 health care organizations and programs in the USA. It regularly issues Tissue Storage and Issuance Standards (www.jointcommission.org). Accreditation requires hospitals, critical access hospitals, ambulatory office-based surgery, and outpatient centers to adhere to procedures that minimize the risk of disease transmission during tissue recovery and storage, ensure record-keeping and -tracking, and report adverse events/infection follow-up. These written procedures and guidelines should warrant hospitals and surgery centers to bidirectionally trace allografts and report any potential disease transmission to the recipient of an allograft and any adverse reactions to the donor facility. The majority of state governments recognize Joint Commission accreditation as a condition of licensure and the receipt of financial reimbursement by state and private insurance companies. Therefore, surgeons should be informed about the accreditation of their meniscus allograft supplier before surgery.

Currently, the most important accreditation organization of tissue suppliers and personnel is the AATB [13]. The AATB is a nonprofit organization that is aimed at improving voluntary safety standards and facilitating the safe and infectious-free transplantation of human tissue. It regularly publishes its Standard for Tissue Banking, most recently in 2012 [3], which updates all safety standards with the current medical knowledge. It stringently requires its accredited institutions and personnel to adhere to the updated standards, such as new testing methods in the detection of possible infectious pathogens, inclusion and exclusion criteria for donor tissue or any other issue related to the prevention of disease transmission, and safe allograft use. There are currently more than 100 AATB-accredited tissue banks that supply more than 90 % of all MSK tissue in the USA. The American Academy of Orthopedic Surgeons has officially recommended orthopedic surgeons to work with AATB-accredited tissue banks [4] because of the highest standards of constantly updated regulatory guidelines, ensuring optimal quality and tissue safety of distributed allografts.

If a surgeon plans to obtain a meniscus allograft from an institution based in the USA, it should be ensured that it is accredited by the AATB. Such institutions can be found at http://www.aatb.org/Accredited-Bank-Search. All accredited tissue banks must guarantee tissue sterility. However, technologies employed to achieve such tissue sterility vary substantially between tissue banks. Most tissue banks use proprietary cleansing procedures to eliminate pathogens, which are often combined with low-dose irradiation procedures [5]. As it has been shown that even low-dose irradiation can have adverse effects on the healing meniscus allograft [1], surgeons must query the distributing tissue banks with regard to the sterilization method applied. Often, the large tissue suppliers in the USA conceal the specifics of their cleansing/sterilization procedures. Therefore, it is recommended to inquire about the effects of their technologies on the mechanical and biological properties of the meniscus tissue. Currently, nonsterilized deep-frozen, cryopreserved, or fresh-frozen meniscus allografts are considered the golden standard for meniscus transplantation [1]. Tissue suppliers should be asked if they offer these types of meniscus allografts.

In summary, in the USA, the establishment of nationwide standards based on state and federal law regulations, which are constantly updated by the widely accepted accreditation organizations, such as the AATB and the JC, has allowed the development of a large network of tissue institutions that engage in all aspects of allograft tissue handling, from donation to procurement, processing, storage, and distribution. This, in turn, has led to a constant supply of meniscus allografts to the orthopedic community on an on-demand basis, with a minimal risk of disease transmission.

In Europe, the differences in the implementation of European guidelines by local national authorities have led to a situation of variable availability of nonsterilized meniscus allografts. Therefore, further efforts are required to either unify regulations that are the basis for improved meniscus allograft availability or develop sterilization procedures that do not compromise meniscus function and biology.

48.3 Tissue Procurement Overview

Tissues are obtained worldwide and used to restore quality of life in millions of recipients yearly. Among other types of tissues, meniscus allografts provide recipients with enormous benefits, and in spite of other type of tissues that can be substituted with autologous tissues (such as autologous ligaments that can replace broken tendons), some meniscus defects can be successfully treated by substituting a healthy meniscus donated by a recently deceased person.

Difficulties with sufficient tissue availability are well known, but menisci has even more limited availability than other tissues, because some important factors are inherent to this kind of tissue. Among these factors, upper age limits, family consent, and size compatibility are most frequently noted.

Some tissue standards and tissue banking standard operating procedures establish an age range for meniscus donation of between 17 and 45 years old [6] because of the quality of the tissue recovered. This limitation is one of the most important constraints to obtaining menisci from tissue donors. As an example, in Catalonia (population 7 million), in 2014, there were 218 effective organ donors for organ donation, and the mean age of the deceased donors was 57.7 years, 10 years over the age limit for obtaining meniscus grafts (Fig. 48.1). Tissue donation also has to face difficulties related to family consent. While organ donation is well known among most of the family members requested, fewer families are aware of the need for tissue. In fact, in most communities, refusal of the family to donate is higher when asking for tissue donation than when organ donation is requested [7].

Meniscus recovery is a procedure that requires highly skilled professionals owing to difficulties in the recovery procedure. More errors occur during meniscus recovery than for other tissue types and require a longer learning curve before competency is acquired.

Finally, tissue size compatibility between the donor and recipient is crucial for a good outcome from a meniscus allograft [8]. Matching meniscus graft recipient needs with tissue availability in a tissue bank is often a crossroads, because before recovery it is not possible to know if donor's size fulfills a patient's requirements.

Taking into account all the factors explained, it is easy to understand that covering patient needs for meniscus transplant is complex and requires a large number of tissue donors with a large number of menisci of different sizes.

Considering the characteristics of generic meniscus graft, activity on donation and transplantation also varies depending on regulations, standards, and guidance provided by scientific organizations at local and international levels.

In the present chapter, differences and similarities in meniscus tissue regulations, standards, donation, family consent, processing, and allocation from the European and American models are described. The differences are described, even though the essence of all the organizations that participate in the composition of all regulatory and guidance documents is similar: looking for ethical and professional tissue donation and transplantation, protecting the donor and the recipient, and establishing transparent and safe activity on transplantation.

48.4 Comparison of Regulations, Standards, and Other Initiatives

Authorities have been working hard over the last two decades to create a regulatory framework for tissue banking activities, from donation to transplantation to ensure the quality and safety of tissues and cells for therapeutic purposes. Before these regulations were established, there was no clear jurisdiction on tissue and cell donation and transplantation. In parallel, and in combination, scientific societies and

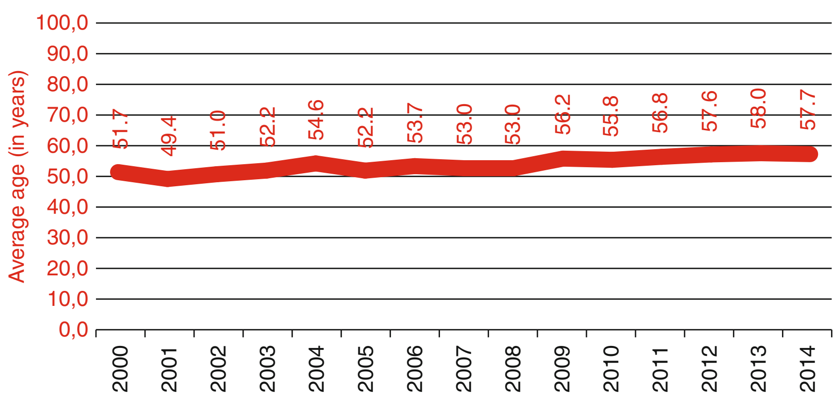

Fig. 48.1 Evolution of the mean age of deceased donors (over the age of 14), 2000–2014 in Catalonia

professionals have worked to develop standards and guidance to harmonize quality and safety at the international level. At the European Union (EU) level, funded projects and EU scientific societies have developed a number of initiatives that have brought together professionals and authorities helping to develop the best practices in tissue banking activities, inspections, and biovigilance programs. This first section is focused on exploring tissue and cell regulations in Europe and the USA, the standards that are in place, and a summary of the different projects and realities of the USA and Europe.

48.4.1 Europe

In the 1990s, there were a wide range and variety of realities among EU members related to tissue regulations. In Europe, it was possible to start to regulate at the European level in 1995 when EU competence was extended to the standards and the quality and safety of organs, tissues, blood, and blood components. In 2004, the EC published the so-called mother Directive for tissues and cells: Directive 2004/23/EC of the European Parliament [9]. The main objectives of publishing a European directive (legislative act) on tissue and cell activities were to set up minimum standards to guarantee quality and safety at all stages of tissue and cell activity, to establish the criteria for authorizing tissue establishments, to have a comprehensive registry of officially authorized tissue banks, to create the basis for a common system of coding, traceability, and the communication of adverse events, and finally to harmonize the import/export rules among EU and non-EU countries.

To implement the mother Directive, on 2006, two technical directives, Directive 2006/17/EC and Directive 2006/86/EC [10, 11], were published with regard to certain technical requirements.

Member States have transposed the Directives into national laws and put in place the implementation measures.

Related to European standard and good practice publications, the Council of Europe, which represents 47 member states and 800 million Europeans, has been actively promoting the publication of a guide to the quality and safety of tissues and cells for human application. This international organization was founded to share and disseminate fundamental values throughout Europe. Work on organ, tissue, and cell transplantations started in 1984, and in 2013 the first edition of the Guide to safety for tissues and cells was published. The Guide succeeded in bringing together the results of the work of the European Directorate for the Quality of Medicines, EU projects, professional groups, and the World Health Organization to build a comprehensive consensus document incorporating the state of the art in the field of tissues and cells for human application. It was the first of its kind to define detailed ethical and technical guidance for tissues and cells in Europe, incorporating the generic requirements of the EU Directives.

Finally, some EU projects funded through calls for proposals have also guided some of the new technical aspects of tissue banking. The European Quality System for Tissue Banking Project (EQSTB) analyzed European tissue legislation, showing in 2007 that 100 % of the participating countries followed the European Association of Tissue Banks (EATB) standards, only 83 % adapted their legislation to the EU Directive, and only 43 % had regular inspections for tissue banking authorization by competent authorities [12].

Other projects have to harmonize standards and methodologies for inspections and accreditations (EUSITITE), develop detailed European Good Tissue Practices for the activities carried out in tissue establishment (EuroGTP), and develop a shared view of how serious adverse reactions and events in this field are reported, evaluated, and investigated (SoHo vigilance and surveillance of Substances of Human Origin).

48.4.2 USA

Tissue procedures in the USA are based upon federal government regulations and standards, which are represented by different organizations.

The Food and Drug Administration (FDA) is an agency within the Department of Health and Human Services of the USA that has been promoting different initiatives regarding the regulation of activities of tissue recovery, processing, and distribution, and published in the 1990s the first regulation: the Interim Final Rule “Human Tissue Intended for Transplantation-21 CFR Part 1270”. In 1997, it published a Final Rule and Guidance Document. The purpose of this regulation was to create a unified registration and listing system for establishments that manufacture human cells, tissues, and cellular- and tissue-based products (HCT/Ps) and to establish donor eligibility, current good tissue practice, and other procedures to prevent the introduction, transmission, and spread of communicable diseases by HCT/Ps. The FDA’s rules are mandatory and enforceable by law and cover tissue recovery, donor screening and testing, processing, packaging, storage, and distribution. The FDA also interacts with other government agencies such as the Centers for Disease Control (CDC) or the Health Resources and Services Administration (HRSA), which oversees all organ, tissue, and blood cell donations.

The FDA issued Guidance on the regulation of HCT/Ps. This guidance is intended to help small entity establishments that manufacture HCT/Ps to better understand and comply with the comprehensive regulatory framework.

Professional associations have been contributing in-depth to the current safety of tissue banking in the USA.

(a) The Joint Commission (TJC) has standards for tissue storage, tracking, and adverse reaction investigation in the hospitals that they accredit.
(b) The AATB and the Eye Bank Association of America (EBAA) issue voluntary standards and have active accreditation programs. Since 2005, the AATB has published multiple guidance documents on different technical aspects: physical assessment of tissue donors, the prevention of contamination and cross-contamination at recovery, current good tissue practice, pre-sterilization/pre-disinfection cultures, evaluation of body cooling, and guidance for tissue donor families [12].

48.4.3 Overview

International regulations establish the rules on tissue banking activities from tissue donation, recovery, processing, packaging, labeling, and testing, but they also cover the rules on organizing and managing a tissue bank. It is important to emphasize that there are also rules on importing and exporting tissues that we have to take into account when requesting tissue from another country. With access to tissue regulations, it is possible to analyze the potential quality and safety of the tissues to be imported. Tissue establishments have the obligation to fulfill the laws, follow recommendations and standards, and have the autonomy to have stronger protocols in place.

An alternative to allograft meniscus transplant has appeared in the recent years and consists of cell-therapy-based products. To ensure patient safety, specific regulatory and quality requirements are applied to cell-based medicinal product (CBMP) development programs, which must comply with current Good (Laboratory/Tissue/Manufacturing/Clinical/Distribution) Practice Standards according to the legislative frameworks of the FDA and the EMA [14].

48.5 Activity

Tissues from a single donor can be used to treat as many as 100 patients, or more. In some countries, tissue mainly comes from organ donors, but other countries have developed referral systems to recover tissues from only tissue donors.

In Europe, data are collected by the EC, which receives the information from each one of the EU countries. In the USA, data are collected by the FDA (Table 48.1).

Even if complete and accurate data are not available in Europe as in the USA, the difference showing that MSK transplantation per million

Table 48.1 Tissue activity in the European Union and the USA

2014 data	European Union	USA
Countries	28 countries	50 states
Population	506 million	321 million
TE (including ART)	2,336	2,208
MSK TE	464[b]	781/75[c]
Number MSK donors	90 % living donors 3,200 deceased donors	Only 2 % living donors 30,000 deceased donors
Allografts transplanted[a]	76,300 Data available on only 16 out of 28 EU countries	1,000,000

TE tissue establishment, *ART* assisted reproduction technology, *MSK* musculoskeletal

[a]A total of 781 bone tissue establishments perform at least one activity. Seventy-five MSK tissue establishments perform processing

[b]Eurocet data

[c]Data on European MSK tissue establishments are from tissue establishment that performs any kind of activity under the tissue establishment European directive

population (pmp) in the USA is more frequent than in Europe is notable. Further studies should analyze if the greater use of MSK tissue in some areas is because of a higher number of tissue prescriptions requested by professionals, greater health insurance coverage, or because there is greater tissue availability.

48.6 Consent/Authorization

Organ and tissue donation rates around the world vary substantially (Fig. 48.2). In this chapter, we also analyze how interviewing the family is one of the crucial stages of the process of organ and tissue donation. Providing and receiving bad news and requesting and authorizing organ and tissue donation are very stressful situations for deceased relatives and for professionals. For this reason, the dynamic process of requesting organ and tissue donation requires a multidisciplinary

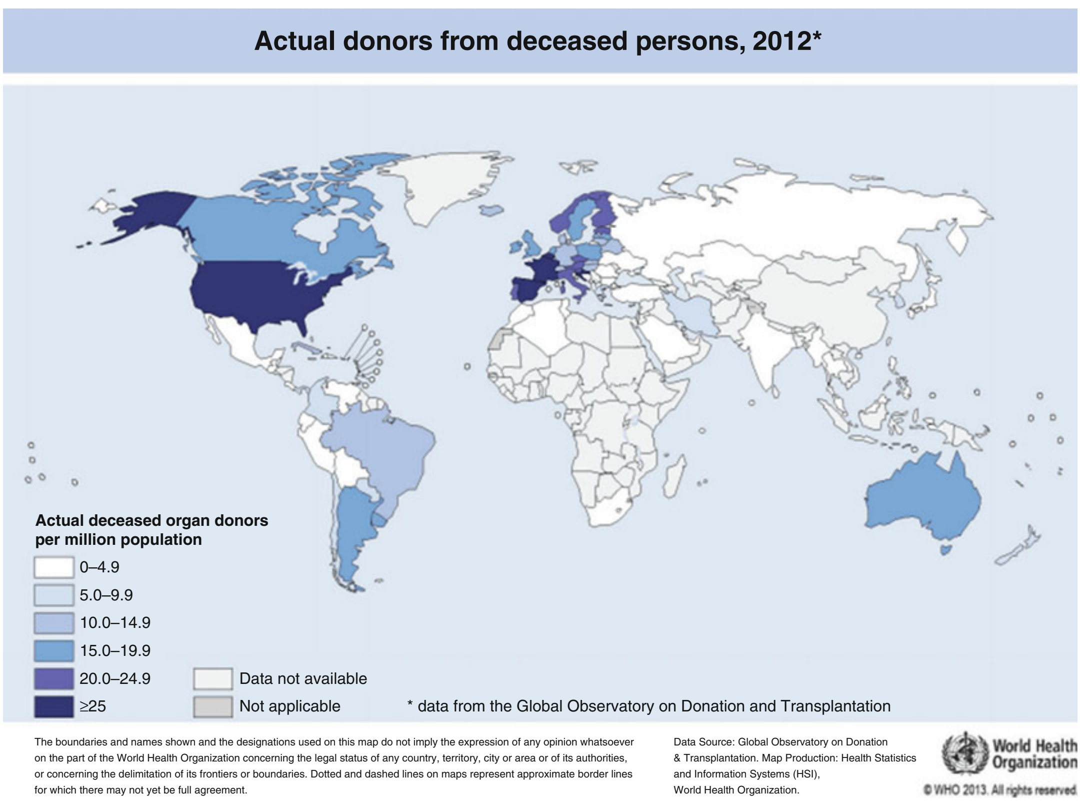

Fig. 48.2 Actual deceased organ donors, 2012 (Data from the Global Observatory on Donation and Transplantation)

team. Professionals must be trained and need to manage in an appropriate manner the emotional reactions of the relatives.

In Europe, there are different regulations relating to consent to donation, but countries have mainly adopted presumed consent or opt-out organ donation in which individuals are automatically considered a potential donor when they die, unless they expressly opt out (in writing) of becoming a donor. European countries that developed and maintain presumed consent in their laws do not rely on it to actually recover organs and require family consent before recovery, as shown by a survey in 2012 [15]. Actually, in 2014, there was a wide disparity in the donation rate within European countries practicing presumed consent, from a high of 35.5 in Spain to a low of 5.6 in Greece (average of 12.5 pmp). Therefore, variations in presumed consent and explicit consent donation rates are not statistically definitive when studying intercountry European donation data.

The United States have adopted opt-in organ donation, in which a person provides consent to becoming a donor before their death so that organ donation can be carried out when they die. Organ procurement organizations (OPOs) and tissue banks may approach families to discuss donation and consult the state donor registry. In the USA, donation rates of 25.8 pmp are similar to those of European countries with presumed consent (Fig. 48.3), and attempting to improve the donation rate is a controversial topic.

Finally, refusal of the family to donate tissue is higher than for families refusing organ donation, because society, and even health care professionals, usually know better the need for organs for patients on waiting lists than the patients waiting for a tissue. Another factor that influences family refusal is the donor's age [16].

In conclusion, family consent to tissue, and specifically to meniscus grafts, is a crucial part of the whole donation process. In this sense, tissue transplant surgeons who suffer from a shortage of meniscus availability can raise awareness of tissue graft needs among recipients waiting for a transplant [17].

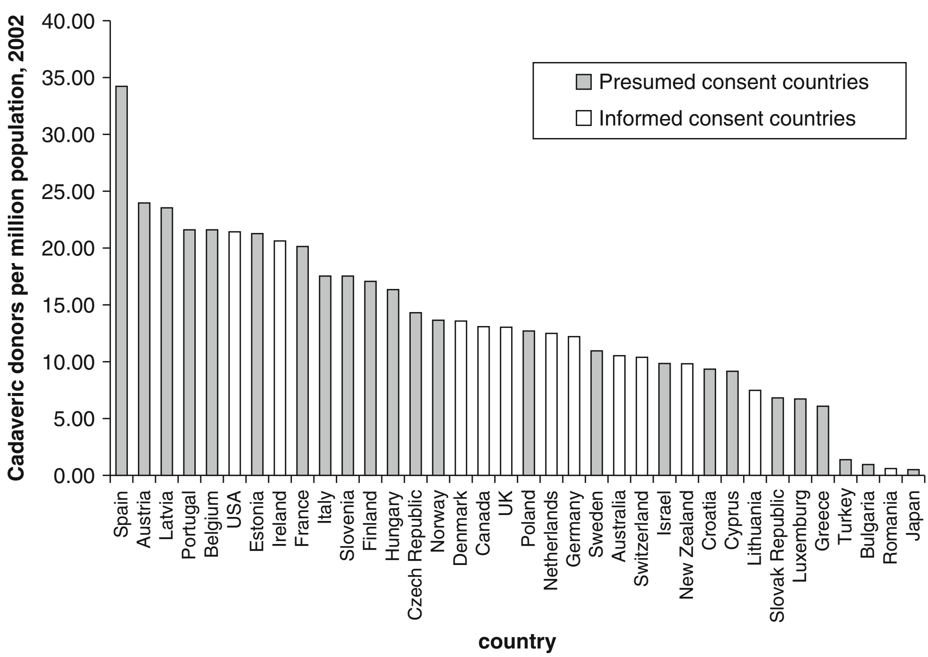

Fig. 48.3 Countries with presumed consent and informed consent (http://www.quora.com/How-can-organ-donation-rates-be-improved)

48.7 Quality

Tissue regulations, standards, organizations, and professionals work for good-quality and safe grafts for their donors and recipients. In this chapter, it has been explained that differences exist in tissue donation and banking regulations and standards for transplantation. Types of tissue donors, types of recovery teams, and even tissue banking organizations have different models and are organized in different ways depending on the country of origin. However, all of them have established rules to ensure safe transplants and all the professionals involved in this field have the goal of helping tissue recipients to avoid any kind of harm.

The EC has verified through extensive work the compliance of Article 16 of the Directive 2004/23/EC, which states that all necessary measures to ensure that each tissue establishment puts in place and updates a good-quality system based on the principles of good practice in Europe. Of the 84 participating tissue establishments, 29 undergo thorough inspections, 26 authorization requirements, 12 external audits, and 17 internal audits. Thus, even if the tissue establishment uses a different system, they do comply with the article relating to quality management. The EC also verifies how tissue establishments comply with Article 17 of the Directive 2004/23/EC relating to the designation within the tissue establishment of those responsible for inspections, authorization requirements, regular evaluation of the personnel, and mandatory training courses.

In the USA, quality management falls under the FDA's quality system regulation for medical device manufacturers and current good manufacturing practice requirements at 21 CFR part 820, which includes internal audits, reagents/supplies, management responsibility, suppliers, purchasing controls, staff training, in-process controls, investigations, and process validation studies. The AATB's "Standards for Tissue Banking" reflect the collective expertise and conscientious efforts of tissue bank professionals to provide a comprehensive foundation for the guidance of tissue banking activities. The Standards are reviewed periodically and revised by the AATB Standards Committee to incorporate scientific and technological advancements. Section K establishes the key elements of the quality assurance program, quality control program, investigations, complaints, internal audits, and electronic systems controls. There are 115 AATB-accredited tissue banks in the USA for MSK tissues.

Global quality of a tissue graft such as a meniscus graft is based on safety and on the morphological and functional properties for its clinical use.

For many years, complications related to tissue safety transplant have been reported to the authorities, and there are some data that can help us to understand the risk of the transmission of infections or malignancies and also the risk of having immunological reactions or other types of problems after transplantation. Bacterial contamination of tissue allografts obtained from cadaveric donors has been a serious cause of morbidity and mortality in recipients [18]. Table 48.2 shows a compendium of adverse events caused by MSK transplantation.

As shown in Table 48.2, the risks of transmission in MSK transplants (including meniscus) are mainly related to infections. Therefore, the factors that can directly influence the risk of transmitting infectious disease include the following: donor screening including cause of death, procurement site, recovery techniques, testing for serology and tissue sterility samples, clean room processing facilities, types of sterilization, and types of tissue processing and final packaging. These factors are analyzed comparing European and US practices/standards. All can influence disease transmission, but some can also influence meniscus graft quality such as donor age limit, a recovery technique that can damage the tissue, and types of processing that can damage the structure of the meniscus matrix.

48.7.1 Donor Suitability

Donor suitability analysis includes the knowledge and review of relevant medical records before and

Table 48.2 Adverse events as result of MSK transplantation

Harm to recipient	Infection	Malignancies	Immunological	Others
MSK	39	1	2	9
Meniscus grafts	2	0	0	0

Data from www.notifylibrary.org

during admission, cause of death, physical assessment, and screening for infectious disease. Also, previous malignancies and quality of the tissue during recovery are taken into account in this review.

48.7.1.1 Medical Records and Cause of Death

The main clinical contraindications for tissue donation in Europe and the USA are common and include systemic autoimmune diseases, neurological disorders, genetic diseases, chronically persistent infection, and toxic substance intoxication, which could be transmitted through tissue transplantation.

Looking into MSK and meniscus grafts in more detail, both standards advise against the use of donors if there are some specific tissue contraindications related to metabolic bone disease or tissue alterations due to toxics, tissue radiation, or trauma.

Cause of death has to be known at the moment of donation, or at least a differential diagnosis of its cause that does not confer any risk to tissue transplantation.

48.7.1.2 Malignancy

Member states of the EU, in accordance with the Directives on tissues and cells, must consider malignancies when evaluating a donor. Unless justified on the basis of a documented risk assessment by the person responsible at the tissue bank, only patients with primary basal cell carcinoma, in situ carcinoma of the cervix, and some primary tumors of the central nervous system can be accepted as a cell or tissue donor, according to scientific evidence. Now, it is a matter for debate whether this European regulation could be discussed taking into account aspects such as:

1. Some tissue processing reduces many viable cells and thus the risk of malignancy transmission. These types of processing include freeze-dried bone irradiation.
2. Currently, there is better knowledge on the type of malignancy and the time the patient has been free of disease than several years ago. Therefore, the risk of metastasis and the concept "free of disease" are better understood. It is also now known if a specific malignancy has been transmitted through organ or tissue transplantation in the past.
3. International knowledge of the few cases of the transmission of malignancy through tissue transplantation.

As per the AATB Standards for Tissue Banking, donors with a current or previous diagnosis of malignancy are evaluated by the Medical Director or licensed physician designee for suitability in accordance with the Standard Operating Procedures (SOP) manual of the tissue bank. The evaluation includes the type of malignancy, the clinical course, and treatment before acceptance of a donor. The evaluation and reasons for acceptance are documented in the donor's record. Survey results reported at Tissue Donor Suitability Workshops held by the AATB from 2006 to 2010 showed very few differences among six tissue banks with regard to policies established for evaluating donor malignancy history. The FDA regulations for the donors of human cells, tissues, and cellular and tissue-based products do not consider malignancy a relevant communicable disease.

In conclusion, by law, malignancy history must be a consideration for donors of meniscus allografts in Europe (most tissue banks contraindicate any kind of malignancy) and its evaluation is required by the tissue bank's Medical Director. However, in the USA, this latter risk assessment only applies if the tissue bank is credited by the AATB [13]. A meticulous risk analysis is preferred when evaluating each donor's history, and there is a consensus that considerations should be based on an analysis of the risks relating to the application of the specific cells/tissues.

48.7.1.3 Age Criteria

In the US standards, an open rule states that the Medical Director shall determine age limits for bone and soft tissue donors. Council of Europe Tissue Guidance [6] does not recommend an upper age limit for donors of cancellous bone, a range of 15 to 55 years of age for long bones, osteoarticular grafts, cartilage, and menisci, and an upper limit of 65 years of age for tendons. As there is no accreditation process for this guidance, it is difficult to know if tissue banks follow these recommendations.

48.7.1.4 Physical Evaluation

Physical evaluation is a crucial step in donor suitability, and is established worldwide. Evidence of a high risk of transmissible disease must be identified. The physical examination results in the rejection of 5 % of deceased donors, thereby demonstrating its importance [19] in preventing disease transmission. If there is any sign of the risk of disease transmission, the donor is rejected.

48.7.1.5 Donor Screening: Required Infectious Disease Testing

As a minimum requirement, the following biological tests must be carried out on the serum or plasma of the donor according to the manufacturer's instructions for each test kit by the AATB Standards and Guide to the quality and safety of tissues and cells for human application in Europe and the USA (Table 48.3).

In recent years, the advances in donor screening have improved, thanks to nucleic acid testing, which shortens the window periods and increases the sensitivity and specificity of detection methods diminishing potential disease transmission.

Table 48.3 Minimum serological requirements

	AATB standards USA	Guide to the quality and safety of tissues and cells for human application Europe
Antibodies to the human immunodeficiency virus, type 1 and type 2 (anti-HIV-1 and anti-HIV-2)	Negative	Negative
NAT HIV	Negative	Recommended as an additional test
HBsAg	Negative	Negative
Total anti-HBc	Negative	If anti-HBc (total, i.e., IgG and IgM) is positive (repeat reactive) and HBsAg is negative, further testing is necessary to determine hepatitis. Usually involves anti-HBs, anti-HBc IgM (only), and/or NAT for HBV. Risk assessment must be carried out
Antibodies to the HCV	Negative	Negative
NAT for HCV	Negative	Recommended as an additional test
Antibodies to HTLV type I and type II	Negative	Testing for HTLV-I antibody must be undertaken for donors living in or originating from high prevalence areas
Syphilis	Negative	Negative When a nonspecific test is performed, a reactive result will not prevent procurement or release if a treponemal-specific (confirmatory) test is nonreactive A donor whose specimen is reactive in a treponemal-specific test requires a thorough risk assessment by a responsible person to determine donor eligibility before their donation is released for clinical use

NAT nucleic acid test, *HIV* human immunodeficiency virus, *AATB* American Association of Tissue Banks, *HBsAg* hepatitis B surface antigen, *IgG* immunoglobulin, *IgM* immunoglobulin M, *anti-HBc* antibody to hepatitis B core antigen, *HBV* hepatitis B virus, *HCV* hepatitis C virus, *HTLV* human T-lymphotropic virus

48.7.1.6 Procurement Site and Time Limits for Recovery

Procurement must ensure safety during tissue recovery and must take place in an appropriate facility, following technical procedures that minimize bacterial contamination of procured tissues and cells. MSK tissue recovery requires sterile recovery methodology and approved sterile instruments and sterile disposable materials. In general, the use of disposable instruments for procurement is recommended, whenever feasible. SOPs for tissue procurement must control contamination and cross-contamination during procurement.

The maximum frametime for MSK excision are (from asystole of the donor to recovery):

1. Body not cooled after asystole: within 15 h of death in the USA and 12 h with no refrigeration and 15 consecutive cumulative hours in Europe
2. Body cooled after asystole: commence within 24 h in the USA and 48 h in Europe

Musculoskeletal tissue wrapping after recovery must be performed in an aseptic way and transported to the tissue bank as soon as possible. In general, the time limit for processing or freezing the tissue after recovery is 72 h in the USA.

Time limits can be a clue to tissue suitability. It has been studied and concluded that clostridial contamination in tissue donors is possible, particularly with increasing time between death and tissue excision [20]. It is recommended to adequately culture the tissue before exposure to solutions containing antibiotics or disinfectants to properly identify the presence of pathogens and to avoid further contamination, to recover tissue as soon as possible after death.

48.7.1.7 Testing the Tissue

1. Contamination considerations: tissue testing during recovery, processing, and packaging is a common and required protocol in all tissue banks, but some difficulties have to be taken into account: difficulties in detecting highly virulent, pathogenic bacteria, the possible occurrence of false-negative sterility tests, and unreliable results of inhibitory substances, such as antibiotics or other chemicals, remaining on the tissue. There is a need to control microbial contamination, and the sterilization of tissue allografts should be carried out whenever possible.

2. Biomechanical considerations: process validation protocols are important in understanding and controlling the effect of the process on the material aspects of the tissue. Treatment of the tissue using chemicals, irradiation, and other handling steps must be examined to understand their influence on the biomechanical behavior of the tissue graft.

48.7.1.8 Tissue Processing

Processing methods are intended to remove blood, lipids, and extraneous tissue, rendering tissue suitable for transplantation. MSK processing usually consists of physical debridement, mechanical agitation, ultrasound processes, alcohol solutions, rinses, antibiotic decontaminations, and, in some cases, final sterilization procedures.

Meniscus grafts have to comply with technical specifications for transplantation; namely, dimensions, quality, and integrity, and they have to be processed according to the standard procedures of the tissue bank that fulfill regulations. Complications related to meniscus morphological and functional properties should be avoided by implementing an evaluation of tissue characteristics during processing. Nevertheless, there is an increasing demand for the production of safer tissues. In the case of meniscus grafts, all actions are directed at avoiding tissue damage and at preserving tissue characteristics after processing and freezing [21]. Tissue dimensions before and after processing must be maintained because tissue matching between the donor and recipient is mandatory.

In the USA and Europe, tissue establishments have been targeting tissue sterility for years and have developed and in some cases registered different types of bone processing. Methods available include gamma irradiation, supercritical carbon dioxide, among others. Regardless of the technique used, the final objective is to remove all possible infectious microorganisms, while maintaining the structural and biological properties essential for clinical use.

Conclusion

Allograft availability for transplantation, particularly meniscus allografts, cannot always meet the patient's needs. Instruments for establishing good tissue practice from donation through to transplantation are in place in Europe and the USA, and the professionals involved have the commitment to work under safety and quality requirements. In summary, it is possible to have a high level of confidence regarding tissue allograft safety if all the professionals and organizations involved follow the regulations, standards, and guidance. It is more complex, however, to predict the final outcome of meniscus allograft transplantation because the prognosis includes the patient's inclusion for transplant, the severity of degenerative changes, limb stability and alignment, graft sizing and processing methods, graft placement, and graft fixation [22]. In this sense, tissue establishments must work together with orthopedic transplant surgeons to validate and study tissue functionality and safety after transplantation.

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Surgical Technique for Open Meniscal Allograft Transplantation

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Olaf Lorbach, Romain Seil, and Dieter Kohn

Contents

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49.1 Indication

The best indication for allogenic meniscus transplantation is the symptomatic lateral knee syndrome after subtotal or total loss of the lateral meniscus in a patient with a stable knee, straight leg axis, and only slight to moderate degenerative changes of the tibiofemoral cartilage in the lateral compartment.

The indication for medial meniscus allograft transplantation is less frequent. High tibial osteotomy is may be a better alternative, especially in patients with varus alignment and already moderate to severe cartilage damage in the medial compartment.

Allograft meniscal transplantation may be combined with additional procedures such as ACL reconstruction or cartilage cell transplantation (ACI) if necessary.

Contraindications for isolated allogenic meniscus transplantation are severe malalignment, instability, and severe degenerative changes of the involved compartment with full-thickness cartilage defects of femur and tibia as well as an extension deficit of more than 5° compared to the contralateral knee or a reduced knee flexion of less than 125°. A patient age of 50 years or older and a BMI of more than 35 are considered as relative contraindications [1, 2].

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_49

49.2 Clinical Examination and Preoperative Management

Careful patient selection is mandatory in order to achieve satisfactory clinical results. Clinical examination x-rays and MRI are required. The patient must be able to fully extend the knee. A slight flexion deficit with a minimum flexion of 130° can be tolerated.

Malalignment and ligament insufficiency have to be excluded prior to surgery or have to be addressed as well during surgery as meniscus transplantation is not suited for the ACL-deficient knee. Moreover, it is important to analyze the existing pain of the patient. The typical postmeniscectomy pain after total lateral meniscus loss is localized in the lateral tibiofemoral compartment especially during weight bearing. Postmeniscectomy pain should be differentiated from patellofemoral pain or other symptoms, which are not related to the resected meniscus.

Additional important information is obtained by x-ray examination and MRI to AP; long leg weight-bearing x-rays are needed to evaluate the leg axis in a frontal plane and exclude cases that need correction osteotomy rather than meniscal transplantation. MRI primarily serves for evaluation of the articular cartilage. The size of the meniscus allograft is matched to the individual patient by gender and height but also from standard AP and lateral x-ray examinations with calibrating markers (Fig. 49.1). This information is sent to the tissue bank in order to obtain an almost perfect match concerning the meniscus size, which has shown to be an important factor for a good clinical as well as biomechanical result [3, 4].

Fig. 49.1 Preoperative x-rays (AP and lateral view) with 25 mm calibrating markers which are sent to the tissue bank for adequate sizing of the meniscus allograft

49.3 Surgical Technique (Lateral Meniscus Allograft Transplantation)

Before the anesthesiologist puts the patient to sleep, we recommend the meniscus allograft to be unpacked and subjected to close inspection to evaluate whether it is suitable for the planned meniscus replacement procedure.

In general, one half of a tibial plateau including bone, the hyaline cartilage, and the meniscus is received from the tissue bank. The following criteria should be checked: correct side, appropriate for the recipient; intact inferior and superior meniscal surfaces; and intact ligaments for horn insertions (Fig. 49.2). The meniscal allograft may be damaged by the saw during the harvest. If the osteotomy is performed too far laterally in the region of the tibial cruciate ligament insertion sites, the meniscotibial ligaments may be damaged. In this situation, it is necessary to assess whether there is still sufficient ligamentous tissue available for soft-tissue fixation. Alternatively, it may be possible to change to soft-tissue fixation to a fixation via bone blocks. If none of these alternatives is possible, it may be considered to postpone the operation [5].

The surgical procedure can be performed under general or spinal anesthesia with the patient in a supine position. The patient's leg is placed in an arthroscopic leg holder with a tourniquet. If isolated open meniscus allograft transplantation is done, the patient is positioned supine with a sand bag at the end of the table to support the foot during knee flexion. The leg is positioned on a large sterile roll with the knee flexed approximately 50–70°. However, free mobile leg positioning is important, as different leg positions are necessary during the procedure to expose the anterior as well as the posterior meniscus attachments adequately.

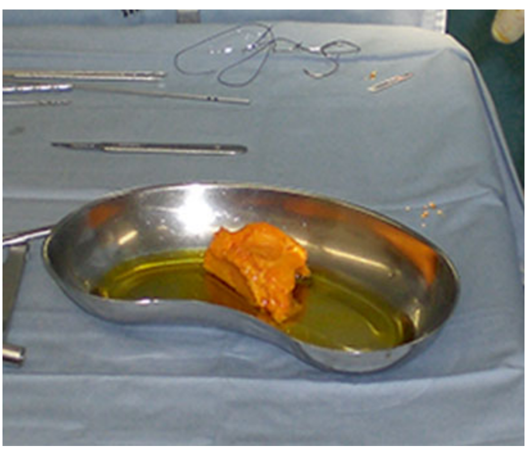

Fig. 49.2 After thawing of the frozen allograft, the meniscus is closely inspected in order to find out if the allograft is applicable for transplantation

If the allograft is suitable for the planned procedure, it is mandatory for the technique introduced here to detach the meniscus very carefully from the bone with special care not to violate the meniscotibial ligaments. They are armed with a strong suture (i.e., Fiberwire, No. 2, Arthrex, Naples, USA) in a modified Mason-Allen configuration or with a modified Krackow stitch depending on the anatomy of the insertion ligaments.

A secure fixation of the meniscus is mandatory as the sutures will be used for the transtibial fixation of the allograft.

The tourniquet is inflated to 250–300 mmHG according to the patient's blood pressure. A curved lateral incision of approximately 10 cm is made over the palpable dorsal margin of the iliotibial tract from approximately three fingers proximal of the upper patellar pole extending distally to a point that lies about one fingerbreadth anterior and distal to the fibular head (Fig. 49.3). After division of the subcutis, the dorsal skin flap is dissected from the fascia. The dorsal margin of the iliotibial tract is identified and the fascia is divided longitudinally beginning over the lateral epicondyle with the knee in 50° of flexion.

After retraction of the iliotibial tract, the lateral femoral condyle is identified with the insertion of the fibular collateral ligament as well as the tendon of the M. popliteus, the arcuate popliteal ligament, and the tendon of the lateral head of the gastrocnemius muscle.

The preparation is restricted anterior to the biceps tendon and the fibular head in order to

Fig. 49.3 Lateral skin incision of approximately 10 cm is made over the palpable dorsal margin of the iliotibial tract from approximately three fingers proximal of the upper patellar pole extending distally to a point that lies about one fingerbreadth anterior and distal to the fibular head

Fig. 49.4 Detached lateral epicondyle with the attached LCL-popliteus complex after osteotomy using 15 mm Lambotte osteotomes

avoid injury of the peroneal nerve. The anterior cranial and posterior margin of the LCL and popliteus complex at the lateral epicondyle are marked and osteotomized with 15 mm Lambotte osteotomes. Special care is necessary at the distal margin beneath the ligaments, which is directly related to the bone cartilage border of the lateral femur condyle. Therefore, the inferior margin should be perforated with a small osteotome to prevent accidental damage of the cartilage [5, 6].

The bony fragment with the attached LCL-popliteus complex should be approximately 15 × 15 mm and 8–10 mm thick to achieve a secure fixation of the fragment at the end of the procedure (Fig. 49.4).

The detached lateral femoral epicondyle is retracted and a Hohmann retractor is inserted posterior to the tibial plateau. A Langenbeck retractor is positioned anterior to the lateral condyle in order to achieve a clear sight into the lateral joint compartment under slight flexion and valgus stress. The meniscus remnant is excised to the base of the capsule in order to achieve a secure fixation of the allograft as well as an optimal healing area with a sufficient blood supply at the attachment site.

The meniscus horn attachment areas can be identified easily if the remnants of the meniscus horn ligament were preserved. Otherwise, precise anatomic knowledge of the correct insertions areas is necessary in order to identify anatomic footprint areas of the anterior and posterior meniscus horns. Alternatively this step can be performed under fluoroscopic control [7–9].

An ACL tibial drill guide is used to place a guide wire at the anatomic footprint of the anterior and posterior meniscus horn insertions. The drill tip is secured with a small spoon and the guide is over-reamed with a 4.5 mm cannulated drill. A suture lasso is inserted in the bone tunnel through the cannulated drills. The attached sutures at the anterior and posterior horn of the allograft are shuttled through the tibial bone tunnels with the suture lassos (Fig. 49.5). Two or three nonabsorbable sutures will be placed as vertical mattress sutures at the posterior horn for the fixation of the allograft to the capsule with special care not to attach the allograft to the popliteus tendon.

Subsequently, vertical nonabsorbable sutures are positioned around the meniscus-capsular junction to achieve a secure fixation of the meniscus to the capsule.

The transtibial sutures are fixed at the desired tension temporarily with a clamp and the knee is moved from full extension to 130° of flexion to control the position and the mobility of the meniscus allograft. If the correct tension is verified, the sutures are tied over a bone bridge or a suture button (Arthrex, Naples, USA).

Fig. 49.5 The sutures at the anterior and posterior meniscus are shuttled transtibially. Moreover, two or three additional nonabsorbable sutures were rendered in the posterior meniscus horn in a vertical stitch configuration for adequate posterior fixation of the allograft

Finally, the lateral epicondyle is reattached under fluoroscopic control to the femoral epicondyle in correct anatomic position using a cancellous 6.5 mm bone screw with a washer. The screw should be oriented approximately 15° in the anterior and cranial direction to avoid accidental penetration of the intercondylar fossa (Fig. 49.6).

After deflation of the tourniquet, subtle hemostasis, and insertion of an intra-articular redon drain, the arthrotomy is closed with absorbable sutures, following closure of the iliotibial tract, subcutaneous sutures, as well as closure of the skin incision.

49.4 Postoperative Management

The knee is immobilized with a brace in full extension. Partial weight bearing with 20 kg is advised for 6 weeks. Passive flexion is allowed to

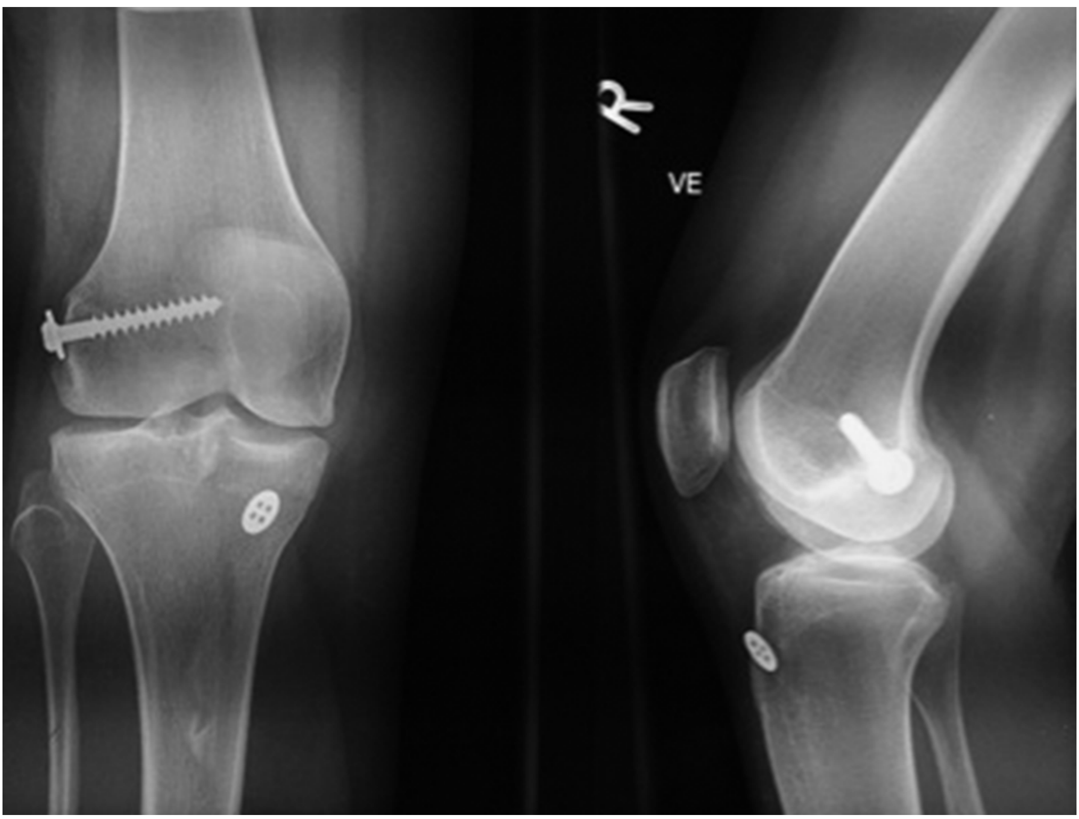

Fig. 49.6 Postoperative x-rays after lateral meniscus allograft transplantation to verify adequate position of the suture button and the 6.5 mm screw

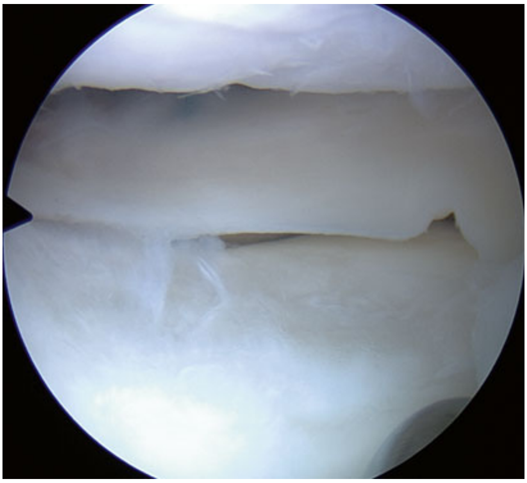

Fig. 49.7 Arthroscopic view of the meniscus allograft 1 year after lateral meniscus allograft transplantation. Arthroscopy was performed during hardware removal

90°. Valgus stress has to be avoided for 6 weeks as well.

Depending on the muscular control of the knee joint, gradual transition to full load bearing and walking can be enabled over a period of 2–4 weeks. Flexion can actively be increased. Forced passive flexion >90° or deep flexion under load should be avoided for another 3 months. Ergometer bicycle training can be added from the 7th postoperative week and gentle running and noncontact sports from the 12th week postoperatively. Contact sports should be avoided for at least 1 year after the operation.

Hardware removal can be planned 3 months postoperatively at the earliest (Fig. 49.7).

Conclusion

The introduced open approach offers a good overview over the lateral compartment even in tight knees with excellent exposure of the allograft position during passive range of motion. More important, a very secure fixation of the allograft is achieved by placing multiple vertical sutures. However, the need of a bony detachment and reattachment of the collateral ligament complex remains the main disadvantage compared to an all-arthroscopic approach.

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Meniscus Allograft Transplantation with Bony Fixation

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50.1 Introduction

The medial and lateral menisci possess different morphologic characteristics. The medial meniscus is crescent shaped and covers approximately one-third of the tibial plateau (Fig. 50.1). The medial meniscus root attachments are more anterior and posterior than those of the lateral meniscus, with the posterior root attachment adjacent to the posterior cruciate ligament (PCL) tibial insertion (Fig. 50.2). The medial meniscus also has a capsular attachment to the deep medial collateral ligament (MCL). In contrast, the lateral meniscus is semicircular in shape and covers greater than 50 % of the lateral tibial plateau [3] (Fig. 50.1). The anterior and posterior lateral meniscal root attachments are closely associated with the anterior cruciate ligament (ACL) [11, 19] (Fig. 50.2). Additional attachments of the lateral meniscus include the meniscofemoral ligaments of Wrisberg and Humphrey, the popliteomeniscal fascicles, and the coronary ligaments [9, 17]. The meniscofemoral ligaments contribute significantly to lateral meniscal stability as their cross-sectional area averages approximately 7–35 % of the cross-sectional area of the PCL [8]. Despite these attachments, the lateral meniscus is more mobile than the medial meniscus [3]. The semicircular shape of the lateral meniscus, with root attachments in close proximity to each other, differs from the crescent shape of the medial meniscus; this feature plays a role in possible transplantation techniques. In the procedure section of this chapter, a bone

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_50

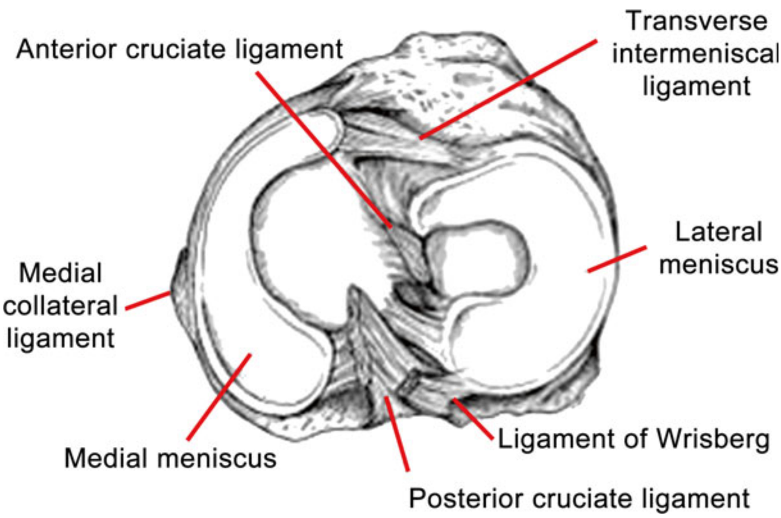

Fig. 50.1 Diagram of meniscal anatomy demonstrating the semicircular shape of the lateral meniscus and the crescent shape of the medial meniscus

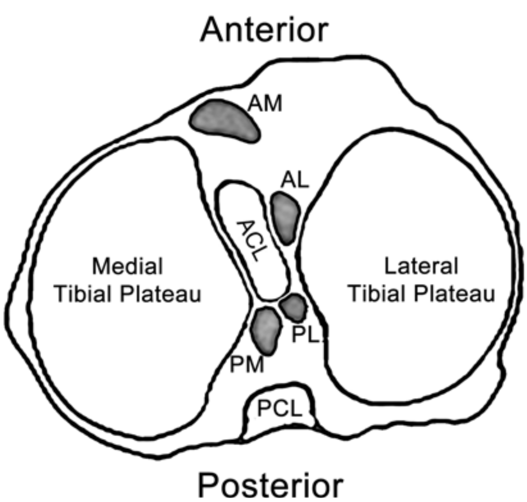

Fig. 50.2 Diagram showing the attachment sites for the lateral and medial meniscus

bridge technique for lateral meniscus transplantation will be discussed. However, a bone block technique is more difficult for medial meniscus transplantations, because the tibial root attachment sites are far apart. Further, a bone block technique for medial meniscus transplantation requires the removal of the medial tibial spine and a small portion of the articular cartilage of the medial tibial plateau.

The medial and lateral menisci are necessary for proper knee function and play a role in shock absorption [13, 14], load distribution [1, 6, 28], joint lubrication [22], proprioception [2], increasing joint congruity [9], and joint stabilization [9, 10, 25]. The medial meniscus is an important secondary stabilizer to anterior tibial translation. The lateral meniscus improves the congruity of the lateral compartment, which has an inherent bony instability as it consists of two convex surfaces. The meniscofemoral ligaments may play an important role in improving the congruity of the lateral compartment by tethering the meniscus anteriorly [7]. In addition, approximately 70 % of the lateral compartment load is transmitted through the lateral meniscus, whereas only 50 % of the medial compartment load is transmitted through the medial meniscus [1, 28]. A complete lateral meniscectomy decreases tibiofemoral contact area by 40–50 % and increases the contact stress by 200–300 % [5, 6, 10]. While a complete medial meniscectomy does not change the loading forces as much as a lateral meniscectomy, it still decreases the tibiofemoral contact area by 50–70 % and increases the contact stress by 100 % [5, 6, 10]. These increased contact stresses can lead to early-onset osteoarthritis [6]. Understanding the details of the anatomy, insertion sites, and mechanical properties of the menisci is critical for successful transplantation of the meniscal allograft.

50.2 Clinical Evaluation

A detailed history, physical examination, and radiographic studies are essential in the evaluation and management in patients being considered for meniscal allograft transplantation. If available, it is extremely helpful to obtain copies of the prior operative notes and arthroscopic pictures. Depending on the temporal proximity of the previous surgery, the arthroscopic pictures may provide information on the articular cartilage status. Furthermore, if additional procedures are needed such as revision ligamentous surgery, the prior operative reports can help determine whether a staged procedure may be necessary. With respect to the history, critical components of the patient's symptoms include instability, location of pain, swelling, and mechanical symptoms. In regard to the location of pain, it should be specifically isolated to the meniscal deficient joint line.

A detailed physical examination of the knee should be performed with particular attention given to the axial alignment, presence of an effusion, ligamentous stability, range of motion (ROM), and joint line tenderness. Axial alignment should be evaluated in the standing position and during gait. This gives the physician a general idea of alignment, but is not a substitute for full-length weight-bearing alignment radiographs. A careful and detailed ligament exam is essential. In our experience, approximately 66 % of meniscal transplantations require either primary or revision collateral or cruciate ligament reconstruction procedures. During the physical examination, the physician should factor in the possibility of pseudolaxity secondary to meniscal deficiency [15, 16]. Ultimately, failure to address ligamentous laxity at the time of meniscal transplantation will lead to early graft failure.

Multiple imaging modalities are necessary in the assessment of meniscal allograft transplantation, including detailed radiographs that assess joint space narrowing (weight bearing) and alignment (long cassette), magnetic resonance imaging (MRI), and occasionally a triple-phase bone scan. Weight-bearing anterior-posterior (AP) x-rays are crucial for evaluating suitability for meniscal transplantation. The standard knee series used is a bilateral posterior-anterior (PA) 30° flexion weight-bearing view and a non-weight-bearing lateral view. Radiographs should also be utilized to evaluate previously placed hardware and tunnels (location and expansiveness) in order to determine potential surgical technical challenges. Finally, a good lateral x-ray is necessary for proper sizing of a potential meniscal allograft.

Full-length bilateral standing alignment x-rays are necessary to assess the weight-bearing axis. The senior author will make a decision based on the alignment measurements whether or not an osteotomy is necessary. Valgus or varus alignment of greater than 2° places extra load on the lateral or medial meniscal allograft, respectively, and leads to early failure. In this situation, it is recommended to correct the malalignment with either a proximal tibial or distal femoral osteotomy prior to meniscal transplantation. The threshold for osteotomy should be low in the setting of malalignment. If an osteotomy is necessary, it is our recommendation to correct the malalignment first and allow the osteotomy to heal for at least 12 weeks prior to performing the meniscal transplantation. If there is a concomitant cruciate instability, then a biplanar osteotomy should be considered. For posterior cruciate ligament (PCL) deficiency with varus alignment, the senior author prefers a medial opening wedge osteotomy which increases the tibial slope. For chronic ACL deficiency with varus alignment, the senior author prefers a lateral closing wedge osteotomy which decreases the tibial slope. A recent MRI scan can help evaluate for articular cartilage damage, subchondral bone edema, meniscal volume, and ligament integrity. Avoid using MRI scans which are outdated. MRI scanners have improved with recent improvements to magnet strength and processing algorithms designed specifically to visualize articular cartilage [21]. However, even with these improvements, MRI scans are not a substitute for an examination under anesthesia and arthroscopic evaluation. For this additional information, the surgeon can now make a final decision regarding the exact procedures to restore joint function.

50.3 Surgical Indications

The ideal candidate for meniscal allograft transplantation is a young, nonobese, nonsmoking patient with a history of prior meniscectomy in a ligamentously stable knee with neutral alignment and no chondral damage. However, a patient with all of the aforementioned criteria is uncommon. Ligamentous instability would lead to an early failure of the allograft and is a contraindication unless it is also addressed at the time of surgery. Concurrent ACL reconstruction is difficult to perform using a bone bridge for lateral meniscal transplantation due to the position of the tibial tunnel.

The traditional contraindications for meniscal allograft transplantation include malalignment and Outerbridge grade III and IV changes. However, in certain cases with focal chondral deficits, concomitant meniscal and osteochondral transplantation has been described. There is little high-level evidence in the literature to guide treatment for these combined lesions. The size, depth, and location of the lesion along with the quality of the surrounding cartilage can be influential in the decision for the appropriateness for meniscal allograft transplantation. When in doubt from the preoperative data (history, physical examination, and radiographic images), a preliminary diagnostic arthroscopy may be necessary to obtain final information for surgical management. For example, if a grade IV focal lesion is located in the meniscal weight-bearing zone, then the senior author feels it is acceptable to proceed with the meniscal allograft transplantation. However, if there is diffuse thinning of the cartilage surrounding a grade III/IV lesion in the non-meniscal weight-bearing zone, then meniscal allograft transplantation would be contraindicated.

Meniscal transplantations are typically performed in "young" patients who are typically less than 50 years old. However, the senior author has performed meniscal transplantations in patients older than 50 years old when the proper indications were met. Obesity remains a relative contraindication. Other potential contraindications to meniscal allograft transplantation include open physes, previous infection, and inflammatory arthropathy.

50.4 Procedure

The focus of this chapter is meniscal allograft transplantation using bony fixation. The senior author prefers transosseous fixation for his medial meniscus transplantations, rather than bone plugs or a bone bridge as shown in Fig. 50.3. A bone bridge technique for lateral meniscal transplantations due to the close proximity of the anterior and posterior lateral meniscal root attachments is recomended. The focus of this chapter will be on lateral meniscal allograft transplantation using a bone bridge procedure (Fig. 50.4).

Patients under general anesthesia are positioned supine on a standard operating table. A tourniquet is not used. A pneumatic leg holder is helpful for limb positioning, although sandbags attached to the bed at multiple flexion angles may also be used (Fig. 50.5). All planned incisions are marked. This step can be challenging if patients have multiple prior incisions. The goal is to have a minimum 6 cm skin bridge between adjacent skin incisions. Sometimes this requires using a less than ideal prior incision and creating a skin

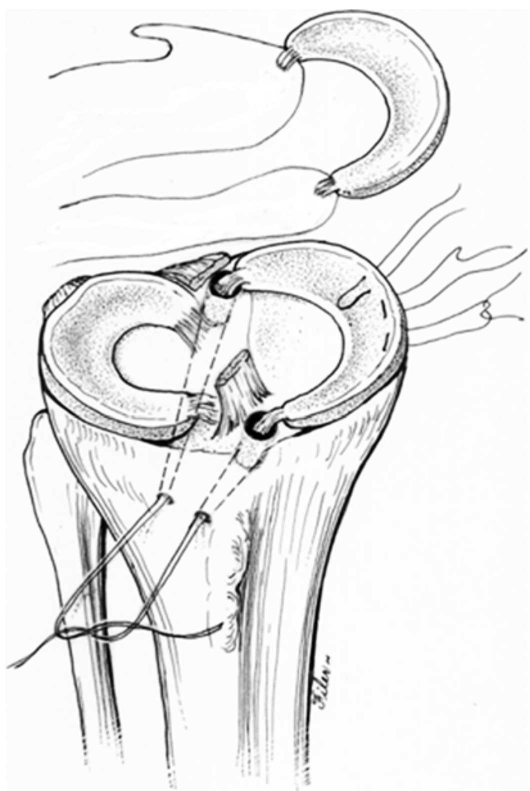

Fig. 50.3 Line drawing of transosseous technique for medial meniscus transplantation

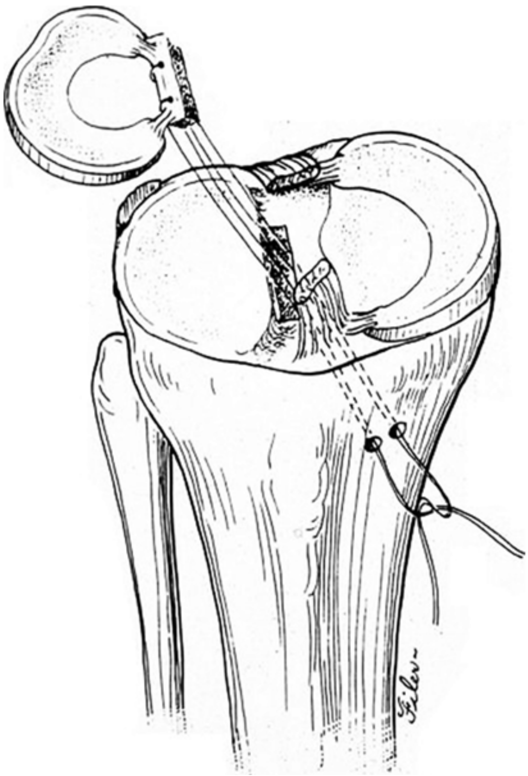

Fig. 50.4 Line drawing of bone bridge technique for lateral meniscus transplantation

flap to gain access to the appropriate position within the knee. The procedure commences with a diagnostic arthroscopy to evaluate the chondral surfaces to reconfirm that the patient is a candidate for meniscal allograft transplantation according to the aforementioned indications (Fig. 50.6). The diagnostic arthroscopy should also include an anterior to posterior measurement of the tibial plateau to make sure that the meniscal allograft is appropriately sized for the patient (Fig. 50.7). If all of the above criteria are met, then the allograft can be thawed and the case continued.

A ¼ inch curved osteotome is passed through the anterolateral portal to create a 1 cm wide trough between the anterior and posterior meniscal root attachment sites; this trough will inherently pass through the lateral tibial spine (Fig. 50.8a). The trough is approximately 12 mm in depth at the deepest point. An arthroscopic rasp is used to square off the corners of the trough (Fig. 50.8b). Next the remnant meniscus is trimmed back to its peripheral one-third rim. A 3 cm medial incision is made centered between the tibial tubercle and the posteromedial tibia approximately 2 cm distal to the medial joint line. Using an ACL tip guide, a 0.62 mm Kirschner wire is drilled to a position that would correspond to the posterior margin of the anterior root of the lateral meniscus. A second 0.62 mm Kirschner wire is placed at the anterior margin of the posterior root of the lateral meniscus (Fig. 50.9).

Attention is then turned to graft preparation. The meniscal allograft transplant graft is measured to ensure that it matches that measurement of the tibial plateau (Fig. 50.10). The tibial bone block is cut with an oscillating saw to a width of 1 cm while preserving the meniscal root attachments (Fig. 50.11a). The depth is cut to 12 mm to match the tibial trough (Fig. 50.11b). A #5 braided nonabsorbable suture is placed in a mattress fashion through the two drill holes in the tibial spine at the midportion between the anterior and posterior roots. The allograft is marked "TOP" on the superior portion of the graft so that proper orientation can be recognized arthroscopically. A #2 nonabsorbable braided suture is placed in a vertical mattress manner at the junction of the body and posterior horn (Fig. 50.11c).

Next, an anterior arthrotomy is made just lateral to the patellar tendon. Four #0 nonabsorbable braided sutures are placed into the anterior horn of the remnant meniscus. A 5 cm posterolateral arthrotomy is also made just posterior to the lateral collateral ligament (LCL) centered over the joint line and proximal to the fibular head. The interval between the biceps femoris and iliotibial band is developed, and the lateral head of the gastrocnemius is elevated off of the capsule so that a Henning retractor can be easily positioned.

The previously placed Kirschner wires are exchanged for Hewson suture passers. The graft is brought to the front table. The #2 suture through the meniscus graft is passed through the posterior capsule. The #5 suture previously placed through the bone block is passed through

Fig. 50.5 Photograph of lateral meniscus allograft transplantation setup utilizing a pneumatic leg holder

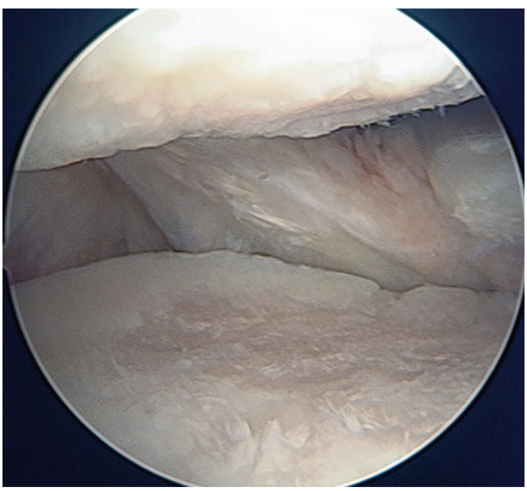

Fig. 50.6 Arthroscopic image of the diagnostic arthroscopy demonstrating meniscal deficiency. The chondral deficit is felt to be located in the meniscal weight-bearing region

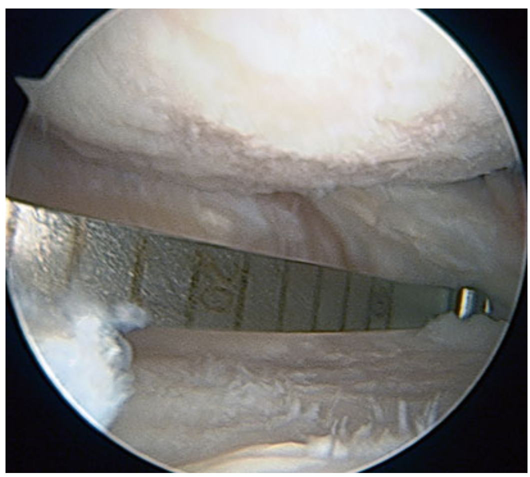

Fig. 50.7 Arthroscopic image measuring the tibial plateau

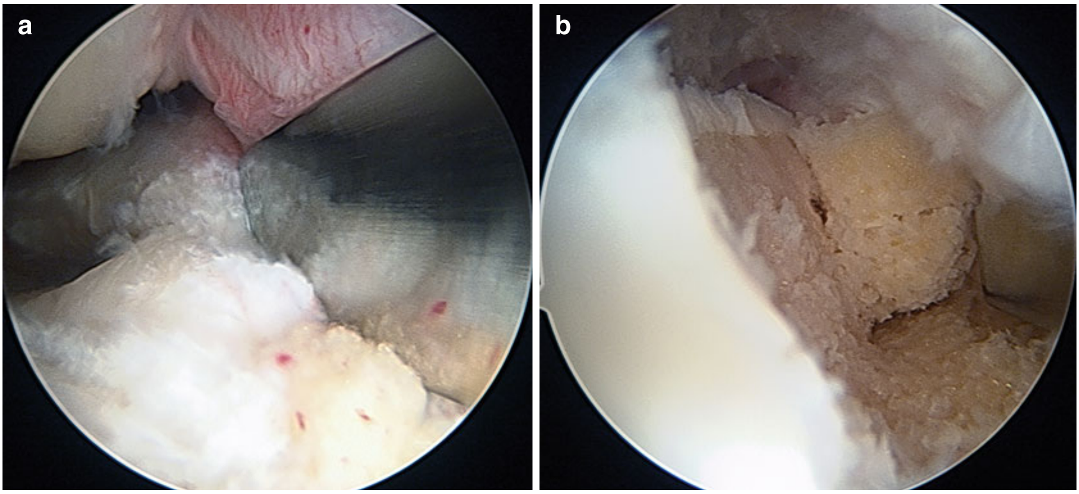

Fig. 50.8 Arthroscopic images of the steps of trough preparation on the lateral tibial plateau, including (**a**) osteotome advanced to define the border of the trough and (**b**) finishing the trough preparation with the final bone removal

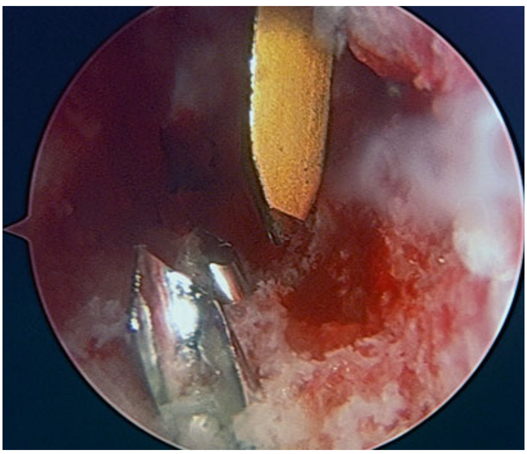

Fig. 50.9 Arthroscopic image demonstrating the position guide pins into the tibial trough for reduction of the mattress suture placed between the meniscal root attachments

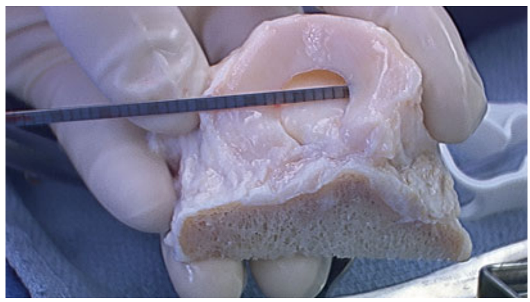

Fig. 50.10 Photograph measuring the lateral meniscus allograft transplant graft

the tunnels in the tibia with the Hewson suture passers but is not secured. As the sutures are tensioned, the bone block and meniscus are reduced into position. After confirming reduction of the meniscus arthroscopically, the bone bridge sutures are tied with the knee flexed at 90°.

The four sutures previously placed into the anterior meniscal remnant are placed through the meniscal allograft in a vertical mattress pattern. Next, with the leg in the figure-4 position, a Henning retractor is placed through the posterolateral incision. Using zone-specific cannulas through the anteromedial portal, six 2-0 nonabsorbable braided sutures are placed in an inside-out manner using a combination of vertical and horizontal mattress patterns (Fig. 50.12). It is important to make sure that the meniscus is balanced. The knee is brought into 45° of flexion and the sutures are tied over the posterior capsule. The knee is then taken through an ROM from 0 to 90° to make sure that the meniscal allograft tracks well with the femoral condyle. The wounds are copiously irrigated and the lateral retinaculum closed with #0 braided absorbable sutures in a figure-of-8 pattern.

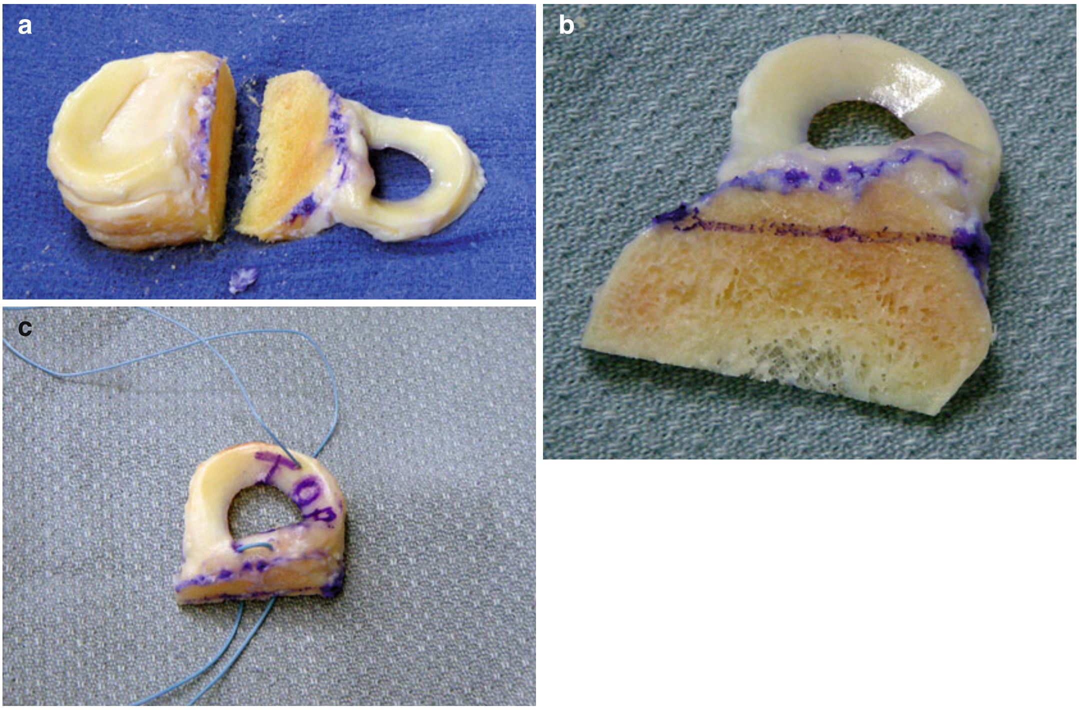

Fig. 50.11 Photograph of steps involved in lateral meniscus allograft transplant graft preparation, including (**a**) sectioning of the graft to a width of 1 cm and preserving the meniscal root attachments, (**b**) cutting the graft bone bridge to a height of 12 mm to match the created trough, and (**c**) placement of a nonabsorbable braided mattress suture between the root attachments and at the junction of the body and posterior horn. The femoral side of the graft has been marked "TOP" to help with arthroscopic placement

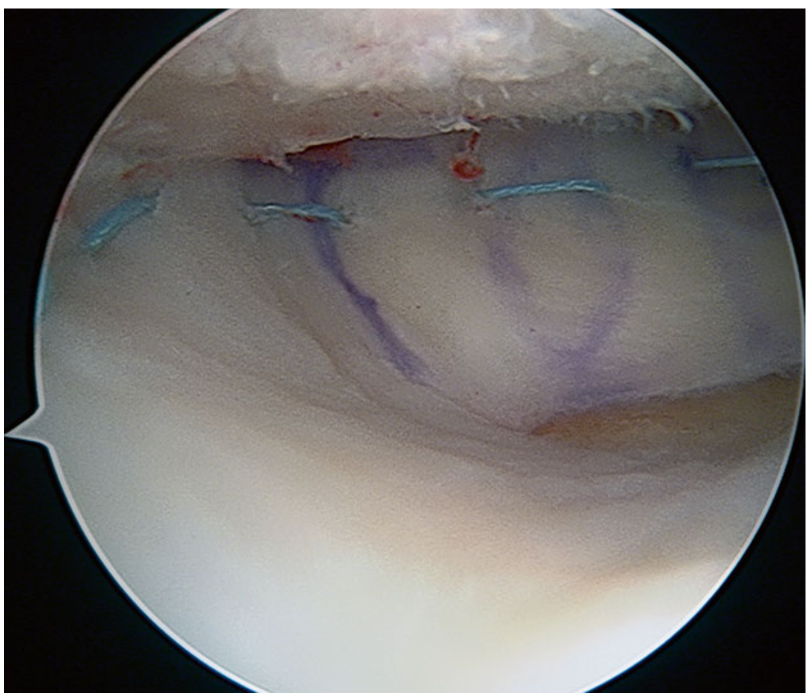

Fig. 50.12 Arthroscopic image demonstrating the placement of inside-out repair sutures

50.5 Postoperative Course and Rehabilitation

Postoperatively, patients are placed on anticoagulation for 2 weeks postoperatively to prevent deep vein thrombosis. Patients are placed into a hinged knee brace locked in extension. The brace remains locked in extension during gait and sleep for the first 6 weeks postoperatively. It is only unlocked for heel slides from 0 to 90° of knee flexion. The brace is discontinued at 8 weeks postoperatively. Patients are allowed to weight bear as tolerated with two crutches for the first 8 weeks postoperatively. No open kinetic chain hamstring exercises, terminal knee extension exercises, or knee flexion past 90° are allowed until 3 months postoperatively. A running program begins at 9 months postoperatively, and complete return to sport after the patient passes functional testing.

50.6 Complications

In addition to the standard risks of surgery, the most pertinent complications of lateral meniscal allograft transplantation include progression of osteoarthritis, tearing of the allograft, infection, and peroneal nerve injury. Patients who return to high-level cutting and pivoting sports or wrestling have the highest risk of tearing the allograft. Unlike many procedures in sports medicine, meniscal allograft transplantation should be viewed as a salvage operation, and patients should be encouraged to change their activities. Sometimes it may be prudent to delay meniscal allograft transplantation until the patient has completed his/her competitive career. In these cases, patients need to be advised they are placing their knee at an increased risk of chondral wear.

50.7 Outcomes

Studying outcomes of meniscal allograft transplantation remains difficult because, presently, there are no randomized controlled trials in the literature. Furthermore, there only exist few studies with long-term follow-up. Midterm outcome studies demonstrate that meniscal allograft transplantation is effective at reducing pain and improving knee function [4, 12, 18, 20, 23, 24]. However, long-term outcome studies demonstrate worsening symptoms and disability [27]. Overall, there is a cumulative graft survival rate of approximately 70 % at 10 years [26]. Risk factors for early failure include limb malalignment, ACL deficiency, and grade IV articular cartilage defects [26]. Further high-quality studies are needed to better predict which patients will benefit the most from meniscal allograft transplantation.

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Arthroscopic Meniscal Allograft Transplantation with Soft Tissue Fixation Through Bone Tunnels

51

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51.1 Introduction

This chapter details the technique for arthroscopic meniscal allograft transplantation with soft tissue fixation without bone plugs. This technique is less complex than bone plug methods; it is less invasive but still provides stable and secure graft fixation.

Firstly the meniscal bed is prepared and the allograft in parachuted into the knee, usually through a silicone cannula, and the meniscal horns are fixed with sutures through bone tunnels. The body of the meniscus is then fixed with a combination of all-inside and inside-out sutures. This technique is reliable and reproducible and has comparable clinical outcomes to bone plug fixation techniques.

51.2 Soft Tissue Versus Bone Plug Fixation Techniques

We prefer the use of soft tissue versus bone plug fixation for the meniscal roots as recent biomechanical studies have found no advantage with the addition of bone plugs [5, 7]. Meniscal transplants secured by soft tissue fixation only have shown histological advantages compared to bone plug fixation grafts. A significantly higher cellular viability and collagen organization were found on biopsy of the grafts secured by soft tissue fixation only [10]. This may be related to a

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_51

higher immunological host response caused by the addition of bone plugs. Creation and passage of bone plugs are challenging, and avoiding this reduces the risk of increased articular cartilage damage if they are malpositioned [6].

Biological healing of the horns and peripheral rim is enabled by the stable and secure fixation [2]. This is supported by a meta-analysis and multiple clinical studies that have shown comparable graft survival and outcomes between the two different fixation techniques [1, 3, 4, 8, 9, 11–18].

51.3 Surgical Technique

51.3.1 Principles

The technique involves dissecting the meniscus off the donor tibial plateau and preparing each end with non-absorbable sutures. The sutures are then led through carefully placed bone tunnels in the prepared meniscal horn insertion sites. The graft is passed into the knee through a working portal and fixed in place with a combination of all-inside devices and inside-out suture loops tied over the capsule. Sutures for the anterior and posterior horns are tied over a bone bridge on the proximal tibia (Fig. 51.1).

51.3.2 The Key Stages

1. Patient positioning
2. Graft preparation
3. Knee arthroscopic evaluation
4. Recipient bed preparation
5. Posterior and anterior horn insertion site preparation
6. Posterior and anterior horn tunnel creation
7. Middle traction suture placement
8. Graft passage
9. Graft fixation
10. Final suture fixation
11. Wound closure
12. Post-operative rehabilitation

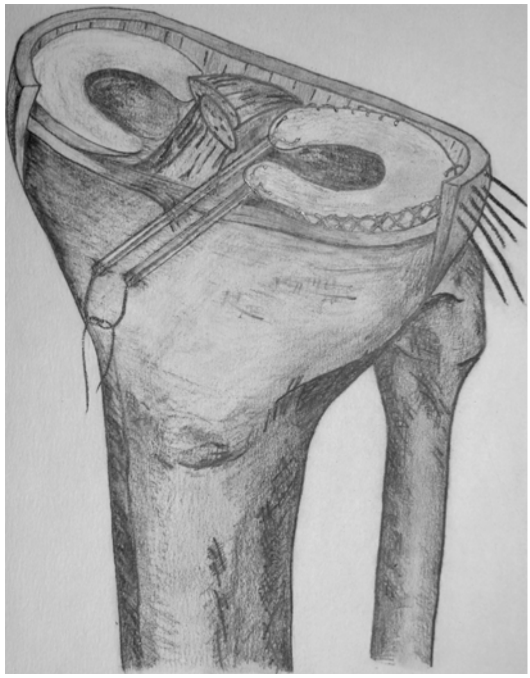

Fig. 51.1 Artistic representation of lateral meniscal allograft transplant

51.3.3 Technique Decision Options

Decisions need to be made for two broad aspects relating to parachuting the graft into the knee and preparing suture tunnels.

Issue 1. Same or contralateral compartment insertion of the graft? The favoured technique is to insert the graft from the contralateral portal while maintaining the arthroscope in the affected compartment. Previous scars or personal preference may dictate insertion from the same side.

Issue 2. Anterior horn suture tunnel preparation before or after insertion of the graft? With a well-sized graft, the favoured technique is to prepare both posterior and anterior horn suture tunnels prior to insertion. However, if there is doubt about adequate graft size, then the anterior horn tunnel can be fashioned later, once the most appropriate position has been chosen, tailored to the graft.

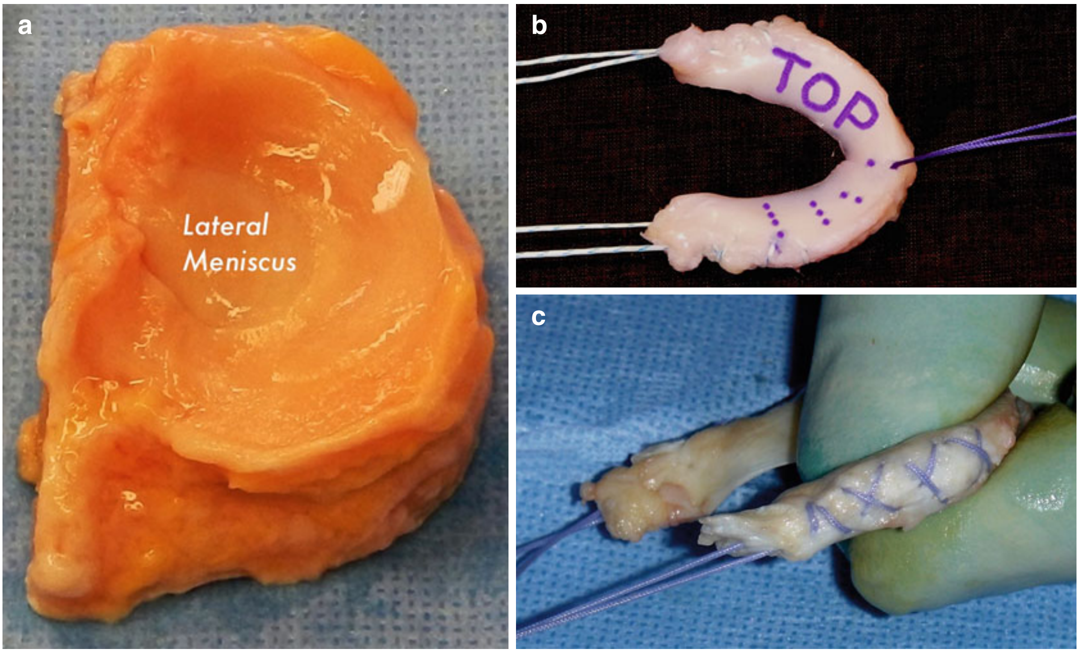

Fig. 51.2 (**a**) Meniscal allograft as supplied by tissue bank. (**b**) Prepared meniscal allograft with meniscal root sutures and middle traction suture. (**c**) Whip stitch preparation, exiting through meniscal root footprint

Stage 1: Patient Positioning Surgery is performed under general or regional anaesthesia with appropriate prophylactic antibiotics. The patient is supine on the operating table with a thigh tourniquet, single thigh side support, and a footrest supporting the knee at 90°. For a lateral meniscal transplant, the knee will be moved to the figure-4 position. For a medial meniscal transplant, the leg will be abducted and rest against the outer hip of the operating surgeon.

Stage 2: Graft Preparation The meniscus allograft is usually supplied as a medial or lateral hemi-plateau with the meniscus attached as shown in Fig. 51.2a. The graft is confirmed to be of the correct side and limb prior to anaesthesia and is thawed to room temperature per the tissue bank-specific instructions (usually about 15 min in warm water or 1 h in room temperature). Preparation prior to the start of surgery or preparation by an assistant during the initial arthroscopy helps minimize tourniquet time.

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. 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 hiatus is also marked and a number 2 non-absorbable suture is placed as an oblique vertical mattress. For the medial meniscus, a similar vertical mattress suture is inserted 40 % of the circumference from posterior to anterior. These sutures represent the middle traction suture (Fig. 51.2b).

The meniscus is sharply dissected off the plateau and excess soft tissue is trimmed from the meniscal horns. Number 2 Ultrabraid (Smith & Nephew, Massachusetts, USA) sutures 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 (Fig. 51.2c). It is important to ensure the sutures emerge on the inferior aspect of the footprint of the meniscal root. The prepared graft (Fig. 51.2b) is then wrapped in a vancomycin-soaked swab (500 mg in 100mls saline), in order to reduce the risk of bacterial infection, and is placed securely on the scrub table awaiting implantation.

Stage 3: Knee Arthroscopic Evaluation The tourniquet is inflated just prior to incision to minimize tourniquet time for the surgery. Longitudinal anteromedial and anterolateral arthroscopy portals are made just next to the patella tendon, allowing for later extension.

Chondral lesions in the affected compartment are treated, noting that the optimal indication for transplantation is chondral surfaces showing changes of ICRS grade 3a or less. Small areas of bare bone (ICRS grade 3b or c) can be treated by the microfracture procedure. Treatment options for larger cartilage defects are dependent on the surgeon's preference.

Stage 4: Recipient Bed Preparation The host meniscus is assessed and prepared by resecting the 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 are rasped using a diamond tip rasp and fenestrated with a microfracture awl to assist with healing and vascularization of the graft (Fig. 51.3a–d).

Stage 5: Posterior and Anterior Horn Insertion Site Preparation The tunnel positions for meniscal root attachment points, as shown in Fig. 51.4, are identified in the knee and prepared using the shaver and punches. A closed-cup curette is used to expose subchondral bone over a 5–6 mm diameter area.

For the medial meniscus:

- Posterior horn insertion is just posterior to the medial tibial spine in a small fossa.
- Anterior horn insertion point is anterior and medial to the insertion of the ACL on the superior surface of the tibial plateau.

For the lateral meniscus:

- Posterior horn insertion is just posterior to the ACL, between the tibial spines.
- Anterior horn insertion is identified anterior to the lateral tibial spine and just lateral to the ACL. Some of the ACL attachment fibres may cover the meniscal insertion and these can be elevated to show the insertion.

Stage 6: Posterior and Anterior Horn Tunnels A 2 cm horizontal skin incision is made on the proximal tibia on the opposite side of the tibia to the meniscus being transplanted. This is the starting point for the bone tunnels. On the medial side, this is just above the hamstring tendon insertion on the bare area of the tibia, and on the lateral side, this is just under the flare of the anterolateral tibia. 1 cm of bare bone is exposed, elevating the tissue and periosteum. The knot of the anterior and posterior horn sutures will later be tied over a bone bridge and buried close to the bone to avoid subcutaneous irritation.

Our preference is to create a working portal on the contralateral side to the affected compartment and view from the affected side, for example, a medial working portal and lateral arthroscopy portal for a lateral meniscal graft. The working portal is created by extending the relevant longitudinal arthroscopy portal to 2 cm, followed by insertion of a silicon cannula (10×20 mm cannula in thin patients or 10×30 mm cannula in larger patients) (Fig. 51.5d)

The meniscal allograft transplantation drill aimer guide is inserted through the working portal and positioned in the posterior horn insertion point (Fig. 51.6). 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 pin, visualizing the tip emerging through the bone. The guide wire is overdrilled with a cannulated Endobutton 4.5 mm drill (Smith & Nephew), leaving the tip carefully positioning just proud of the tibial plateau surface. A closed-cup curette can be used to help protect inadvertent damage to articular surfaces and to help retract meniscal tissue, aiding visualization. The guide wire is removed, leaving the Endobutton drill bit in situ. A loop of 2/0 Prolene is passed through the Endobutton 4.5 mm drill bit on a suture passer and is retrieved through the working portal using a suture manipulator (Fig. 51.5a). The 4.5 mm drill is removed, leaving the suture in situ. The free end of this lead

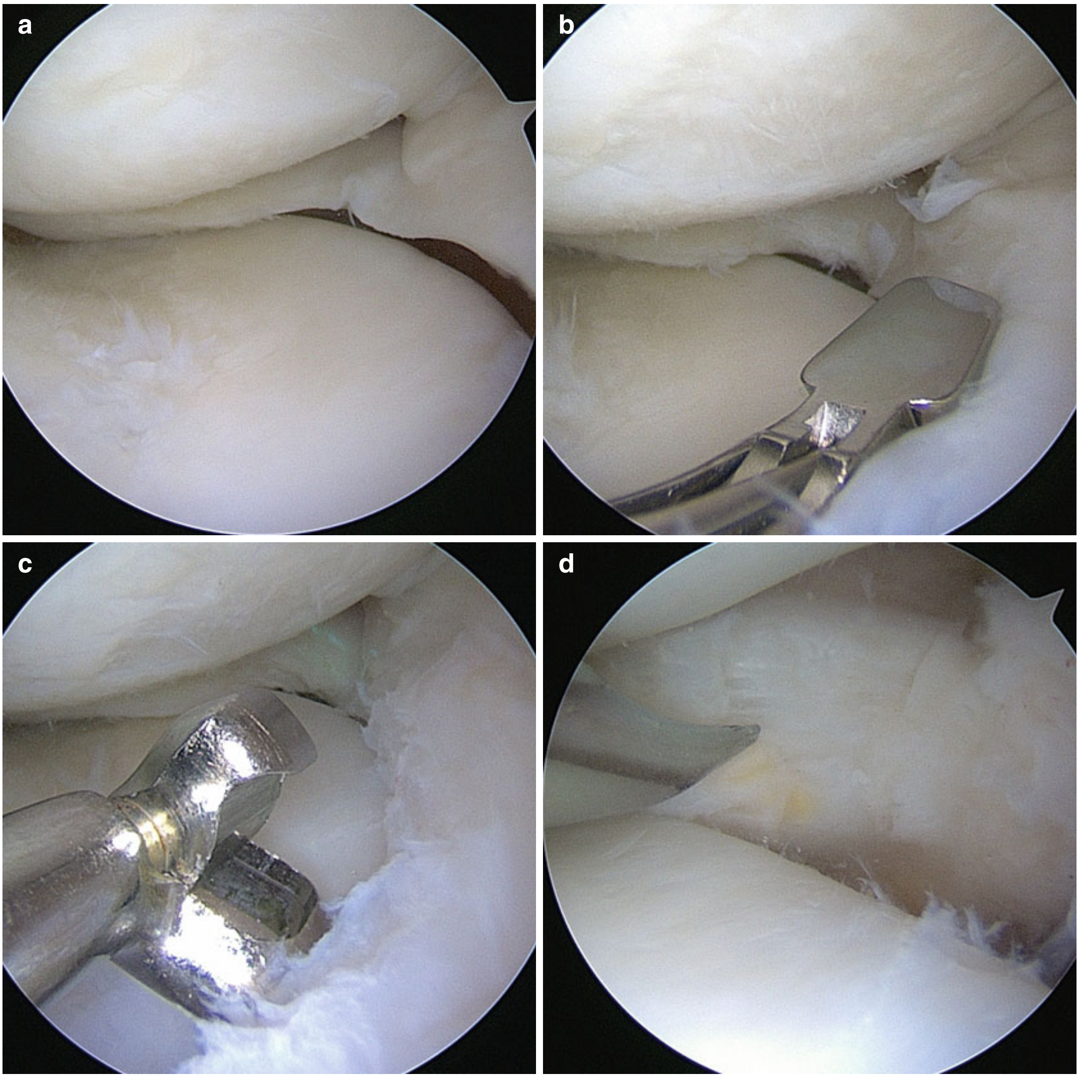

Fig. 51.3 (**a**) Pre-transplant arthroscopic image of an extruded and deficient lateral meniscus after prior meniscectomy. (**b**, **c**) Straight and 90° punches are used to resect residual meniscal tissue to the vascular rim. (**d**) Chondral pick being used to puncture meniscal rim to encourage bleeding and vascular ingrowth

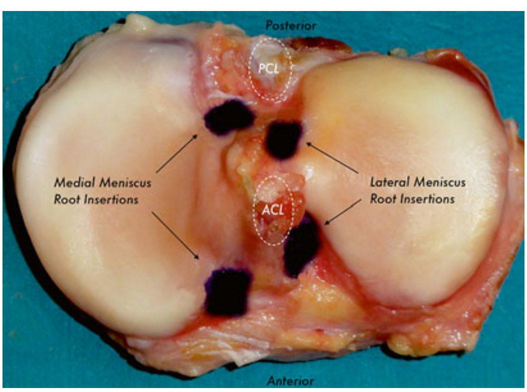

Fig. 51.4 The anatomical insertions of the meniscal roots

suture is then 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 working portal and the tunnel for the anterior horn is drilled in the centre of the attachment footprint with the same sequence of steps (Fig. 51.5b). The suture ends are brought out through the working portal, clipped, and hung to the opposite side of the knee (Fig. 51.5c, d). The suture manipulator is run along the sutures to ensure there is no twisting or inadvertent creation of a soft tissue bridge if a cannula is not being used.

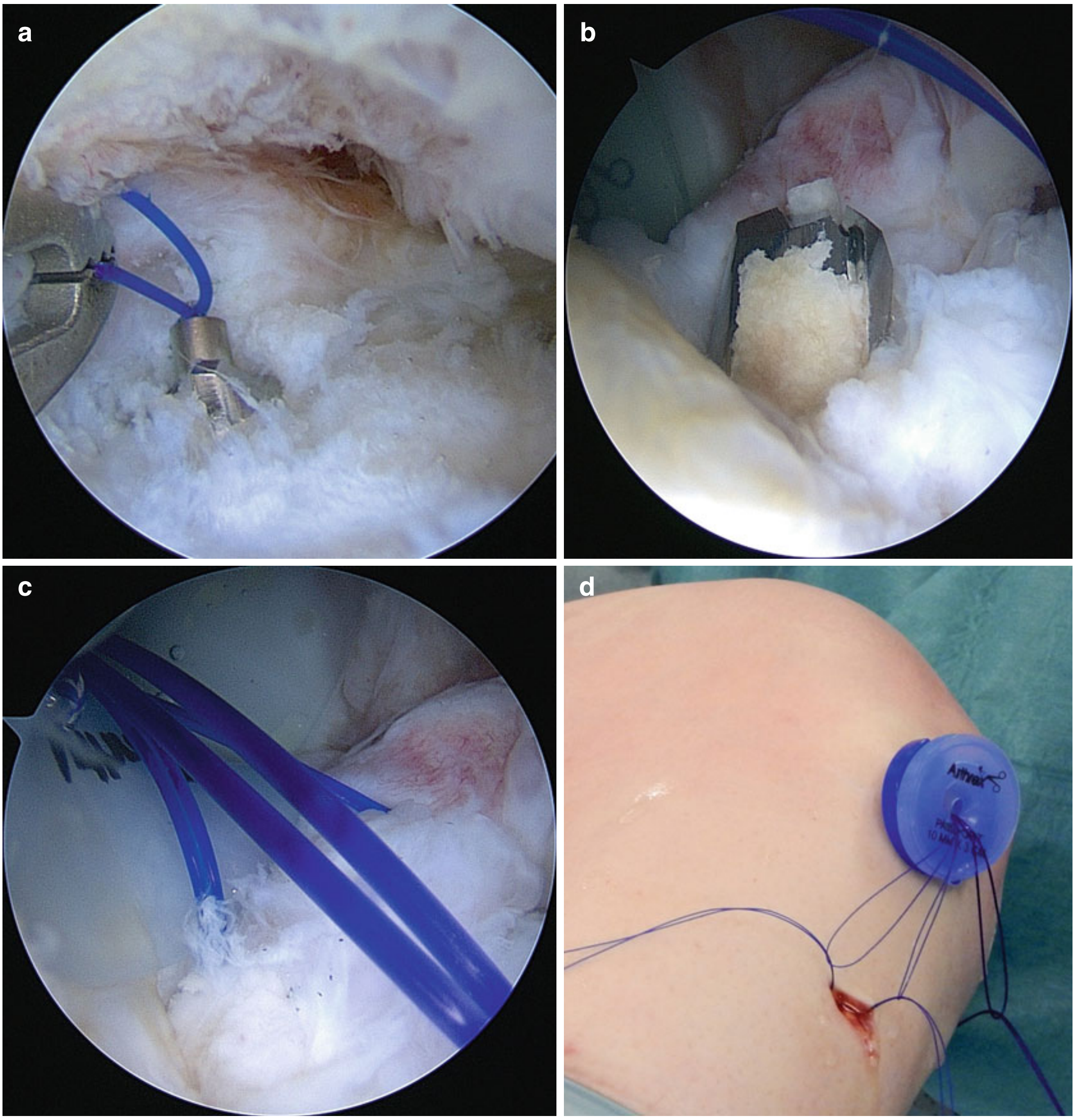

Fig. 51.5 (**a**) Posterior root insertion site for lateral meniscus. Lead suture is passed through the 4.5 mm cannulated drill and retrieved out through the working portal. (**b**) 4.5 mm cannulated drill in position for anterior root insertion site of the lateral meniscus. (**c**) Arthroscopic image of lead sutures passing out through the working portal. (**d**) Photograph of medial working portal with lead sutures for lateral meniscus allograft

Alternative Technique for Anterior Horn Tunnel Preparation If the size of the graft is considered potentially small, then the anterior tunnel can be drilled after insertion of the meniscus in order to allow for the anterior horn to be fixed in the optimal position, avoiding over tensioning and early tearing from the rim. The posterior two thirds of the meniscus are held in position and the anterior horn is drawn towards the anatomical insertion point. The optimal anterior tunnel position is then drilled; the anterior horn sutures are passed through the bone tunnel and tied with the posterior horn sutures over the tibial bone bridge.

Conversely, if the graft is larger than ideal, then the anterior tunnel can be overdrilled to 6 mm and the anterior horn pulled into the tunnel slightly after peripheral fixation.

Stage 7: Middle Traction Suture The next stage is insertion of two loops for the middle traction

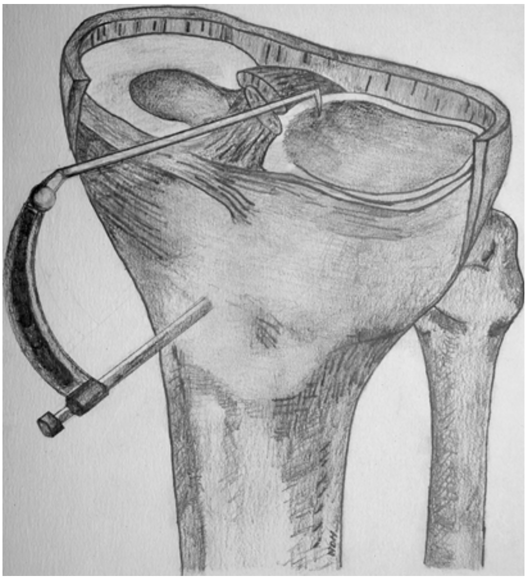

Fig. 51.6 Artistic representation to illustrate aimer guide on the lateral meniscal posterior root insertion site

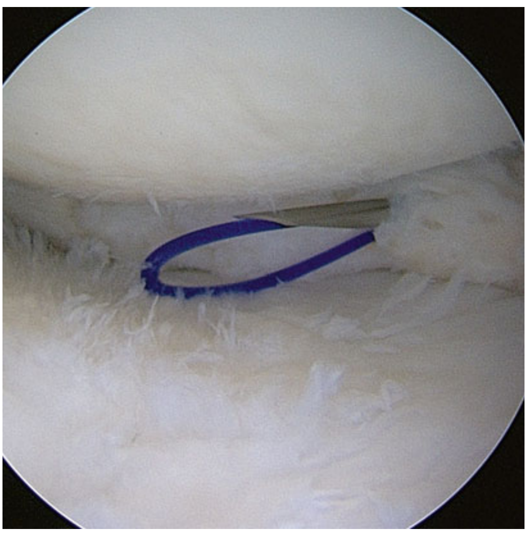

Fig 51.7 Insertion of middle traction suture from outside-in

and fixation suture. An 18-gauge needle is used to localize the correct insertion point (Fig. 51.7). For the lateral meniscus, this point is just anterior to the popliteus tendon. For the medial meniscus, it is 40 % of the meniscal circumference from the posterior horn insertion. An ACCU-PASS suture device (Smith & Nephew)

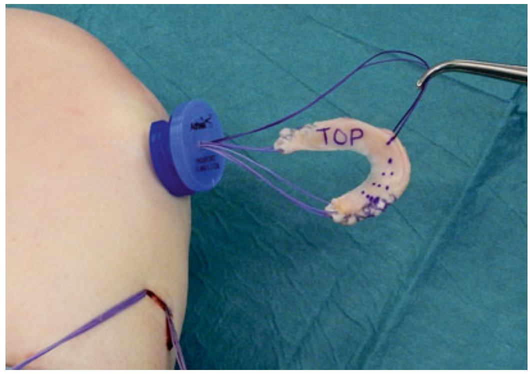

Fig. 51.8 Lateral meniscal allograft positioned for insertion into the knee

preloaded with a loop of No1 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 working portal and clipped to one side, once again checking for twisting with the other suture loops. Care is given to clearly identify the inferior and superior suture loops separately by, for example, clipping the inferior one with a small clip and the superior one with a large clip.

Stage 8: Graft Passage Now that all the passing sutures are in place, the graft can be "parachuted" through the working portal into the knee joint. The assistant holds the graft in the correct orientation adjacent to the working portal (Fig. 51.8). Commencing with the posterior horn sutures and then working anteriorly, all the meniscal sutures are pulled into position using the pre-placed shuttle suture loops. The graft is delivered into the knee through the working portal by pulling on the posterior and middle traction sutures. Sometimes it is necessary to "persuade" the meniscus into position under the femoral condyle using the arthroscopy blunt obturator. Traction is applied to the anterior horn suture, pulling the meniscus into place, and the anterior and posterior horn sutures are 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.

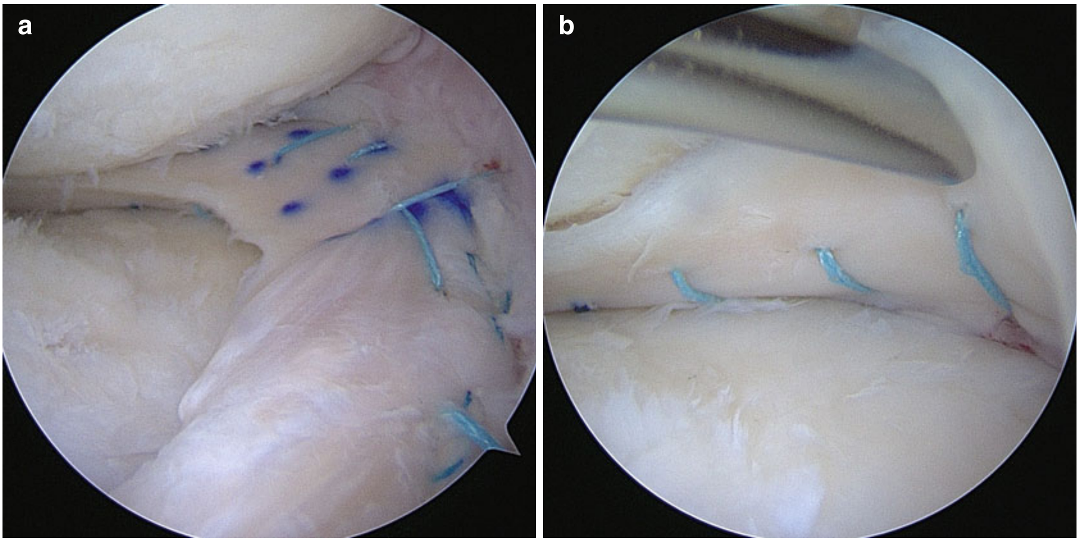

Fig. 51.9 (**a**, **b**) Vertical mattress sutures are placed on superior and inferior surface of meniscal graft

Stage 9: Graft Fixation The graft is fixed using a hybrid technique of all-inside, inside-out, and outside-in suture systems. With the arthroscope initially in the working portal, the first Fast-Fix 360 Meniscal Repair device (Smith & Nephew) is introduced through the ipsilateral compartment portal using a slotted cannula. Holding tension on the middle sutures the posterior third is fixed to the prepared meniscal rim using the Fast-Fix 360 System, inserting sutures on the superior and inferior surfaces in a stacked vertical mattress pattern. Portals can be switched to ensure an adequate fixation angle is achieved. A minimum of four suture devices is recommended, and by joysticking with the needle, the allograft can be optimally placed on the rim.

The middle and anterior thirds of the meniscal graft are secured using an inside-out suture technique with 2/0 Ultrabraid (Smith & Nephew). The sutures are inserted from the working portal in a stacked vertical mattress pattern. A curved inside-out cannula system is used, preferably achieving at least 6–8 loops in the body and anterior third, evenly spread on the superior and inferior surface of the meniscus. Great care must be taken not to invert or evert the meniscus with the final suture configuration (Fig. 51.9a, b).

If there is inadequate suture hold on the anterior 1–2 cm, then outside-in needle suture placement is required, using a needle technique such as the Meniscal Mender suture system (Smith & Nephew).

The inside-out sutures initially emerge directly through the skin. Once the fixation is complete, a 2–3 cm longitudinal skin incision is made between the sutures and a full thickness flap is elevated down to the IT band laterally or the MCL medially, using dissection scissors avoiding damage to the suture threads. With a Langebeck style retractor elevating the skin and subcutaneous tissue, the sutures can be seen and retrieved using an arthroscopic hook (Fig. 51.10).

Stage 10: Final Suture Fixation 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. In general, the capsule sutures are tied first before the anterior and posterior root sutures are tied under strong tension over the bone bridge. This has the effect of pulling the meniscus and capsule into the correct position, helping to minimize radial displacement and extrusion. Figure 51.11a, b illustrates the arthroscopic images before and after meniscal transplantation, showing the tibial plateau coverage provided by the graft.

Stage 11: Wound Closure The capsule in the extended portal used for insertion of the graft is closed with heavy No 1 absorbable suture, and the skin is closed with skin staples or subcuticular sutures. Local anaesthetic infiltration is performed according to personal preferences.

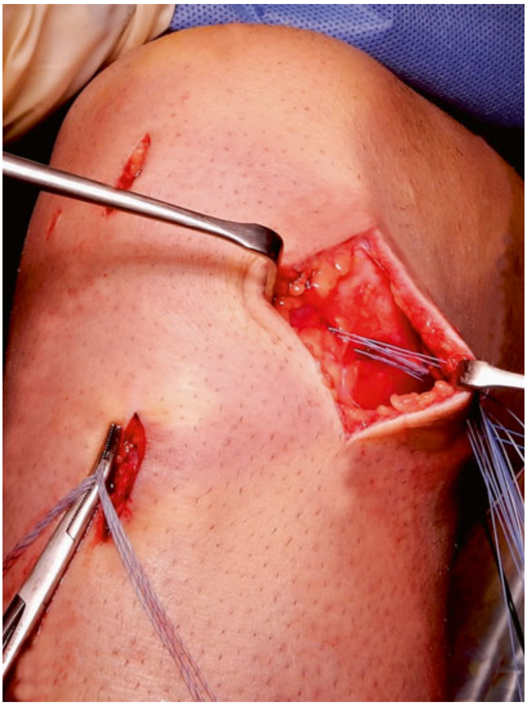

Fig. 51.10 Inside-out sutures are retrieved and tied over the capsule. For illustrative purposes, a larger than normal incision has been made to demonstrate this step

Stage 12: Early Rehabilitation The knee is placed in a range of motion brace post-operatively and weight bearing is limited to touch weight bearing for 6 weeks to minimize the hoop stress placed on the graft. During this initial period, the brace should be locked in extension when walking. Active and passive flexion up to 90° are encouraged when non-weight bearing. From 6 weeks, the brace is removed and full flexion is allowed. Weight bearing is gradually increased from 6 weeks, until full weight bearing with a normal gait is commenced at 8 weeks. Squatting and loading in deep flexion are to be avoided for a minimum of 3 months. Isometric quadriceps, hamstring, and straight-leg raise exercises can commence immediately post-operatively, with closed-chain exercises introduced at 8 weeks.

The rehabilitation is based on a goal-orientated program, with patients progressing on an individual basis once they achieve certain key functional levels. Generally, patients can be ready for normal activities by 9 months. If the patient is keen to get back to sport, a second-look arthroscopy

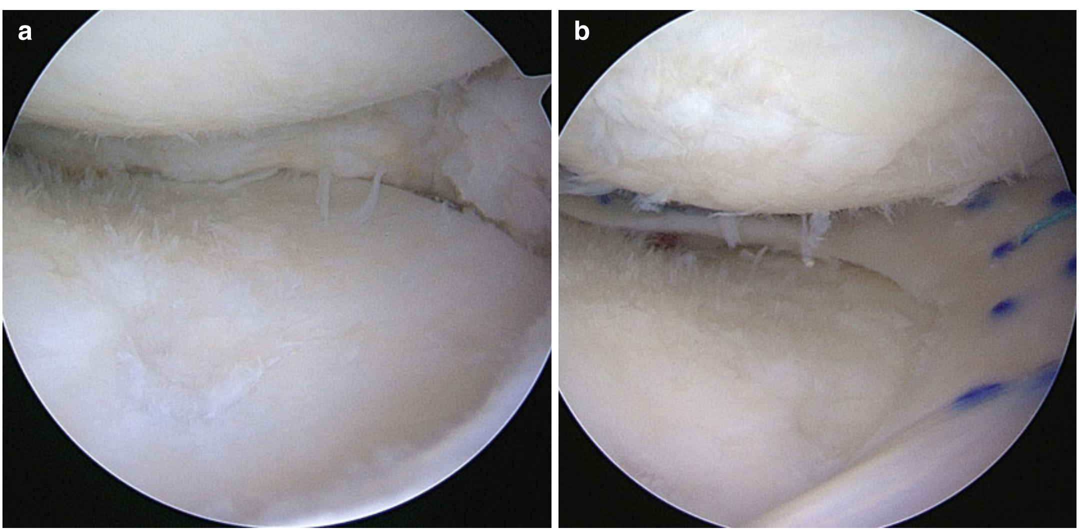

Fig. 51.11 (**a**, **b**) Pre- and post-lateral meniscus transplant

or MRI can be performed to assess the graft and aid in decision making as to whether participation in sports could be commenced. Patients are advised of the risks involved in participating in high-impact and loading sports after a meniscal transplant.

Conclusion

This minimally invasive arthroscopic meniscal transplantation technique has provided secure and stable fixation over the last decade while avoiding the need for the complexity of preparing inserting and fixing grafts with bone plugs. The technique provides an adaptable and reproducible system to accommodate individual graft sizes without compromising the fixation.

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52 Arthroscopic Technique with One Bone Plug: Meniscal Transplantion – How I Do It

E.R.A. van Arkel

Contents

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52.1 Prerequisites

In my opinion, there are some prerequisites when considering a meniscal transplantation:

A. The donor meets the criteria of the American Association of Tissue Banking (standards for tissue banking http://www.aatb.org/AATB-Standards-for-Tissue-Banking). In Europe the minimal standard is defined in the Commission Directive 2006/17/EC: Technical requirements for donation, procurement and testing of human tissues and cells. Off J Eur Union. 8 Feb 2006 and the Guide to the Quality and Safety of Tissues and Cells for Human Application of the European Directorate for the Quality of Medicines & Healthcare (EDQM) 1st edition 2013 (https://www.edqm.eu/en/organ-tissues-cells-transplantation-guides-1607.html). The last guideline involves donor screening, procurement, storage, packing, and distribution.
B. Sizing the appropriate meniscal allograft is done based on long-leg standing X-rays and MRI (Fig. 52.1) combined with the height, weight, and gender of the recipient [6].
C. Long-leg standing X-rays are obtained to measure the mechanical axis. A normal mechanical axis of the knee joint in the coronal plane is advised when considering meniscal transplantation. When varus or valgus malalignment is present, abnormal load transmission will occur on the medial or lateral

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_52

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E-mail: orthopedie@mchaaglanden.nl
Telefoon:
Telefax:

Sticker with data of the patient

Uw referentie:
Onze referentie:
Datum:

Centrum voor Beweging

Orthopedie
Traumatologie

Referentiecentrum
Traumatologie
Knie & Schouder

dr. E.R.A. van Arkel
R.E. van der Flier
P.H.C. den Hollander
S.B. Keizer
J.W.A. Swen
dr. P. van der Zwaal

Dear Madam, Sir,

For the above mentioned patient I would like to order a lateral / medial donor meniscus for transplantation in the right / left knee.

The necessary data are:

Gender:
Length:
Weight:

Measurements on MRI are:

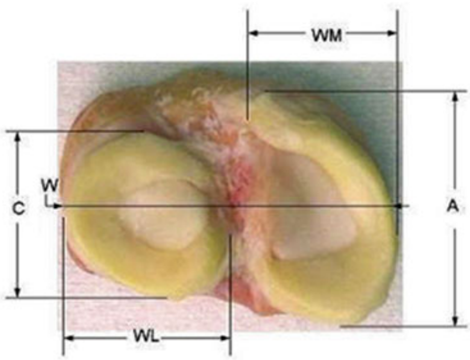
W :

WM :

WL :

A :

C:



Menisci Left w/ Tibial Plateau

Enclosed is a DVD with the radiographs and MRI.

Sincerely,

Dr. E.R.A. van Arkel, orthopedisch chirurg

Postadres:
Postbus 432
2501 CK Den Haag
tel. 070 330 20 58
fax. 070 330 28 39

Bezoekadres:
MCH Westeinde
Lijnbaan 32
Den Haag

MCH Antoniushove
Burg. Banninglaan 1
Leidschendam

D.C. Haaglanden
tel. 070 330 12 00
D.C. Voorschoten
tel. 071 580 55 20

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	Aandachtsgebied:		Aandachtsgebied:
dr. E.R.A. van Arkel	[illegible]	S.B. Keizer	[illegible]
R.E. van der Flier	[illegible]	J.W.A. Swen	[illegible]
P.H.C. den Hollander	[illegible]	dr. P. van der Zwaal	[illegible]

Fig. 52.1 Donor meniscus request form

tibial plateau, respectively. When meniscal transplantation is performed in a knee joint with an abnormal mechanical axis, malalignment is hypothesized to cause abnormal stress on the meniscal allograft resulting in impaired revascularization which might lead to impaired healing of the allograft to the capsule, degeneration, and eventually loosening of the graft. Therefore, a high tibial osteotomy will be performed to correct any abnormal loading stress on the knee that is caused by abnormal mechanical axis in the coronal plane [5, 7].

D. It is well known that in knee joints with ACL deficiency, the menisci are at risk of secondary damage, with the frequency of meniscal tears increasing significantly over time since ACL injury [1, 3]. The clinical success rate for all meniscal repair techniques in stable knees is reasonable, ranging from 70 to 95 %. In unstable knees however, the success rate of meniscal repair decreases significantly, ranging from 30 to 70 %. When meniscal repair is performed in conjunction with an ACL reconstruction, meniscal repair success increases up to 90 % [4].

   Since the menisci are secondary stabilizers, they are at risk in unstable knees. The same has been shown in meniscal transplantation: survival analysis showed a significant negative correlation between rupture of the ACL and successful meniscal transplantation [2, 8]. Therefore meniscal allografts should only be transplanted in stable joints or in conjunction with a reconstruction of the ACL [8].

E. The meniscus transplantation is done under the same strict operative conditions as when performing a joint replacement.

52.2 Preoperative Workup

A detailed history is obtained and a meticulous physical examination is performed. Next, long-leg standing X-rays to evaluate the mechanical axis and an MRI for sizing of the meniscal allograft and for the assessment of the ligaments and cartilage status are made. Evaluation of the video of the last arthroscopy is done to evaluate intra-articular cartilage according to the International Cartilage Repair Society (ICRS) cartilage evaluation package. If this video information is unavailable, or older than 6 months, a diagnostic arthroscopy could be considered.

52.3 Implantation of the Graft

The meniscal allograft is delivered on the donor tibia plateau. On a side table the allograft is thawed in a 0.9 % saline solution under sterile conditions. Next, the meniscal allograft is dissected from the tibial plateau leaving both anterior and posterior meniscal ligaments intact to the donor meniscus. The posterior horn preparation differs from the anterior horn preparation in that it includes a small bony attachment. After preparing the posterior horn including the posterior meniscal ligament from the tibial plateau, a small osteotome is used to detach the ligament with a sliver from the donor tibia plateau, leaving a small bony attachment to the ligament. Thus, the posterior horn connection site consists of the posterior horn and the posterior meniscal ligament attached to a sliver of bone. Next FiberWire sutures 2.0 (Arthrex, Naples, FL) are placed in the meniscus. The first suture is placed through the posterior meniscal ligament including the small bony attachment (Fig. 52.2a), the second suture is placed through the anterior meniscal ligament, and the next two sutures are placed at each one-third from posterior to anterior (Fig. 52.2b).

Standard anesthesia is performed and prophylactic antibiotics conform our hospital protocol for joint replacement is given. Then, the procedure is started with a diagnostic arthroscopy. Next, the recipient compartment where the donor meniscus will be implanted is prepared using a small rasp and small shaver blade abrasing the meniscal rim and removing any small osteophytes of the tibia plateau. Next, an additional posterior portal in the recipient compartment leaves the peripheral rim intact, followed by a small anterolateral or anteromedial arthrotomy.

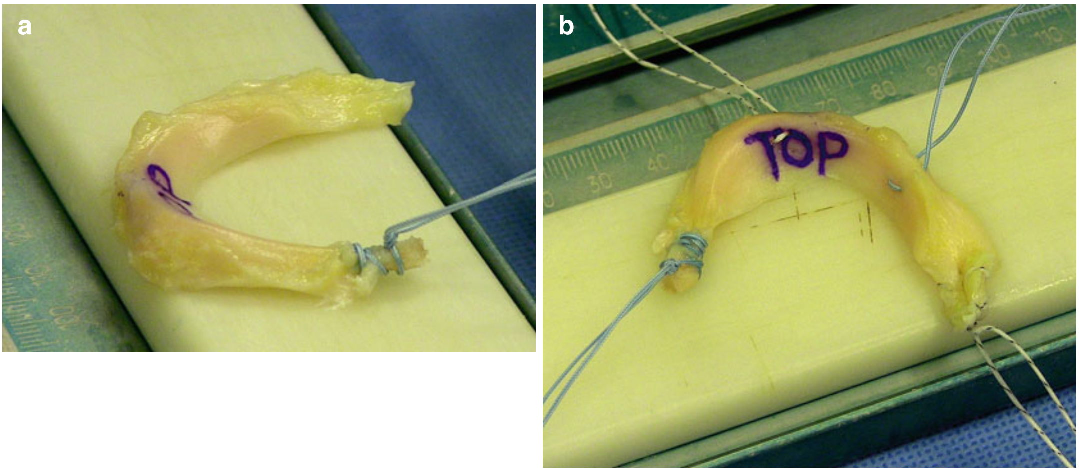

Fig. 52.2 The first suture is placed through the posterior meniscal ligament including the small bony attachment (**a**), the second suture is placed through the anterior meniscal ligament, and the next two sutures are placed at each one-third from posterior to anterior (**b**)

The diameter of the posterior horn attachment (ligament including the small bony attachment) is measured, and a FlipCutter (Arthrex, Naples, FL) with the same diameter is used to create an inside-out socket in the tibia plateau with the depth of the tunnel equal to the length of the ligament including the bony attachment. Through the drill tunnel a passing suture is brought intra-articularly and taken out of the joint through the posterior portal. A second passing suture is attached extra-articularly to the first suture, at the suture end which exits through the posterior portal, and both are pulled through the anterior arthrotomy wound leaving one passing suture through the tibia tunnel and the second suture through the posterior portal. The two posterior sutures of the donor meniscus are fixed to the two passing sutures, and gradually the graft is pulled into the joint in the anatomical position by pulling the posterior ligament into the socket. The posterior horn suture is then fixed over a button anterior to the tibial cortex. The donor meniscus is further tensioned by pulling on the suture through the posterior portal and attached with two or three all-inside meniscal repair systems (FAST-FIX, Smith & Nephew, Memphis, TN) in the posterior donor meniscus. The midportion of the donor meniscus is fixed with two or three inside-out meniscal sutures using meniscal repair needles (Arthrex, Naples, FL). Therefore, the incision of the posterior portal is lengthened by approximately 2 cm and the needles of the inside-out sutures are pulled outside through this portal, with knots placed over the capsule. While knotting the inside-out sutures, the meniscus is held under tension by pulling on the anterior horn. Finally, the anterior horn suture is fixed under tension to the tibia plateau using a self-punching SwiveLock anchor (Arthrex, Naples, FL). After a final arthroscopic inspection of the knee with the donor meniscus in place, both arthrotomy wounds are closed (Fig. 52.3).

52.4 Postoperative Rehabilitation

There is no scientifically proven postoperative rehabilitation protocol. The following is the comprehensive protocol we use at our clinic. For a more detailed description of the rehabilitation program, see www.meniscustransplantatio.nl/nabehandeling.

52.4.1 Week 0–3

Range of movement: 0–60°. Brace: 0–60°. Weight bearing: 25 %. Exercises: isometric quads

Fig. 52.3 Postoperative X-ray; the posterior horn suture is then fixed over a button anterior to the tibial cortex; the anterior horn suture is fixed under tension to the tibia plateau using a self-punching anchor

exercises, patella mobilization, heel glide 0–60°, quads sets 0–60, and stretching Achilles tendon

52.4.2 Week 4–6

Range of movement: 0–90°. Brace: 0–90°. Weight bearing: 50 %. Exercises: isometric quads exercises, patella mobilization, heel glide 0–90°, quads sets 0–90, and stretching Achilles tendon

52.4.3 Week 7–9

Range of movement: 0–120°. Brace: no brace. Weight bearing: 100 %. Exercises: see week 4–6 home trainer and closed chain exercises (leg press, rowing). Lunges and squat 0–90°, proprioceptive training, and dynamic quads training

52.4.4 Week 10–12

Range of movement: free. Brace: no brace. Weight bearing: 100 %. Exercises: see week 4–6 home trainer and closed chain exercises (leg press, rowing). Lunges and squat 0–90°, proprioceptive training, dynamic quads training, and cross-training

52.4.5 Week 13–18

Range of movement: free. Brace: no brace. Weight bearing: 100 %. Exercises: see week 4–6 home trainer and closed chain exercises (leg press, rowing). Lunges and squat 0–120°, proprioceptive training, dynamic quads training, cross-training, and open chain exercises

52.4.6 Week 19–24

See week 13–18 but training will be more intensive.

52.5 Follow-Up

At the preoperative visit, we use the IKDC scoring system, the KOOS and the WOMET score, and the Tegner activity scale. Postoperative evaluation is done at 6 weeks and 3, 6, 9, and 12 months. At the 6-week follow-up visit, we repeat the abovementioned questionnaires and then follow the patients on a yearly basis or when there are complaints. The Tegner activity scale is only used on an annual basis. After 12 months, follow-up is planned on a yearly basis up to 5 years postoperatively.

Conclusion

The most common types of meniscal horn fixation are either a soft tissue or a bone fixation with pros and cons for each one. However, the key fact to succeed is to perform a good preoperative physical inspection with proper radiological examination.

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Meniscal Allograft Transplantation: Results and Indications

53

Nick Smith, Peter Verdonk, Joan Carles Monllau, and Tim Spalding

Contents

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53.1 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 tibio-femoral joint [6, 12, 29]. In the loaded knee, the lateral meniscus transmits 70 % and the medial meniscus 50 % of the load through the respective compartments of the knee [28]. The menisci have also been shown to provide secondary constraint to the knee [15, 16, 18].

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 [22]. The consequences of meniscectomy are now well understood. Biomechanical studies have shown that meniscectomy decreases the tibio-femoral contact area by 50–75 % and increases the peak contact pressure by 200–300 % [3, 20, 40]. 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 [24].

Meniscal allograft transplantation was first performed in the 1970s as part of an osteochondral allograft resurfacing procedure in patients with post-traumatic osteoarthritis following tibial

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_53

plateau fractures [17, 41]. Free meniscal allograft transplantation was performed in 1984 and it has since been advocated for the treatment of patients with a symptomatic knee following a meniscectomy [21]. 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 and, secondly, the published clinical outcome results and data on the chondroprotective effect to support the advised indications.

53.2 Indications

The primary indication for meniscal allograft transplantation is a patient with a symptomatic knee and a history of meniscectomy in the 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 [32]. It is generally agreed that alignment and stability of the knee should be normal or corrected at the time of surgery [32]. 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 [32]. 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 [35]. 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 didn't fail were similar in both groups [11].

53.3 Patient-Reported Outcomes

Virtually all case series evaluating meniscal allograft transplantation reported in the literature show an improvement in PROMs at latest follow-up [32, 39]. The Lysholm score [36] has been the most commonly used PROM to evaluate the outcome following meniscal allograft transplantation [32]. 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 [32]. 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 [36] 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 [26, 39]. 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) [37]. 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].

53.4 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 [32]. One study specifically analysed whether return to sporting activities resulted in increased complications or failure, finding no correlation [34]. 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 [27].

53.5 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 [33]. 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 [25, 30].

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 [33]. A few studies have reported changes in articular cartilage on MRI scans following meniscal allograft transplantation [33]. 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 [38].

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 were unable to draw conclusions due to the variability of reporting within these studies [23]. Another systematic review reported that in studies reporting absolute extrusion, the mean extrusion was between 1.7 and 5.8 mm [33]. 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 [33]. 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]; 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.

53.6 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 [26, 32]. A recent large case series of 172 meniscal allograft transplantations reported a reoperation rate of 32 %, which may reflect a more accurate complication rate [19]. 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 [32]. A recent large case series reported a 95 % survival at a mean of 5 years [19]. 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 [39]. 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 [37].

53.7 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 [20]. 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 [31]. 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

- Free 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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Synthesis

54

R. Verdonk

Contents

54.1 Introduction

Based on the current knowledge of the biology and biomechanics of the human meniscus, two areas of active research and growing knowledge can be identified: the meniscus itself and its anchorage to the bone. To date, first no consensus exists among clinicians whether the use of a viable, deep-frozen, or cryopreserved allograft results in a better clinical and biological outcome and second whether the fixation should be with bone blocks or only soft tissue.

This illustrates the lack of supporting scientific evidence in favor of one or the other. Despite this black hole in our current knowledge, a better understanding of the biology of the meniscus and its influence on the overall homeostasis of the knee joint is of utmost importance to further develop one of the aforementioned options for substitution.

What have we learned from meniscus substitution using natural tissues? From the extensive literature it appears that the meniscus allograft is currently accepted as the gold standard in the treatment of a younger patient who has undergone (subtotal) meniscectomy remaining painful at 6 m po.

Carl Wirth and Gabriela von Lewinski investigated the basic science in meniscal transplantation. The interest taken by their German group in meniscal transplants was fueled by clinical needs.

The concept of the meniscus also being a stabilizing structure in the knee joint is not new, but they were the first to consider the meniscus as a primary stabilizer after knee ligament injury and repair. Simply removing the meniscus had proven deleterious to the long-term results after ligament repair.

In animal experiments, the authors were able to show healing after meniscal allograft implantation.

Also in human clinical studies, satisfactory healing occurred at the meniscosynovial junction, but whether this was also true for the meniscal horns remained a controversial issue. Horn fixation is being mandatory for true hoop stress protection.

Nowadays, no clear consensus is available on whether bony fixation of meniscal allografts is essential for normal homeostasis. In most instances indeed the meniscal allograft is positioned inside the original meniscal "hoop" of the

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donor knee, thus allowing for original horn fixation to be functional.

And choosing meniscal allograft tissue as a replacement tissue, although of limited availability, is a logical option.

54.2 Procurement and Preservation of Meniscal Allograft

Various methods can be used to preserve fresh meniscal allografts.

Divergent results have been obtained with cryopreservation. Short-term storage does not appear to affect the morphological appearance or biochemical characteristics of the menisci.

However, biosynthetic activities are diminished to less than 50 % of normal control values and only 10 % of meniscal cells present metabolic activity.

Excellent fixation of the meniscal body is also obtained with gamma-sterilized, lyophilized meniscal allografts, but the fine architecture of the meniscus is totally disrupted and the tissue is nonviable.

Solvent-dried menisci show a fairly normal collagen bundle structure but are also nonviable.

Because of the successes achieved by Zukor et al. in the transplantation of fresh allografts, we have opted for a viable meniscal alternative, i.e., meniscal culture.

Donor menisci are removed in the operating room under strict aseptic conditions, mainly in conjunction with the procurement of other organs [heart-beating (multiple organ donors) or non-heart-beating donors]. Cold ischemia must not exceed 12 h. During this period meniscal viability remains intact.

The macroscopically intact specimens are removed for clinical use.

Both menisci of each knee are removed with a small synovial rim for manipulation. The meniscus itself is treated in a strictly atraumatic fashion.

The menisci are placed in a culture medium immediately after harvesting. The medium consists of Dulbecco's modified Eagle's medium (DMEM) with 0.002 ml glutamine, 1/1000 antibiotic-antimycotic suspension (streptomycin 10 mg/ml, penicillin 10 U/ml, Fungizone 0.025 mg/ml), and 20 % of the recipients' serum.

The menisci are stored in a plastic container (DANCON, Teknunc-4000 Roskilde, Denmark); 70 ml of incubation medium is added. The containers are placed in a modular incubation chamber (Flow Laboratories – Del Mar, CA, USA) at a constant temperature of 37 °C and under continuous air flow (95 % air and 5 % CO_2).

Humidity is controlled by placing an open receptacle filled with sterile water in the incubation chamber. The incubation media are replaced every 3 days.

After 14 days usually, surgery can be performed since transmissible diseases have been excluded through the tissue bank investigation.

Nowadays deep-freezing appears to be the most accepted method of preservation as standards of procurement have been well established. Tissue banking and storage are thus allowed facilitating surgical planning and organization.

When harvesting has been done in an unsterile fashion, the issue of sterility requires appropriate attention and management. Avoiding irradiation as such is essential in order not to be detrimental to meniscal structure and thus good postoperative function.

However, national laws and regulations can interfere with good clinical practice on grounds of legal constraints based on earlier infringements and exposures.

In this and in the future, it should be possible to follow the rules established for *ORGAN* transplantation and put them into practice for tissue transplantation. Eurotransplant in Europe is a very well-functioning organization keeping track of viable organs (donors) and recipients to match accordingly in a strict time schedule and with optimal results. This approach should be attained for tissues on a European basis increasing clinical application and thus limiting recipients' waiting time, and donor availability would increase.

54.3 Surgical Technique

Meniscal transplant surgery, as it started in the 1990s, required an open approach because at that time arthroscopic meniscal fixation devices were limited and not really appropriate. Additionally, in the early beginning, meniscal transplantation was very often associated with other repair surgeries (mostly ligamentous).

It is only because meniscal surgery and repair indications experience has increased that arthroscopic transplantation has been initiated.

Without bone plug fixation the technique becomes an arthroscopic soft-tissue procedure, with improved fixation and stabilization devices as applied routinely in meniscal repair procedures.

With growing surgical expertise and better visualization of anatomic positioning of both the anterior and posterior meniscal horns, bone plug fixation has become technically less challenging.

Earlier literature could not clarify whether one or the other technique is superior in terms of results.

The study of meniscal extrusion retains differences between medial and lateral menisci/compartments.

Normal menisci in healthy individuals do not present with extrusion on MRI AP images in a supine fashion. When showing signs of incipient degeneration, the medial meniscus is extruding less than in the lateral compartment. The lateral meniscus shows frank extrusion when the popliteus hiatus is ruptured. Thus, as a rule, when transplanting medial meniscal allografts, most often within the existing anterior and posterior horns of the recipients, meniscus fixation with bone *tunnels* is appropriate. This approach is less prone to malpositioning and thus loss of function of the transplant.

Investigations have shown less extrusion with bone *tunnel* fixation vs bone *block* fixation. Overall lateral meniscal allograft transplantation is performed more often as the popliteal hiatus is the weak link, and when ruptured, it equals total meniscectomy status.

Conclusion

When confronted with chronic painful (>6 m) total or near total meniscectomy, meniscal allograft transplantation is a well-documented option. The more so in the lateral compartment. In the medial compartment other standard alternatives are available such as optimizing axial alignment leading to standard good clinical results.

In usual practice, sterile procurement of the allografts from donors is the rule. Preservation techniques use deep-freezing for banking and storage. Cryopreservation can also be used but is somehow more complex and more expensive.

If procured in a non-sterile fashion, then irradiation is required but highly detrimental to the mechanical meniscal structures impacting on results.

These techniques to preserve the knee weight-bearing cartilage and leading toe long-term good results are only indicated when alignment is correct (or corrected) and the knee is stable (or stabilized) with almost pristine (<gr 3) cartilage to begin with.

Part X

Meniscal Reconstruction: Substitutes

55 Collagen Meniscus Implant: Basic Science, Technique and Results

Pedro Hinarejos, Cristoph Erggelet, and Joan Carles Monllau

Contents

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55.1 Introduction

Menisci are fibrocartilage structures situated in the knee joint between the femoral and tibial condyles. They are made up of collagen fibres, mostly type I, that form a tridimensional net structure combining radial and circumferential fibres, and some cells are inside this net. They have the ability to synthesize the extracellular matrix. The meniscus has multiple functions. It contributes to the nutrition and lubrication of the joint structures, has some role in proprioception, assists in the joint stabilization and is very important for shock absorption and force transmission during weight-bearing [16]. The circumferential fibres resist hoop stresses, while the radial fibres handle shear stresses [17]. All these significant functions explain the importance of the menisci in protecting joint cartilage.

The number of meniscus-related surgeries rises in Western countries every year due to ageing and having a more active population [39]. The total number of meniscal surgeries is estimated to be about 1 million annually in the USA and 400,000 in Europe [38]. Most meniscal lesions affect the white-on-white zone of the meniscus, making them unsuitable for meniscal suturing. These lesions must be treated by partial or subtotal meniscectomy.

Although most of the patients treated for a meniscal lesion with meniscectomy experience pain relief and functional improvement, there is an increase in contact stresses on the tibial plateau [26], which is

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_55

proportional to the amount of removed meniscal tissue [1, 19, 37]. The radiographic signs of joint degeneration after meniscectomy (joint line narrowing and flattened femoral condyles) as well as its long-term adverse effects have been widely recognized since the last century [5]. After meniscectomy, some patients complain of pain in the affected joint line. Hede et al. [13] found that 14 % of the meniscectomized patients have fair to poor Lysholm scores at 7.8 years after surgery. Therefore, surgeons should attempt meniscal repair whenever feasible and resect as little meniscal tissue as possible in irreparable meniscal tears [2]. Over the last decade, the concept of meniscal substitution, either with meniscal allografts or with meniscal implants, has been developed. It has been further refined in an effort to preserve the meniscal's functions in symptomatic postmeniscectomized knees. The aim of this chapter is to review the current concepts and results of the Collagen Meniscus Implant (CMI), the first meniscal implant developed and used.

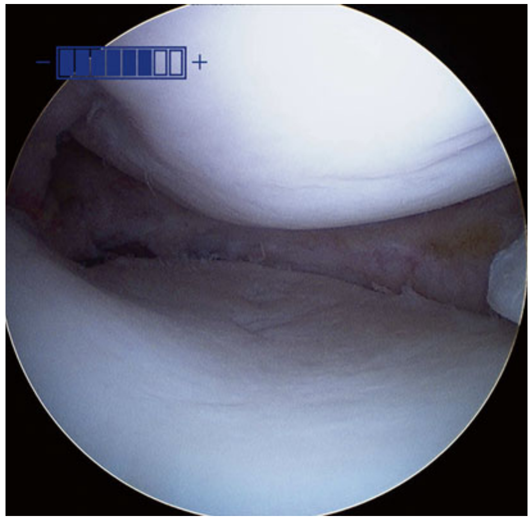

Fig. 55.1 Arthroscopic view of the medial compartment of the right knee. A meniscal defect extending to the red-red zone with the margins trimmed square can be seen

55.2 Basic Science

55.2.1 Development of the Collagen Meniscus Implant (CMI)

Although allografts used for meniscal substitution have shown good early results [17], information about the long-term effects of this procedure and particularly its protective effect on cartilage is scarce [7, 32]. The accepted indication for meniscal allografts is a complete absence of the meniscus. Therefore, a partial defect is not an appropriate indication for this type of surgery. Furthermore, the limited availability of meniscal allografts and potential infectious disease transmission has motivated some authors to explore the possibilities of scaffold-guided meniscal tissue regeneration.

The CMI (Ivy Sports Medicine, Gräfelfing, Germany) was developed by ReGen Biologics (Hackensack, New Jersey, EEUU). It is a highly porous scaffold (not a prosthetic device) made up of type I collagen fibres from purified bovine Achilles tendon. The tendon tissue is minced, and the collagen fibres are purified by using various chemical treatments to remove non-collagenous proteins and lipids. Next, the purified collagen fibres are placed in hyaluronic acid and chondroitin sulphate to well and then homogenized. The swollen collagen fibres plus the glycosaminoglycans are co-precipitated with the addition of ammonium hydroxide. The precipitated fibres are dehydrated, manually oriented in a mould, lyophilized and chemically cross-linked. Finally, terminal sterilization is performed with gamma-irradiation [35].

The scaffold is 7.5 cm long and 1 cm wide, which is quite close to the anatomical shape and size of the human menisci, and has a density of 0.20 g/cm^3. The implant is designed to be trimmed and adapted to the meniscal defect during surgery. Based on previous experimental studies, its porosity was planned to favour filling in by host cells [18]. The CMI has no cytotoxicity, pyrogenicity or carcinogenicity. In addition, the product is bioresorbable, and most of the scaffold has been proven to be resorbed over a 12–18-month period [26] (Figs. 55.1 and 55.2).

The medial CMI has been available for use in Europe since the beginning of this century. However, the Food and Drug Administration has

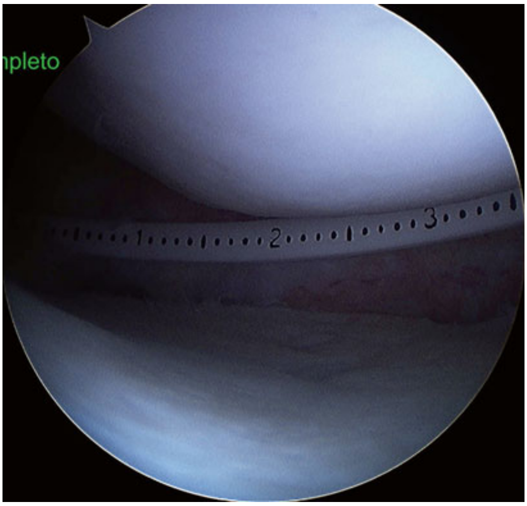

Fig. 55.2 Measurement of the meniscal defect using a graduated Teflon rod

not again granted permission for use in the USA. This was after a short-term approval period in December 2008 and a posterior rescission in October 2010 [16]. More recently, in 2006, the lateral CMI received the CE mark.

55.2.2 CMI Animal Studies

The CMI was first attempted in immature pigs and mature dogs to replace defects caused by meniscectomy. The results demonstrated that the collagen-based scaffold is compatible with meniscal fibrochondrocytes, which are able to grow both in vitro and in vivo, promoting meniscal regeneration in an immature pig. It may also induce regeneration greater than 60 % of the meniscus tissue defect in a mature dog model [35]. Similar results were later found in canine models, with collagen scaffold integration and active angiogenesis in most of the cases [10]. CMI does not cause articular cartilage damage in animal experimentation, unlike other experimental polymer implants [9].

Some animal investigations have suggested that collagen scaffolds could be seeded with cells [15, 25]. In a study done on Merino sheep, the scaffolds seeded with fibrochondrocytes prevented the invasion of the scaffold by inflammatory and reparatory cells, which led to larger and better vascularized menisci with improved biomechanical properties [21]. Furthermore, the seeded collagen scaffolds promoted the generation of meniscal tissue even in experimental lesions created in the white-white zone of the meniscus [27]. Recently, a technique of seeding collagen scaffolds with human bone marrow stem cells has been described [28].

Table 55.1 Contraindications to CMI

Allergies to collagen
Allergies to bovine products
Inflammatory arthritis
Degenerative changes on X-ray greater than Ahlback grade I
Full-thickness chondral lesions (Outerbridge grade IV)
Osteonecrosis in the knee
Obesity
Posterior cruciate ligament insufficiency
Aged patients (older than 50–55 years)
Acute meniscal lesion suitable for meniscal suture
Small meniscal lesions leading to <25 % of the meniscal tissue loss
Malalignment of the lower limb assessed with the weight-bearing axis (unless it is corrected concomitantly with an osteotomy)
Anterior cruciate ligament insufficiency (unless it is treated when the CMI is implanted)
Systemic or local infection
Pregnancy

55.3 CMI Surgical Technique

The indications for CMI are irreparable meniscal tears leading to a meniscal tissue loss greater than 25 % in cases with intact anterior and posterior horn attachments as well as an intact meniscal rim over the entire circumference of the involved meniscus [43].

Contraindications to the use of CMI are shown in Table 55.1.

55.3.1 Medial CMI Technique

The patient is positioned supine on the surgical table. The affected limb is placed with the knee flexed at 90° and the thigh well beyond the table hinge. This position provides access to the posteromedial corner of the knee, which can be useful in the subsequent suturing procedure. The authors use a lateral post placed some 5–10 cm proximal to the patella and apply a valgus load to open up the medial compartment. The use of a tourniquet is optional although recommended if an inside-out suture technique is used [24].

Standard knee arthroscopy anterolateral and anteromedial portals are established to perform a thorough joint exploration. Accessory portals may be used to obtain a better access for the suturing procedure. In acute cases, meniscal suture repair should be done whenever possible. If it is not possible and/or in chronic cases, the damaged meniscus is debrided until healthy tissue is reached. For that purpose, a combination of straight and angled basket punches as well as a 4.0 mm motorized shaver is useful. Since the objective is to obtain a press-fit meniscus implant, the anterior and posterior horns should be squared off to adjust the CMI with maximum congruence.

When the medial compartment is too tight, a partial release of the medial collateral ligament permits both proper visualization and good access to the most posterior aspect of the compartment. This can easily be done with multiple outside-in needle punctures while applying valgus stress (pie-crusting technique).

The prepared site should extend into the vascular zone of the meniscus to guarantee an adequate blood supply. If the outer limit of the prepared meniscal rim is in the red-white zone, this can be accomplished by making puncture holes in the meniscal rim from the inside with a microfracture awl or with an 18-gauge spinal needle from outside the joint. However, since this technique may impair the collagen network in the remnant meniscus, an alternative method is high-frequency trephination. High-frequency trephination uses radiofrequency to create an area of synovial necrosis (approximately 30 μ) adjacent to the implant that is promptly substituted by a newly formed and more vascular synovial layer at the periphery of the scaffold [24].

After preparation of the anterior and posterior horns and the rim, the length of the meniscal defect is carefully measured using a special

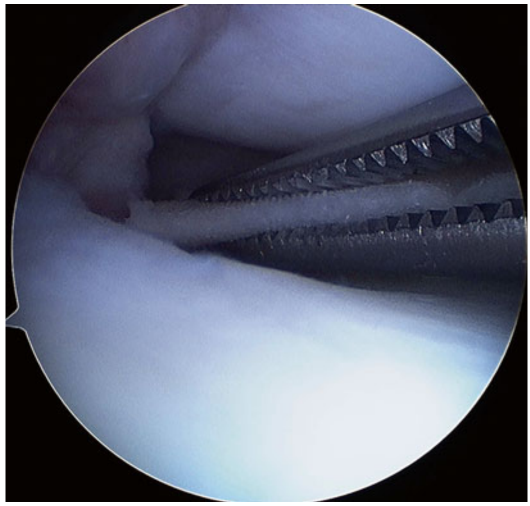

Fig. 55.3 Dry insertion of a medial CMI® using a vascular clamp

Teflon ruler. The anteromedial portal should be enlarged up to 2 cm using a vertical cut in order to facilitate the delivery of the implant.

The CMI is trimmed to the appropriate size, oversized by 10 %, to achieve a perfect press fit in the meniscal defect. The average length of the required implant ranged from 36 to 48 mm in several previous studies [4, 23, 43]. Although previous rehydration and insertion into a specific delivery cannula was advised in the past, the tailored implant can be simply mounted on a curved vascular clamp and directly inserted into the joint after stopping the inflow to avoid the flip-out of the CMI into the joint (dry insertion) (Fig. 55.3).

When the CMI is in place, it is sutured to the host meniscus remnant with 2.0 nonabsorbable sutures by using an inside-out technique or all-inside sutures. If an inside-out technique is chosen, the sutures are retrieved through a 4 cm long posterior-medial approach made parallel to the posterior margin of the medial collateral ligament. A spoon retractor is placed as deeply as possible between the posterior capsule and the medial gastrocnemius to retrieve the needles. For this purpose, an inside-out suture repair system equipped with zone-specific cannulas, like the SharpShooter® Tissue Repair System (ReGen Biologics, 545 Penobscot Drive, Redwood City, CA), is convenient. The CMI is sutured to the remaining meniscus rim with

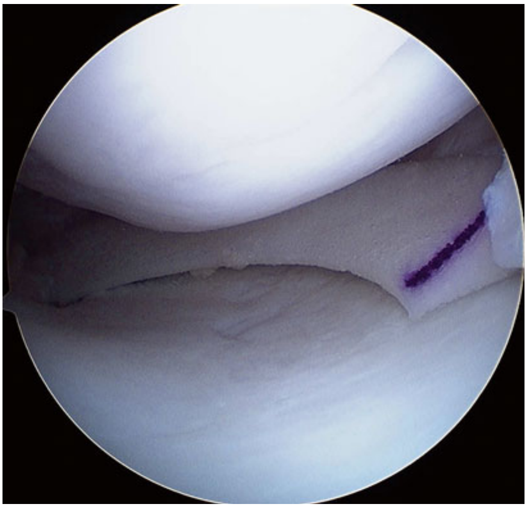

Fig. 55.4 CMI® in place ready for fixation. Note the good press fit achieved at both ends

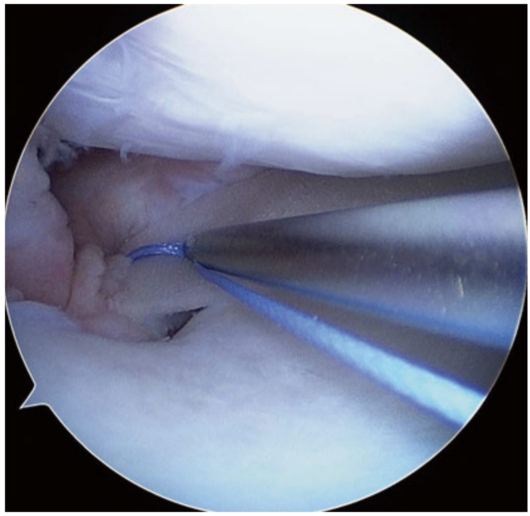

Fig. 55.5 Suturing the implant to the remnants of the posterior meniscal horn using a horizontal stitch

2.0 braided polyester vertical mattress sutures placed approximately 5 mm apart. The anterior and posterior ends of the implant are secured to the meniscal horns with horizontal sutures. All the suture ends are knotted over the capsule outside the joint. Alternatively, all-inside sutures, like the FasT-Fix® Suture System (Smith & Nephew, Inc., Andover, MA), can also be used. They are faster and avoid the need for any additional approach to retrieve sutures. Regardless the suturing technique, vertical mattress sutures are preferred to minimize the risk of implant damage. However, horizontal sutures are chosen for the anterior and posterior fixation points. It is likely that a distance of 10 mm between sutures is adequate to properly fix the CMI when using all-inside sutures [22] (Figs. 55.4, 55.5 and 55.6).

No drains should be placed in the knee joint after surgery, particularly if an isolated meniscus procedure has been performed, as postoperative hemarthrosis might create an appropriate biological environment to start the healing process of the CMI [24].

55.3.2 Lateral CMI Technique

The basic sequence of steps for repairing the lateral CMI is similar to that for the medial one. The suitability of the procedure should be carefully

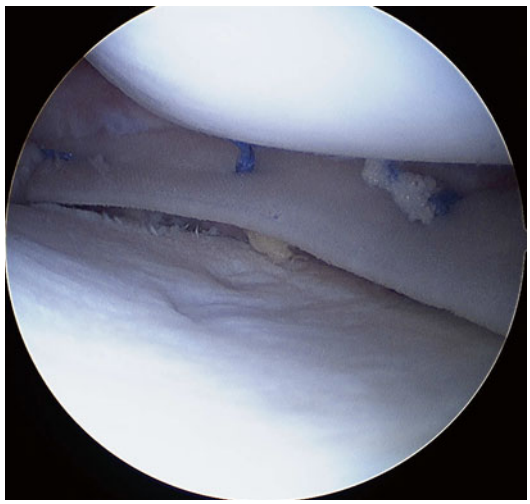

Fig. 55.6 Fixation completed using a combination of vertical mattress sutures placed every approximately 10 mm along the implant and horizontal sutures at the horns

considered if there is complete disruption of the meniscal rim at the popliteal hiatus. When no rim is present, the newly formed meniscus tends to extrude under loading conditions. In addition, the use of sutures across the popliteus tendon cannot be recommended in the case of substitution because the physiological micro motion of this tendon might damage the CMI scaffold.

Although, Zaffagnini et al. [42] did not consider a deficient popliteal hiatus as an absolute contraindication for the use of a lateral CMI, an oversized implant that is not fixed at the hiatus seems to be the most prudent recommendation if the surgeon decides to use a CMI in this particular situation.

The patient is placed supine on the operating table. The affected leg is positioned with the knee hanging free at 90° of flexion, with the contralateral leg fully extended on the surgical table. This allows the leg to be flexed over the contralateral knee in a figure-of-four position. This position applies a varus force across the knee, opening up the lateral compartment, and provides easier access to the posterolateral corner.

Standard anterolateral and anteromedial portals are established, and a complete revision of the joint is performed. As in the medial compartment, damaged meniscus debridement is completed if meniscal suturing is not possible. The O-shape of the lateral meniscus might make a square cut more difficult, particularly at the anterior horn. After preparation of the meniscal bed and trephination, the anterolateral portal is enlarged to accommodate the surgeon's index finger [24]. This simple manoeuvre will facilitate the delivery of the lateral CMI. A probe can be used to manipulate the implant into its correct position.

Although an inside-out suture technique is also feasible in this compartment, through a 4 cm longitudinal incision just posterior to the lateral collateral ligament, the all-inside technique is preferable due to the proximity of the peroneal nerve and the popliteal artery. Some inside-out sutures or even the addition of an outside-in stitch to fix the anterior horn might also be useful [24].

55.3.3 Combined Surgeries

Since medial meniscectomy in an anterior cruciateligament (ACL)-deficient knee may lead to asignificant increase in laxity the combined reconstruction of both structures is particularly recommended as it may create a more favourable environment for meniscus healing. Based on the existing literature, the combination of both procedures is very frequent (27 % in the series of [30], 52 % in the series of [23] and up to 67 % in the series of [14]).

When combining both procedures, some especial tips should be considered. When applying a valgus load to an ACL-deficient knee to open up the medial compartment, the tendency of the tibial plateau to glide forward may add some more difficulty. The recommended sequence for combined ACL-CMI reconstruction is as follows: the meniscus bed is prepared first and then the femoral and tibial tunnels for ACL are drilled. Next, the ACL graft is passed and fixed at the femoral site. At that point, the CMI is inserted and sutured, and, finally, the ACL graft is fixed at the tibial site at 20° of flexion [22].

Any angular deformity of the involved knee greater than 5° in the preoperative long-length weight-bearing X-ray (or greater than 3° with respect to the contralateral limb) should be corrected before or, preferably, concurrently with CMI implantation. According to the general guidelines, varus malalignment should be corrected by a high tibial osteotomy (HTO). Linke et al. [20] reported a series of 30 combined CMI and HTO surgeries. Both an opening-wedge and a closing-wedge HTO can be used. When using the open wedge, special care should be taken not to increase the tibial slope. On the other hand, proper release of the medial collateral ligament is necessary so as not to overload the medial CMI. The less common valgus malalignment is usually corrected on the femoral side to avoid an oblique joint line unless the deformity involves the tibial bone. Regardless of the technique used, the authors recommend doing the arthroscopy and implanting the CMI prior to performing the osteotomy during the same surgical session.

55.3.4 Rehabilitation Protocol

In the postoperative period, a knee brace is applied and locked in full extension, and it is worn for 6 weeks. The patient removes the brace three to four times per day to perform self-assisted passive range-of-motion exercises. The knee brace is unlocked and worn for comfort only after 6 weeks [30].

Range of motion is limited to a range of 0° to 60° for the first 4 weeks and from 0° to 90° for the fifth and sixth weeks. Unlimited range of motion, with active and passive exercises, is encouraged after 6 weeks.

The patients are not allowed weight-bearing for 2 weeks. Partial weight-bearing is permitted between weeks 3–6 and full weight-bearing is allowed after 6 weeks. The use of crutches is discontinued after 8 weeks.

Stationary cycling and aquatic therapy could be done after 3–4 months [12]. A return to impact sports is not recommended earlier than 6 months after CMI implantation.

If a CMI is implanted concurrently with an ACL reconstruction or a realignment osteotomy, the CMI-specific rehabilitation program should have preference [22].

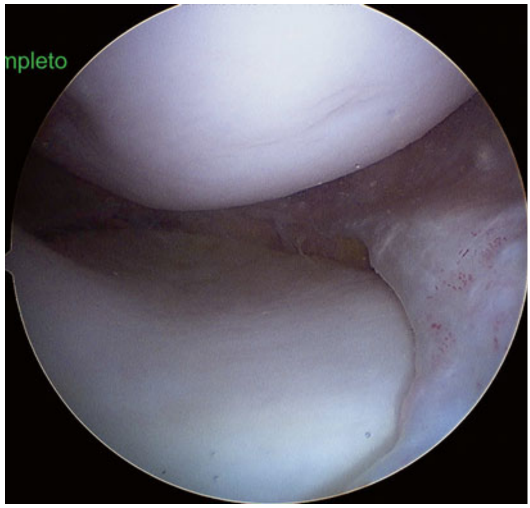

Fig. 55.7 An 8-year follow-up second-look arthroscopy. Most of the implant seems to be resorbed leaving only a small meniscal rim in the posterior area. Note the good aspect of the hyaline cartilage surfaces that suggests some protective functioning of the implant

55.4 CMI Results

55.4.1 Medial CMI Clinical Results

The first series of CMIs in humans was reported in 1997; this study showed no adverse clinical effects, the formation of new tissue and improved clinical scores 3 years after the index procedure [36]. Subsequently, a phase II feasibility study in 8 patients again showed improvement in pain and the subjective scores as well as fibrocartilage matrix formation on biopsies [31]. Some years later, these 8 patients were re-evaluated both clinically and with a second-look arthroscopic examination. The authors found a significant improvement in Lysholm and Tegner activity scores and in VAS pain scores and 69 % of filling of the meniscal defect in a second-look arthroscopy [34].

Zaffagnini et al. [40] prospectively evaluated a group of 8 patients after medial CMI implantation at 6–8 years follow-up. In that series, all the patients were able to return to daily life activities 3 months after surgery. The Cincinnati Knee Rating Scale and the objective IKDC scores improved in all but one case (Fig. 55.7).

Bulgheroni et al. [4] reported on the clinical at results from a series of 34 medial CMI at up to 5 years follow-up. Again, improvements in the Lysholm and Tegner activity scores with respect to the preoperative scores were clearly demonstrated.

Zaffagnini et al. [43], in a nonrandomized study, found better results for several outcome scores (IKDC, Tegner index and SF-36) and a lower visual analogic scale (VAS) for pain in a group of patients treated with medial CMI compared to a group of matched controls treated with partial meniscectomy.

Monllau et al. [23] reported significant improvement in clinical functional scales (Lysholm score) and VAS for pain in 22 patients followed up at a minimum of 10 years. The improvements in the clinical scores were very significant at 1 year and remained almost stable until the final follow-up 10 years after surgery. There were no complications related to the CMI device, and the failure rate was found to be 8 % (2 out of 25).

In a large randomized multicentre prospective clinical trial including 311 patients, the use of medial CMI was compared to a partial meniscectomy [30]. The authors failed to prove significant clinical benefits 5 years after surgery when the implant was used in acute patients (without previous meniscal surgery). However, they found some improvement in the Tegner index when the implant was used in chronic patients (up to 3 previous meniscal surgeries), meaning that these patients recovered more of their lost activity. Moreover, the risk of reoperation 5 years after surgery was 2.7 times greater in the group treated with partial meniscectomy than in the group of patients in which the CMI was implanted.

In a recent comparative study in patients with combined ACL reconstruction and meniscal surgery, CMI patients have less VAS pain than chronic meniscectomized patients in the long term (9.6 years follow-up in average). Additionally, CMI implantation combined with ACL reconstruction leads to a lesser degree of displacement as measured with the arthrometer KT-2000 when compared to a medial meniscectomy. This last finding highlights the role the reconstructed meniscus plays in knee stability [3].

In a recently reported systematic review of the previous CMI literature, the preoperative Lysholm score of 63.3 improved to an average 90.5 at 6 months after surgery, and this improvement remained almost stable up to 10 years later. The average preoperative VAS pain score of 39.4 improved to 18.3 at 6 months and also remained stable up to 10 years later [8]. Nevertheless, the improvement in the Tegner score from preoperative to 1 year after surgery tends to slowly worsen from 2 to 10 years [8].

The most frequently reported complications after implanting a medial CMI were swelling (50 %) and residual compartmental pain (15.2 %). Some other complications with an incidence of less than 10 % that also have been reported are nerve injuries, infection, deep venous thrombosis and implant failure. However, many of the reported complications might be explained by the high rate of concomitant procedures, mainly the ACL reconstruction and tibial osteotomy [8].

55.4.2 Lateral CMI Clinical Results

There is less knowledge of the lateral CMI evolution than the medial because the lateral design is newer and the accumulated experience is less (only 9.8 % of the cases in the systematic review reported by [8]).

Hirschmann et al. [14] reported the results of a series of 12 patients after lateral CMI, showing significant improvements in VAS for pain, Tegner, Lysholm and IKDC scores, similar to a group of 55 medial CMI.

Zaffagnini et al. [42] reported the 2-year results of a series of 24 lateral CMIs, with significant improvement in the Lysholm scores, VAS for pain, Tegner scores and objective IKDC scores. Knee function was improved in 96 % of the patients, and the Lysholm scores were excellent or good in 87 %.

More recently, Zaffagnini et al. [41, 44] clinically evaluated a multicentric series of 43 patients with a mean age of 30.1 ± 12.0 2 years after implantation of a lateral CMI. All clinical scores significantly improved from preoperatively to final evaluation. At final follow-up, 58 % of patients reported activity levels similar to their pre-injury values, whereas 95 % of patients reported that they were satisfied with the procedure. A higher body mass index, the presence of concomitant procedures and a chronic injury pattern seemed to negatively affect the final outcomes. Serious adverse events with a known or unknown relation to the scaffold, such as pain, swelling and scaffold resorption, were reported in 6 % of patients, leading to CMI explantation, debridement or synovectomy.

Therefore, it seems that in spite of the shorter experience with the lateral CMI, the clinical results are similar to those reported with the medial implant, with significant clinical improvements at 6 months follow-up that are maintained up to 2 years after surgery [8].

55.4.3 Radiographic Results

In the phase II feasibility study, Steadman and Rodkey [34] found no significant radiographic changes from the preoperative up to 5–6 years in terms of joint line height measurements or changes in the mechanical axis.

Bulgheroni et al. [4] found no degenerative changes in 53 % of his series and Kellgren-Lawrence grade I in 35 %, with grades 2–3 in 26 % and grade 4 in 3 % at 5 years after CMI surgery. However, the preoperative radiographic status was not informed because preoperative radiographs were not available for all patients.

Zaffagnini et al. [43] found less joint space narrowing in a group of patients treated with CMI compared to a group of patients treated with partial meniscectomy.

Monllau et al. [23] reported minimal or no narrowing of the joint line in all but one of the 22 patients followed for a minimum of 10 years.

Unfortunately, radiographic analysis was not done in the largest CMI study because it was a multicentre study with great variability in the radiographic views and techniques used among the involved sites [30].

55.4.4 MRI Results

Several studies evaluated the MRI signal after CMI surgery. Genovese et al. [6] proposed an MRI-based score to analyse the size and signal intensity of the CMI after implantation (Table 55.2).

Several studies recognize a frequent and progressive decrease in size of the implants during the follow-up period compared with the original native meniscus [4, 6, 23, 33]. In a systematic review of CMI MRI evaluations, it has been reported that the size of the implant considered as grade 3 (similar to the normal meniscus) in 87.5 % of the cases at 6 months after surgery decreased to only 36.4 % at 12 months. This figure decreases progressively up to 10 years when only 8.3 % of the cases could be considered grade 3 and 75 % grade 2. On the other hand, the implant was considered absolutely reabsorbed in 16.7 % of the cases [41]. These MRI results seem to be worse for the lateral CMIs.

There was frequently an altered signal intensity of the implant even many years after implantation [23]. The signal intensity according to the Genovese scale seems to mature progressively up to 2–5 years (33 % considered isointense, 56 % slightly hyperintese and 11 % markedly

Table 55.2 Genovese score for MRI size and signal intensity after CMI implantation

Characteristic	Morphology and size	Signal intensity
Type 1	Totally reabsorbed CMI	Markedly hyperintensity
Type 2	Small CMI Regular or irregular morphology	Slightly hyperintensity
Type 3	Shape and size identical to normal meniscus	Isointensity relative to the normal meniscus

hyperintese). Later than 5 years, the signal intensity could worsen in some cases, as the normal meniscus does (Zaffagnini et al. 2014). In a prospective study, after 10 years of follow-up, the prevalence of signals of myxoid degeneration was found in one third of the implanted CMIs [43].

MR imaging of the synovial reaction could be seen infrequently during the first year (5 % in the 6-month MRI in the Genovese study). Consequently, the use of intravenous contrast material for the MRI study has no potential interest after 1 year [6].

Hirschmann et al. [14] reported extrusion of more than 3 mm in 72 % of the meniscus including CMI when they analysed MR images 1 year after surgery. This extrusion could cause a decreased load-sharing effect.

The MRI aspect of the tibial and femoral cartilage has also been studied with the Yulish scores. They seem to be stable and show no progression of the cartilage lesions with either the medial or lateral CMI [42]. Overall, more than 60 % of the patients had a normal cartilage signal relative to the Yulish score at both the 2-year and 5-year follow-up.

55.4.5 Histological Results

Rodkey et al. [30] studied 141 CMI biopsies obtained from a second-look arthroscopy 1 year after surgery (as it was part of the protocol of a multicentre randomized trial). They reported macroscopic integration between the meniscus-like tissue generated over the CMI scaffold and the host meniscus rim. They did not found lack of healing or exuberant tissue growth in the interface or gross tearing in the CMI. Moreover, no chondral damage caused by the CMI was seen. Nevertheless, they found a partial resorption of the implant in many cases, leading to incomplete defect filling. The average of meniscal tissue remaining after meniscectomy was 51 % in the acute group and 37 % in the chronic group and both increased up to 73 % 1 year after CMI implantation.

The histological findings obtained 1 year after surgery with a 14- or 15-gauge needle biopsy demonstrated that host cells (likely derived from the adjacent synovium) migrate into the collagen meniscus scaffold, differentiate into fibroblast-like cells and synthesize the appropriate extracellular matrix, providing a meniscus-like fibrochondrocitic tissue. One year after implantation, only 10–25 % of the original CMI was present, and most of the implant was replaced by the new host tissue [30]. In less than 5 % of the cases, there was inflammation of the synovium in the biopsy specimen, but without clinical findings of synovitis in the arthroscopy [11]. The majority of the scaffold was expected to be reabsorbed over 12–18 months [4, 33]. A complete absorption of the original scaffold was reported in a histologic study done 5 years after the implantation.

The ultrastructure of the CMI 6 months after implantation was studied with a scanning electron microscopy and transmission electron microscopy [29]. CMI sections appeared composed of parallel connective laminae of 10–30 µm, connected by smaller bundles (5–10 µm). This connective network formed lacunae with diameters of between 40 and 60 µm. The lacunae were filled with connective tissue that contained newly formed vessels and fibroblast-like cells, presenting an abundant rough endoplasmic reticulum and several mitochondria. The original structure of CMI was still recognizable 6 months after implantation and no inflammatory cells were detected within the implant. It demonstrated that CMI provides a three-dimensional scaffold suitable for colonization by precursor cells and vessels and leads to the formation of functional tissue.

55.5 Summary

The CMI is a type-I collagen scaffold designed to develop a tissue-engineered meniscus. Both medial and lateral CMI had been developed for this purpose.

The device is placed arthroscopically in the space where a damaged meniscus has been removed, creating a partial meniscal defect, and is anchored to the surrounding tissue. Selecting the suitable candidate is one of the key factors in achieving a successful outcome. The knee must be stable and well-aligned (or the ACL deficiencies and malalignment should be treated concomitantly). Technically, a secure intra-articular attachment is probably the most critical factor in achieving implant stability, so the surgeon should be skilled in performing meniscus repair and reconstruction techniques. Following implantation, the scaffold has been seen to be invaded by cells and undergoes a process of remodelling. The CMI has already been applied clinically for partial meniscus replacement, and some studies with an improvement in clinical scores and VAS pain score with respect to the preoperative status with a 10-year follow-up have been reported. Subsequently, the formation of newly formed meniscus-like tissue was observed in over two thirds of cases, but the size of this is usually smaller than the native meniscus.

Although the CMI is safe for the joint, the clinical benefits of its use seem to appear mainly in symptomatic patients with a previous meniscectomy. However, the supposed chondroprotection effect in reducing the degenerative changes of the meniscectomized knees remains to be proven.

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Actifit Polyurethane Meniscus Scaffold: Basic Science, Techniques, and Results

56

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Contents

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56.1 Introduction

Injury to the meniscus or loss of meniscal tissue may lead to the degeneration of cartilage, pain, and osteoarthritis. Healing is usually limited to the vascularized areas in the outer two-thirds of the meniscus. Hence, various techniques have been used to improve healing, such as the introduction of a fibrin clot [11, 12], vascular access channels [18], or platelet-rich plasma [16]. In cases of extensive destruction and loss of the meniscus among young patients who suffer pain after a meniscectomy, a meniscal replacement procedure can be discussed. Moreover, allografts and meniscal scaffold are two current options to treat sequelae of irreparable meniscal tears in young patients. This chapter will discuss the basic science of polyurethane meniscal scaffolds, indications, surgical techniques, and results for treating these challenging cases.

56.2 Basic Science

A meniscus scaffold should in theory provide optimal mechanical strength, biocompatibility, porosity, safe degradation, and ease of use in surgical practice. The Actifit® implant (Orteq Bioengineering, London, UK) is an aliphatic polyurethane-based scaffold, specifically based and tuned for meniscal application [10], which is made of two components: polyester (soft segments) and polyurethane (hard segments). The soft segment

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_56

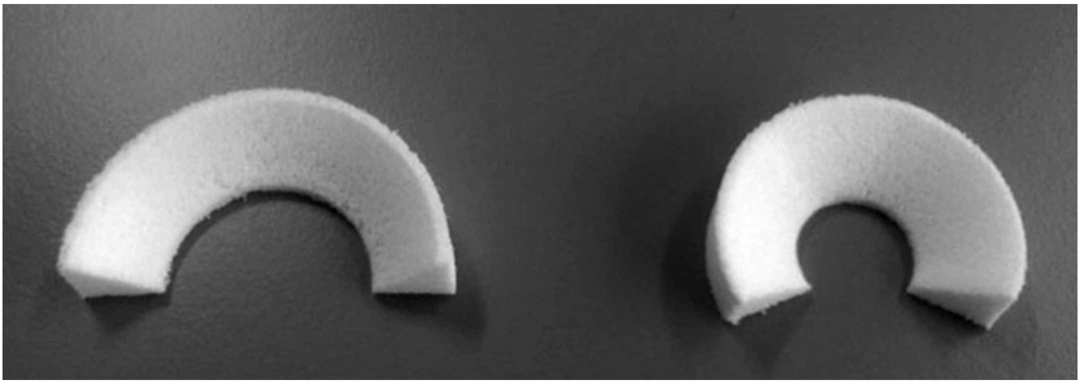

Fig. 56.1 Actifit® polyurethane scaffold, medial and lateral shape

(80 % of the polymer) is a biodegradable polyester, which provides flexibility and determines the degradation rate. The semi-degradable, semicrystalline polyurethane hard segments (20 % of the polymer) are of uniform size and provide mechanical strength to the implant.

The biocompatibility of the scaffold has been demonstrated in animals and humans [19, 22, 23]. Additionally, no safety issues were observed that relate to this scaffold, including cartilage damage or inflammatory reaction to the scaffold, or its degradation products. Indeed, it has been reported to degrade into nontoxic decomposition products [15, 19], as well as support migration of cells and ingrowth of new tissue in vitro and in vivo [14, 22]. Likewise, preservation of cartilage status following implantation of the polyurethane scaffold has been demonstrated in several studies [21]. In addition, the frictional properties of the porous polyurethane scaffold have been shown to approach those of native meniscus after 6–12 months in sheep [7]. Hence, lateral and medial designs are available for use (See Fig. 56.1).

56.3 Indications/Requirements

The main indication of the scaffold is to treat painful sequelae of extensive, although not subtotal, meniscectomies in young patients. The knee joint should be well aligned (favorable axis of less than 5°), stable or stabilized (ACL noninjured or reconstructed), the ICRS classification should be less than grade 3, with a body mass index <35 kg/m^2, and the absence of systemic disease or infection sequelae. Furthermore, local criteria for use include an intact meniscal rim and sufficient tissue in the anterior and posterior horns to allow fixation of the scaffold to the remaining meniscus tissue. Thus, the meniscal root lesions are not indicated for scaffolding.

Preoperative imaging includes:

- Bilateral and comparative weight-bearing radiographs include AP, lateral, Schuss or Rosenberg views, and skyline view at 30° of flexion to assess the cartilage and degenerative articular changes which are systematically needed in these cases. The Schuss view has a good reproducibility when joint space is superior to 3 mm. Narrowing of the cartilage space of 2 mm or more is strongly correlated with grade 3 or 4 cartilage degeneration on an MRI [3]. Consequently, if there is a joint space narrowing on standard radiographs, there is no valuable indication for a meniscal substitution by a scaffold.
- MRI of the knee – Mandatory in order to assess the meniscal remaining tissue, cartilage status, bone marrow edema, and meniscal extrusion (see Figs. 56.2 and 56.3).
- Arthro-CT scan – This can be helpful and complementary to an MRI scan to assess meniscal volume and chondral damage.
- Diagnostic arthroscopy – Sometimes a diagnostic arthroscopy can be useful to ascertain

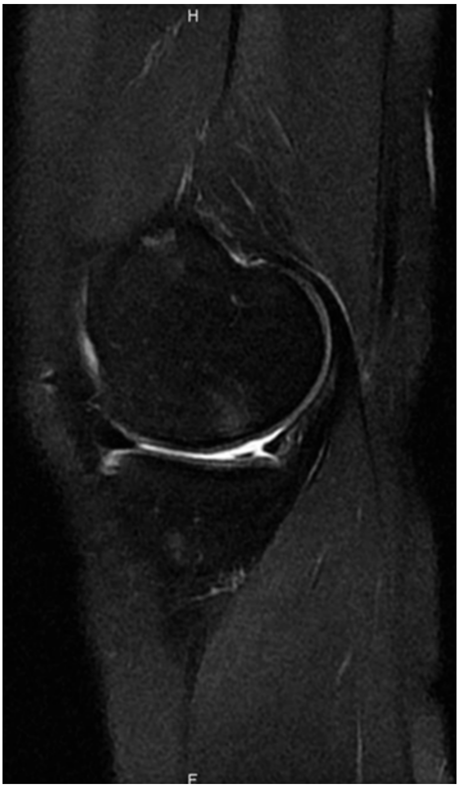

Fig. 56.2 Preoperative MRI (frontal view) of a patient with painful sequelae of partial medial meniscectomy: no chondral damage, meniscal rim and roots still present

Fig. 56.3 Preoperative MRI (sagittal view) of a patient with painful sequelae of partial medial meniscectomy: no chondral damage, meniscal rim and roots still present

the best indication between meniscal allograft and scaffold. Moreover, it is important to say that these two techniques are complementary, not in concurrency. After a diagnostic arthroscopy, the appropriate material can be ordered and the appropriate operation planned.

56.4 Surgical Technique and Postoperative Rehabilitation

56.4.1 Surgical Technique

The procedure is performed arthroscopically, usually with spinal or general anesthesia. Indeed, standard anteromedial and anterolateral portals are used.

Following the exploration of all compartments and verification of cartilage status, debridement and preparation were performed: Damaged and fibrous tissue around the meniscal rim are removed and cut back to an area with good blood supply. Moreover, abrasion of the meniscal wall is an important step, in order to promote healing and future tissue ingrowth (See Fig. 56.4). In cases of tight medial compartment, a posteromedial capsular and medial collateral ligament release with the pie-crusting technique is advised [1].

The meniscal defect is then measured along the curvature of its inner edge using a flexible intra-articular ruler (See Fig. 56.5). On the sterile field of the back table, the scaffold is then cut to an appropriate size, with an oversizing by 10 % to allow for shortening caused by suturing. The anterior cut is made at a 120° angle to fit with the anterior segment of the remaining meniscus, and it should be handled with care, even though the Actifit® material is easy to manipulate and is

Fig. 56.4 Visualization of the segmental defect, after abrasion of the meniscal rim

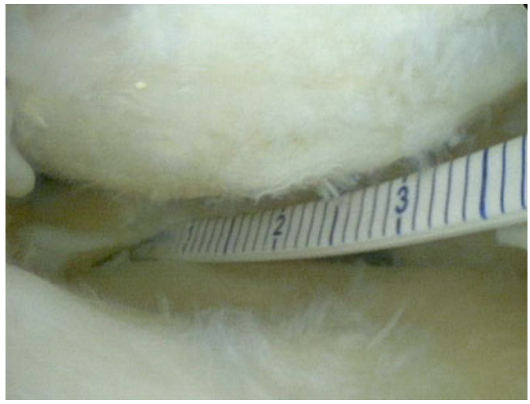

Fig. 56.5 Sizing of the defect

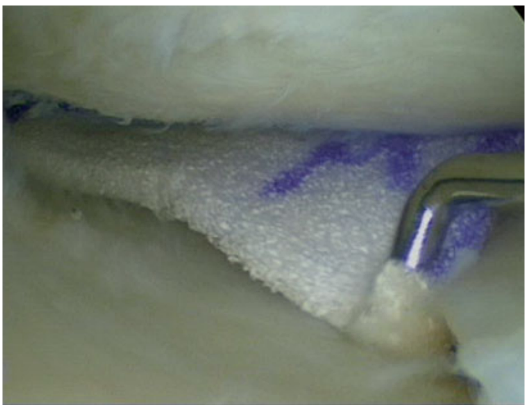

Fig. 56.6 Insertion and placement of the scaffold

Fig. 56.7 Fixation of the scaffold to the meniscal rim and roots (all-inside and outside-in techniques)

strong and flexible. In fact, marking the cranial and caudal scaffold surface helps to avoid problems in positioning. The implant is then introduced into the joint by the ipsilateral portal with a curved delivery clamp. At this step it is important to seat the implant gently into the meniscal defect with a probe or a smooth elevator (See Fig. 56.6). The attachment with the posterior root is made by one or two horizontal all-inside sutures (See Fig. 56.7).

Outside-in meniscus repair techniques are used to fix the anterior part, as well as all-inside devices are used to fix the scaffold to the native meniscus body (horizontal sutures are recommended, Fig. 56.8). The stability of the fixation is tested using the probe and moving the knee through a range of motion 0–90°.

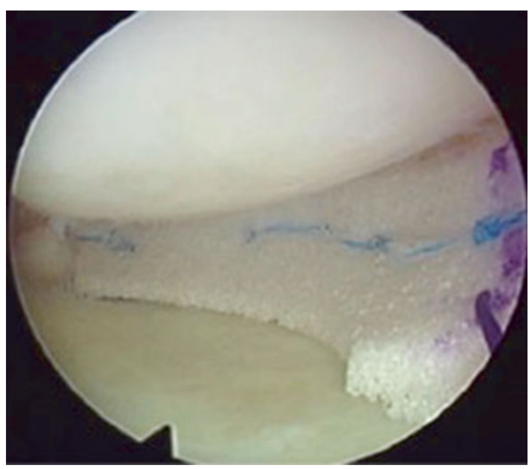

Fig. 56.8 Final aspect

In the cases of concomitant, ACL reconstruction alongside tibial and femoral tunnels are prepared prior to the implantation of the scaffold. Then the ACL graft is passed and fixed after scaffold implantation.

56.4.2 Postoperative Rehabilitation

Immediate passive range of motion is started early, although limited to 90° by 4–6 weeks. Weight bearing is not allowed during the first month, with a gradual increase in loading up to 100 % load after 8 weeks. Similarly, an extension brace is recommended for 1 month. Cycling, swimming, and active range of motion exercises are initiated after 8 weeks, and the gradual resumption of other sports are generally restricted during 6–8 months.

56.5 Results

56.5.1 Clinical Results

The researcher carried out a systematic literature review on Actifit® meniscal scaffold polyurethane using PubMed. Clinical series were extracted from the database, and it yielded only 8 level of IV series between January 2012 and March 2015: 180 cases overall. Thus, the comparative series CMI® vs. Actifit® were excluded. The results are presented in Table 56.1.

Clinical results are good in the short term, with significant improvements in all subjective outcome criteria (e.g., 20–25 points of each parameter of the KOOS). Nevertheless, after 24 months, patients' outcomes are far from normal uninjured knees, which is a vital point that should be clearly explained to the patient before the surgical procedure. It is a salvage procedure to treat severe post-meniscectomized pain syndromes in young patients without early osteoarthritis. In such specific cases, improvement of the knee function can be achieved on the short term [22].

The main limitations of these published studies are the study design with low evidence level, the short follow-up (around 24 months in all series), and the high number of combined procedures that hinder the evaluation of the specific contributions of the meniscal scaffold to the clinical improvement. Therefore, further studies are still required to confirm the real usefulness of these scaffolds, in order to better understand the most suitable indications and to determine if it could prevent further knee degeneration. Even though uncorrected malalignment is a contraindication for meniscal scaffold implantation [9], partial substitution with a polyurethane scaffold does not improve outcome after an open-wedge high tibial osteotomy [8].

56.5.2 MRI Results

Verdonk et al. [20] have reported the MRI results from a multicenter cohort of 52 patients. Dynamic-enhanced MRI showed tissue ingrowth in 81.4 % of patients at 3 months. Efe et al. [6] reported in regard to postoperative MRI of ten patients that there was a presence of the scaffold at 6 months with evidence of some tissue integration and a resolving bone bruise edema at 12 months. Similarly, Schüttler et al. [17] performed MRI in 18 patients 2 years after a medial implantation, and a complete resorption of the scaffold was observed in one patient. In 17 re-paining patients, scaffolds showed altered hyperintense signal intensity when compared to the residual meniscal tissue (See Figs. 56.9 and 56.10).

De Coninck et al. reported radial displacement of the meniscus after a meniscal scaffold implantation [5]. An MRI was performed preoperatively at 3 months, 12 months, and 24 months. There was a preoperative relative extrusion of the remaining meniscal rim (or radial displacement), meaning that even after a partial meniscectomy and preserved meniscal rim and roots, the meniscus begins to gradually be released from the joint (early OA stage?). This radial displacement increased significantly with time, especially for the medial side. Furthermore, at this midterm follow-up, there was no correlation between clinical outcome scores and amount of radial displacement. Nevertheless, this has to be confirmed in larger studies with a longer follow-up.

Table 56.1 Clinical results of published series

Author	Year	*n*	Medial/lateral	Age (y)	Sex M/F	Follow-up (months)	IKDC (pre-/post-op)	KOOS (pre-/post-op)
Verdonk et al. [20]	2012	52	34/18	31	39/13	12	45.4/70.1	Symptoms 64.6/78.3 Pain 57.5/78.6 Activities 68.8/84.2 Sports 30.5/59 Quality of life 33.9/56.6
Efe [16]	2012	10	10/0	29	8/2	12	–	Symptoms 60.8 /85.9 Pain 45.7/82.5 Activities 53.7/90 Sports 29.5/79 Quality of life 27.6/70.8
De Coninck [18]	2013	26	18/8	35	14/12	24	39.18/64.17	Symptoms 53.5/77.2 Pain 53.2/74.6 Activities 58.8/78.5 Sports 20.2/52.1 Quality of life 30/52
Kon et al. [13]	2012	18	13/5	45	11/7	24	47.3/74.6	–
Bouyarmane et al. [4]	2014	54	0/54	28	37/17	24	47.0/67	Symptoms 59.1/79 Pain 56.6/78.5 Activities 64/84.2 Sports 30/54 Quality of life 29.6/50.9
Schütler et al. [17]	2014	18	18/0	32.5	–	24	–	Symptoms 60/81 Pain 47/83 Activities 53/91 Sports 26/66 Quality of life 28/63
Baynat et al. [2]	2015	18	13/5	20–46	13/5	24	Lysholm 55.2/94.3	–
Gelber et al. [8]	2015	30	30/0	45.1	21/9	31.2	19.1/69.4	–
Total	–	226	136/90	34.1	–	Mean 22.1	Mean 40.8/68.6	Symptoms 60.2/79.1 Pain 54.6/78.7 Activities 62.8/84.4 Sports 28.1/58.2 Quality of life 30.8/55.5

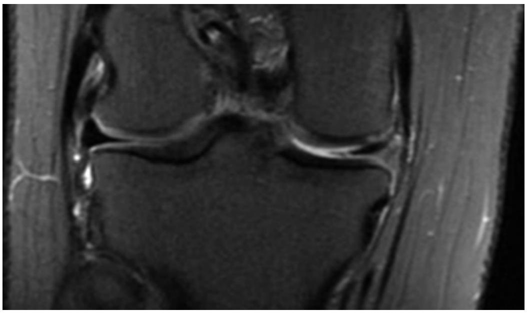

Fig. 56.9 MRI at 1 year after a medial Actifit®, frontal view

56.5.3 Complications

No specific device-related serious adverse events were reported in the abovementioned clinical studies. A very small number of reoperations were reported (Table 56.2), with a cumulative failure rate of 5 %. The most reported reoperation is a partial removal of the scaffold (See Fig. 56.11), due to partial integration failure and a lack of biological response. This is in accordance with the early safety and efficacy that is also reported in animal studies.

Fig. 56.10 MRI at 1 year after a lateral Actifit®, sagittal view

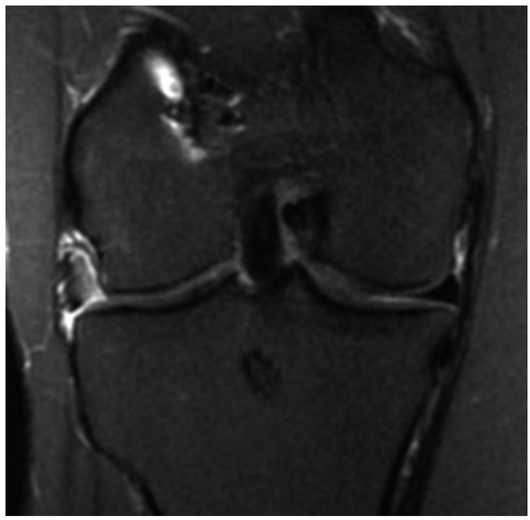

Fig. 56.11 Arthroscopic partial removal of the scaffold at 1 year, lateral side

Table 56.2 Summary of complications after scaffold implantation

Author	*n*	Worsening cartilage lesions (*n*)	Partial removal of the scaffold (*n*)	Total removal of the scaffold (*n*)	Knee arthroplasty (total, uni) or osteotomy (*n*)
Verdonk et al. [20]	52	3	2	2	1
Kon [7]	18	–	–	–	–
Efe [23]	10	0	0	0	0
De Coninck [18]	26	–	–	–	–
Baynat [12]	0	0	0	0	0
Bouyarmane et al. [4]	54	–	3	0	0
Schüttler et al. [17]	18	2	0	1	0

Conclusion

Partial meniscal replacement using the polyurethane meniscal scaffolds is safe (no adverse reaction due to the device) and achieves significant and encouraging improved clinical results. This therapeutic option represents a major addition toward meniscal reconstruction for treating painful segmental meniscal defects in young patients without osteoarthritis after arthroscopic meniscectomy. Nonetheless, there is a lot of work that remains to be completed. For instance, the most appropriate indications and timing for surgery should be better determined, as well as the addition of any biological enhancers should be discussed. In addition, mid- to long-term follow-up studies with a high level of design are still recommended in the future.

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Meniscal Substitutes Synthesis

57

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Contents

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57.1 Introduction

The meniscus has a crucial physiological as well as biomechanical role in the knee. As it distributes loads across the articulating surfaces, it protects the hyaline cartilage from wear [1]. Meniscal tears are one of the most common injuries of the knee joint. In most cases, they are not amenable to repair procedures and so surgical excision of the damaged tissue is required. However, a large meniscectomy results in an enormous decrease in the contact area of the articulating surfaces, which in turn leads to increasing the mean and peak contact stresses. Due to the impairment of these biomechanical functions, irreversible degenerative changes and osteoarthritis in the knee will often follow the loss of meniscal tissue [2, 3]. Therefore current concepts of meniscal surgery are aimed at preservation, either by suture repair or replacement of the lost tissue.

57.2 Scaffolds

In an effort to keep the knee joint functional and pain free, an emergent interest in meniscal substitution techniques has increased over the last decades. The limited availability of meniscal allografts and the concerns related to its use, namely, the transmission of infectious diseases, have pushed orthopedic surgeons to explore

C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_57

alternative options for meniscal replacement. The concept of meniscal scaffold was introduced in the 1990s to stimulate and drive new growth of meniscal tissue and has been refined over time [4]. Meniscal scaffold implantation requires anterior and posterior horn remnants as well as an outer rim of meniscal tissue to properly fix the implant and so that it is indicated only for partial meniscus regeneration [5]. Currently, two such devices are available in Europe for clinical use. The older is the collagen meniscus implant or CMI (Ivy Sports Medicine, Lochhamer, Germany), a bioresorbable type I highly purified bovine collagen matrix [4]. More recently, a synthetic biodegradable and acellular scaffold composed of aliphatic polyurethane called Actifit (Orteq Bioengineering, London, UK) has been introduced [6]. Both of them were designed to serve as a scaffold for the ingrowths of new meniscal tissue, which eventually leads to a regeneration of the lost meniscus.

Meniscal scaffolding implants have been proven to be safe. Furthermore, both available implants have shown good clinical results in the treatment of partial medial and lateral meniscal defects in terms of pain reduction and improved knee function. Those were the outcomes at 2 years with the Actifit [7–10] and at 10 years follow-up with the CMI [11, 12]. The CMI also demonstrated clinical and histological improvement in patients with an acute or chronic meniscal deficiency in a level I study [13]. Strict selection criteria seem to be crucial to getting good results and that includes preservation of the cartilage of the articulating surfaces at the time of substitution. However, satisfactory clinical results might be obtained with the polyurethane scaffold as suggested more recently even with a deteriorated hyaline cartilage [9]. The role of the scaffolds should be further clarified in cases of associated surgical procedures like high tibial osteotomy [10]. Therefore, proof of chondroprotection is currently only indirect and the ideal candidate for this biological approach still remains a matter of debate.

57.3 New Approaches

A second generation of implants, pre-cultured in vitro to allow for cell adhesion and extracellular matrix production and then implanted in meniscal defects, will probably follow as cell seeding has been demonstrated to improve the mechanical properties and histological results [14].

Recent investigation in this field has focused on the use of stem cells alone or in combination with scaffolds for meniscal regeneration. Some models have used a combination of mesenchymal stem cells and different scaffolds to replace meniscal tissue in an experimental setting. They have demonstrated the feasibility of regenerating meniscal tissue using that tissue-engineering method [15, 16]. Recently, the use of adult human mesenchymal stem cells delivered via intra-articular injection to the knee following partial medial meniscectomy has produced a significant increase in meniscal volume as determined by quantitative MRI at two years follow-up [17]. However, none of these cell-based strategies has yet to enter into routine clinical practice and many related issues have to be further clarified before extending its use.

Conclusion

To sum up, meniscus implants are safe and have rendered good clinical outcomes in symptomatic partial meniscal defects although the newly generated tissue is less than expected in most of the cases.

The results obtained with the much refined tissue-engineered products are still experimental even though it is likely that they will compete against the current techniques of meniscal replacement one day.

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Part XI

Substitutes and Future Technology

Gene Therapy, Growth Factors, Mesenchymal Cells, New Trends and Future Perspectives

58

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1_58

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58.1 Introduction

Meniscal tears are a common, prevalent intra-articular knee injury and the most frequent cause of orthopedic surgical procedures [1], being a significant risk factor for the development of osteoarthritis (OA) [2]. As widely documented in the previous chapters, tears in the peripheral (vascularized) portion of the meniscus can be repaired using a variety of operative procedures, while those in the central (avascular) area have a poorer healing capacity. Reconstruction of a torn meniscus in this location is challenging, and the long-term effect of allografts on the progression of OA remains uncertain [3].

The results of the available literature highlight that while various options are available in the clinics to manage meniscal lesions, there is a critical need for novel, effective treatments to enhance the processes of meniscal repair.

58.2 Gene Therapy for Meniscal Repair

Gene therapy is an attractive strategy already in use in patients with monogenic disorders that may provide new therapeutic tools to promote the healing of the affected meniscus: in the next paragraphs, an overview of the current gene transfer methods adapted to treat the highly specialized meniscal tissue will be presented, discussing the progress and remaining challenges for future clinical translation.

58.2.1 Target Cells and Candidate Factors

Different targets may be used in approaches that aim at improving meniscal repair: meniscal fibrochondrocytes, meniscal tissue, and progenitor cells like mesenchymal stem cells (MSCs) from the bone marrow, adipose tissue, synovium, periosteum, trabecular bone, umbilical cord blood, amniotic fluid, Wharton's jelly, or skeletal muscle [4].

Factors with a therapeutic potential targeting cells for meniscal repair include activators of cell proliferation and anabolic mediators such as basic fibroblast growth factor (FGF-2), platelet-derived growth factor (PDGF), transforming growth factor beta (TGF-β) or insulin-like growth factor I (IGF-I), bone morphogenetic protein 7 (BMP-7), hepatocyte growth factor (HGF), and inhibitors of inflammation and of catabolic pathways such as interleukin-1 receptor antagonist (IL-1Ra), tumor necrosis factor (TNF) antibody, and inhibitors of matrix metalloproteinases (MMPs) [5].

58.2.2 Gene Transfer Vectors

As recombinant factors have short pharmacological half-lives (sometimes less than an hour) [6], their delivery in the form of gene sequences has been proposed to enhance the duration of their therapeutic effects. Various vectors, either nonviral or virus-based constructs, have been applied to relevant cells and tissues for meniscal repair (Table 58.1).

Nonviral vectors are considered safe as they may not acquire replication competence like viral vectors, yet they lead only to rather low and short-term transgene expression [7].

In contrast, adenoviral vectors promote high levels of transgene expression but are very immunogenic while mediating again only short-term expression of the therapeutic sequences (1–2 weeks maximum) [8].

Long-term transgene expression may be promoted by retro-/lentiviral vectors. Retroviral vectors have an ability to integrate in the host genome

Table 58.1 Gene transfer vectors adapted for meniscal repair

Vector	Advantages	Limitations	Integration
Nonviral	Nontoxic Large capacity	Relatively low efficiency Short-term expression	No
Adenoviral	High efficiency Large capacity	Possible replication competence Immunogenicity/toxicity Short-term expression	No
Retro-/lentiviral	High efficiency Relatively large capacity Long-term expression	Possible replication competence Risk of insertional mutagenesis	Yes
HSV	High efficiency Large capacity	Possible replication competence Toxicity Short-term expression	No
rAAV	High efficiency Long-term expression Low immunogenicity/toxicity	Difficult to produce Size limitation Serotype-restricted cell specificity	Mostly episomal

HSV herpes simplex virus vectors, *rAAV* recombinant adeno-associated virus vectors

leading to long-term transgene expressions. Still, integration of the recombinant material may activate the expression of tumor genes via insertional mutagenesis. Also, such vectors transduce only dividing cells, at low efficiency, or require a preselection of the cells effectively modified prior to reimplantation [9]. Lentiviral vectors instead can integrate in the genome of nondividing cells, leading to higher levels of gene transfer [10], but they still display a potential for insertional mutagenesis.

Herpes simplex virus (HSV) vectors can carry long transgenes in almost all known cell types including nondividing cells, but they are toxic and lead only to short-term transgene expression [11].

A potent alternative is based on the use of recombinant adeno-associated virus vectors (rAAVs) that are derived from a nonpathogenic, replication-defective human parvovirus. rAAVs are less immunogenic than adenoviral vectors and more effective than nonviral and retro-/lentiviral vectors and can modify both dividing and nondividing cells. They lead to sustained transgene expression as they are maintained as stable, episomal forms and can reach target cells even through a dense extracellular matrix due to their small size (20 nm) [12]. The recent marketing of Glybera® (alipogene tiparvovec), an rAAV vector encoding the lipoprotein lipase (LPL) to treat patients with LPL deficiency (www.ema.europa.eu/ema: EMA/506772/2012), shows the promise of these vectors for human gene therapy.

58.2.3 Genetically Enhanced Tissue Engineering

Gene therapy can be combined with tissue engineering (TE) approaches for meniscal repair using acellular or cell-seeded matrices. Work is ongoing to test such biomaterials concomitantly with cell- and gene-based approaches for meniscal repair, including alginate [13], type I collagen solution [14] or sponge [15], type I collagen/GAG matrix [16], and polyglycolic acid (PGA) scaffold [17].

58.2.4 Strategies and Applications of Gene Therapy

Gene therapy for meniscal repair might be performed via direct injection of a gene transfer vector, by administration of genetically modified cells, by application of a biomaterial coated with a gene transfer vector, or by transplantation of a biomaterial seeded with genetically modified cells. Cell-free strategies are less invasive, but the presence of cells in a therapeutic composition might be useful to repopulate meniscal lesions.

Applications in vitro Nonviral, adenoviral, HSV, and rAAV vectors have been successfully employed to modify meniscal fibrochondrocytes and progenitor cells in vitro to influence the repair processes in these relevant cells for meniscal repair (Table 58.2).

Table 58.2 Gene therapy approaches *in vitro* for meniscal repair

Vector	Gene	Biomaterial	Cells	Activities	References
NV	IGF-I	–	Meniscal cells	Cell proliferation	[18]
	FGF-2	Alginate	Meniscal cells	Cell proliferation	[4]
AdV	TGF-β	Type I collagen/GAG matrix	Meniscal and progenitor cells	Cell proliferation Matrix synthesis	[16]
RV	TGF-β	–	Meniscal cells	Matrix synthesis	[73]
	hTERT	–	Progenitor cells	Cell proliferation	[19], [74]
rAAV	FGF-2	–	Meniscal and progenitor cells	Cell proliferation	[13], [75]
	TGF-β	–	Meniscal cells	Cell proliferation Matrix synthesis	[12]

NV nonviral vectors, *AdV* adenoviral vectors, *RV* retroviral vectors, *rAAV* recombinant adeno-associated virus vectors, *IGF-I* insulin-like growth factor I, *FGF-2* basic fibroblast growth factor, *TGF-β* transforming growth factor beta, *hTERT* human telomerase, *GAG* glycosaminoglycans

Table 58.3 Gene therapy approaches *in situ* and *in vivo* for meniscal repair

Setting	Vector	Gene	Biomaterial	Cells	Activities	References
In situ	AdV	TGF-β	Type I collagen/ GAG matrix	Meniscal and progenitor cells	Repair of meniscal lesions	[16]
	rAAV	FGF-2	–	–	Cell proliferation, contraction, repair of meniscal lesions	[13]
		TGF-β	–	–	Cell proliferation, contraction, repair of meniscal lesions	[12]
In vivo	NV	IGF-I	Alginate	Progenitor cells	Repair of meniscal lesions	[18]
	AdV	HGF	PGA	Meniscal cells	Repair of meniscal lesions, vascularization	[17]

HGF hepatocyte growth factor, *PGA* poly-glycolic acid

Cell proliferation: Stimulation of proliferative activities in meniscal and progenitor cells was achieved by gene transfer of IGF-I [18], FGF-2 [13], TGF-β without [12] or with a type I collagen/GAG matrix [6], and human telomerase (hTERT) [19].

Anabolism: Successful activation of biosynthetic processes was seen following gene transfer of TGF-β without biomaterial [12] or with a type I collagen/GAG matrix [16].

Applications in situ and in vivo In situ, transplantation of progenitor cells modified by a TGF-β adenoviral vector in type I collagen/GAG matrix in bovine torn meniscal explants [16] or direct injection of either rAAV FGF-2 or TGF-β vectors in human meniscal lesions [12, 13] enhanced meniscal repair for ~15–21 days (Table 58.3). Remarkably, rAAV TGF-ß vector application stimulated the levels of cell proliferation and matrix synthesis (type I collagen) and led to a significant reduction of the amplitude of meniscal tears, an effect that was associated with increased expression levels of the α-smooth muscle actin contractile marker. In vivo, subcutaneous implantation of meniscal cells modified by an HGF adenoviral vector in a PGA scaffold in athymic mice [17] or of progenitor cells modified by an IGF-I nonviral vector in alginate in goat meniscal lesions [18] improved meniscal repair for up to 16 weeks (Table 58.3).

Gene therapy is a promising method to improve meniscal repair as shown by the current advances in experimental research. Yet, no clinical trial using therapeutic gene transfer has been initiated to our best knowledge. The most appropriate candidate gene(s) and vector and the optimal cell source and biomaterial still need to be defined, and robust preclinical data in relevant animal models in vivo are needed prior to clinical translation.

58.3 PRP and Future

Platelets are cytoplasmic fragments of megakaryocytes formed in the marrow with an approximate diameter of 2 μm. They contain more than 30 bioactive proteins, many of which have a fundamental role in hemostasis or tissue healing. Many fundamental growth factors (GFs), which are actively secreted by platelet once activated, initiate the wound healing process. PRP also contains adhesion molecules like fibrin, fibronectin, and vitronectin. After platelets activation, whether ex vivo (by thrombin and calcium) or in vivo by exposure to collagen, the alpha-granules contained in platelets degranulate and the secreted proteins, including GFs, are released [20, 21]. These molecules bind to transmembrane receptors of target cells such as fibroblasts, osteoblasts, endothelial cells, as well as mesenchymal stem cells, initiating a healing cascade mediated by cellular chemotaxis, angiogenesis, collagen matrix synthesis, and cell proliferation [22]. PRP is prepared by differential centrifugation, during which acceleration force is adjusted to sediment certain components based on different specific gravities. Still today a clear and univocal definition of PRP is lacking, and as a consequence, several PRP formulations are currently available on the market, differing in terms of cell content, platelet concentration rate, activation methods, and many other features [23].

The available studies differ in several parameters including PRP formulation, way of preparation, number of applications, length of follow-up, type of patients, and other relevant factors. In this confuse scenario, it is thus very difficult to find a definitive proof of the possible efficacy of PRP in a given application. Nonetheless, the relative ease of preparation, applicability in the clinical setting, favorable safety profile, and possible beneficial outcome have made PRP to be considered a promising therapeutic approach for future regenerative treatments, including for meniscal tears. However, there is a large knowledge gap not only in the definition of PRPs mechanism of action but also in the correlation between the promising in vitro effects and the understanding of the real clinical efficacy.

58.3.1 PRP and Meniscus: Are In Vitro Evidences Correlated with Clinical Benefit?

For what concerns meniscus, even though PRP has been a part of clinical practice for some time also in the meniscal repair enhancement, very few studies investigated its clinical effect in this application. In a recent work, Griffin and colleagues [24] investigated whether PRP augmentation during meniscal repair decreased the likelihood of subsequent meniscectomy and if it affected functional outcome scores and clinical and patient-reported outcomes. Of 35 isolated arthroscopic meniscal repairs, 15 were augmented with PRP, and 20 were performed without PRP augmentation. Data analyzed at a minimum follow-up of 2 years showed no difference in any of these outcome measures between patients who had PRP or not. However, this study presents some critical limitations, including the small number of patients, the lack of subgroup analysis, and of a random allocation of the patients; moreover, no postoperative MRIs were performed, and thus, no data about the regeneration process were available. In another study, PRP was used in 17 patients out of 34 who underwent arthroscopic surgery for an open meniscal repair to treat symptomatic grade 2 or grade 3 horizontal meniscal tears. At a minimum of 2 years of follow-up, significantly better results were only found in the PRP group in terms of pain and sports parameters of the KOOS scale, thus showing a slight improvement mediated by the addition of PRP [25]. The controversial findings of these studies indicate that, despite the theoretic benefits of PRP augmentation in orthopedic soft tissue healing including meniscus, the clinical effects are far from being clearly demonstrated.

The literature shows a lack of new clinical studies about the efficacy of PRP in meniscal healing; thus, as the clinical research seems to be quite stationary, probably to move forward in this field we need to come back to the laboratory to look for better indications and optimize this biological strategy to increase meniscal healing potential.

58.3.2 PRP and Growth Factors: A Future in Meniscal Healing?

Starting from the evidence that in vitro cultured meniscal cells presented an increased expression of mRNA of extracellular matrix proteins when cultured in PRP in comparison to the controls [26], in recent years different strategies to implement the use of PRP have been proposed.

TE is one of the most promising approaches to regenerate tissue, including meniscus [27]. Commonly TE is characterized by three main factors: cells, scaffolds, and GFs. Thus, PRP, which contains a pool of GFs, could be a good candidate to be associated to cells and/or scaffold and develop innovative strategies to improve meniscal healing. In a recent study, one million of cells were seeded on either a poly-lactic-co-glycolic acid (PLGA) scaffold or PLGA pretreated with PRP in order to evaluate whether PRP was able to increase the healing capacity of the meniscus once implanted in vivo [28]. After 7 days from cell seeding, the constructs were placed between human meniscal discs and implanted subcutaneously in nude mice for 6 weeks. Cell attachment analysis revealed a significantly higher number of chondrocytes on PRP pretreated than non-treated scaffolds. Moreover, of the 16 constructs containing PRP-pretreated scaffolds implanted in mice, 6 menisci healed completely, 9 healed incompletely, and one did not heal, while of the 16 non-treated scaffolds, none healed completely, 4 healed incompletely, and 12 did not heal. These results suggest that PRP can act as a biochemical attraction for cells, allowing to speculate that PRP could provide a valid appropriate regenerative environment for resident meniscal cells.

While most of the research on TE approaches focuses on mesenchymal stem cells (MSCs) to successfully regenerate meniscal defects in the avascular zone, in daily clinical practice a single stage regenerative treatment would be preferable for meniscal injuries. For this reason, Zellner and colleagues tested the effects of PRP and BMP7 (bone morphogenetic protein-7) on the regeneration of avascular meniscal defects. Although in vitro analysis showed that PRP secreted multiple GFs over a period of 8 days and that BMP7 was able to enhance the collagen II deposition in an aggregate culture model of MSCs, in vivo application of PRP or BMP7 in combination with a hyaluronan collagen matrix failed to improve the healing of meniscal tears in the avascular zone [29].

As the biological enhancement of meniscal repair addresses the healing of the avascular zone of the meniscus, researchers' efforts have been also conveyed to key GFs, such as VEGF (vascular endothelia growth factors), HGF (hepatocyte growth factors), and TGF-β (transforming growth factor beta). HGF was demonstrated to enhance vascularization of engineered meniscal fibrochondrocyte-PGA constructs, even though without improving mechanical properties [17]; on the other side, IGF-1, known to positively affect cartilage regeneration, could act on the inner part of the meniscus which is characterized by an ECM similar to that of articular cartilage. For this reason, the use of these two GFs could be a promising combination to be evaluated [30]. However, differently from what is expected, some GFs were demonstrated not to be able to initiate meniscal tissue formation, as, for example, TGF-β3 [31]; this observation brings to consider that further information of the repair mechanism at the defect site is still needed to develop the most appropriate application of GFs to support biological augmentation of meniscal regeneration. In vitro cells of the vascular and avascular area of meniscus, cultured in the presence or absence of VEGF, TGF-b, FGF, and IGF, and compared in terms of expression of genes of matrix and metalloproteinases, showed that GFs provoked different gene modulations according to the different areas [32], thus behaving differently in terms of repair and underlining the need to further understand meniscal repair mechanisms to better develop the new emerging regenerative treatment options.

In conclusion, the future of PRP in meniscal healing seems to be less promising than its use in other applications. The use of single GFs or the combination of few of them seems to deserve to be investigated. Finally, it will be also useful to determine whether PRP or GFs would act alone or synergically with other biologics or materials in order to further improve treatment strategies to regenerate the meniscal tissue.

58.4 Mesenchymal Stem Cells in Meniscal Repair

Endogenous repair of meniscal lesions is based on MSCs, which can either be located in the meniscal tissue itself or entering the meniscus predominately via circulation. Thus, exogenous application of mesenchymal-based stem cells may offer intriguing novel strategies in regenerative medicine in order to enhance the intrinsic repair. To this regard, MSCs fulfill a dual role for musculoskeletal repair, since they have the potential to differentiate into the repair cells themselves and to produce special GFs for its repair [33].

58.4.1 Endogenous Mesenchymal Cell-Based Meniscal Repair

Endogenous repair of meniscal injury seems to be dependent on the different vascularizations of the outer and the inner zone of the meniscus [34]. Repair in the vascularized outer zone can be achieved, but fails to encourage healing in the avascular inner zone of the meniscus.

Stem cells are characterized by self-renewal capacity and multilineage differentiation potential to a variety of cell types of mesenchymal tissue like bone, cartilage, or fat [33, 35]. Recently, the stem cell perspective has changed by the identification of pericytes around almost every blood vessel in the body, which present stem cell characteristics [36]. The existing traditional view, which focuses on the multipotent differentiation capacity of these cells, has been expanded to include their equally interesting role as cellular modulators that bring them into a broader therapeutic scenario [37].

Some studies also showed some regeneration in the inner zone of the meniscus indicating regenerative potential independently from the vascularization [37]. MSCs have been identified in the surface zone of other avascular tissues, mainly in the articular cartilage [38], but little is known about meniscal stem cells. Mauck et al. described regional multilineage differentiation potential of meniscal cells in both zones available; however, they showed differences in pluripotency between the zones [39]. In particular, pluripotent cells from the avascular tissue seem to lack osteogenic differentiation potential, which could be of clinical interest for meniscal regenerative approaches [39, 40].

Besides the existence of MSCs in the meniscus, the synovium and the synovial fluid also contain stem cells for meniscal regeneration, and Matsukura and co-workers found elevated levels of MSCs in the synovium fluid after meniscal injury compared to normal knee joints suggesting that MSCs in the fluid may play a role in the regeneration of meniscus [41, 42].

In summary, local or systemic MSCs seem to play a fundamental and essential role in the regeneration of meniscal injury, either as direct repair cells or as a source for secretion of bioactive modulators.

58.4.2 Mesenchymal Cells for Enhanced Meniscal Tear Repair

If the meniscal repair succeeds, then the patient is left with a normal or near-normal meniscus, and thus no increased risk of OA in the future [37]. However, in a recently published meta-analysis, the long-term outcome of meniscal repair showed a mean failure rate of 23.1 % [43]. Can MSCs help to enhance meniscal tear repair/regeneration?

Preclinical trials have shown enhanced healing of meniscal lesions with the application of mesenchymal-based cells (Tables 58.4 and 58.5) [37]. While control groups with untreated tears, treatment with meniscal suture alone or meniscal suture in combination with implanted cell-free biomaterials revealed no recognizable healing, locally applied expanded MSCs from the bone marrow have achieved regeneration of longitudinal meniscal tears in the avascular zone in the lateral meniscus of New Zealand white rabbits [44]. Moreover, injection of autologous MSCs into the knee joints after partial meniscectomy showed an increased meniscal tissue formation mainly due to direct repair effect of the injected stem cells in a preliminary human study [45].

Table 58.4 Mesenchymal stem cells for meniscal regeneration

Pro/advantages	Cons/disadvantages
High regenerative potential Self-renewal capacity Cellular modulation at lesion site Potential of differentiation into meniscal repair cells Secretion of bioactive substances like growth factors Support/promotion of intrinsic meniscal healing capacity	High treatment costs Regulatory burden Missing knowledge of underlying repair mechanisms Possible need for cell expansions prior to application

Nonetheless, despite the fact that meniscal regeneration seems to be feasible by GFs and mononucleated cells, none of the cell-based strategies has entered clinical practice to date. The implementation of cell-based strategies is mainly limited by regulatory burdens and by the necessity to expand cells prior to transplantation resulting in high treatment costs. Alternative treatment modalities, which use GFs concentrated from peripheral blood aspirates or mononucleated cells concentrated from bone marrow aspirates, are currently in development in order to allow an attractive one-step procedure without the need for cell expansion in cultures and thus with lower efforts, costs, and regulatory restrictions (Table 58.5).

58.4.3 Mesenchymal Cells for Enhanced Meniscal Defect Repair

Searching for optimal restoration of meniscal tissue, biocompatible scaffolds came in the focus for the treatment of large meniscal defects in the last decade [46]. The rationale for using cell-free biomaterials after extensive loss of meniscal tissue is based on repopulation of the scaffold by host cells recruited from the synovium or the meniscal remnants [30, 47].

The amount of the developed repair tissue and its quality induced by the cell-free implants still seem to be crucial and improvable. Scar formation, repair tissue rich of vessels, and vascularization into the tip of the new meniscal tissue show the need of improvement of this treatment technique. At the moment, the cell-free meniscal

Table 58.5 Regenerative treatment options for meniscal lesions

Treatment	Pro/cons
Augmentation of meniscal suture and meniscal reconstruction by intra-articular microfracturing	Easy to perform Adhesion of stem cells at lesion site
	Uncertain effect Low concentration of stem cells at defect site
Augmentation of meniscal suture or meniscal cell-free reconstruction (e.g., Actifit) by locally applied growth factors (e.g., PRP)	Application directly at meniscal lesion site High concentration at lesion site Support of intrinsic healing potential One-step procedure
	Preparation time Short-term effect at lesion site Uncertain local effect
Augmentation of meniscal suture by locally applied MSCs (e.g., bone marrow derived)	High potential differentiation Application directly at meniscal lesion site Support of meniscal regeneration Use of autologous cells Potentially one-step procedure
	Preparation time Regulatory burden Missing knowledge of repair mechanisms
Intra-articular injection of MSCs/growth factors	Adhesion at lesion site Easy to perform
	Uncertain effect Low concentration of stem cells at lesion site Harvesting and preparation prior to application Side effects in the knee joint beside the defect site
Intravascular injection of MSCs	Adhesion at lesion site
	Uncertain effect Low concentration of stem cells at lesion site Harvesting and preparation prior to application Side effects in other areas besides the defect No clinical experience
Implantation of MSC loaded carrier/scaffold at meniscal defect site	Potential for treatment of meniscal critical size defects Application directly at meniscal defect site Option for predifferentiation of MSC/carrier construct Use of autologous cells
	High costs Missing knowledge of repair mechanisms Necessity of cell expansion prior to implantation/two-step procedure No clinical experience

implants are only used in a very selective group of patients [46]. Despite promising short-term results of meniscal implants [48, 49], none of them has currently demonstrated regeneration of a functional, long-lasting meniscal tissue.

In experimental trials, different settings have been tested for MSC-based TE approaches for the treatment of meniscal defects (Table 58.4). Stem cells can be administered by different ways of application. In most studies, the local application of MSCs has been used (Table 58.5). Ischimura et al. (1991) showed a faster and improved healing of avascular meniscal defects in a rabbit model by using bone marrow fibrin clot constructs compared to fibrin clot alone [50]. They postulated that the benefit of this treatment is due to the pluripotent stem cells in the bone marrow. Analogously, in another preclinical study, Angele et al. could achieve the repair of critical size meniscal defects with stable differentiated meniscus like tissue by local application of MSCs loaded in hyaluronan collagen composite matrices [51]. Nonetheless, as for the treatment of meniscal tears, also in the case of meniscal defects despite the intriguing potential of MSCs in optimizing the meniscal repair of actual clinically available cell-free biomaterials, the implementation of cell-based strategies in the clinical setup is currently limited by regulatory burdens and by the necessity to expand cells prior to transplantation resulting in high treatment costs.

58.5 New Trends and Future Perspectives

TE is probably one of the areas of knowledge undergoing faster development in our days, with strategies combining the use of three main variables: scaffolds, cells, and bioactive agents or GFs. Cells expanded in vitro are seeded into an appropriate scaffold, and then, either directly or after in vitro conditioning, the cell-scaffold construct is implanted into the injury site (Fig. 58.1). Alternatively, regenerative medicine is a wider concept which combines TE principles but also gene therapy, soluble molecules, stem cell technology to restore or establish the normal functions of cells/tissues/organs.

So far, concerning meniscal repair, clinical experience with TE and regenerative medicine has been limited to more simple approaches. However, basic science research is already pointing new trends with promising future, and some of the most promising topics for the future of meniscal repair and/or substitution will be described in the following paragraphs.

58.5.1 Scaffolds: New Materials? New Methods? Patient Specific?

Scaffolds are three-dimensional (3D) porous structures made from biodegradable biomaterials aiming to receive cells enabling them to become active, grow, and differentiate. It needs to be much more than a physical construct with appropriate size and shape. Size and geometry of single pores and their interconnectivity must also be matched to facilitate the interaction between cells and scaffold. The end result of this interaction is determinant for the success of biomimicry of the ECM of the damaged/diseased tissue. Cells are the basic constituent of a tissue by synthesizing the ECM of the tissue which is ultimately responsible for function. Both stem cells and differentiated cell have been employed in preclinical TE strategies [52]. However, so far only acellular scaffolds have been employed in TE strategies for clinical meniscal partial replacement: despite promising early results from collagen-based and polyurethane-based scaffolds, the obtained neo-tissue showed some dissimilarity in characteristics with the native fibrocartilaginous meniscal tissue [53]. Some limitations may be due to the fact that the conventional scaffold manufacturing methods do not permit precise control of size of the whole construct comparing to patient's anatomy. Moreover, there are also limitations concerning size and geometry of single pores and their interconnectivity. To this regard, rapid prototyping (RP) techniques represent a technology by which a physical construct can be created layer-by-layer using a computer-aided design based on medical imaging (e.g., CT or MRI). RP approach could allow in the near future to manufacture customized scaffolds with

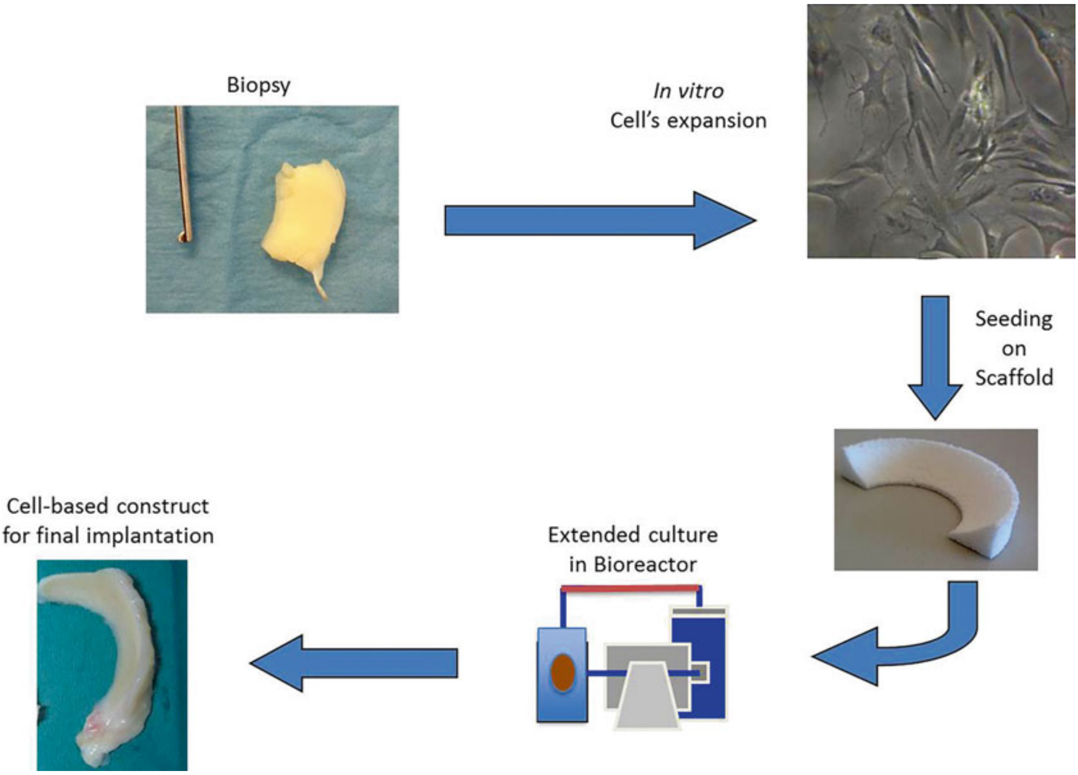

Fig. 58.1 Summary of TE approach for meniscal tissue: cell source is defined (differentiated or MSCs); these cells are expanded in vitro and then seeded on an appropriate scaffold (construct); the achieved construct is taken into a bioreactor to mature the tissue improving cellular and biomechanical features; a final implant is obtained mimicking as close as possible the characteristics of native tissue

precise anatomical shape and better architecture, producing patient-specific implants for partial and total meniscal replacement which will match each patient's anatomy (Fig. 58.2) [52]. Moreover, RP could also allow to facilitate the right distribution of different cell populations within the meniscus besides manufacturing patient-specific scaffolds with the right architecture, which might be one more step forward in the long road to develop TE constructs capable to mimic the native meniscal tissue characteristics for clinical application [52].

Interesting developments may be also offered by the several new biomaterials still being tested preclinically [53] including silk fibroin [54], polycaprolactone-polyurethane [55], hyaluronic acid-polycaprolactone [27], and polyglycolic acid [56]. Furthermore, a novel promising solution is the use of hydrogels. Hydrogel is a network of natural or synthetic polymer chains that are water insoluble in which water is the dispersion medium (sometimes found as a colloidal gel). Hydrogels are useful in TE as they present cells in a 3D context for tissue formation and defect repair. These water-swollen networks provide a local microenvironment that can signal to cells through various chemical and mechanical signals and serve as a permeable matrix for the diffusion of soluble factors [57]. Hydrogels have also shown to improve mechanical properties and delayed enzyme-triggered degradation of collagen scaffolds for meniscal repair [58]. Finally, hydrogels can also be used to improve cell-based constructs and possibly even to control the neovascularization process [59].

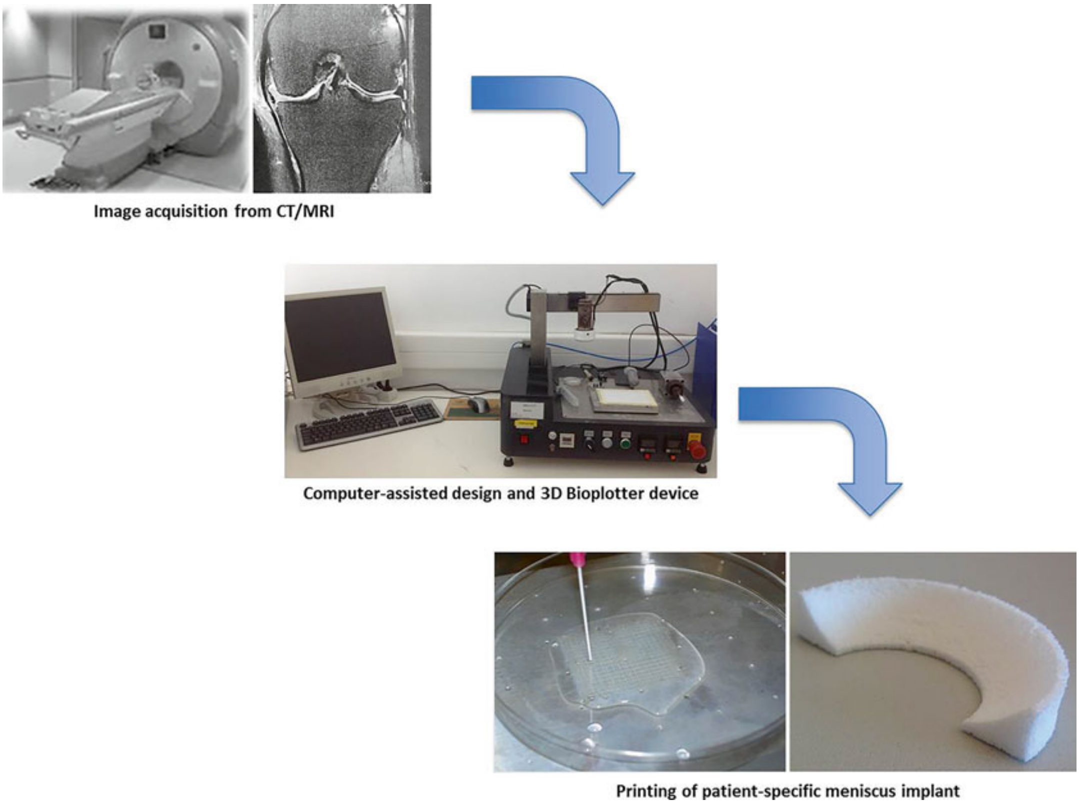

Fig. 58.2 Summary of rapid prototyping (RP) techniques: Image acquisition by MRI/CT will enable to define characteristics of patient-specific meniscus (or meniscal defect); computer-assisted technology will use this information, and a 3D Bioplotter device will be capable to print layer-by-layer an optimized implant matching the patient's needs

58.5.2 Controlling Growth Factors

GFs are countless polypeptides which transmit signals and have a specific effect on the activity of cells, and incorporating GFs into TE strategies for treating meniscal lesions has a great potential. For example, IGF-1 plays a role in chondrogenesis and similarly in the regeneration of meniscus: Zhang et al. [18] combined GF gene therapy and TE and performed a preclinical study with IGF-1-transfected cells that were incorporated into injectable gels. They were able to obtain repaired meniscal defects more similar to native meniscus. Huey and Athanasiou [60] demonstrated that two bioactive agents, chondroitinase-ABC (C-ABC) and TGF-β1, can be used for maturational growth of meniscal neo-tissue both biochemically and biomechanically, and BacBarb et al. [61] further reinforced the role of C-ABC and TGF-β1 in the development of meniscal tissue. Ionescu et al. [62] also demonstrated that in vivo short-term delivery of bFGF and in vivo sustained delivery of TGF-β3 stimulated meniscal repair.

Furthermore, chondrogenic GFs can be used to influence cell's differentiation in vitro for meniscal TE [63]. Differentiation of myoblasts was achieved with cartilage-derived morphogenetic protein-2 (CDMP-2) alone or combined with TGF-β1 [63], and Hoben et al. [64] investigated a large number of strategies for the differentiation of human embryonic stem cells to fibrochondrocyte-like cells by using a variety of GFs.

As previously stated, GFs can be used alone or in association as in platelet-rich plasma (PRP).

GF technology is under development in different directions and might be a future answer enabling the control of cell's activity to accelerate tissue healing in loco or enhance repair strategies or even to enable to optimize meniscal regeneration.

58.5.3 Cell-Based Strategies and Bioreactors

The strategy of using cell-laden scaffolds for meniscal repair has been reported in several preclinical studies. There is a continuous search for the best cell source, the best protocol for activation, growth, and differentiation, but a fibrocartilage with the same biomechanical features as the native meniscus is still far from being obtained. Advanced TE strategies are trying to develop the "perfect tissue" in vitro, thanks to meniscal-specific bioreactors.

Bioreactors are devices that are used to mimic the in vivo conditions for cell culturing in TE applications (oxygen ratio, pH, temperature, nutrients, osmolality) [65]. It is known that cell's differentiation is improved by mechanical stimulation, whereas cellular proliferation is stimulated by continuous perfusion [66]. Based on this rational, Martinez et al. [67] demonstrated that the use of a bioreactor improved collagen synthesis, and Fox et al. proved the positive effect of bioreactors in meniscal TE as well [68].

The "ideal" bioreactor for meniscal TE research should be capable to mimic the complexity of compressive, strain, and shear forces acting on menisci within the knee joint. This would be another decisive advance in TE for meniscus, but unfortunately, while preliminary steps have been performed, this development is still far from being accomplished [52].

Conclusion

The future of meniscal substitution is strongly supported by a clinical need. In fact, the clinical demand for partial substitution is growing based on the awareness that the risk of OA development is related to the amount of meniscal tissue lost. Meniscus is a complex and challenging tissue with a major role in the homeostasis and function of the knee joint. However, it is known to have limited inherent capacity for healing.

Considering the current "state-of-the-art" scientific knowledge, the first step for developing new possibilities for repair of any tissue is a more precise understanding on the internal architecture and biological constituents and function. In this light, in recent years, research efforts allowed to significantly evolve fundamental knowledge on meniscal biology. Besides the "classic" fibroblast-like and chondrocyte-like cells, another type of flattened and fusiform cells present at the superficial zone of the meniscus has been described, which seems to behave as specific progenitor cells with a higher migration capability [69]. A small population of meniscal cells (0.2 % ± 0.1 %) are positive for CD45 (marker for hematopoietic stem cells), and it has been suggested that these cells may influence the chondrogenic differentiation of MSCs as well as the stimulation of repair responses through paracrine signaling [70]. Moreover, recent studies underline how the meniscus is not a completely uniform structure, with segmental variation concerning microarchitecture, cell's distribution, and biomechanical properties: the anterior segments seem to have lower cellularity and higher damping mechanical properties, while the posterior segments are stiffer, with the viscoelastic behavior directly correlated to the extracellular matrix (ECM) composition of the meniscus [71]. Despite these recent advances, biological characterization of human meniscus is not yet completed. This is determinant for the success of future technologies, and further research efforts are needed to bring new insights concerning meniscal biomechanics, biology, and on how to modulate the recruitment and activation of specific cells for healing mechanisms.

The pillars for the future [72] are therefore in basic science research, to unravel the mechanisms that could increase the healing potential and favor the possibility to develop new effective treatments to regenerate the damaged tissue. To this regard, different approaches are currently under investigation, and the main highlights have been summarized in this chapter.

Gene therapy is a promising technology to improve meniscal repair as shown by the current advances in experimental research. Yet, no clinical trial using therapeutic gene transfer has been initiated to our best knowledge. The most appropriate candidate gene(s) and vector and the optimal cell source and biomaterial still need to be defined, and robust preclinical data in relevant animal models in vivo are needed prior to clinical translation, both in terms of safety and healing potential. Similarly, the use of GFs holds promise but is still far from the clinical application. GF technology is under development in different directions and might be a future answer enabling the control of cell's activity to accelerate tissue healing in loco or enhance repair strategies or even to enable to optimize meniscal regeneration. However, GFs are countless polypeptides, and the understanding of the mechanisms of signal transmission to have specific effects on the activity of cells, as well as their interaction, is far from been fully elucidated. The relative ease of preparation, applicability in the clinical setting, favorable safety profile, and possible beneficial outcome have made PRP to be considered a promising therapeutic approach to take advantage of GFs potential for future regenerative treatments, including for meniscal tears. However, there is a large knowledge gap not only in the definition of PRPs mechanism of action but also in the correlation between the promising in vitro effects and the understanding of the real clinical efficacy, which currently lacks of sufficient literature support.

Interesting developments may be also offered by the several new biomaterials still being tested preclinically including silk fibroin, polycaprolactone-polyurethane, hyaluronic acid-polycaprolactone, and polyglycolic acid, all candidates to offer to cells a 3D context for tissue formation and defect repair. Furthermore, a novel promising solution is the use of hydrogels, water-swollen networks to provide a local microenvironment that can signal to cells through various chemical and mechanical signals and serve as a permeable matrix for the diffusion of soluble factors.

Among the possible cell sources to be seeded in these three-dimensional structures, the most exploited option is represented by MSCs, which fulfill a dual role for musculoskeletal repair, since they have the potential to differentiate into the repair cells themselves and to produce special GFs for its repair. Unfortunately, the implementation of the promising MSC-based strategies is mainly limited by regulatory burdens and by the necessity to expand cells prior to transplantation resulting in high treatment costs. Thus, alternative treatment modalities, which use mononucleated cells concentrated from bone marrow aspirates, are currently in development in order to allow an attractive one-step procedure without the need for cell expansion in culture and thus with lower efforts, costs, and regulatory restrictions. The strategy of using cell-laden scaffolds for meniscal repair has been reported in several preclinical studies. There is a continuous search for the best cell source, the best protocol for activation, growth, and differentiation, but a fibrocartilage with the same biomechanical features as the native meniscus is still far from been obtained. Further improvements could be offered by new technologies such as RP, which could facilitate the right distribution of different cell populations within the meniscus besides manufacturing patient-specific scaffolds with the right architecture, one more step forward in the long road to develop TE constructs capable to mimic the native meniscal tissue characteristics for clinical application. Moreover, advanced TE strategies are trying to develop the "perfect tissue" in vitro, thanks to meniscal-specific bioreactors to provide the most appropriate environment and stimulation for an optimal tissue formation. This would be another decisive advance in TE for meniscus, but unfortunately, while preliminary steps have been performed, this development is still far from being accomplished.

TE is probably one of the areas of knowledge undergoing faster development in our days, with strategies combining the use of three main variables: scaffolds, cells, and bioactive agents or GFs. So far, concerning meniscal repair, clinical experience with TE and regenerative medicine has been limited to more simple approaches, but basic science research is already pointing new trends with promising future. The complexity of meniscal lesion patterns together with patient-specific variability and the often associated altered joint environment are challenges that will require the development of different solutions, to tune and improve the combination of the different regenerative options in order to obtain the best solution for each specific lesion.

In conclusion, despite the challenges in the healing of this tissue, basic science advancement provides a powerful armamentarium of effective tools with the potential to enhance the reparative capacities of the meniscus. High costs and regulatory burdens are major limitations, and there is still a road ahead in bringing the new advanced biological strategies from the research bench to clinical application. However, TE and regenerative medicine offer broad perspectives in terms of future developments, and the combination of these technologies is likely to be the "road for the future" to overcome the limitations of the current treatment options, reproducing a valid biological tissue and improving the treatment of meniscal lesions.

Acknowledgment Parts of this chapter have been published by Angele et al., JEO1 (2014).

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C. Hulet et al. (eds.), *Surgery of the Meniscus*, DOI 10.1007/978-3-662-49188-1

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