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Editors

The Meniscus

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(Eds.)

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ISBN: 978-3-642-02449-8 e-ISBN: 978-3-642-02450-4

DOI: 10.1007/978-3-642-02450-4

Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2009938033

Cover design: eStudio Calamar, Figueres/Berlin

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

The Meniscus

The management of meniscus lesions is an unbelievable story of so-called scientifically based, controversial treatment, covering a time span of more than 120 years, including:

- The time when a locked knee was manipulated in order to reduce a bucket-handle or a flap tear back into place to restore motion.
- The time when famous surgeons excised the meniscus in thousands of patients and kept the resected specimens as trophies in large glass jars.
- The time of animated discussions on whether either partial meniscectomy, only removing the ruptured parts, should be performed or total meniscectomy, as advocated by Smillie, because some meniscus-shaped semilunar tissue regeneration had been shown by Mandic after complete removal.
- The time when the next milestone was reached as Trillat introduced intramural resection, which preserved the circular stabilizing fibrous rim with its menisco-ligamento-capsular attachments to the tibia and femur, to maintain more rotational knee stability.

Prior to these mainstream meniscal resection treatments, pioneering work had been done by Thomas Annandale in 1883 and Moritz Katzenstein in 1908, who sutured the menisci back into place, with the latter achieving a series of good results. In 1921, Eugen Bircher was the first to perform a diagnostic knee arthroscopy for internal knee derangement, just using a standard Jacobaeus laparoscope!

Nowadays, the fundamental importance of the menisci to normal knee function, e.g., motion, load distribution, and rotational stabilization, is scientifically acknowledged.

Many years have passed before surgeons could understand what Kapandji had shown decades ago, namely that the menisci form some kind of three-dimensional figure of eight together with the attached anterior and posterior cruciate ligaments, including the meniscofemoral ligaments of Humphrey in the front and of Wrisberg in the back of the posterior cruciate ligament.

The two cruciate ligaments alone, with their short lever arm, do not effectively control rotation, but together with the attached menisci they are capable of acting as rotatory stabilizers.

These facts have been well-known ever since ACL rupture combined with meniscus avulsion became a tactical problem for open or arthroscopic treatment.

Bearing all that in mind, there is no doubt that we have to preserve the menisci or at least their functional parts and to even replace them by implants or transplantation if necessary. In this book, conceived by the masters of the art René Verdonk and Philippe Beaufils, the readers will find all that they need to know about the anatomy and function of the meniscus, the classification of meniscus lesions, and the examination techniques (clinical, X-rays, MRI, arthro CT scan, bone scan, etc.) to establish the correct diagnosis and the proper therapeutic approach.

A large part of the book is devoted to the technique, postoperative evaluation and results. The indications in traumatic stable and unstable knees and in knees with degenerative lesions are extensively described.

The very important issue of meniscus pathology in children is addressed in a separate chapter, followed by the postmeniscectomy knee and a lengthy chapter on meniscal reconstruction. The book concludes with a chapter on future developments and directions, such as animal models, tissue engineering, and gene therapy.

All the chapters have been written by internationally acknowledged experts in the field. It will be a pleasure to read and learn from them.

Werner Müller

Preface

The meniscus has been forgotten!

It is not long ago that any suspicion of a meniscal lesion eventually led to an open meniscectomy, which in most of the cases was total. This solution was widely proposed as it was considered to be a simple and effective procedure followed by speedy recovery. It was recommended mainly because the importance of the biomechanical role of the meniscus was not recognized.

The studies of Fairbank on the consequences of meniscectomy, those of Smillie and Noble on the prevalence of meniscal lesions acknowledging the process of meniscal aging, the study of Trillat who proposed a classification of meniscal lesions and opted for an intramural meniscectomy (the first hint of a partial meniscectomy), the studies of Watanabe on dysplastic menisci, and many more have increased the awareness about the fact that pathologic conditions of the menisci have repercussions on the entire knee joint and that surgical treatment must be adjusted accordingly.

In the 1970s and 1980s two truly revolutionary improvements were introduced: arthroscopic surgery and magnetic resonance imaging (MRI). It should be emphasized that arthroscopy was introduced into clinical practice before MRI and the order in which the diagnosis and treatment take place today (physical examination, MRI, arthroscopy) is different from that followed earlier. Arthroscopy has played an important role in the diagnosis of meniscal lesions.

These technological advances contributed to a better understanding of meniscal pathology, diagnostic techniques, and principles of treatment, and resulted in a lower complication rate. Like all technical innovations, they also entailed some disadvantages, such as the risk of resorting too often to surgical treatment, particularly meniscectomy, as a result of the sensitivity of these methods.

However, the advantages prevailed over the drawbacks. It was then realized that the menisci play a prominent role in knee joint biomechanics, and that there is not just one but many different meniscal lesions and consequently not just one but various treatment methods, adapted to the type of lesion and its clinical context.

This has led to the concept of meniscal preservation or meniscal sparing, which is based on three pillars: as partial a meniscectomy as possible, thanks to arthroscopy, meniscal repair, and leave the meniscus alone. The first surgical repair of a meniscus was performed in 1885 by Annandale. Now the technique of meniscal repair has become more refined, proceeding from open meniscal suture to combined open and arthroscopic techniques and then to all-inside techniques, which are now widespread. The results have been evaluated and the indications have been clearly defined, particularly those concerning the choice among meniscectomy, surgical repair, and leave the meniscus alone.

Meniscal lesions in children have been the subject of intensive investigation and comprise dysplastic and traumatic lesions. Meniscectomy, which would be particularly devastating in these young patients, has been progressively abandoned in favor of conservative techniques.

By the end of the 1980s and during the 1990s the era of meniscal replacement began in Europe, pioneered by the German (C. Wirth) and Belgian (R. Verdonk) schools. This new exciting approach to treating meniscal pathology was focused on finding a modern solution to the particularly challenging problem of a symptomatic postmeniscectomy knee. Meniscal replacement, performed earlier with an allograft and recently with an artificial substitute, is a fascinating surgical concept in this respect, but the procedure must be carefully evaluated before it can be generally adopted.

Surprisingly, to the best of our knowledge there is no book devoted exclusively to the meniscus, although many books have been written on the anterior cruciate ligament, osteoarthritis of the knee, total knee arthroplasty, etc. For this reason, we have come up with the idea of filling this vacuum by compiling current knowledge of the meniscus in one book. The aim of this book is to share the experience gained over the years by two teams interested in meniscal pathology, one from Ghent and the other from Versailles. Many chapters have been written by current and past members of these teams and we hope that this has made our work more coherent. Apart from this, we welcome the contributions of many knowledgeable European and American colleagues, who are also our friends. We would like to thank all of them.

The book is divided into chapters, from basic science to meniscal transplantation through pathogenesis, clinical and radiological manifestations, treatment methods, their outcome and evaluation, indications, the particular case of meniscal pathology in children, and the difficult problem of a symptomatic postmeniscectomy knee. At the end of each section, a brief synthesis is provided, highlighting all the main points as well as our suggestions and unresolved issues. We do not intend to claim that we have exhausted the subject: some important information may have been omitted. Nevertheless, we hope that this book will help one to approach meniscal lesions in a modern, well-considered, and appropriate manner.

Versailles, France Philippe Beaufils, MD
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Acknowledgement

First of all, we would like to thank all the current and past members of our teams. Through numerous discussions, studies, papers, ... they encouraged us to improve and to share our knowledge of the meniscus. This book is the result of this permanent exchange.

We also thank all the contributing authors for accepting the assignment and for giving so generously of their time and effort in meeting the requirements. They simply built this book.

Nicolas Pujol and Andrzej Podgorski reviewed with us the manuscripts and the final proofs. Thank you so much for this meticulous work.

Our gratitude also goes to Karolien Bral and Jocelyne Herruel for their continuous support and the editorial work to finalize the scientific papers.

And last but not least, Iris Wojtowicz reviewed the English usage in all the papers authored by contributors from non-English-speaking countries. This not only allowed to improve the quality of the text but also to harmonize the manuscripts. We are deeply grateful to her for this huge work.

This book is endorsed by the European Society for Sports Traumatology, Knee Surgery and Arthroscopy (ESSKA), the Société Française d'Arthroscopie (SFA), and the Arthroscopie Belge/Belgische Artroscopie Association (ABA). These scientific societies have always supported our work and have made it available to many colleagues through their meetings and scientific journals.

We are well aware of the major role these scientific societies play in our professional life and we are greatly indebted to them.

Ghent, Belgium — René Verdonk, MD, PhD
Versailles, France — Philippe Beaufils, MD

Contents

Part III Preoperative Clinical Examination and Imaging

Part IV Technique

Part V Postoperative Evaluation

Part I

Basic Science

Ontogeny-Phylogeny

1.1

B. Lebel, C. Tardieu, B. Locker, and C. Hulet

Introduction

Knee anatomy can be traced back to more than 300 million years, to the pelvic appendages of Sarcopterigian lobe-finned fish [7]. Thorough knowledge of the gross anatomy and histology of the meniscus is a prerequisite for understanding its function. Furthermore, knowledge of meniscus-meniscal ligament complex phylogeny and ontogeny is necessary to correlate meniscal gross anatomy to meniscal function [4]. The menisci are important primary stabilizers and weight transmitters in the knee. They primarily act to redistribute contact forces across the tibiofemoral articulation. This is achieved through a 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) [33]. This asymmetry of kinematics between the medial and lateral compartment, an established characteristic of human and many other extant mammalian knees, results in an internal rotation of the tibia relative to the femur with increasing flexion. As described by Tardieu [27], three different human femorotibial characters are selected as derived hominid features and are relevant to modern bipedal striding gait. One of these characters concerns the lateral meniscus and its double insertion on the tibial plateau. This chapter explores and successively describes meniscal phylogeny, meniscal ontogeny, and the particular case of discoid meniscus.

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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, birds' knees share similar morphologic characteristics with humans' 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], who in 1942 reported an impressive dissection study of numerous living tetrapods. Mossman and Sargeant [18] 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. Eryops' knee is not so different from *crocodilus* knee. *Crocodile* menisci are both massive structures fitted between

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_1.1, © Springer-Verlag Berlin Heidelberg 2010

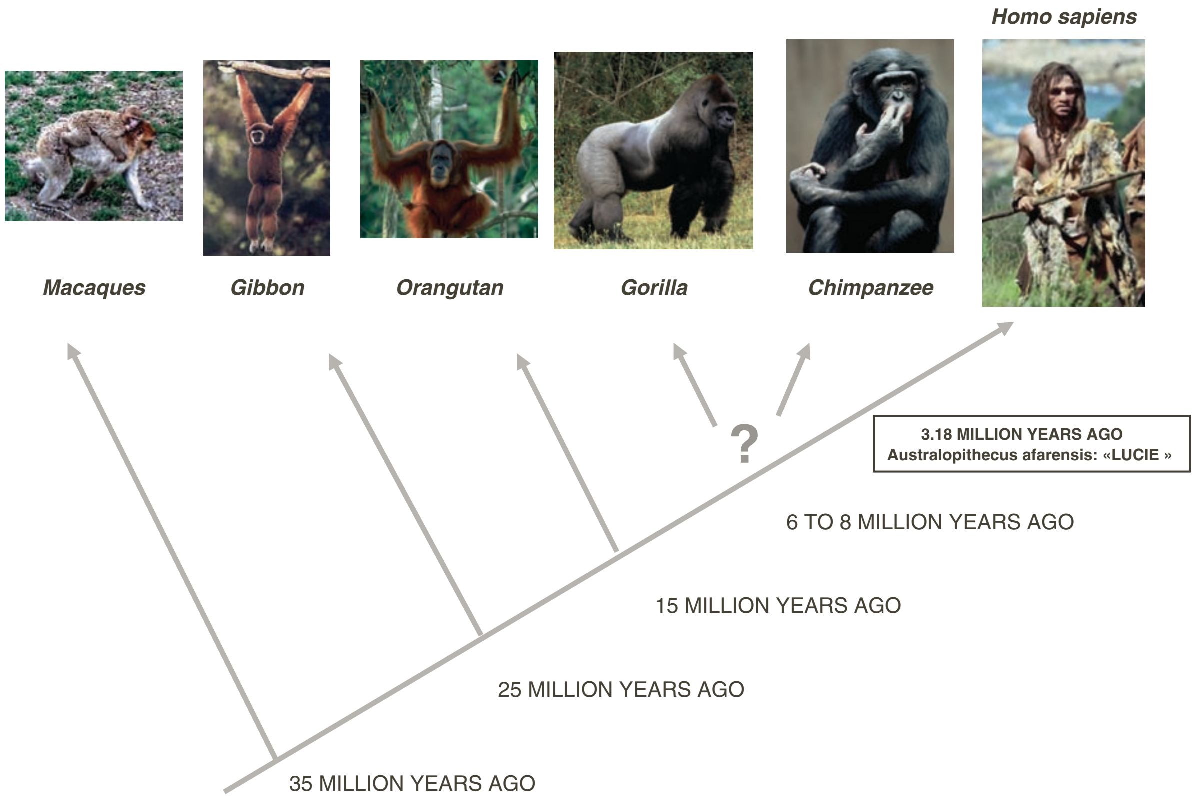

Fig. 1.1.1 The primate lineage leading to *Homo sapiens*

surfaces of the femur and tibia and 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 pass the cruciate ligaments. The lateral meniscus is also attached to the fibula by a posterior fibulomeniscal ligament. Anatomic features and knee movements are different in these two specimens, illustrating a correspondence between shape and function during evolution.

With Eryops, the lineage that leads to mammals includes Pelycosaurs such as Dimetrodon (sail-backed animal) [18]. During the Mesozoic era, 215–70 million years ago, the femurs of protomammals and dinosaurs rotated internally, such that the knee became 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 [22]. An inspection of the knee of the black bear reveals a classic mammalian knee very similar in morphologic features to a human knee [19]. In the primate lineage leading to humans (Fig. 1.1.1), the hominids evolved to bipedal stance approximately 3–4 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 [29].

Three different human femorotibial characters were selected as derived hominid features relevant 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 and grooved in humans. Finally, the third feature concerns the lateral meniscus and its double insertion on the tibial plateau. In humans, the presence of a posterior tibial insertion of the lateral meniscus

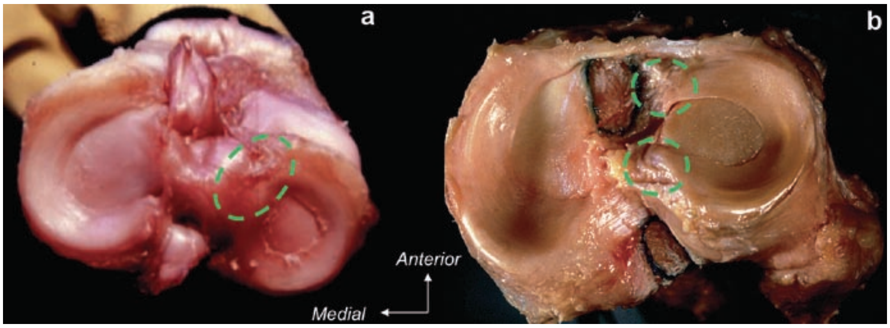

Fig. 1.1.2 Comparison between human meniscal morphology (**b**) and chimpanzee meniscal morphology (**a**). The *green circle* represents the lateral meniscus insertion

limits its mobility on the tibial plateau. The second posterior insertion aids in preventing extreme anterior gliding of the lateral meniscus during frequent extension [26]. The lateral meniscus is also strongly pulled anteriorly during medial rotation of the femur on the tibia. As in extension, the posterior attachment of the lateral meniscus limits this anterior movement [27]. This insertion, posterior to the external tibial spine, is a derived feature, unique among living mammals (Fig. 1.1.2). 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 the abilities of arboreal climbing and suspension and was different from that of modern humans [25], Tardieu 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. 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 [21, 28, 30]. A crescent-shaped lateral meniscus with one tibial insertion, anterior to the lateral tibial spine, is present in lemuriforms, *Tarsius*, platyrhines, 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. 1.1.3). The fossil record also provides evidence of a transition from a single to a 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 [20].

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. 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. Nonhuman lateral femoral condyle are more spherical with a shallow trochlear groove and no bicondylar angle. On the other hand, human femoral trochlea has a higher lateral lip. In human knees a decrease of lateral plateau convexity may also be observed. All these modifications are in coincidence with pelvic modification, especially with a decreasing interacetabular distance. According to Tardieu, modification of the bicondylar angle is an epigenetic functional feature and has never been included in the genome since three million years [27]. The higher lateral lip of the femoral trochlea already present in the fetus today is genetically determined. Nevertheless, it has probably been first acquired epigenetically and then "genetically assimilated" [29].

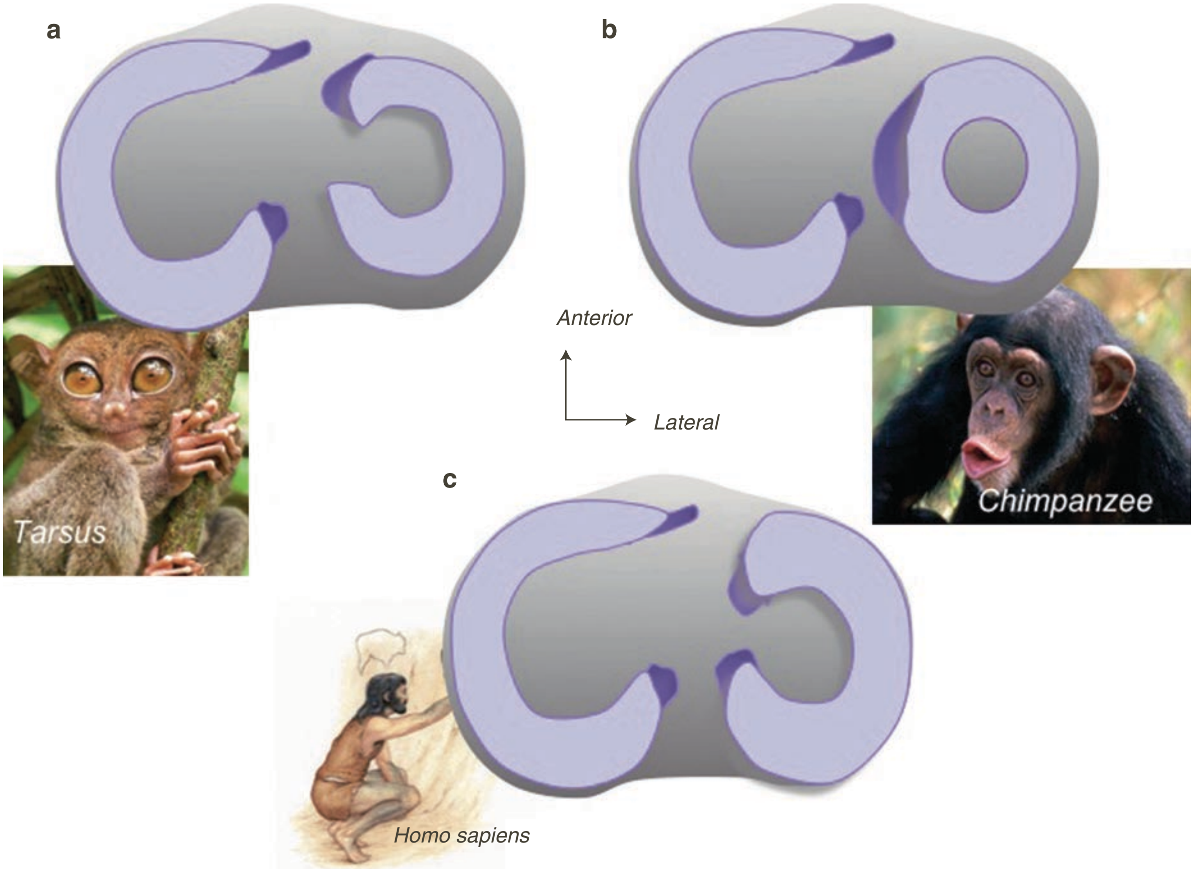

Fig. 1.1.3 The three distinct morphologies of menisci in extant primates. (**a**) Crescent shape of the lateral meniscus with one anterior insertion. (**b**) Ring shape of the lateral meniscus. (**c**) Crescent shape of the lateral meniscus with two insertions

Meniscal Ontogeny

Even if several longitudinal developmental studies of nonhuman vertebrate knees exist, literature data on developing menisci are scarce [16]. Gardner and O'Rahilly [8], McDermott [15], 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 [32]. 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

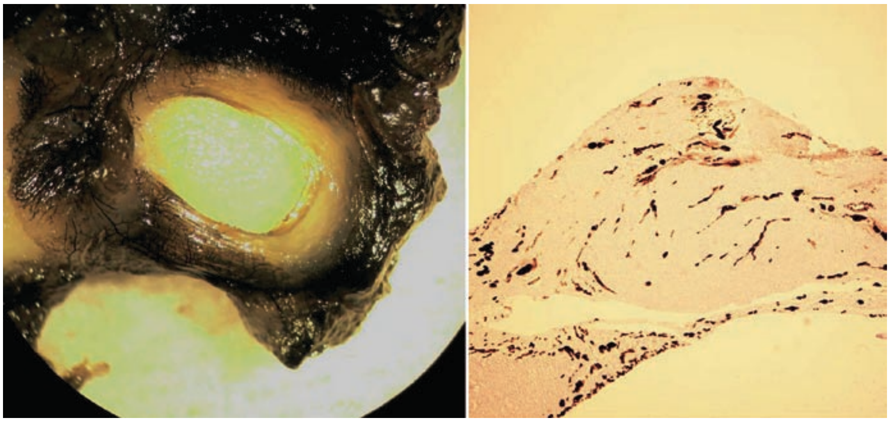

Fig. 1.1.4 Vascularization of a human fetal medial meniscus (21 weeks old). The *left picture* shows that blood vessels are prominent along capsular and meniscal attachment sites. The *right picture* shows the disposition of blood vessels in the anterior horn of the medial meniscus using immunomicroscopic analysis

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. 1.1.4). 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 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 along 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. [12] 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 peculiarity emphasizes the fact that especially in children every effort should be made to preserve peripherally detached menisci by careful reattachment.

The Particular Case of Discoid Meniscus

Discoid meniscus is a morphologic abnormality of the knee occurring almost exclusively on the lateral side [6]. Discoid lateral meniscus was first described by Young [34] in 1889. The prevalence of discoid meniscus has been reported to range from 0 to 20% among patients undergoing arthroscopy (Fig. 1.1.5).

The etiology of discoid meniscus is only partially explained. Smillie [24] 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 disk. Kaplan [13,14] 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

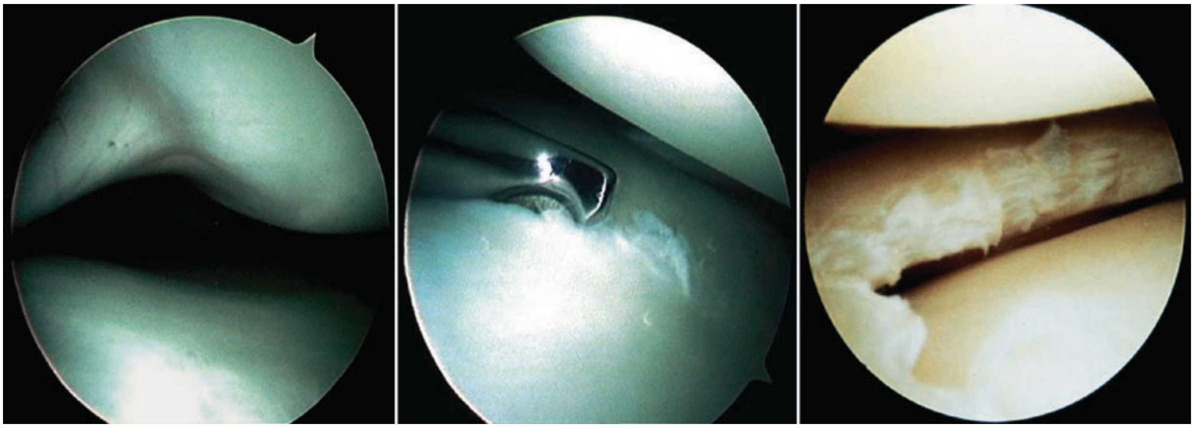

Fig. 1.1.5 Arthroscopic view of a complete discoid lateral meniscus before and after meniscal saucerization

specific conditions and was influenced by mechanical factors. According to Ross et al. [23], 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 disk. 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 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. [31] in 1978. They described three major meniscal abnormalities: (1) complete, disk-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. [17] 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

In this chapter, 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, the knee joint evolved from having a single insertion of the lateral meniscus on the tibia to a double one. 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. Considering all these facts, discoid meniscus can be considered as a reversion of character.

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Anatomy

1.2

I. D. McDermott, S. D. Masouros, A. M. J. Bull, and A. A. Amis

Morphology

The menisci are two crescent-shaped fibrocartilagenous structures that are found within each knee between the femoral condyles and the tibial plateau (Fig. 1.2.1). For many years, the menisci were considered to be the functionless remains of a leg muscle [31]. Indeed, in his paper in 1942, McMurray [21] stated that "When the knee-joint is opened on the anterior aspect, and the suspected cartilage appears normal, its removal can be undertaken with confidence if the diagnosis of a posterior tear has been arrived at (clinically) prior to operation. A far too common error is shown in the incomplete removal of the injured meniscus".

Attitudes towards the menisci have changed dramatically, and since King's pivotal paper in 1936 [17], numerous studies have shown that the menisci do in fact play various important functional roles within the knee (see Chap. 1.4).

The menisci are sometimes referred to as "the semilunar cartilages", even though they are crescentic when viewed from above, not half-moon shaped. They are wedge-shaped in cross-section and are attached to the joint capsule at their convex peripheral rim, and also to the tibia anteriorly and posteriorly by insertional ligaments. They partially cover the tibio-femoral joint surface.

Fukubayashi and Kurosawa [7] examined intraarticular contact areas using a casting method employing silicone rubber and found that the menisci combined occupied 70% of the total contact area within the joint. Walker and Erkman [34] also used casting techniques and found that under no load, contact occurred primarily on the menisci, but that with loads of 150 kg, the menisci covered between 59 and 71% of the joint contact surface area.

The peripheral rim of each meniscus has a length of approximately 110 mm [18]. Except for a portion of the lateral meniscus (LM) in the region of the popliteus tendon, the menisci are attached at their peripheral rims to the inside of the joint capsule throughout their length. This capsular attachment is often referred to as the coronary ligament. At its mid-point, the medial meniscus also has a firm attachment to the deep portion of the medial collateral ligament. The central border of each meniscus tapers to a free edge.

A congenital variant of the normal morphology of the meniscus is the discoid meniscus. Smillie [29] suggested that this variation in structure is due to a failure of the foetal discoid form of the meniscus to involute. It is difficult to determine the true incidence of discoid menisci, but in a study by Nathan and Cole [22], only 30 out of 1,219 menisci (2.5%) that had been surgically removed were found to have been discoid. Smillie [29] found 185 discoid menisci in 3,000 meniscectomies (6%). Discoid menisci are more common on the lateral side than the medial side, and they are only rarely ever found in both compartments of the knee.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_1.2, © Springer-Verlag Berlin Heidelberg 2010

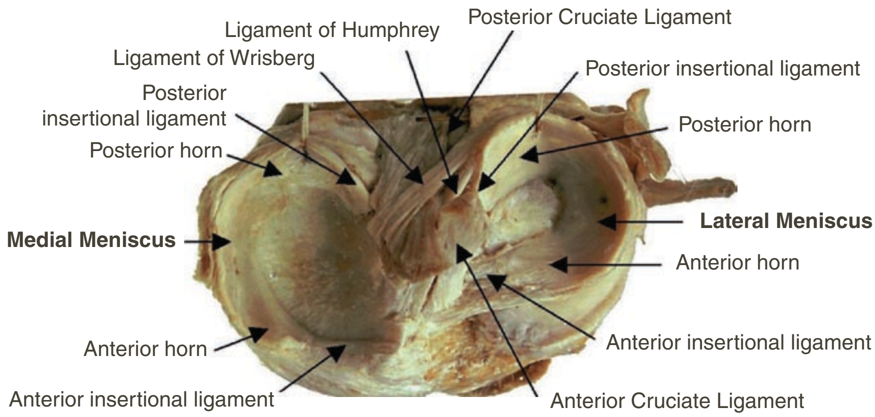

Fig. 1.2.1 Gross anatomy of the menisci and associated structures. (From The Interactive Knee, © Primal Pictures, London, with permission)

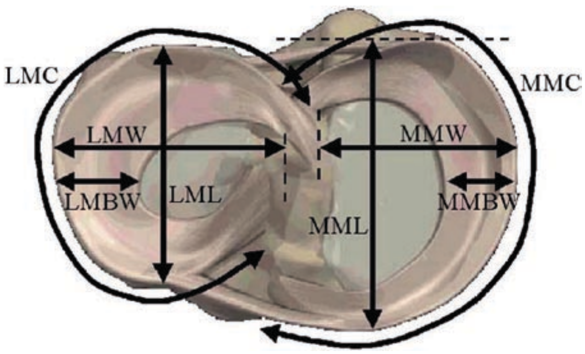

Fig. 1.2.2 Meniscal dimension measurements. (Reproduced from McDermott et al. [20], with permission from Springer.) *LMC* lateral meniscal circumference; *LMW* lateral meniscal width; *LMBW* lateral meniscal body width; *LML* lateral meniscal length; *MMC* medial meniscal circumference; *MMW* medial meniscal width; *MMBW* medial meniscal body width; *MML* medial meniscal length

Table 1.2.1 Meniscal dimensions (mm) measured from cadaver knees

	Mean	SD	Range
Medial meniscal circumference	99.0	9.3	84–119
Medial meniscal body width	9.3	1.3	6.7–12.4
Medial meniscal length	45.7	5.0	30.1–56.1
Medial meniscal width	27.4	2.5	23.3–32.7
Lateral meniscal circumference	91.7	9.6	78–112
Lateral meniscal body width	10.9	1.3	8.3–14.5
Lateral meniscal length	35.7	3.7	29.5–51.2
Lateral meniscal width	29.3	3.0	24.0–36.3

They may cause symptoms of snapping and popping in the knee in children, usually between the ages of 6 and 12 years. A discoid LM is a constant finding in some of the great apes, with substantial meniscofemoral attachments and absent tibial insertions.

In our centre, the various meniscal dimensions were measured as part of a study on meniscal allograft sizing [20]. Examining 88 menisci (medial and lateral) from a total of 22 pairs of dissected cadaveric knees, the dimensions demonstrated in Fig. 1.2.2 were determined using digital Vernier callipers. The results are given in Table 1.2.1. These results are of significant interest, as they demonstrate the very wide range that exists in dimensions between different knees. Table 1.2.2 shows the percentage difference between the largest and smallest values for each dimension,

Table 1.2.2 Percentage differences between largest and smallest values for each meniscal dimension (expressed as a percentage of the smallest value)

	Smallest value	Largest value	Percentage difference
Medial meniscal body width	6.7	12.4	85.1
Lateral meniscal body width	8.3	14.5	74.7
Medial meniscal length	30.1	56.1	86.4
Lateral meniscal length (LML)	29.5	51.2	73.6
Medial meniscal width	23.3	32.7	40.3
LML	26.3	36.3	38.0

expressed as a percentage of the smallest values. The relevance of these values lies in the critical importance that exists in accurate meniscal allograft sizing while performing meniscal transplantation using a bony bridge fixation technique [27].

The Tibial Insertional Ligaments

The circumferential collagen fibres of the meniscal body continue into the anterior and posterior insertional ligaments, which attach to the subchondral bone of the tibia. The insertional ligament of the anterior horn of the medial meniscus is fan-shaped and attaches to the tibia in the area of the intercondylar fossa, about 6 or 7 mm anterior to the attachment of the anterior cruciate ligament (Fig. 1.2.3).

In a cadaveric study of 46 donors, it was found that in 64% of cases, posterior or upper fibres from the anterior insertional ligament blended with fibres of the transverse intermeniscal ligament (which connects the anterior horns of the medial and lateral menisci) [18].

The posterior horn of the medial meniscus is attached to the tibial intercondylar fossa between the posterior attachment of the LM and the posterior cruciate ligament (PCL). Kohn and Moreno [18] found that the tibial attachments of the medial meniscus were fixed in areas that could be defined by bony landmarks, and that the anterior insertion covered an area of 139 ± 43 mm^2 and the posterior insertion an area of 80 ± 10 mm^2. The bony tibial insertions of the LM, however, were found to be less well defined.

The anterior insertional ligament of the LM inserts into the anterior intercondylar fossa of the tibia, lateral to the attachment of the anterior cruciate ligament and just anterior to the lateral intercondylar eminence. The posterior insertional ligament of the LM attaches to the tibia posterior to the lateral intercondylar eminence, but anterior to the posterior attachment of the medial meniscus.

The insertional ligaments have fibrocartilagenous transition zones that make the change in stiffness between ligament and bone tissue at the enthesis less sudden, thereby reducing the stress concentration in this unit and preventing failure. They may also diminish the risk of fatigue failure during motion.

The functional importance of the insertional ligaments was demonstrated in a study in rabbits, where transection of the anterior or posterior insertional ligaments of the meniscus led to osteochondral changes in the knee after 6 and 12 weeks that were similar to those found after total meniscectomy [30].

The Intermeniscal Ligaments

The anterior intermeniscal ligament, also known as the transverse geniculate ligament, connects the anterior fibres of the anterior horns of the medial and lateral menisci (Fig. 1.2.4). An anatomical study by Nelson and LaPrade [23] found that a transverse ligament could be identified in 94% of fifty unpaired cadaveric knees

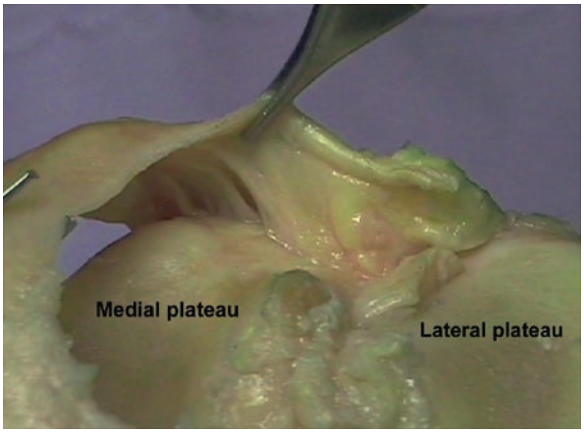

Fig. 1.2.3 Anterior insertional ligament of the medial meniscus. (Right knee, viewed posteriorly. Medial peripheral meniscal attachment released and lateral meniscus excised)

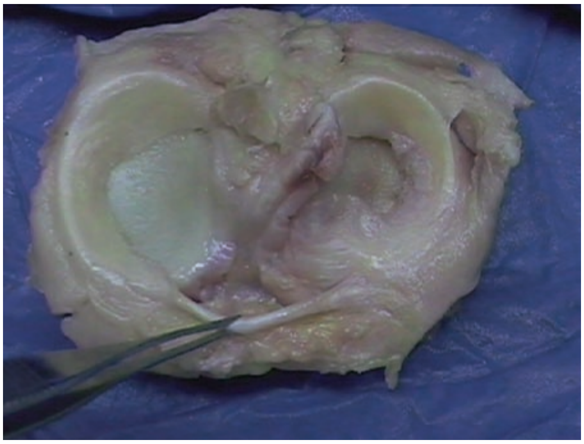

Fig. 1.2.4 The transverse geniculate ligament (shown being held with forceps)

dissected. A study of 92 knees, performed by Kohn and Moreno [18], found a ligament in 64% of specimens. The ligament can be visualised as an opacity of soft-tissue density apparent in the posterior part of the Hoffa's fat pad on 12% of plain lateral knee radiographs and 58% of magnetic resonance imaging (MRI) scans [28]. The functional relevance of this ligament has not been studied, but it may have a role in moving the menisci during tibial internal–external rotation.

Nelson and LaPrade [23] showed that the average length of the transverse ligament was 33 mm and the average midsubstance width was 3.3 mm. They also identified three distinct patterns of attachment of the ligament. In type I (46%) the ligament passed primarily between the anterior horn of the medial meniscus and the anterior margin of the LM (a true anterior intermeniscal ligament). Type II ligaments (26%) passed from the anterior horn of the medial meniscus to the joint capsule, anterior to the LM. For type III ligaments (12%), the main attachments were to the anterior capsule only.

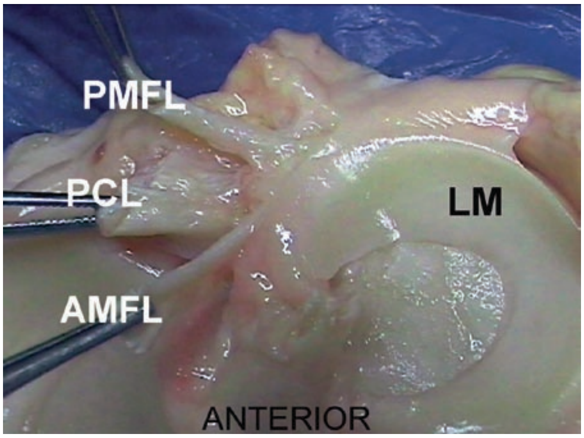

Fig. 1.2.5 The meniscofemoral ligaments (seen with the posterior cruciate ligament held in-between). *LM* lateral meniscus; *PMFL* posterior meniscofemoral ligament; *AMFL* anterior meniscofemoral ligament; *PCL* posterior cruciate ligament

The Meniscofemoral Ligaments

Two ligaments have also been identified joining the posterior horn of the LM to the lateral side of the medial condyle of the femur in the intercondylar notch. These are known as the meniscofemoral ligaments [26]. The anterior meniscofemoral ligament runs anterior to the PCL, and is known as the ligament of Humphrey. The posterior meniscofemoral ligament runs posterior to the PCL, and is known as the ligament of Wrisberg (Fig. 1.2.5). Kohn and Moreno [18] found the ligament of Humphrey to be present in 50% of 92 cadaveric knees dissected, and the Wrisberg ligament to be present in 76%. This is in keeping with other studies such as that by Lee et al. [19], who found that MRI showed either one or both meniscofemoral ligaments to be present in 83% of 138 patients scanned. Heller and Langman [12] found a meniscofemoral ligament in 71% of 140 cadaveric knees. In this study, they noted that the Humphrey ligament was up to 1/3 of the diameter of the posterior cruciate and that the Wrisberg ligament could be up to ½ the size of the PCL. It has also been noted that meniscofemoral ligaments can frequently be found in one knee, while being absent from the other knee [35]. A review of the literature by Gupte et al. [9] suggested that at least one meniscofemoral ligament was present in 93% of knees, with a significantly higher prevalence in younger knees than in older ones.

Although they have often been assumed to be only vestigial structures, there has recently been renewed interest in the meniscofemoral ligaments. They have mechanical properties comparable to the posterior bundle of the PCL [10], and it has been found that they might serve a mechanical role in the knee, acting as secondary restraints to tibial posterior drawer [11].

Further ligaments have been identified, connecting the anterior horns of the menisci to the intercondylar area of the femur, although these are far less commonly found. The antero-medial meniscofemoral ligament has been described arising from the anterior horn of the medial meniscus, and the antero-lateral meniscofemoral ligament arises from the anterior horn of the LM. In a cadaveric study of 60 knees by Wan and Felle [35], these ligaments were each found in 30% of knees.

Similarly, there are capsular bands that pass from the patella, on either side of the patellar tendon attachment, to the anterior tibia. These patello-tibial ligaments attach to the anterior horns of the menisci on their superficial aspects. These attachments appear to pull the meniscal horns anteriorly, when the knee extends.

The Composition of Meniscal Tissue

Normal human meniscal tissue has been found to be composed of 72% water, 22% collagen, 0.8%

glycosaminoglycans and 0.12% DNA [13]. On a dry weight basis, normal adult menisci contained 78% collagen, 8% non-collagenous protein and 1% hexosamine [14]. Histologically, the menisci are fibrocartilagenous and are primarily composed of an interlacing network of collagen fibres interposed with cells, with an extracellular matrix of proteoglycans and glycoproteins.

Type I collagen accounts for over 90% of the meniscal collagen, the remainder consisting of types II, III and IV [6]. Cheung [4] found that the proportion of the different collagen types within bovine menisci varies according to location. Except for trace amounts (<1%) of types III and V collagens, the peripheral two-thirds of bovine menisci consist solely of type I collagen, whereas the type II collagen (60%) predominates over type I (40%) in the inner third [4]. The collagen fibres themselves have been shown to be heavily cross-linked by hydroxylpyridinium aldehydes [6].

The Fine Structure of Menisci

The orientation of the collagen fibres within the meniscus relates directly to the function of the tissue (Fig. 1.2.6). Bullough et al. [3] found that the principal orientation of the collagen fibres is circumferential, to withstand tension. They also found that other radially orientated collagen fibres were present, predominantly in the mid-zone of the meniscus and also on the exposed surfaces. They stated that these radial fibres might act as "ties" holding the circumferential fibres together to help prevent longitudinal splitting of the menisci.

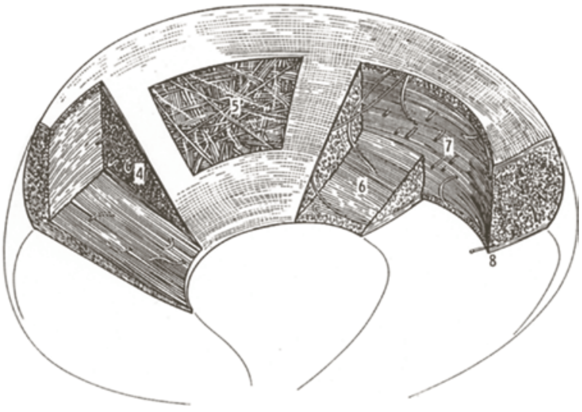

Fig. 1.2.6 Diagram showing the orientation of collagen fibres within the meniscus. (Reproduced with permission and copyright from the British Editorial Society of Bone and Joint Surgery from Bullough et al. [3])

Beaupre et al. [2] identified two well-differentiated regions within the menisci: the inner two-thirds and the peripheral outermost third. In the inner part, the collagen bundles were primarily radially orientated and were also parallel to the articular surface. In the peripheral part, the bundles were larger and were circumferential. They related these differences to function, and stated that the radial fibres of the inner part were best adapted to transfer of compressive axial load from the femur to the tibia, while the peripheral circumferential fibres resisted tensile forces. The collagen bundles of the surface layer are randomly orientated with a composition similar to articular hyaline cartilage (Fig. 1.2.6).

There are two types of cell found within the meniscus [8]. The superficial zones contain cells that are oval or fusiform, with few processes and scant cytoplasm, resulting in the nucleus appearing disproportionately large. The deep zones of the menisci are populated by rounded or polygonal cells with a large amount of rough endoplasmic reticulum. These cells are usually solitary, but are occasionally found in groups of two or three. They have properties that are found in both fibroblasts and chondrocytes, and in 1985, Webber et al. [36] proposed the term "fibrochondrocytes" to describe them.

Blood Supply and Innervation

It has been shown that at birth, the whole meniscus is vascularised [24]. However, an avascular area soon develops in the inner zone of the meniscus, and in the second decade, blood vessels occur only in the outer third. This progressive loss of vascularity may be due to weight-bearing and knee motion.

Anatomical studies [1] have shown that vessels to the menisci arise mainly from the medial and lateral inferior, and the middle geniculate arteries. Branches from these vessels form a perimeniscal capillary plexus that was first identified by Policard [25]. Radial branches from this perimeniscal capillary plexus penetrate the periphery of the meniscus at intervals, with a richer supply to the anterior and posterior horns [5].

The degree of vascularity varies within each meniscus, and the extent of the peripheral vascular zone also varies between individuals, ranging from 10 to 30% of the meniscal width [1]. The extent of the vascular zone has implications for the healing of meniscal tears.

There is an area in the posterolateral region of the LM, adjacent to the popliteus tendon, where the meniscus does not have any capsular attachment. This area is relatively avascular.

Reports on the innervation of the menisci are conflicting. Kennedy et al. [16] found abundant axons, large nerve bundles, free nerve endings, and specialised receptors including complex end bulbs and Golgi-type type III endings in perimeniscal capsular tissue. However, this innervation did not extend into the meniscal body itself. Day et al. [5], however, demonstrated that nerves run with the radially oriented blood vessels in the outer portion of the meniscus. As with the blood supply, there was a greater innervation of the anterior and posterior horns of the menisci, and unlike in the body of the meniscus, here, axons were found in the inner one-third.

Wilson et al. [37] also showed penetration of neural tissue into the outer third of the meniscus. However, they showed that the neural elements were not exclusively paravascular in position, and postulated that the nerves may not be exclusively vasomotor in function, but that they may perform an afferent function. They felt that this was most likely to be "slow" pain.

Zimny et al. [38] also found axons penetrating from the perimeniscal tissue into the outer third of the meniscus, with a heavier concentration at the horns. They comprised all three types of encapsulated end organs (Pacini corpuscles, which are usually involved in continued information of position, and the slowly adapting Ruffini endings and Golgi tendon organs, which respond when extreme stress is applied), and free nerve endings (type IV).

The presence of mechanoreceptors in the menisci suggests that the menisci may play a role in knee-joint afferent nerve transmission. This neural information may be important in joint proprioception. Indeed, it has been shown that proprioception was disturbed in knees with an isolated meniscal lesion, and that it improved after partial meniscal resection [15].

Meniscal Motion During Knee Flexion

The menisci are dynamic structures, and to effectively maintain an optimum load-bearing function over a moving, incongruent joint surface, they need to be able to move as the femur and tibia move, to maintain maximum congruency. Thompson et al. [32] were the first to describe meniscal movements through a full flexion-extension arc in the intact knee using MRI of cadaver knees. They showed that from full extension to full flexion, there was posterior excursion of the medial meniscus of 5.1 mm and of the LM of 11.2 mm, with the anterior horns moving more than the posterior horns. However, these observations were made in unloaded cadaver knees, and may, therefore, not be representative of the in vivo weight-bearing situation. Furthermore, Thompson et al. failed to comment on the medio-lateral movement of the meniscal tissue.

More recent technical advances in the field of radiographic imaging have led to the development of the so-called "open" magnetic resonance scanners. These scanners allow a subject to lie, stand, sit or squat within the imaging field, and thus, permit imaging of the intact in vivo knee under load in all positions. Using such a scanner, Vedi et al. [33] described meniscal motion in the normal knee, in both the weight-bearing and non-weight-bearing situation (Fig. 1.2.7). They found that the menisci moved less than was reported by Thompson et al. [32]. However, in common with Thompson et al.'s findings, they observed that the menisci move posteriorly as the knee flexes. The anterior horns were also noted to be more mobile than the posterior horns, and the LM to be more mobile than the medial. The posterior

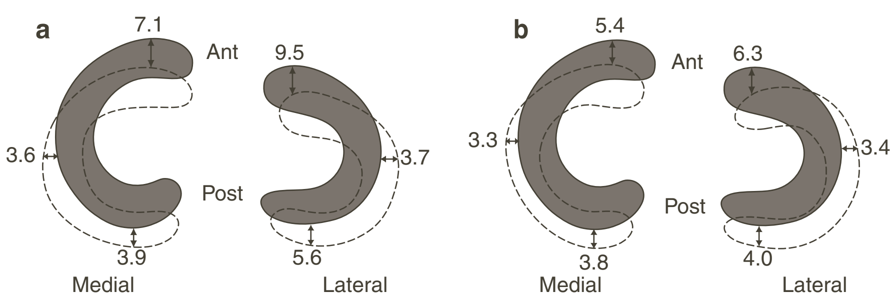

Fig. 1.2.7 The mean movement (mm) in each meniscus from extension (*shaded*) to flexion (*hashed*) in (**a**) the weight-bearing and (**b**) the unloaded knee. (Reproduced with permission and copyright from the British Editorial Society of Bone and Joint Surgery from Vedi et al. [33])

horn of the medial meniscus was found to be the least mobile. Vedi et al. also showed that there was significant movement of the bodies of the menisci peripherally with knee flexion, reflecting the anterior to posterior divergence of the femoral condyles from anterior to posterior.

Vedi et al. [33] compared the meniscal movements observed in the unloaded knee with those found when weight-bearing. They showed that there was significantly greater movement in the anterior horn of the LM when the knee was weight-bearing, but no significant differences were demonstrated between the other meniscal movements.

Summary

The menisci of the knee are highly complex structures, whose form is intricately linked to their various functions. Although far more is now understood about their functional importance in the knee, and even though meniscal preservation is now practised at surgery, where possible, there are still a number of anatomical features of the menisci that at present are all but ignored, from the surgical reconstructive perspective. This includes structures such as the meniscofemoral ligaments and the transverse ligament.

Greater understanding of the relevance of the detailed anatomical features of the menisci is an essential part of developing a deeper knowledge that will hopefully enable more accurate modelling of this tissue, with the aim of some day perhaps being able to manufacture or even grow appropriate artificial scaffolds or tissue-engineered replacement tissue.

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Histology-Ultrastructure-Biology

1.3

P. Verdonk

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. 1.3.1).

Only if both of these developmental processes proceed undisturbed will normal formation and maintenance of synovial joints be observed [1]. 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 [2].

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 [3]. 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 [3]. Once this condensation is complete, mesenchymal cells differentiate into fibrochondroblasts. Acquisition of a chondrocyte-like phenotype by meniscal cells is in coincidence with the loss of expression of BMP-4 and GDF-5 (stage 2) [3]. Meniscal cells now begin matrix synthesis, producing an extracellular matrix of type I and type III collagen and aggrecan (stage 3) [3]. Type II collagen expression by meniscal cells occurs late in meniscal morphogenesis (stage 4) [3]. These results suggest that the meniscus is a unique connective tissue with a distinct developmental profile.

Chemical Composition and Organization of Normal Meniscal Tissue

Normal human meniscal proteoglycans contain approximately 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 [4, 5]. In dry weight, the inner third of the meniscal body contains 8% glycosaminoglycans, and its peripheral third only 2% glycosaminoglycans. Aggrecan has been found to be a major proteoglycan in adult bovine and canine menisci (Fig. 1.3.2).

Its biosynthesis and accumulation begin in meniscal tissue and insertional ligaments during foetal

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_1.3,

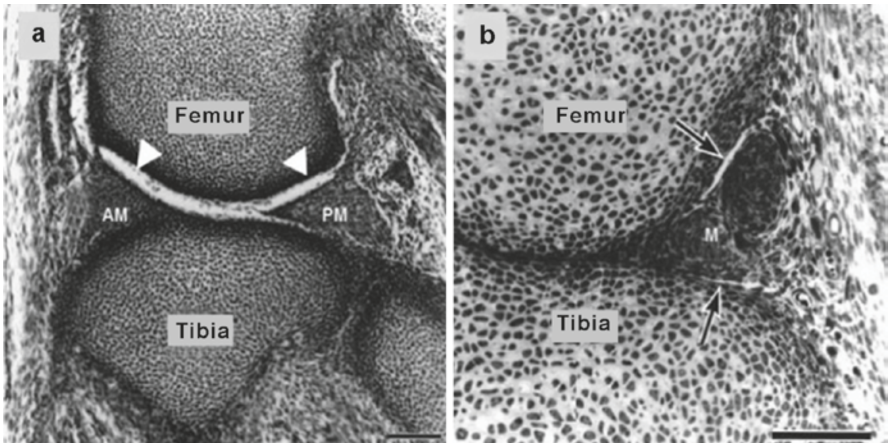

Fig. 1.3.1 (**a**) Progress of cavitation in a paraffin section at E17±5 of a rat. Cavitation has advanced at the femoromeniscal junction (*arrowhead*) and has started between the tibia and the posterior horn of the lateral meniscus (PM) in this sagittal section. No cavitation is seen between the tibia 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, 100 µm. Pictures courtesy Ito and Kida [1]

development [6]. 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 [7]. Aggrecan is not produced in the outer region of the canine meniscus [8]. In general, the concentration of aggrecan produced in the meniscus averages 1/8th to 1/10th of the concentration in articular cartilage. 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 [9]. 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.

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 [10].

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 [10]. 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 [11]. 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 [12]. 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; (c) superficial zone cells, located in the surface zone of the meniscus that interfaces with the synovial fluid (Fig. 1.3.3). Cells of intermediate morphology

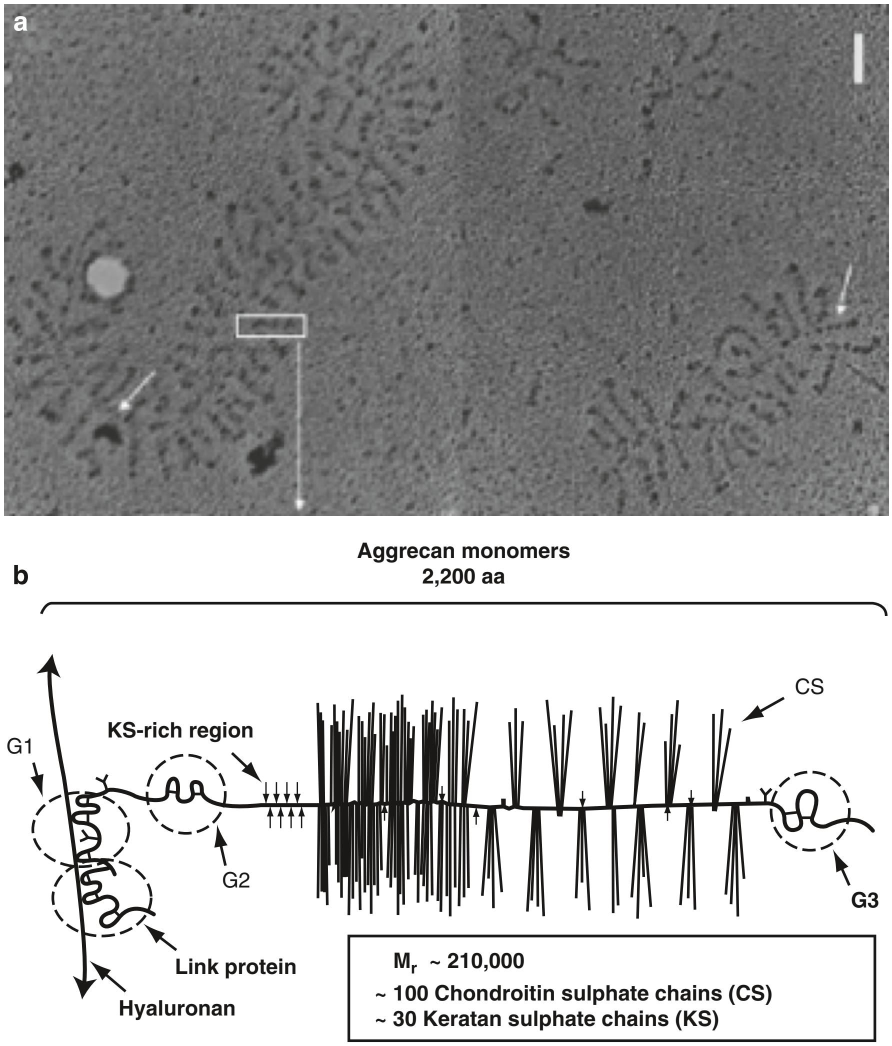

Fig. 1.3.2 (**a**) The structure of aggrecan aggregate. Aggrecan monomers (*square*) are attached on a hyaluronan backbone (*arrow*) to form aggregates of different sizes. (**b**) In the aggrecan monomer, the three globular domains (G1, G2 and G3) are separated by two extended segments which carry the glycosaminoglycans chrondroitin sulphate and keratan sulphate. The link protein stabilizes the aggregate structure between hyaluronan and the aggrecan monomer. Up to 200 aggrecan monomers may bind to one hyaluronan

between that of a fibrochondrocyte and fibroblast are located in the outer portion of the tissue.

Fibrochondrocyte

A fibrochondrocyte is defined as a round or oval-shaped cell that synthesizes 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 synthesized 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 which predominantly experiences compressive forces.

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

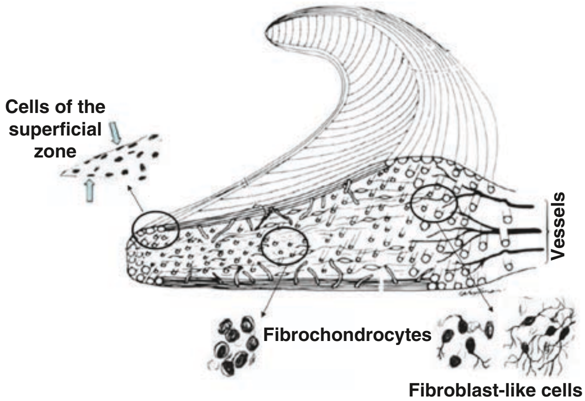

Fig. 1.3.3 Schematic representation of the human meniscus showing the distinct cell type populations and their regional distribution. Fibrochondrocytes are round cells with no cellular projections, located in the avascular portion of the meniscus, while fibroblast-like cells are located in the vascular portion and reveal thin cytoplasmatic projections. Cells from the superficial area are fusiform

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 [13]. Moreover, these cells contained two centrosomes, one associated with a primary celium 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) [13]. 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.

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 [10, 13]. These cells have long been recognized 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 [14]. The intriguing possibility arises that the superficial zone contains specialized 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 [15]. 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 [16].

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.

Model I: Transection of the Anterior Cruciate Ligament

Transection of the 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 [17–22]. In general, histological observations showed a progressive destruction of both the meniscus and the articular cartilage after ACL transection [17, 19]. 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

Table 1.3.1 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-selectin; IL-1β; proteoglycans; entactin; ovostatin; MMP-2; MMP-9
MMP-3	Stromelysin-1, proteoglycanase	Collagens (III, IV, V, IX); gelatin; aggrecan; perlecan; decorin; laminin; elastin; caesin; osteonectin; ovostatin; entactin; plasminogen; MBP; IL-1β; 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

type II collagen, in the pathologic specimens compared with controls [17]. Specific proteoglycans staining indicated an increased expression of these molecules in the pathological meniscus [17]. 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 1.3.1) [18].

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 [18]. In summary, the meniscus responds to injury by increased expression of genes for matrix protein and enzymes.

Model II: Plug Model

In this interesting canine model, a plug was removed from a non-vascularized portion of the meniscus, rendered acellular by repeated freeze–thawing cycles and then re-implanted into the defect [14]. 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.

Model III: Tear Model

Tears in the vascularized zone in the peripheral third of the meniscus body heal similarly as for other vascular tissues [23–25]. 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 requires several months until it acquires a meniscus tissue-like shape and biomechanical properties [26, 27]. 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 [28–30]. It also seems that a once healed meniscal tear remains as stable as an initially intact meniscus [30, 31].

In contrast to tears located in the vascularized zone, the more frequently encountered ruptures in the avascular zone heal poorly [23, 32]. 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-vascularized 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 [25, 33]. For this procedure, a major radial split through the peripheral third of the meniscus to create the channel should be avoided to minimize 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 that is sutured directly or through a tunnel into the lesion [34–38]. Use of fibrin clot alone or together with endothelial cell growth factor or autogenous pre-cultivated stem cells and even implantation of porous polymers did improve the healing response of experimentally created lesions in the avascular region of the meniscus [39–43]. However, the strength of the scar tissue that was measured after the use of fibrin clot and stem cells only achieved 40% of normal within 4 months after implantation [41]. 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 [32]. 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.

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. 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 polylactic acid, polyglucuronic acid and polyurethane

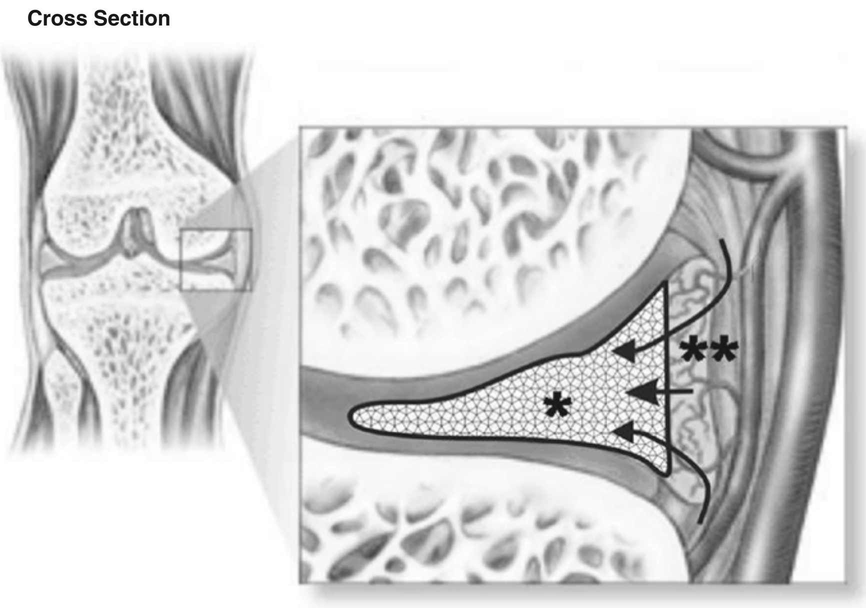

Fig. 1.3.4 Acellular meniscus grafts or scaffolds (*asterisk*) are colonized by host cells (*arrow*) which are probably derived from the synovium and the joint capsule (*double asterisk*)

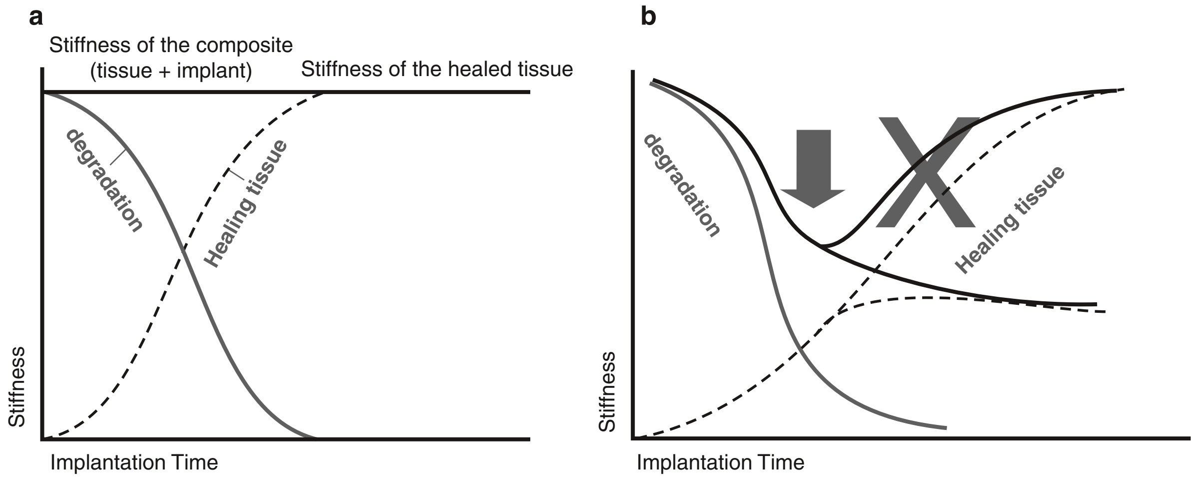

Fig. 1.3.5 (**a**) Idealistic degradation kinetic of a resorbable scaffold (*grey line*) related to tissue healing (*dashed grey line*). The sum of these processes (*black line*) guarantees the stiffness of the construct. (**b**) In the human model, tissue healing is considered much slower than the resorption of many grafts and scaffolds, resulting in reduced stiffness (*arrow*) and early failure of the construct

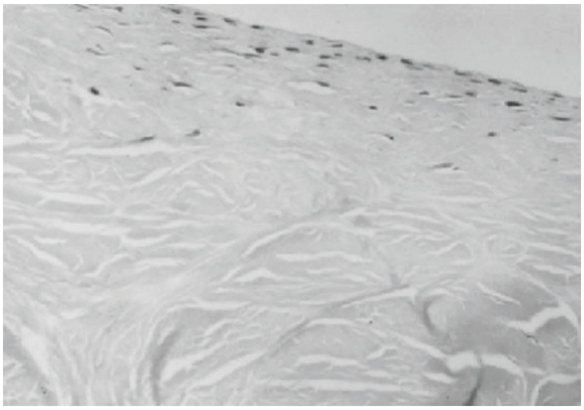

Fig. 1.3.6 Histological section of a deep-frozen meniscal allograft 6 months post-transplantation in a human demonstrating only superficial cell repopulation. The central core of the grafts remains acellular. Picture reproduced from Rodeo et al. [55]

[44–53]. Other than meniscal allografts and a collagen type I-based meniscus scaffold (CMI®, Regen Biologics, Franklin Lakes, NJ), none of these materials have advanced to human clinical use. These surgical approaches are based on the concept of a timely colonization of the acellular scaffold or allograft tissue by host cells, which are probably derived from the synovium and joint capsule (Fig. 1.3.4) [54, 55].

The phenotype of these host-derived scaffold-colonizing 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 colonization of the scaffold or tissue: since these scaffolds or tissues are biodegradable, the colonization 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. 1.3.5).

Previous animal studies have provided evidence that fresh meniscus allografts are quickly invaded by host cells within 1 month after transplantation [54, 56]. In the human model, however, only limited data are available. A previous study performed at our institution has provided evidence that this process of colonization is considerably slower in the human model: DNA fingerprint analysis, performed on human viable meniscal allograft biopsies taken up to 36 months after transplantation, 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. 1.3.6) [56, 57].

Hence, an increase of the initial cell number at the defect site, and thus, a decrease of the time needed for colonization 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.

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Biomechanics

1.4

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Introduction

The menisci of the knee act primarily to redistribute the contact force across the tibiofemoral articulation. This meniscal function is achieved through a combination of the material, geometry and attachments of the menisci. The main ligaments that attach the menisci to the tibia (insertional ligaments, deep medial collateral ligament (dMCL)), the femur (meniscofemoral ligaments – MFLs, dMCL), and each other (anterior intermeniscal ligament (AIL)) all contribute to this function.

Over the years, there has been a complete reversal of attitudes to the menisci among orthopaedic surgeons that has resulted in many novel surgical interventions intended to restore or preserve their function. Before their important roles within the joint were appreciated, menisci were excised routinely if they had been damaged and were causing symptoms of pain, locking or giving way. Meniscal tears are the most common knee injury [8, 14], and it is now fully appreciated that meniscectomy increases the probability of developing degenerative changes within the joint and accelerates the degeneration in joints with pre-existing osteoarthritis [7, 28, 41, 56]. A number of studies have shown that the menisci play important roles in load bearing [11, 21, 57, 68] and shock absorption within the knee [32, 33, 67], and that they are also secondary stabilisers of the joint [22, 35, 36, 39, 40, 47, 60, 69]. Further roles in joint lubrication and nutrient distribution [53] as well as sensory function and proprioception [43] have also been proposed.

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Material Properties of Meniscal Tissue

The microstructure of the meniscal tissue, as in all materials, principally defines the material properties and thus the mechanical behaviour of the tissue. The predominantly circumferential orientation of its fibres [10, 11, 49] is directly correlated to the tissue's behaviour in tension and compression.

Tensile Material Properties

There have been attempts in the literature to quantify the meniscal response in tension [20, 24, 34, 44, 50, 64]. In order for testing to accommodate for the tissue's microstructure, the samples were harvested in all studies to be orientated either radially or circumferentially. All studies resulted in an order of magnitude weaker response of the tissue in tension radially as compared to circumferentially. For example, Tissakht and Ahmed [64] found that the circumferential tensile strength varied from 80 to 125 MPa, while the radial tensile strength was only 1.7–3.6 MPa. This difference in strength may explain the frequency of circumferential splitting of meniscal tissue, rather than radial tears. This difference is in line with the histological observations, whereby

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_1.4, © Springer-Verlag Berlin Heidelberg 2010

Table 1.4.1 Comparison of the tensile modulus [MPa] of intra-articular tissues

Patella tendon	Major knee ligaments	Meniscus (circumferential samples)		Acetabular labrum		Meniscus (radial samples)		Glenoid labrum	Articular cartilage
Human [13]	Human [13, 51, 52]	Bovine [24, 50]	Human [20, 34, 64]	Bovine [19]	Human [29]	Bovine [24, 50]	Human [20, 34, 64]	Human [61]	Human [27]
500–700	300	210	110	75	65	25	10	25	2–20

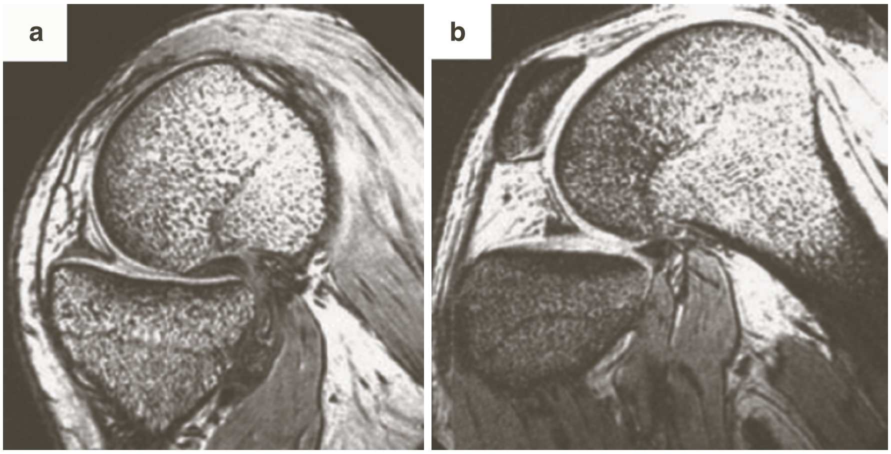

Fig. 1.4.1 The load-bearing knee joint in deep flexion. (**a**) The posterior horn of the medial meniscus is crushed onto the posterior rim of the medial tibial plateau under femoral compression, while (**b**) the posterior horn of the lateral meniscus has moved posteriorly off the lateral tibial plateau. From Yao et al. [70]. © 2008 Orthopaedic Research Society. Reprinted with permission from Wiley-Liss, Inc., a subsidiary of Wiley

the predominant orientation of the fibres in the bulk of the tissue is circumferential [10, 11, 49]. Nevertheless, there is a discrepancy between experimental studies on the variation of the tensile modulus along the circumference of the tissue. Additionally, there is no histological data or any clinically relevant observation that could explain possible differences between anterior, middle or posterior parts of the meniscal tissue. In conclusion, although the experimental protocols used vary among the studies, approximate, literature-based average values of the human meniscal tissue's modulus in tension are approximately 110 MPa circumferentially and 10 MPa radially. Similarly, the tensile moduli of the bovine meniscus are approximately 210 MPa circumferentially and 25 MPa radially.

Table 1.4.1 shows an average tensile stiffness of soft connective tissues of joints for comparison; the circumferential meniscal tensile response is closer to ligaments than to glenoid and acetabular labra or articular cartilage. It should also be noted that the bovine tissue is stiffer than the human tissue.

Compressive Material Properties

Fewer studies have investigated the compressive properties of the tissue [31, 50, 63]. They report values of aggregate modulus (approximately 0.15 MPa) and permeability (approximately $1.9 \times 10^{-15}\,\mathrm{m^4\,N^{-1}\,s^{-1}}$) of the tissue; the former is a measure of the stiffness of the tissue under compression and the latter is a measure of the ease with which fluid flows through the tissue.

The hydraulic permeability of meniscal tissue appears to be an order of magnitude lower than that of articular cartilage. Also, the menisci appear to be 1,000 times stiffer in tension than in compression. These characteristics render the tissue very deformable in compression, which means that it can conform to the variable geometry of the femoral condyles during knee flexion-extension. Also, the lower compressive stiffness when compared to tensile stiffness is an indicator that the tissue's function is mainly to withstand tension rather than compression. This might explain to a degree the loss of functionality, especially of the medial meniscus, in deep flexion, where the meniscus is squeezed against the posterior rim of the tibial plateau [4, 58, 70] (Fig. 1.4.1).

Functional Biomechanics of the Menisci

It has been well established that the main role of the menisci within the knee joint is transmission of the joint force from the femur to the tibia. The shape, structure and attachments of the menisci contribute to

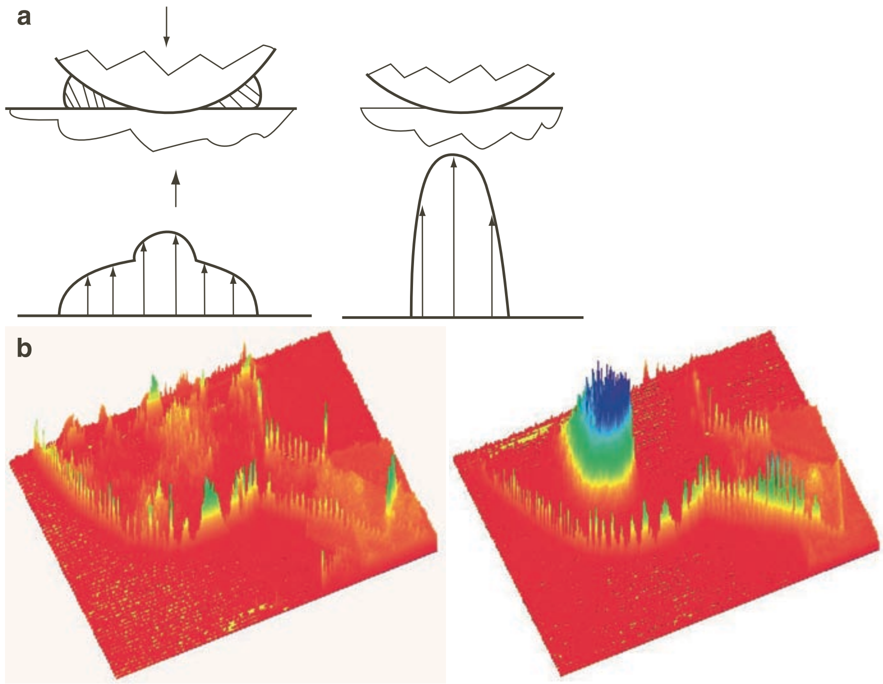

Fig. 1.4.2 (**a**) Contact areas decrease and contact stresses increase following meniscectomy. (**b**) The contact pressures in the lateral compartment when intact and after meniscectomy. (From McDermott et al. [42], with permission from Springer, Berlin)

this essential function, to ensure well-being of the knee joint by reducing the stresses on the articular surfaces.

When bearing load, the knee joint is subjected to axial compression. The compressive force through the joint is distributed over an articulating contact area resulting in contact stresses (contact pressure). The average stresses are proportional to the load and inversely proportional to the contact area; this means that the larger the contact area over which the load is distributed, the less the contact stresses on the contact area. The geometry and range of motion of the knee joint do not allow full conformity between the surfaces in contact, and so the possible contact area across the tibial plateau cannot be utilised to result in minimum contact pressure without the menisci. The medial compartment is more congruent than the lateral compartment because the medial femoral condyle articulates over a concave medial tibial plateau, whereas the lateral femoral condyle articulates over a flat or slightly convex lateral tibial plateau.

Using casting techniques [68], it has been shown that, under no load, contact across the knee occurs primarily on the menisci. With loads of 1470 N the menisci cover between 59 and 71% of the joint contact surface area around the periphery of the tibial plateau, with direct bone-to-bone contact in central areas. Other investigators have also shown that in the absence of the menisci, the load is carried by a much smaller area of cartilage, and so the joint contact pressure is significantly increased (by up to 235%) [9, 58]. This may partly explain the prevalence of osteoarthrosis following meniscectomy and the acceleration of degeneration of the meniscectomised, osteoarthritic joint (Fig. 1.4.2).

The menisci optimise the way the load is transferred across the knee joint by increasing the congruence of the articulation; the areas of contact increase, and as a result, the mean contact pressure on the articulating surfaces decreases. As the femoral condyles bear down onto the menisci, the wedge-shaped cross-section of the menisci causes them to extrude radially out of the joint; this causes their circumference to increase (the circumference being directly proportional to the radius of a circular structure). Each meniscus attaches to the tibia by anterior and posterior insertional ligaments. Thus, the bulk tissue resists radial displacement by developing circumferential tension (and, therefore, hoop stress), that is resisted by the insertional ligaments fixed to the bone. Thus, the load-bearing capacity of the menisci is due to the circumferential stiffness of the meniscal tissue, arising from the predominantly circumferential orientation of the collagen fibres (Fig. 1.4.3).

This mechanism of load-bearing occurs throughout the whole range of knee-joint flexion (up to 160°), precisely because the menisci are mainly attached to the tibia by insertional ligaments at their horns, which are mobile, allowing displacement in all directions. The

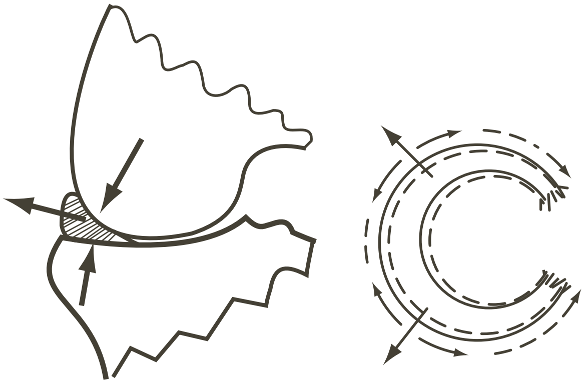

Fig. 1.4.3 Load transfer through the knee joint. The axial compressive force acts on the tapering section of the meniscus to squeeze it out of the joint in a radial direction. This induces stresses around the circumference, that resist the expansion and transfer force to the meniscal insertion ligaments. From Amis et al. [5]

distal aspect of the femur has a large radius of curvature, and hence it contacts the entire area of the menisci, from their anterior to posterior horns, when the knee is fully extended. As the knee flexes, the lesser radii of curvature of the posterior aspect of the femoral condyles result in a decreased contact area that moves posteriorly towards and onto the posterior meniscal horns [4, 30, 46, 58, 70]. This displaces the menisci outwards and more posteriorly, resulting in significant posterior displacements of the anterior horns, up to 10 mm on the lateral side [65], as was illustrated in Chap. 1.2.

The lateral meniscus is more mobile than the medial meniscus; this is because the lateral meniscus is not as tightly attached to the capsule as is the medial meniscus. In addition, 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 (>90°), whereas the convex posterior aspect of the lateral tibial plateau allows the lateral meniscus to displace posteriorly (go "downhill") in deep flexion. Cadaveric data have shown that in the medial side in deep flexion contact is solely between the femoral condyle and the meniscus, suggesting that the whole load of the medial compartment is borne by the meniscus [58].

These observations may explain the increased frequency of medial meniscal tears compared to lateral meniscal tears, at a ratio of 2:1 [14]. Furthermore, they may explain the observations of medial meniscal tears being located more frequently in the posterior horn of the meniscus [17].

The resistance of the menisci to compressive loads by increasing their circumference and developing hoop stresses explains the variable effect and frequency of the various types of meniscal tear. Longitudinal tears do not have as much effect on meniscal function as do radial tears. A longitudinal tear does not disrupt the continuity of the circumferentially orientated fibres that bear load, and is due to fracture of the weak radial tie fibres. In contrast, a radial tear disrupts the continuity of the circumferential fibres, resulting in a loss in the number of fibres bearing load and increase of articular cartilage-to-cartilage contact forces. A corollary of this is that a repair of a longitudinal split should be subjected to much smaller loads than a repair of a radial tear.

The shock absorbing capacity of the menisci has been demonstrated by studies measuring the vibrations in the proximal tibia resulting from gait. From this, it has been shown that shock absorption is approximately 20% less in knees without menisci [67]. This function of the menisci is associated with their viscoelastic properties, the main component of which is the water content of the tissue. Thus, on impact, the load is resisted by hydrostatic pressure, while the shock is mainly absorbed by the high frictional drag forces that are developed as the fluid tries to escape the tissue [37].

Regarding the role of the menisci as secondary stabilisers within the knee, it is well known that the clinical results of anterior cruciate ligament (ACL) reconstruction are markedly impaired by the presence of concurrent meniscal injury. Anterior drawer was not increased significantly after medial meniscectomy when the ACL was intact; however, in the ACL-deficient knee medial meniscectomy caused a further increase in tibial anterior translation of up to 5.8 mm [2], thus highlighting the importance of the meniscus-meniscal ligament construct as a secondary joint stabiliser in synergy with the ACL.

Similarly, the menisci act as secondary restraints to tibial internal–external rotation. Wang and Walker [69] found that meniscectomy increased the range of rotation 5° from a mean of 18–23°, at 0.5 Nm torque. The laxity was further increased if the ligaments were excised: removal of ACL and PCL (posterior cruciate ligament) increased laxity 23°, while removal of both collateral ligaments allowed rotational laxity to increase 49°. These rotations were measured with no axial load on the knee; the addition of axial compression load reduced the laxity greatly, thus protecting the menisci.

Biomechanics of the Meniscal Ligaments

The biomechanics of the menisci are greatly dependent on their material microstructure, but are also related to their attachments to the surrounding structures; the menisci and the meniscal ligaments form a functional unit – the meniscus-meniscal ligament construct – that explains their mechanical response under load.

Insertional Ligaments

The circumferential collagen fibres of the body of the meniscus are known to continue into the anterior and posterior insertional ligaments, which finally attach to subchondral bone via uncalcified and calcified fibrocartilage layers. The tensile behaviour of the meniscal insertional ligaments may be indicative of the physiological loads to which they are subjected. Their properties in the human have not yet been characterised. Their tensile strength in the rabbit has been shown to be in the range of three to four times body weight [23]. In bovine knees, Villegas et al. [66] found that the medial anterior (MA) attachment was significantly less stiff than the medial posterior (MP) and lateral anterior (LA) attachments. The tensile moduli reported in the latter study were 154 ± 134, 248 ± 179 and 281 ± 214 MPa for MA, MP and LA attachments, respectively.

The functional importance of the insertional ligaments has been illustrated by studies investigating the different surgical techniques of meniscal replacement by allograft transplantation. It has been found that after en bloc total meniscectomy followed by replacement of the meniscus with both horns attached to a bony block, similar contact areas and peak contact pressures to the intact knee exist. However, replacing the meniscus with just one horn attached or with neither horn attached leads to significant decreases in joint contact areas and increases in peak contact pressures [1, 15, 42, 48, 59]. Furthermore, in rabbits, transection of the anterior or posterior insertional ligaments of the meniscus has been shown to lead to osteochondral changes after 6 and 12 weeks, similar to meniscectomy [62].

The Deep Medial Collateral Ligament

The dMCL is attached to the medial meniscus. It is a short and thin ligament with clear meniscofemoral and meniscotibial components. The structural properties of the dMCL have been quantified in eight cadaveric knees [54]. The strength, stiffness and extension to failure were 194 ± 82 N, 42 ± 14 N/mm and 7.1 ± 1.1 mm, respectively. The stiffness of the dMCL suggests a significant role in tension and its extension to failure is significantly less than that of the other structures of the MCL complex [54]. Furthermore, due to its short length, the dMCL is tightened rapidly with tibial rotation. Therefore, it is believed that a valgus injury may result in an isolated rupture of the dMCL prior to the failure of other structures. Laxity studies [55] have shown that cutting the dMCL leads to increased tibial external rotation at 60–90° of knee flexion and that the dMCL acts as a secondary restraint to valgus. The association of the dMCL with meniscal function is believed to be the restraint it provides to excessive mobility of the medial meniscus; a ruptured meniscotibial part of the dMCL will allow greater mobility of the medial meniscus. However, the alteration of mensical function in the dMCL-deficient knee has not been addressed in the literature; the effect of the dMCL in meniscal mobility and cartilage contact stresses has not been quantified.

In summary, it is believed that the dMCL acts as a secondary restraint to valgus rotation, provides restraint to excessive mobility of the medial meniscus and is associated with laxity in tibial anterior drawer at high angles of knee flexion where the tibia is externally rotated. Nevertheless, more research on dMCL-deficiency in relation to meniscal function could aid surgical decision making.

The Anterior Intermeniscal Ligament

The AIL connects the anterior fibres of the anterior horns of the medial and lateral menisci. The functional role of this ligament is unclear and its influence on the overall meniscal biomechanics remains elusive. It has been reported to serve in some specimens as the primary attachment of the anterior horn of the medial meniscus and proposed to act as a restraint to anterior subluxation and excessive posterior translation when the menisci are under load [45]. Finally, it is also believed that it acts as a tie between the menisci that controls their relative positioning on the tibial plateau when the tibia rotates.

The Meniscofemoral Ligaments

The MFLs are attached to the lateral meniscus. Gupte et al. [25] studied the properties of the MFLs in 28 human cadaveric knees. They found that the area, load to failure and tensile modulus of the aMFL and pMFL were 14.7 ± 14.8 and 20.9 ± 11.6 mm^2, 300 ± 155 and 302 ± 158 N and 281 ± 239 and 227 ± 128 MPa, respectively. The relatively high tensile modulus (similar to the major knee-ligaments) suggests that they have a functional role within the joint.

The pMFL is tight in the extended knee and slackens with knee flexion, whereas the aMFL is slack in the extended knee and tightens with knee flexion [6]. The MFLs have been demonstrated to act as secondary restraints to posterior drawer [26]. It has also been suggested that they control the motion of the posterior horn of the lateral meniscus with knee flexion [26]. Furthermore, it has been speculated that they can potentially act as splints for a healing PCL after an isolated PCL rupture [6]. The MFLs may remain intact while the PCL ruptures; this is due to their distal attachment to the mobile meniscus, which is lifted off the tibial plateau at the time of injury. More recently, Amadi et al. [3] showed that the MFL-deficient knee experiences a 10% increase in cartilage contact stresses in axial compression in full extension as compared to the healthy joint.

In summary, the meniscus and its insertional ligaments comprise a functional unit that works in harmony to protect the underlying articular cartilage in the load-bearing knee joint. The meniscal ligaments act as secondary stabilisers of the knee joint, but also act to control the mobility and motion of the menisci. Thus, it may be speculated that this may result in the prevention of tears of the meniscus.

The Consequences of Loss of Function of the Meniscus-Meniscal Ligament construct

The functional importance of the menisci in vivo has been proven unequivocally by clinical studies that have documented the long-term results after meniscectomy [41]. As long ago as 1948, Fairbank [18] highlighted the radiographic signs of tibio-femoral cartilage degeneration associated with meniscectomy, and suggested that meniscectomy might not be wholly innocuous. Baratz et al. [9] reported that meniscectomy led to a 75% reduction in tibio-femoral contact areas within the knee and a 235% increase in peak local contact pressures. Long-term studies following up patients after meniscectomy have shown that they are 14 times more likely to develop radiographic signs of osteoarthritis after 21 years [41]. Christoforakis et al. [16] found a strong correlation between severe cartilage degeneration and degenerative (complex and horizontal cleavage) meniscal tears. More recently, total medial meniscectomy has been shown to be associated with altered gait patterns [38].

Burke et al. [12] demonstrated that pressure distribution patterns within the knee were less affected by partial meniscectomy leaving the peripheral portion of the meniscus intact, than by total meniscectomy. This highlights the importance of attempting to preserve the meniscus at surgery with the aim of maintaining optimum residual meniscal function. In particular, the surgery should aim to preserve a continuous ring of tissue around the periphery, ideally linked to the tibia via the insertional ligaments. A radial tear is therefore more damaging than the more common circumferential tear, and more likely to be disrupted by loads imposed in weight-bearing.

The roles of the meniscal ligaments in the overall function of the meniscus-meniscal ligament construct, in both transmitting forces and moving or stabilising the menisci, suggests that these ligaments should be preserved at surgery. In partial meniscectomy, all meniscal ligaments should be maintained; hence, a significant amount of the meniscus-meniscal construct function should be preserved. Also, preservation of the MFLs should be attempted in management of PCL related injuries [6], as the MFLs contribute to the function of the meniscus-meniscal ligament construct and act in synergy with the PCL [26].

Many meniscal tears are irreparable, in which case partial or total meniscectomy is unavoidable. Possible solutions to such cases may lie with techniques such as meniscal allograft transplantation after total meniscectomy or partial meniscal replacement with collagen scaffolds after partial meniscectomy. However, such procedures are still not practised widely and their results have not yet been adequately and rigorously quantified; their long-term results are awaited.

Conclusions

The complex functions of the meniscus-meniscal ligament construct of the knee are intricately related to their composition, fine structure and gross morphology. Much work has helped to clarify many details regarding the biomechanical properties of the menisci, and the importance of their functions in vivo is now well known. Current treatment protocols aim to minimise the resection of meniscal tissue where possible, and many different meniscal repair techniques are currently available. Possible options for those patients who have either already undergone total meniscectomy or have suffered severely irreparable meniscal trauma include meniscal allograft transplantation, and future possibilities may lie in the field of tissue engineering and regeneration.

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Synthesis

1.5

R. Verdonk

The purpose of this book is to look into meniscal disorders and their treatment options.

However, those who do not look back on history are bound to make the same mistakes…

That is the reason why, in this chapter on basic knowledge of the meniscus, the phylogeny and ontogeny are dealt with first.

"Keep the meniscus" is the slogan based on the natural history of this disc of soft tissue in the knee joint, erroneously considered by some to be a vestigial soft-tissue structure in a "self-maintaining transmission system" [3, 10, 2].

These combined sets of asymmetrical components meet the biomechanical need for load transference between the thigh and the leg so well that they have essentially persisted with minimal change for a period of over 300 million years of vertebrate evolution.

The knee thus represents a truly remarkable design of evolutionary biology.

Limbs occur very early in the ontological development of the human embryo, as do menisci in the evolutionary history of the human knee. By the end of the embryological period, the menisci have become further defined, and by 9–10 weeks, they have become completely separated from the articular chondral surfaces of the tibia and femur [8, 6].

The menisci remain of critical importance to the normal functioning of the knee joint.

As the menisci are sometimes referred to as "semilunar cartilages", even though they are crescentic when viewed from above, they are wedge-shaped in cross-section and are attached to the joint capsule at their convex peripheral rim, except for a portion of the lateral meniscus in the region of the popliteus tendon, and also to the tibia anteriorly and posteriorly by insertional ligaments. They thus partially cover the tibiofemoral joint surface [11, 9].

The circumferential collagen fibres of the meniscal body continue into the anterior and posterior insertional ligaments, which attach to the subchondral bone of the tibia. The insertional ligaments have fibrocartilaginous transition zones that make the change in stiffness between ligament and bone tissue at the enthesis less sudden, thereby reducing the stress concentration in this unit and preventing failure. In addition, the anterior intermeniscal ligament, also known as the transverse geniculate ligament, connects the anterior fibres of the anterior horns of the medial and lateral menisci. This anatomical finding has been identified in almost 94% of cases and may have a role in moving the menisci during tibial internal–external rotation.

Two ligaments joining the posterior horn of the lateral meniscus to the lateral side of the medial femoral condyle in the intercondylar notch have also been identified. The anterior meniscofemoral ligament runs anterior to the posterior cruciate ligament and is known as the ligament of Humphrey. The posterior meniscofemoral ligament runs posterior to the posterior cruciate ligament and is known as the ligament of Wrisberg.

A review of the literature by Gupte et al. suggested that at least one meniscofemoral ligament was present in 93% of knees, with a significantly higher prevalence in younger knees than in older ones [5].

Normal meniscal tissue is composed of 72% water, 22% collagen, 0.8% glycosaminoglycans and 0.12% DNA.

Histologically, the menisci are fibrocartilaginous structures and are primarily composed of an interlacing network of collagen fibres interposed with cells,

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_1.5, © Springer-Verlag Berlin Heidelberg 2010

with an extracellular matrix of proteoglycans and glycoproteins.

The fine orientation of the collagen fibres within the meniscus is directly related to the function of the meniscus. The principal orientation of the collagen fibres is circumferential, to withstand tension. Radially oriented collagen fibres are predominantly present in the mid-portion of the meniscus and also on the exposed surfaces. These radial fibres might act as "ties" holding the circumferential fibres together [12].

The entire meniscus is vascularized at birth. An avascular area soon develops in the inner portion of the meniscus, and in the second decade, blood vessels are present only in the outer third. The degree of vascularity varies within each meniscus.

Reports on the innervation of the menisci are conflicting. Wilson et al. also showed penetration of neural tissue into the outer third of the meniscus [14]. The presence of mechanoreceptors in the menisci suggests that the menisci may play a role in knee joint afferent nerve transmission.

The menisci are dynamic structures, and to effectively maintain an optimum load-bearing function over a moving, incongruent joint surface, they need to be able to move with the movements of the femur and tibia, in order to maintain maximum congruency [7].

Recent technical advances in the field of radiographic imaging have allowed in vivo studies of the intact knee under load in all positions. Vedi et al. have described meniscal motion in the normal knee in both weightbearing and non-weightbearing conditions [13].

Biomechanical investigations have looked into the material properties of meniscal tissue.

In the literature, attempts have been made to quantify the meniscal response. A discrepancy exists between experimental studies on the variation of the tensile modulus along the circumference of the tissue.

Fewer studies have investigated the compressive properties of meniscal tissue. Menisci appear to be 1,000 times stiffer in tension than in compression. These characteristics render the tissue very deformable in compression, which means that it can conform to the variable geometry of the femoral condyles during knee flexion and extension.

It has been well established that the main role of the menisci within the knee joint is transmission of the joint force from the femur to the tibia. This mechanism of load-bearing occurs throughout the whole range of knee-joint flexion precisely because the menisci are mainly attached to the tibia by insertional ligaments at their mobile horns, allowing displacement in all directions. The lateral meniscus is more mobile than the medial meniscus.

The resistance of the menisci to compressive loads by increasing their circumference and developing hoop stresses explains the variable effect and frequency of the various types of meniscal tears.

The shock-absorbing capacity of the menisci has been demonstrated by studies measuring the vibrations in the proximal tibia resulting from gait. Shock absorption has been shown to be approximately 20% lower in knees without menisci.

Regarding the role of the menisci as secondary stabilizers within the knee, the clinical results of anterior cruciate ligament reconstruction have been shown to be markedly impaired by the presence of concurrent meniscal injury.

The functional importance of the menisci in vivo has been proven unequivocally by clinical studies documenting the long-term results after meniscectomy [4].

Burke et al. demonstrated that pressure distribution patterns within the knee were less affected by partial meniscectomy leaving the peripheral portion of the meniscus intact, than by total meniscectomy [1].

Many meniscal tears are irreparable, in which case partial or total meniscectomy is inevitable.

Possible solutions to such cases may lie with techniques such as meniscal allograft transplantation after total meniscectomy, or partial meniscal replacement with collagen scaffolds after partial meniscectomy.

Conclusion

The ontogeny of the semilunar cartilages of the knee and their evolution has shown that the menisci are no vestigial structures. Their individual anatomy makes them irreplaceable as far as their biomechanical function is concerned.

Individual meniscal tissue needs to be preserved as much as possible to save the cells maintaining this transmission knee system.

Acknowledgment We wish to thank Dr. S. Dye for managing the preparation of this synthesis.

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Part II

Meniscal Lesions: Classification

Traumatic Lesions: Stable Knee, ACL Knee

2.1

P. Verdonk and P. Vererfve

Introduction

Over the years, the concept of the meniscus has greatly evolved from being just a useless vestigial structure to a multifunctional and essential part of the knee. Currently, menisci are considered to be responsible for load transmission, joint lubrication, shock absorption and joint stability [3,11]. Since they are essential to normal functioning of the knee, it is not surprising that meniscus repair has become a common procedure. With increasing attention to meniscus repair, the need to devise a reliable and reproducible classification of meniscus tears has also arisen.

Classification of Meniscal Tears by Morphology: ISAKOS

In 2006, the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) Knee Committee presented a standardized international meniscal documentation system [4]. This classification is based on morphologic characteristics of the tear at arthroscopy.

Tear Length

Tear length indicates the length of the meniscal tear that reaches the surface of the meniscus. It does not include contained tears (MRI grade II) that do not reach the surface of the meniscus.

Tear Depth

Tear depth mirrors the MRI classification of 0–3. A complete meniscal tear extends through both the superior and inferior surfaces, whereas a partial tear involves only one surface.

Location (Fig. 2.1.1a, b)

Zone 1 includes tears at the meniscosynovial junction and tears with a rim width of less than 3 mm. Zone 2 tears have a rim width of 3–5 mm and zone 3 tears a rim width of more than 5 mm.

These zones correspond with the red–red, red–white and white–white zone, respectively, referring to vascularity, which cannot be evaluated by arthroscopy. Therefore, a zonal classification is more appropriate for preoperative classification of meniscal tears.

The meniscus can also be divided anteroposteriorly into two regions, the anterior and posterior horn. Sometimes, a third middle part is described.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_2.1, © Springer-Verlag Berlin Heidelberg 2010

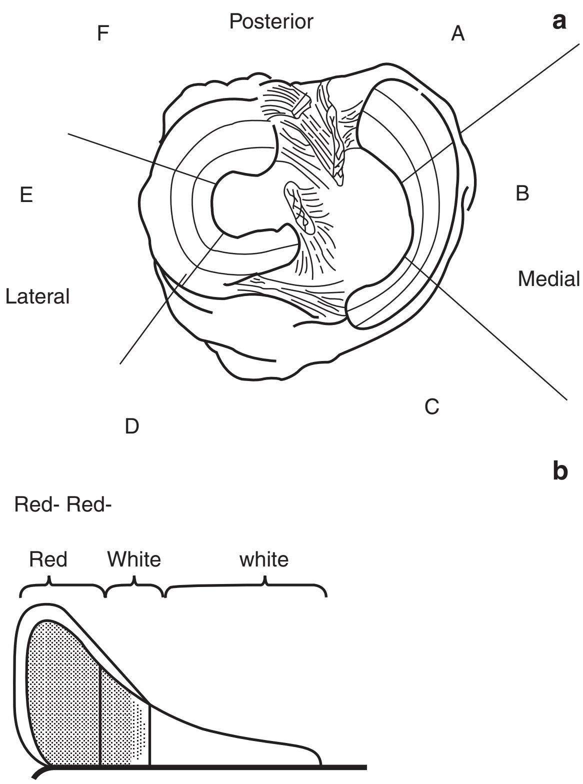

Fig. 2.1.1 (**a**, **b**) Different zones of the meniscus

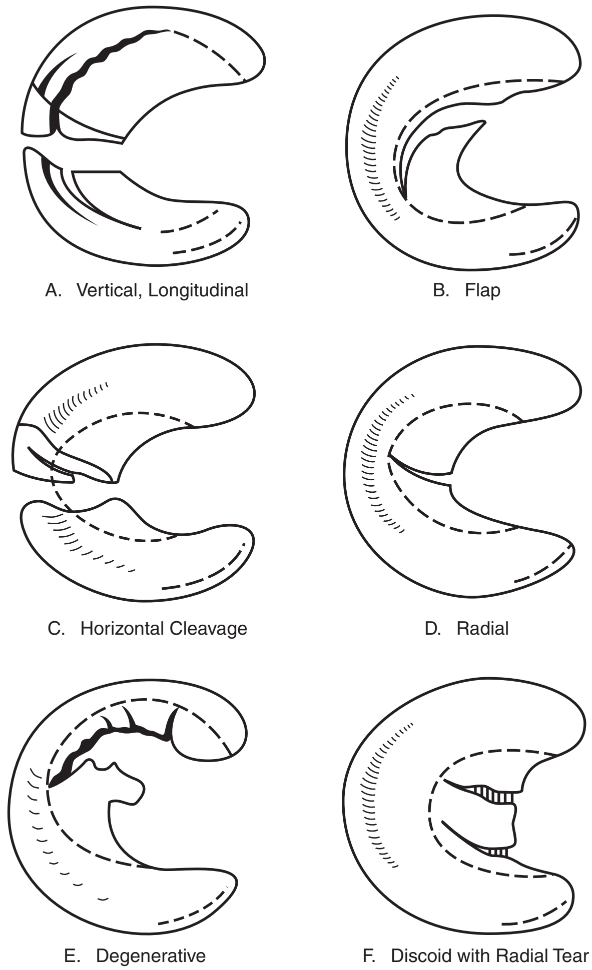

Fig. 2.1.2 Types of meniscal tears

Tear Pattern [5,6] (Fig. 2.1.2)

Longitudinal-Vertical Tear

The longitudinal-vertical tear may be located anywhere along the meniscus. The extension of this tear may result in a bucket-handle tear (see Sect. "Pathogenesis").

Horizontal Tear

The horizontal tear begins at the inner margin of the meniscus and extends towards the capsule.

Radial Tear

The radial tear also begins at the inner margin and extends towards the capsule. This type of tear is typically located at the junction of the middle and posterior thirds of the lateral meniscus (see Sect. "Pathogenesis"). These tears may extend completely through the meniscal rim, transecting the meniscus.

Flap Tear

A flap tear may be either vertical or horizontal. The vertical flap tear extends through both the inferior and superior surfaces of the meniscus. The horizontal flap tear is an extension of the horizontal tear. Either the inferior or superior surface of the meniscus may remain intact in a horizontal flap tear.

Complex Tear

This term describes complex patterns that demonstrate tearing in several planes. These tears are usually, but not exclusively, seen in the degenerative meniscus.

Discoid Meniscus

The discoid meniscus is a congenital variant that usually occurs laterally. Watanabe classified this abnormality into three types [12]. The incomplete discoid type is larger than a normal meniscus and has normal attachments. The complete discoid type covers the entire tibial plateau, but also maintains normal attachment. The third type of discoid meniscus lacks a posterior capsular attachment and is more often symptomatic than the other two types.

Classification of Meniscal Tears by Symptomatology

Despite the increasing availability of superior technical investigations such as MRI, meniscus tears remain a clinical diagnosis. MRI or diagnostic arthroscopy is not routinely indicated. A meniscus tear can be suspected by patient history, typically but not exclusively containing a rotational injury to the flexed knee.

Symptoms vary depending on the chronicity of the injury. A patient with a recent meniscal tear typically presents with complaints of pain and swelling. Physical examination often reveals tenderness over the joint line, a decreased range of motion, and an effusion. Intermittent pain, catching, or locking symptoms are pathognomonic of chronic meniscal tears. Physical examination also reveals tenderness over the joint line, pain with forced hyperflexion, and occasionally muscle atrophy and effusion. A chronic tear may rupture even further, or a second tear can occur in the same meniscus. Patients then often present with chronic complaints as stated above, and sudden deterioration of the symptoms, usually in the form of acute locking of the knee, painful mobilization and swelling of the joint.

Symptoms can be suggestive of the type of tear. In 1975, Andrews et al. pointed out that small tears, limited to the posterior horn, will not cause locking, but rather present in the form of recurrent swelling, pain and instability [1]. By contrast, bucket-handle tears will cause mechanical locking when the central part is dislocated into the intercondylar notch [8]. Locking occurs when femoral extension is blocked by the dislocated torn meniscus, as the latter is caught between the tibial plateau and the femoral condyle.

Pathogenesis

Longitudinal Tears

Most meniscus tears are longitudinal, usually affecting the posterior segment of the meniscus. The lateral and medial menisci are equally affected and complete and partial tears are seen with equal frequency. Because of structural differences, bucket-handle tears are more common in the medial meniscus [5].

The key element in the tearing of the medial meniscus is a rotational force on the partially flexed knee. Internal rotation of the femur pushes the medial meniscus to the centre of the knee and posteriorly. With a strong posterior peripheral attachment of the meniscus, this movement is prohibited. Failure of this attachment, however, causes the posterior part of the medial meniscus to get caught between femur and tibia. In this situation, sudden extension of the knee will cause a longitudinal tear of the medial meniscus. With sufficient length, the central part of the tear can be locked behind the intercondylar notch, and be unable to return to its original position, resulting in a bucket-handle tear and causing acute locking of the knee [5].

The lateral meniscus is torn in a similar fashion. The lateral femoral condyle pushes the anterior horn of the lateral meniscus anteriorly and centrally, countered by a strong posterior peripheral attachment. Failure of this attachment causes a longitudinal tear in the lateral meniscus with extension of the knee [7, 8].

Transverse, Radial, or Oblique Tears

The lateral meniscus is more sharply curved and mobile, making it more vulnerable to incomplete tears.

Transverse, radial, or oblique tears can occur in either meniscus but more commonly involve the lateral meniscus. Transverse tears occur when the meniscus is stretched anteroposteriorly, separating the anterior from the posterior horn. A transverse tear results from the high amount of longitudinal stress on the middle part of the meniscus. The shorter radius of the lateral meniscus makes it more sensitive to this stress, and thus to transverse tears. Any cause of reduction of meniscal mobility also adds to this stress.

The posterior horn of the lateral meniscus is stabilized by both the Wrisberg and the Humphrey ligament. Combined with the attachment to the popliteal tendon, this part of the meniscus is well connected to the lateral femoral condyle, reducing the risk of it getting caught in the centre of the joint. Therefore, tears rarely start from the posterior horn of the lateral meniscus.

A radial tear greatly reduces the functional ability of the meniscus, more so than does a longitudinal tear, which can be explained by the longitudinal orientation of its fibres. As a consequence, radial tears result in massive loss of force transmission, which in turn results in higher pressures on the centre of the medial femoral condyle and medial tibial plateau, eventually leading to degenerative changes in these areas.

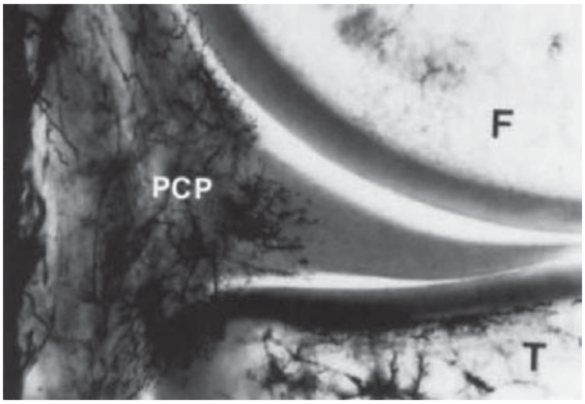

Fig. 2.1.3 Peripheral vascularization (from Arnoczky and Warren [2]

Classification of Meniscal Tears by Reparability

Documented meniscus tears are treated surgically, usually arthroscopically, by partial resection of the meniscus around the tear, creating a new rim. In some cases, the torn meniscus can be repaired by suturing or using an arrow. The therapeutic options and the potential for spontaneous healing of the meniscus are mainly determined by the vascularity of the area in which the tear is located. Meniscal vascularization decreases towards the centre of the joint [3, 7, 11]. The meniscus has therefore been subdivided into three areas.

The red zone is the peripheral third of the meniscus, with good vascularization and thus excellent healing potential. Vascularization varies among patients, reaching 10–30 and 10–25% of the width of the medial and lateral meniscus, respectively (Fig. 2.1.3).

The red–white zone is the middle third, which is poorly vascularized but has some healing potential.

The white–white zone is the central third, which is avascular and has no healing potential.

Subdividing the meniscus into these areas is of biological rather than clinical importance, since the vascularization of the meniscus cannot be evaluated in vivo. The morphologic classification by location is based on this principle.

In addition to vascularization, the suitability of the meniscus for repair is also determined by other factors, the most important of which is tissue quality. We distinguish the healthy and the degenerative meniscus, with the meniscus of undetermined quality in between.

In conclusion, the surgical reparability of a meniscus tear is determined by several factors, including the zones in which the tear is located, the morphologic classification, chronicity, and size [5,10].

Classification of Meniscal Tears by Type of Injury

In 1936, Campbell asserted that "impairment of the anterior crucial and mesial ligaments is associated with injuries of the internal cartilage". Fourteen years later, O'Donoghue described the unhappy triad, consisting of (1) rupture of the medial collateral ligament, (2) damage to the medial meniscus and (3) rupture of the anterior cruciate ligament, for which he recommended early surgical intervention [7]. O'Donoghue estimated this triad to have a 25% incidence rate in the traumatic sports knee [7, 9].

In 1991, Shelbourne and Nitz found that combined lesions of the medial collateral ligament and anterior cruciate ligament were more frequently associated with a lateral meniscus tear [9]. This combination is nowadays known as the terrible triad.

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Degenerative Lesions-Meniscal Cyst

2.2

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Pathology

Macroscopic degenerative lesions of non-disrupted menisci present as yellow, opaque areas of meniscal tissue, which correspond to myxoid degeneration, perimeniscal cysts and meniscal calcifications. Microscopically, the following findings can be noted: (a) acellular eosinophilic hyaline degeneration often associated with fissural or horizontal lesions; (b) myxoid degeneration, which is a collection of a normal mucoid substance. It can be located within the meniscus and is graded according to its severity. It has been found in more than half the cases in a study of Ferrer-Roca and Vilalta [17], who considered it to be a normal condition. Myxoid degeneration can also affect the perimeniscal zone and give rise to tears and pseudocysts, which can lead to the formation of perimeniscal cysts; (c) regeneration zones: peripheral lesions situated within the vascularized zone, which can heal spontaneously forming a scar that is often surrounded by proliferating chondrocytes.

Frequency of Degenerative Meniscal Lesions

The medial meniscus seems to be frequently involved, independent of associated chondral damage. An analysis of 115 cadaveric or postamputation knee specimens, more than half of which were obtained from subjects aged 65 years or older and 61% from male subjects, documented a lesion of the medial meniscus in 38% of cases [16]. These were predominantly horizontal tears, either confined to the posterior horn or generalized, as well as unstable flap tears. Chondral lesions of the femoral condyles or the tibial plateau were a common finding, while there were no abnormalities of the menisci and vice versa. The vast majority of them were localized outside the area covered by the menisci, which seemed to act efficiently in terms of protecting the cartilage. The authors did not consider the menisci, whether torn or not, to be the cause of osteoarthritis.

The prevalence of intra-meniscal high signal intensity on MRI of asymptomatic subjects increases with age. It is estimated to occur in 5% of subjects under the age of 30 years, rising progressively to 13–15% of subjects between 30 and 45 years, 25–63% of subjects above 50 years and 65% of subjects above 65 years of age [1, 21, 32]. In a histomagnetic study conducted by Raunest et al. [30], who analyzed 480 MRI slices of 40 cadaveric knees derived equally from male and female subjects with a mean age of 71 years, meniscal lesions were detected in 80% of knees. In case of painful osteoarthritis of the knee, their prevalence was estimated to be 91% [4]. In 1992 the French Arthroscopy Society carried out a survey of medial meniscus lesions which has now become a reference standard in France [20]. The lesions detected in patients above 50 years of age accounted for one third of all 1,436 reported lesions. Moreover, they were markedly different from those in subjects under 50 years of age. Vertical lesions were traumatic in origin and predominantly occurred in young patients. Complex lesions and flap tears occurred in the absence of major trauma and affected older patients, whose mean age (54 years) was 17 years

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_2.2, © Springer-Verlag Berlin Heidelberg 2010

higher than that of patients with vertical tears (37 years). Flap tears were observed in patients with a mean age of 46 years, situating them in between the previous two age groups.

Arthroscopic Classification

An arthroscopic DML classification system was first proposed in 1983 [6]. It was further developed on the basis of a retrospective study [12] of 2,100 arthroscopies, during which 310 degenerative lesions were detected (Fig. 2.2.1).

Type I represents an alteration of the meniscus without interruption of its continuity. The meniscus is homogeneous but has lost its normal appearance: it is flat, looks drab and frosted, and its colour sometimes resembles that of chamois leather (Fig. 2.2.2). Its surface is irregular and its inner edge is often ragged and frayed. On palpation, it has lost its firm consistency and elasticity, and is sometimes soft to the feel. There are, however, no tears or instability. Only this type corresponds to the so-called meniscosis.

Fig. 2.2.1 Classification of degenerative meniscal lesions

Type II is characterized by the presence of calcium deposits on the surface of the meniscus as well as within its body (meniscocalcinosis) (Fig. 2.2.3).

Type III indicates the presence of a horizontal cleavage tear (Fig. 2.2.4).

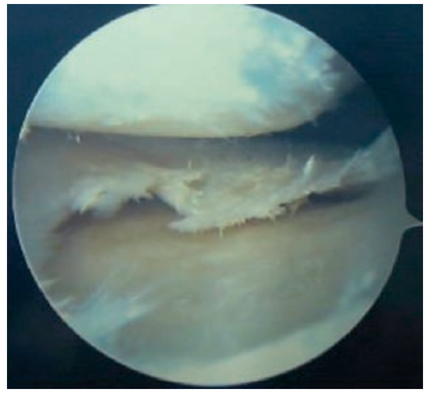

Fig. 2.2.2 Type I – meniscosis

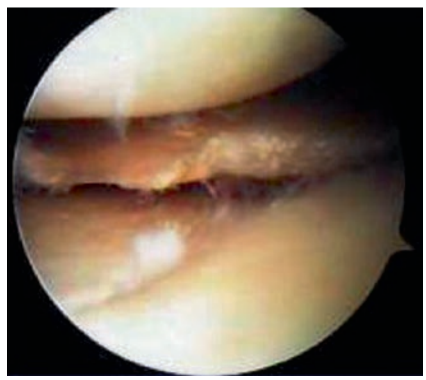

Fig. 2.2.3 Type II – meniscocalcinosis

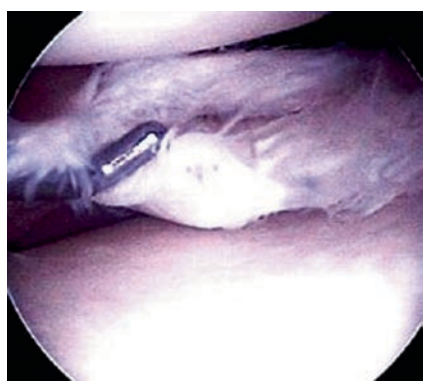

Fig. 2.2.4 Type III – horizontal cleavage tear

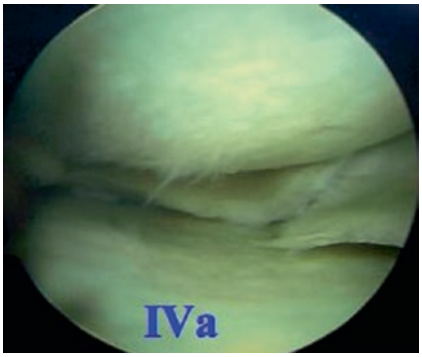

Fig. 2.2.5 Type IVa –degenerative meniscus tear

Type IV refers to the likely presence of a radial tear (IVa), which is slightly oblique and originates from the inner edge of the medial meniscus at the junction of the middle and posterior one thirds of its body, extending towards the peripheral zone anteriorly or posteriorly (Fig. 2.2.5). In case of such a tear, it is possible to mobilize a large pedunculated fragment of the meniscus with an arthroscopic probe. A tear continuing along the inner border of the meniscus, detaching a mobile and palpable flap, is called a type IVb tear (Fig. 2.2.6).

Type V is characterized by the presence of a complex lesion which cannot be precisely described. It is rarely encountered, but when it occurs, it is mostly in an osteoarthritic knee (Fig. 2.2.7).

Initially, in this classification, the definition of a DML excluded a past trauma to the knee and radiologically documented osteoarthritis. Only minimal pinching of the edge of the medial meniscus was accepted. The aim of this definition was to differentiate these lesions from classic traumatic lesions and

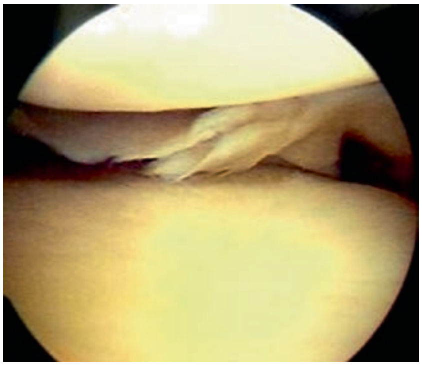

Fig. 2.2.6 Type IVb – tear detaching a meniscal flap

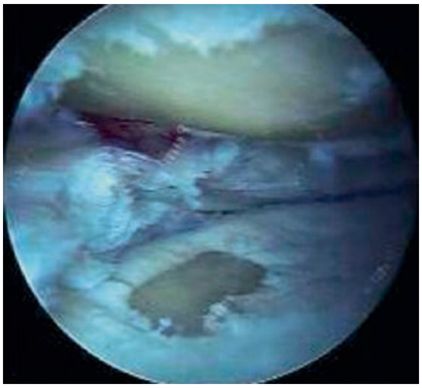

Fig. 2.2.7 Type V – complex lesion in the course of osteoarthritis

from meniscal lesions associated with osteoarthritis. At that time, these three entities were often confused in the Anglo-Saxon literature. Currently, it is thought that DML may occur before, at the same time, or after the onset of chondral lesions.

MRI Classification

The classification system of Crues et al. [11] serves as a reference standard for MRI. It refers to meniscal lesions regardless of whether they are degenerative or traumatic in origin. A healthy meniscus is triangular and prismatic in shape, producing a low-intensity signal in all sequences, with a homogeneous and weaker signal than that of cartilage. Meniscal tears appear as linear areas of high signal intensity located within the normal low-intensity zones on both T1 and T2-weighted images. Degenerative changes related to the presence of local mucoid degeneration are seen as areas of high signal intensity on T1 and particularly T2-weighted scans. Meniscal lesions have been classified to fall within one of the following three grades:

Grade 1 is defined as a high signal intensity area which is round or oval in shape, of variable size, and occupies a variable amount of the meniscal triangle, but does not abut the surfaces (Fig. 2.2.8).

Grade 2 is defined as a high-intensity signal which is roughly linear, almost always horizontal and of variable size. It does not involve the surfaces of the meniscus, but can extend to the meniscosynovial junction. Its frequency is 24% according to LaPrade et al. [24] and 41% according to Jerosh et al. [23].

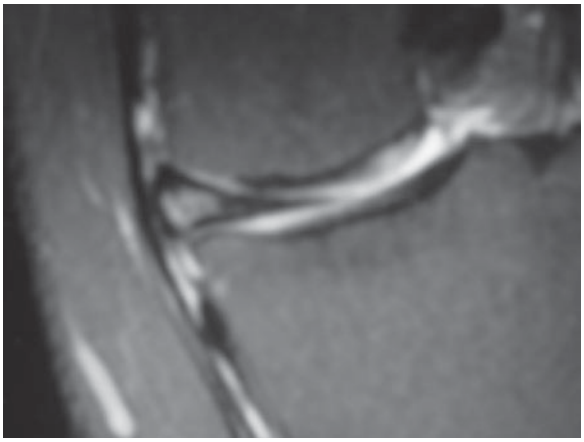

Fig. 2.2.8 MRI grade 1 lesion – intrameniscal degeneration

Grade 3 is defined as an area of high signal intensity extending to the surface of the meniscus or to its free edge. It indicates a meniscal tear (Fig. 2.2.9).

Correlation Between MRI and Histology

The correlation between the MRI and histological findings has been the focus of much research. In 1992 Hodler et al. [22], after having analyzed 179 MRI scans and histological specimens of 20 cadaveric menisci, found the MRI results to have a relatively moderate sensibility of 72% and a specificity of 80% for the detection of tears. In fact, some fibrous and mucoid areas mimicked meniscal tears, which was the reason why the accuracy or the efficiency was only 76%. This number rose to 93% in a histomagnetic study of Raunest et al. [30], which included all types of lesions, from degenerative ones to tears.

Correlation Between MRI and Arthroscopy

Arthroscopy of the knee remains the gold standard, but it does not allow detecting lesions which do not extend to the surface of the meniscus. It is of little use in case of grade 1 and 2 MRI abnormalities, which represent intrameniscal degeneration. However, in grade 1 lesions, a soft, compressible area can be sensed on the superior surface during meniscal probing. Tiny openings in the meniscal wall, through which intrameniscal lesions communicate with the articular cavity, are not always detected. The correlation between MRI and arthroscopic findings has been studied by many authors. According to Fischer et al. [19] the sensibility and specificity of MRI were 89 and 84%, respectively, for the medial meniscus and 69 and 94% for the lateral meniscus. We have no knowledge of any studies specifically dealing with DML. Bin et al. [5] demonstrated the superiority of arthroscopy over MRI for radial tear detection. Briole [8] conducted a prospective study on the value of MRI in determining the instability of DML. The specificity was good for flap tears but weak for radial tears (type IVa).

Fig. 2.2.9 MRI grade 3 lesion – extending to the inferior surface of the meniscus

Clinical Aspects

Arthroscopic type I and II and MRI grade 1 and 2 DML are a priori asymptomatic and cannot be considered responsible for symptoms arising in the course of painful osteoarthritis of the knee. It is not inconceivable, however, that lesions extending to the innervated peripheral zone of the meniscus may cause pain, as was suggested by Englund et al. [15], but this has not been sufficiently substantiated during further research.

Some of the types of DML deserve a specific clinical approach.

Horizontal Cleavage Tear and Meniscal Cyst

Horizontal cleavage tears are predominantly found in the lateral meniscus owing to the physiological characteristics of the lateral compartment, where the meniscus is subjected to shearing forces. A horizontal tear is not always symptomatic and can hardly be considered as a source of knee pain. Clinical symptoms, if present, include pain which can be located on the lateral side of the joint, diffuse transient joint effusion, and possibly a parameniscal cyst. Radiographic examination is essential to exclude osteoarthritis while MRI is the reference standard allowing the surgeon to assess the shape and the depth of a meniscal tear. The choice of the appropriate treatment depends on various criteria [2]. A meniscal lesion in a stable knee is treated by partial meniscectomy if it is located within the avascular zone. It can be repaired if it lies in the vascular zone which has the potential to heal. A horizontal tear of the lateral meniscus can occur early in life. This tear presents a specific clinical picture in a young patient and usually results from excessive strain due to sports activity. Sometimes a cyst of the lateral meniscus and a grade 2 or 3 high-intensity MRI signal are present. Beaufils et al. [2] have recommended an open repair in young athletes. Two types of meniscal cysts can be distinguished, with different pathogenetic mechanisms. The first one is secondary to a meniscal lesion, particularly a horizontal cleavage tear of the lateral meniscus [18]. Although it is degenerative in nature, it can affect patients of any age. When mucoid degeneration reaches the margin or the surface of the meniscus, it begins to communicate with the joint cavity. The joint fluid penetrates the tear and migrates towards the meniscal wall due to the intra-articular pressure, which leads to deformation of the joint capsule and to the formation of a cystic cavity. Owing to the pressure gradient, this fluid cannot flow back into the joint cavity, becomes trapped within the cyst and undergoes subsequent dehydration, changing its consistency to that of a jelly. The second type of cyst is an autonomous cyst, which is the result of mucoid degeneration of the juxtacapsular part of the meniscus and does not communicate with the joint cavity. Its existence is disputed and it is thought that it concerns only a small number of meniscal cysts. The treatment of painful cysts initially consists of non-specific measures including intraarticular steroid injections. If it fails, an attempt can be made to inject the steroid into the cyst itself. Surgery, which consists of partial meniscectomy (or rather remodelling meniscectomy aiming to spare as much of the meniscus as possible) and intraarticular cyst drainage, is the treatment of choice when conservative therapy has failed. Meniscal repair with extraarticular drainage of the cyst has been proposed by Beaufils et al. [2] and Lu [27].

Horizontal tears may also involve the medial meniscus but mainly occur in the course of pre-existent osteoarthritis, where meniscal lesions constitute an additional disorder.

Non-Traumatic Degenerative Tear of the Medial Meniscus or Type IV DML

This lesion, described in the 1980s because of the advent of arthroscopy [6], consists of a posterior segment tear of a degenerative meniscus and is unrelated to trauma and osteoarthritis. It forms a separate entity, which has its own symptomatology [12, 20], and requires specific treatment.

Epidemiology

Age

In a study conducted by Dorfmann et al. who focused exclusively on type IV DML, mean patient age was 51 years (range 27–73 years). Contrary to traumatic tears, these lesions are generally observed in older patients but may also occur earlier in life.

Gender

There is a clear male preponderance, with a male:female ratio varying from 2:1 to 3:2 [13, 25]. This ratio lies between that of traumatic meniscal lesions where male patients account for 80%, and osteoarthritis where they constitute a minority of only 20%.

Triggering Conditions

A history of strenuous knee-loading activities or repetitive microtrauma is reported in about two thirds to three quarters of cases. These are either sports-related (jogging, tennis, golf, etc.) or occupation-related (tilers, plumbers, bricklayers, etc.). Squatting is thought to play a particularly important role. Excessive body weight is also a contributing factor. Obesity as such is found in less than 10% of cases, which means that it is less common than in the general population and significantly less common than in patients affected by osteoarthritis of the knee. Genu varum is only considered as a pre-disposing factor as it is found in only 20% of patients with type IV DML, which differs only slightly from the general population [13]. Probably, the meniscal tear occurs as a result of everyday activities, the threshold level of which is thought to decrease proportionally to the increasing damage to the meniscus. In extreme cases, the tear can be assumed to be spontaneous in nature.

Clinical Symptoms

The functional signs are related to the presence of unilateral internal derangement of the knee and are not specific to its type. The principal sign is knee pain, which can be either diffuse or localized medially, anteromedially and sometimes posteriorly. Its characteristics indicate a mechanical background but nocturnal pain caused by a change of body position has also been reported. The pain is often transient, severe, and aggravated by walking or by performing a torsional movement with the affected knee. The maximum walking distance is restricted in one of every two cases [13], as are sports and professional activity. Weightbearing without carrying out torsional movements is not associated with pain, which is not the case in osseous subchondral lesions. This can be helpful in establishing a basic differential diagnosis. Fifty per cent of patients report a feeling of joint swelling. Classical "meniscal" symptoms, such as limping, true blocking, snapping and a sensation of joint instability, are rare [12]. On physical examination medial joint line tenderness is found in more than 70% of cases. The pes anserinus area is also frequently tender to palpation, which should not be interpreted as "pes anserinus tendinitis". Joint effusion is found in one of every two patients [13] and has mechanical characteristics. Antalgic flessum is seldom present. Classical meniscal tests (McMurray, grinding test) are markedly positive in only one third of patients.

Radiological Evaluation

MRI should not substitute standard radiographs, which are systematic methods of assessment. They should include an anteroposterior schuss view of both knees (i.e. standing with the knee in 20° of flexion in order to expose any arthritic changes) as well as lateral and axial projections. DML are almost never associated with joint line narrowing. If this sign is clearly positive, it is indicative of osteoarthritis, which constitutes another entity.

On MRI a grade 3 meniscal lesion or a complex lesion may be visualized. An exact diagnosis of a radial tear corresponding to a type IV DML is difficult. MRI also provides complementary information, such as coexistent lesions, and is helpful in the diagnostic process.

Searching for MRI signs of perisynovitis is often neglected while this can be an indirect symptom of instability of a torn meniscal fragment. The lesion irritates the surrounding synovium by pulling it or rubbing its surface, leading to contact synovitis which is very clearly seen at arthroscopy [7] (Fig. 2.2.10). On MRI, this synovitis can be seen as zones of low signal

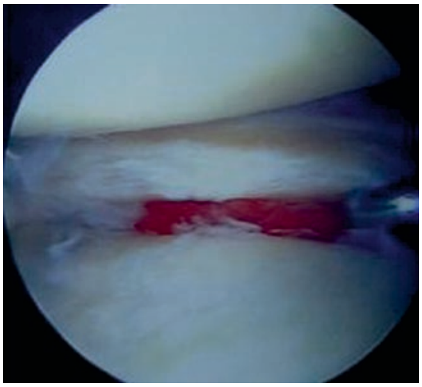

Fig. 2.2.10 Perimeniscitis due to an unstable local flap tear

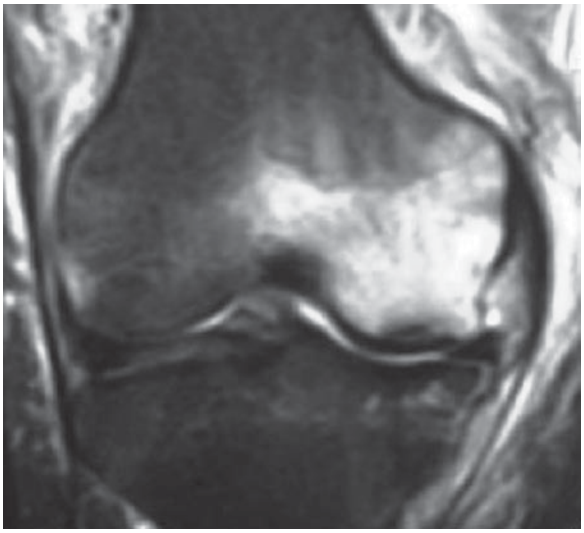

Fig. 2.2.11 Medial condyle edema

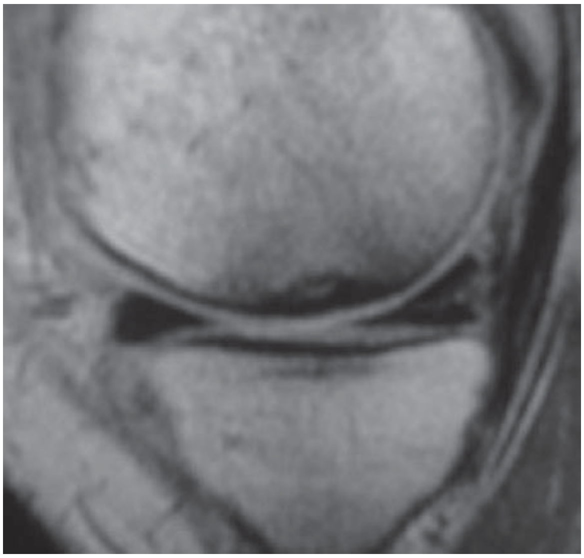

Fig. 2.2.12 Stress fracture of the medial condyle

intensity on T1-weighted images or high signal intensity on T2-weighted images.

Diffuse subchondral bone oedema (Fig. 2.2.11) should be considered as a possible sign of a stress fracture of the bone surface (Fig. 2.2.12). It occurs primarily in the course of osteoarthritis and should be considered in the differential diagnosis. A type IV DML may, however, predispose to stress fractures or even local necrosis (Fig. 2.2.13) due to constantly exerted forces, as was suggested by Muscolo et al. [28]

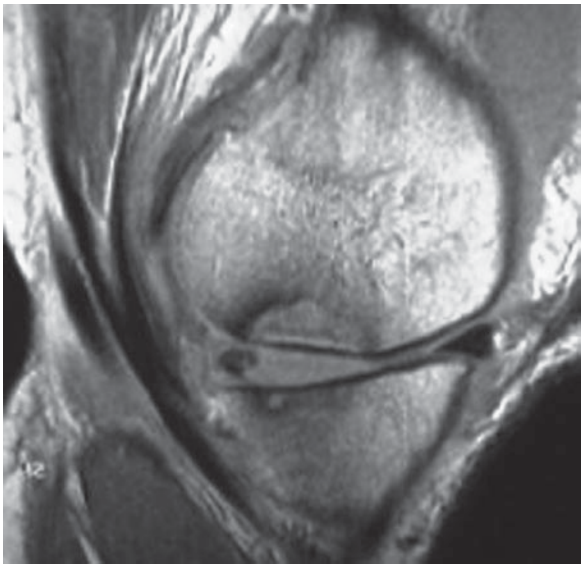

Fig. 2.2.13 Medial condyle necrosis

They reported on a series of five patients with a mean age of 68 years who developed necrosis of the knee. After their first MRI examination they were diagnosed with a meniscal lesion, although they had not undergone a meniscectomy before. In our study of 30 cases we noticed a statistically significant association between type IV DML confirmed by arthroscopy and osseous subchondral fissures related to mechanical stress [7].

The areas of local edema are considered to be trivial and do not cause pain. Their importance and meaning are yet unknown.

Treatment of Degenerative Meniscal Lesions

The treatment of DML includes promoting a healthy lifestyle, analgesic and anti-inflammatory medications, and intra-articular steroid injections. Extra-articular perisynovial injections have also been proposed with some interesting short-term results [25]. If this treatment fails, partial meniscectomy for type IV DML provides excellent results [6, 13, 20], at least in the short and medium term.

The complications of this procedure are generally those of arthroscopic surgery. One should also consider the risk of fissure formation and local necrosis, caused by immediate return to weight bearing while the cartilage has lost its protective properties. To avoid these complications, partial weight bearing and limited physical activity in the post-operative period should be advocated. A potential connection between meniscectomy and secondary osteoarthritis is a controversial issue, which has been the subject of numerous publications. It is believed that any meniscectomy, even a partial one, contributes to the development of osteoarthritis [9], which is directly related with patient age and pre-existent cartilaginous lesions. One may wonder whether a meniscal lesion which is not managed surgically also has consequences. The authors of studies confirming the pathogenic influence of meniscectomy on osteoarthritis have compared operated knee joints with healthy knees and not with non-operated knees with a pre-existent meniscal lesion. This constitutes a serious bias and no treatment decisions can be derived from these studies when faced with a documented and symptomatic meniscal lesion. Some interesting conclusions were presented by Lequesne et al. [25], who examined 30 meniscal lesions detected by MRI, which were subsequently treated by perisynovial steroid injections and not by surgical means. The patients were then followed-up and 60% of them were found to show signs of osteoarthritis on standard radiographs taken after an average period of 9 years. A prospective study of Berthiaume et al. [3] of 24 patients with significant osteoarthritis of the knee who underwent MRI combined with the calculation of cartilage volume every 6 months, showed a strong correlation between the presence of surgically untreated meniscal lesions and the progression of osteoarthritic changes. This correlation has recently been confirmed by Englund et al. [14] in a cohort study with MRI surveillance. They found that the risk of developing osteoarthritis in the absence of surgical treatment is 4.3–7.8 times higher, depending on the type of the initial meniscal lesion. Because of the lack of studies comparing the risk of developing osteoarthritis between patients who underwent surgical treatment and those who did not, it is difficult to deny surgery to symptomatic patients with MRI evidence of a meniscal lesion.

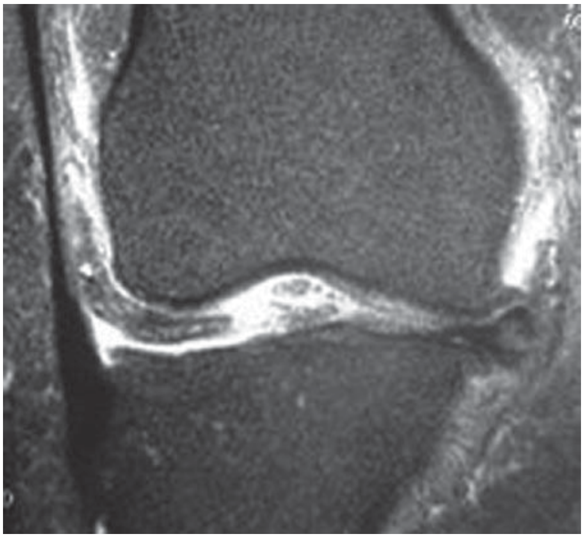

Fig. 2.2.14 Meniscal extrusion beyond the edge of the tibial plateau

Meniscal Extrusion

Meniscal extrusion is defined as a more than 3 mm peripheral displacement of the middle segment of the meniscal body in relation to the edge of the tibial plateau (Fig. 2.2.14). While it remains significantly correlated with osteoarthritis of which it is an early prognostic sign, its minor forms can occur without coexistent chondral lesions [29]. Costa et al. [10] found a strong relationship between meniscal extrusion and radial tears, particularly those located within the posterior insertion of the meniscus (Fig. 2.2.15). In a prospective study which included an analysis of 205 MRI examinations Lerer et al. [26] demonstrated a frequent coexistence of radial tears and osteoarthritis. While a meniscal lesion can precede the onset of osteoarthritis, the loss of the protective features of the meniscus accelerates the degeneration of cartilage. Due to the absence of specific criteria, it is not easy to diagnose

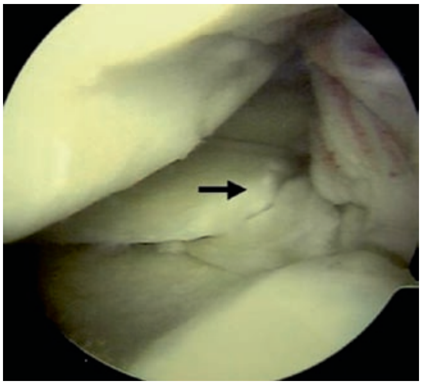

Fig. 2.2.15 Transverse fissure (*arrow*) at the posterior attachment of the medial meniscus contributing to its extrusion

meniscal extrusion during arthroscopic surgery, nor does there exist a specific treatment.

Complex Meniscal Lesions (Type V)

Usually these lesions are associated with osteoarthritis and are treated in the same way, except for the rare cases of sudden aggravation of clinical symptoms, including severe pain, which are associated with clear MRI findings. If conservative treatment fails, partial meniscectomy is advised and care is taken to preserve as much of the meniscal tissue as possible. Generally speaking, the value of arthroscopic treatment of osteoarthritis has not been proved. However, a recent study of Steadman et al. [31] demonstrated good functional results of extensive *debridement* of the knee including meniscal remodelling, with 87% of satisfied patients. None of them had undergone knee replacement surgery, which was the initially proposed treatment, within the three subsequent years.

Conclusion

DML deserve a distinctive approach and classification, as some of them require specific treatment. It is particularly important to identify those lesions that occur spontaneously in menisci previously altered by an ongoing degenerative process. The relationship between DML and osteoarthritis of the knee is subtle and still poorly understood. Does an unstable meniscal tear which is not managed surgically, contribute to osteoarthritis? If osteoarthritis develops after partial meniscectomy, is it a consequence of the surgery or was the meniscal tear rather the initial manifestation of the disease? Definitive answers to these questions have not yet been found. On the other hand, while even an advanced osteoarthritic process in the knee can remain asymptomatic, we should try to identify the reasons for a clinical deterioration with sudden onset of pain and joint effusion, because in this case the treatment is vastly different. Apart from the exacerbation of pain induced by subchondral bone or chondrolysis-related synovitis, there are situations in which the symptoms are caused by meniscal lesions, which should be identified by confronting the clinical symptoms with the radiological findings.

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Meniscus and Osteoarthritis

2.3

N. Pujol and P. Boisrenoult

Introduction

Degenerative meniscal lesions are frequently found during magnetic resonance imaging (MRI) or arthroscopic procedures on osteoarthritic knees [19]. The goal of this chapter is to describe the different imaging (X-rays, MRI) and arthroscopic features of osteoarthritis (OA) and degenerative meniscal lesions, in order to make the correct diagnosis and institute the proper treatment.

Osteoarthritis

Non-traumatic knee pain in a patient over 40 years of age should be assessed primarily for arthritis. Bilateral weight-bearing X-rays, including anteroposterior (AP) views in extension and in flexion (Rosenberg or schuss views), lateral views and skyline views at 30° of flexion, are systematically required. In knee OA, joint space narrowing (JSN) is more readily identified on the semiflexed view than on the full-extension view, since a semiflexed knee position brings into view a more posterior region of the femoral condyle, where cartilage damage tends to be more prominent [6].

X-Rays

The diagnosis of OA is most often based on radiographic appearance. Radiographic criteria were proposed by Kellgren and Lawrence in 1957 [13]. Other grading scales advanced by Ahlback [1] and Brandt et al. [5] are also frequently used (Table 2.3.1). These systems are equally effective in defining the presence of and estimating the severity of tibiofemoral joint OA, but have only a moderately strong correlation with the actual degree of articular cartilage degeneration seen during arthroscopy [15].

Radiographic features of OA include osteophytes, JSN, subchondral sclerosis and subchondral cysts. Osteophyte formation is the most characteristic feature of OA and is thought to precede JSN. Osteophytes form in areas of low stress, typically at the joint margins, resulting in an increased surface area and hence reduced joint stress.

In knee OA, the discordance between knee pain and radiographic OA has been reported in many studies, with the prevalence of radiographic OA ranging from 15 to 53% in subjects with knee pain [12, 18].

The association of knee pain with the presence of osteophytes has a sensitivity of 83% and a specificity of 93% for the correct diagnosis of OA [2]. JSN should be assessed on the AP view in extension and on the schuss or Rosenberg view, since the most frequently involved zones of articular cartilage are the contact areas of knees positioned in between 30 and 60° of flexion [24]. Because conventional extension weight-bearing anterior radiographs may miss *"slight"* JSN, an AP view in flexion must be added [25].

The schuss view is a weight-bearing posteroanterior radiograph of the knee at 30° of flexion, whereas the Rosenberg view is taken at 45° of flexion.

Because literature data comparing these two views are non-existent, both can be used.

The schuss view has good reproducibility when the joint space is wider than 3 mm [4]. Narrowing of the cartilage space of 2 mm or more is strongly correlated with grade 3 or 4 cartilage degeneration [24]. Moreover, there is no significant difference between pre- and

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_2.3, © Springer-Verlag Berlin Heidelberg 2010

Table 2.3.1 Kellgren-Lawrence, Ahlback, and Brandt radiographic grading systems

grading score	Kellgren-Lawrence	Ahlback	Brandt
0	Normal	Normal	Normal
1	Minute osteophytes or doubtful osteoarthritis	Joint space narrowing <3 mm	<25% joint space narrowing with secondary features
2	Definite osteophytes with intact joint space	Joint space obliterated or almost obliterated	50–75% joint space narrowing without secondary features
3	Definite osteophytes with moderate joint space narrowing	Minor bone attrition (<5 mm)	50–75% joint space narrowing with secondary features
4	Definite osteophytes with severe joint space narrowing and subchondral sclerosis	Moderate bone attrition (5–15 mm)	>75% joint space narrowing with secondary features
5	–	Severe bone attrition (>15 mm)	–

post-meniscectomy height of the medial femorotibial space on standing AP and schuss views, meaning that JSN is not due to the meniscus itself but is always pathognomonic of OA [22].

Radiographic JSN of more than 50% is associated with severe chondral lesions and is indicative of advanced OA [8].

MRI

Cartilage Thickness

Numerous studies have shown MRI to be highly sensitive and specific for detecting focal cartilage defects and thinning [9, 20].

Recently, whole-organ evaluation has been performed using semiquantitative scoring systems [16, 21].

An MRI grading system derived from the French "Society of Arthroscopy (SFA) grading system has been described in good correlation *with arthroscopic findings* ($\kappa = 0.83$) [9, 20].

Quantification of chondropathy with MRI is feasible and well correlated with anatomic cartilage breakdown.

Bone Marrow Oedema

A recent literature review reported a correlation between bone marrow oedema on MRI and painful osteoarthritic knees. Among 400 osteoarthritic patients, bone marrow oedema was found in 78% of painful knees and in only 30% of asymptomatic knees [10].

Another comparative study showed bone marrow oedema to be present in 36% of painful knees vs. 1% of non-painful knees [26].

Bone marrow oedema is strongly correlated with the presence of pain in an osteoarthritic knee, regardless of the presence of degenerative meniscal lesions. Consequently, a degenerative meniscal lesion is not the main cause of pain when bone marrow oedema is seen, especially on the tibial plateau, and a meniscectomy will not resolve the problem.

Arthroscopy

Several arthroscopic classifications have been published, the most useful of which is the SFA classification, in which grade 0 is normal, grade 1 represents chondromalacia, grade 2 superficial chondral fibrillations involving <50% of the thickness of the cartilage, grade 3 deep chondral lesions involving >50% of the thickness of the cartilage, and grade 4 exposure of the subchondral bone [8] (Fig. 2.3.1).

Degenerative Meniscal Lesions

Arthroscopic Classification

For a detailed description of the arthroscopic classification we refer to Chap. 2.2.

MRI Classification (Fig. 2.3.2)

Raunest et al. proposed the following MRI classification: grade I: globular hyper-signal within the meniscal body, not extending to an articular surface; grade

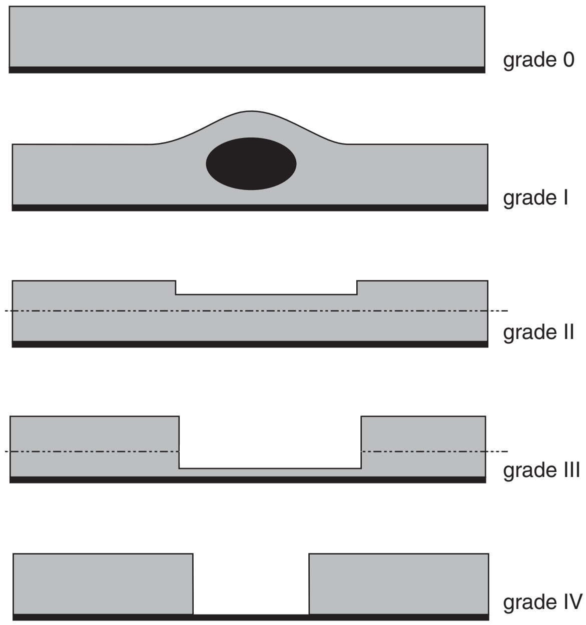

Fig. 2.3.1 SFA grading system of chondral lesions

II: horizontal cleavage within the meniscal body, not extending to an articular surface; and grade III: horizontal cleavage opened into the joint [23].

This classification is currently widely used for the description of non-traumatic degenerative meniscal tears.

Meniscal Extrusion (Fig. 2.3.3)

Medial meniscal extrusion is defined as a significant (>3 mm) medial displacement of the medial meniscus with respect to the central margin of the medial tibial plateau. The presence of pathologic medial meniscal extrusion is significantly associated with moderate to large osteophytes or cartilage loss [11, 14, 17]. The degree of meniscal subluxation correlates with the severity of JSN. Moreover, meniscal subluxation is highly associated with symptomatic knee OA.

Medial meniscal extrusion may be related to loss of meniscal function and interpreted as a total meniscectomy. Benefits of arthroscopic meniscectomy of an extruded meniscus may also be uncertain.

Meniscus and OA

Is a degenerative meniscal tear symptomatic or not?

A cohort study of 100 patients referred for suspected degenerative meniscal tears, assessed the prevalence of meniscal abnormalities on MRI performed on symptomatic and contralateral asymptomatic knees [26]. Meniscal tears were found in 57 symptomatic and 36 asymptomatic knees. Horizontal medial meniscal tears were found in 32 symptomatic knees and 29 asymptomatic knees. In this study, bone marrow oedema and pericapsular soft-tissue abnormalities were most

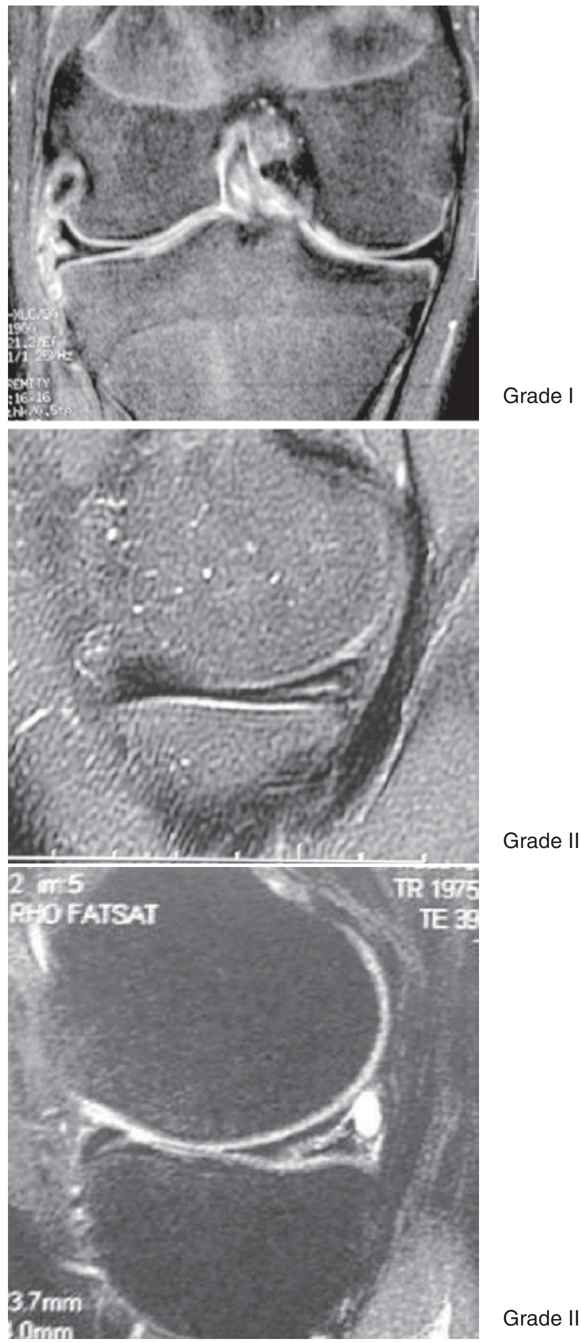

Fig. 2.3.2 MRI classification of degenerative meniscal lesions

Fig. 2.3.3 Medial meniscal extrusion, bone marrow oedema, loss of cartilage

prevalent in symptomatic knees. Radial, complex displaced meniscal tears were mostly symptomatic.

In a comparative study by Bhattacharyya et al. [3] of 154 patients with OA (mean age 53 years), the prevalence of meniscal tears was found to be 76% in asymptomatic patients and 91% in symptomatic patients ($p<0.005$). The OA grade was correlated with a higher frequency of meniscal tears. Within the symptomatic OA group, there was no significant difference in pain or subjective scores between patients with or without meniscal tears.

What is the link between OA and degenerative meniscal lesions?

A case control study of 294 patients with a mean age 47 ± 6 years demonstrated an association between the prevalence of degenerative meniscal lesions and patient age (OR = 16/year) and BMI (OR = 1.06–1.11 kg/m^2). On MRI, patients with a degenerative meniscal tear had more severe cartilaginous lesions than the control group ($p=0.01$), especially on the medial femorotibial side [7].

Degenerative meniscal changes are more common in patients with articular cartilage degeneration.

Conclusion

In an osteoarthritic knee, the cartilage and meniscal surfaces show a similar degree of damage. This strongly suggests a close anatomic relationship between these two tissues and disease progression. Radiographic JSN is correlated with severe loss of articular cartilage. Many features of OA may precede JSN. MRI may help in identifying cartilage lesions, unstable degenerative meniscal tears, bone marrow oedema, and their role in the occurrence of pain.

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2.4 Synthesis

P. Beaufils

Traumatic Meniscal Lesions

For a meniscal lesion to be defined as traumatic in origin, the following two criteria must be met: there must have been a documented injury to the knee as a result of a knee sprain or a forced movement (e.g. on squatting) and the meniscal tissue must be healthy, i.e. of normal macroscopic appearance. The natural ageing process of meniscal tissue does not exclude the possibility of a traumatic lesion. Generally speaking, a traumatic meniscal lesion is a vertical and longitudinal tear.

Referring to the previously mentioned analogy with a bone fracture, involvement of the medial or lateral side, the direction of the tear, its location relative to the meniscosynovial junction and its extension anteriorly and posteriorly are all factors in defining a traumatic meniscal lesion. Moreover, there exist different clinical presentations including lesions confined to one of the meniscal segments, large lesions prone to dislocation (bucket-handle tears), lesions with an additional radial tear resulting in a flap tear and complex lesions, which most often are chronic in nature.

Symptoms are produced by instability of the torn fragment. They can be responsible for locking of the knee in case of bucket-handle tears, or for popping and clicking within the knee when the torn part of the meniscus moves under the femoral condyle. Other more disturbing symptoms include medial or lateral knee pain depending on the affected compartment, which is caused by an abnormal increase in tension of the joint capsule.

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When dealing with a traumatic meniscal lesion, two basic questions need to be answered: (1) is the affected knee stable or not?, and (2) can the lesion be surgically repaired?

The diagnosis of anterior instability of the knee is based on the physical examination and a positive Lachman sign. Because treatment of instability and of a meniscal tear influence one another, it is extremely important that the correct diagnosis be established.

In this chapter devoted to the classification of meniscal lesions, the feasibility of repair and its indications will not be thoroughly discussed. It is, however, important to stress the significance of the initial assessment, which should facilitate further decision making.

A young patient age and a recent injury are common indications for meniscal repair, but only lesions located in the vascular zone of the meniscus can be repaired. Therefore, the aim of preoperative magnetic resonance imaging (MRI) of the knee is not only to diagnose a tear, but also to provide information on its location, size and direction, and to evaluate the condition of the meniscal tissue, helping to decide on surgical repair or not. The efficacy of MRI in predicting the feasibility of repair has been confirmed by numerous studies and it can thus be considered an extremely useful tool, even when the clinical diagnosis is clear.

Degenerative Meniscal Lesions

According to the definition, a degenerative meniscal lesion occurs in the absence of an injury or as a result of decompensation after minor trauma. Contrary to traumatic lesions, it can be assumed that the ageing process of the affected meniscal tissue and its deterioration has

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_2.4, © Springer-Verlag Berlin Heidelberg 2010

advanced to a certain degree. This idea was first introduced by Smillie and Noble based on their clinical and pathological findings. Their conclusions were subsequently confirmed by arthroscopic and MRI evidence. The change in the intra-meniscal MRI signal, most probably due to mucoid degeneration, allowed to detect the last, or rather the first stage of development of these lesions.

The relationship between degenerative lesions of the menisci and osteoarthritis of the knee is unclear and remains a controversial issue in current literature. However, it is clear that lesions occurring in osteoarthritic knees need to be distinguished from those in knees without degenerative changes.

Our current knowledge on this subject can be summarized as follows.

Degenerative meniscal lesions and pathological changes in the menisci are natural consequences of meniscal tissue ageing and are accelerated by joint overuse. Degenerative meniscal lesions are more frequent in men than women (2 to 1), which is exactly the opposite of osteoarthritis and thus supports the concept of primary degenerative meniscal lesions. Degenerative lesions predominantly occur in the fourth or fifth decade of life, but may also develop earlier, even in young athletes. Whatever the arthroscopic or MRI findings, the main tear is either a horizontal or a flap tear originating from a previously horizontal tear. The process of tear formation in degenerative meniscal tissue, which ruptures producing a flap, has been shown on MRI.

The prevalence of abnormal meniscal MRI images suggestive of existent lesions should be emphasized. These images, which reflect the natural changes related to the ageing of meniscal tissue, should not be overinterpreted as meniscal tears or as an indication for surgical treatment. From a practical point of view, the clinician needs to answer two important questions: (1) are the symptoms related to meniscal problems? and (2) what is the condition of the articular cartilage? Is osteoarthritis present?

Owing to the widespread use of MRI, symptoms are commonly attributed to meniscal lesions while they can actually stem from other pathological conditions e.g. affecting the patella or articular cartilage.

In order to solve this problem, two important conclusions should be borne in mind: (1) abnormal meniscal MRI images are common and their prevalence increases with age, and (2) general joint cartilage status should be systematically inspected, which implies the need for a systematic standard radiographic examination including comparative schuss views.

This information is not sufficient to decide whether a degenerative meniscal lesion leads to the development of osteoarthritis. Nevertheless, we are capable of distinguishing lesions occurring in knees with no macroscopically visible cartilage changes from those occurring in osteoarthritic knees. The former can be assumed to be primary degenerative meniscal lesions, a true meniscal pathology, while the latter could be designated as meniscarthrosis. In practice, this distinction is made by analyzing the presence of joint space narrowing on radiographs taken in schuss position. For primary degenerative meniscal lesions, treatment (which essentially consists of a meniscectomy) can be considered to be curative. For other lesions, this procedure can only be regarded as palliative and should be offered with caution.

There is not just one but a variety of meniscal lesions….

The clinician must not limit himself to establishing the diagnosis of a meniscal lesion, but should concentrate on its epidemiological and anatomical features in order to be able to propose adequate treatment.

Part III

Preoperative Clinical Examination and Imaging

Clinical Examination: Standard X-Rays

3.1

N. Pujol and P. Boisrenoult

Introduction

Arthroscopic surgery for meniscal tears is frequently performed. Before surgery, a presumptive diagnosis and a differential diagnosis should be established clinically by history taking, physical examination, and plain radiographs to provide the basis for informed consent discussions with patients and to determine if special studies, such as MRI or arthro CT, are required for further evaluation. This chapter discusses the value of various tests commonly used for assessing meniscal lesions, and the usefulness of standard X-rays before meniscal surgery. The literature is reviewed.

Physical Examination

The physical examination should be preceded by careful history taking. A history of sudden pain on hyperflexion of the knee, catching, mechanical locking, and recurrent effusions requires a thorough investigation. Pain at rest, sick leave, and medial patellar tenderness might be negatively correlated with a meniscus tear [1].

A traumatic painful knee in a young patient should be distinguished from nontraumatic chronic knee pain in a patient over 40 years of age.

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Tests Commonly Used to Assess Meniscal Lesions

McMurray Test [13]

The McMurray test is performed with the patient supine. The examiner stands on the side of the affected knee and places one hand on the heel and the other along the medial aspect of the knee, providing a valgus force. The knee is extended from a fully flexed position while internally rotating the tibia. The test is repeated while externally rotating the tibia. Popping and tenderness along the joint line indicate a positive sign (Fig. 3.1.1).

Fig. 3.1.1 McMurray test

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Apley Test [4]

The Apley compression test is performed with the patient in prone position with the knee flexed to 90°. The tibia is compressed into the distal femur and rotated externally to assess the medial meniscus and internally to assess the lateral meniscus. The test is considered positive if it produces pain, which is less severe or relieved when the maneuver is repeated with distraction of the tibia.

Joint Line Palpation

Pain or discomfort is reproduced by palpation of the joint line.

For a suspected traumatic meniscal tear, the examination, diagnosis, and treatment must take into account the anterior cruciate ligament (ACL) status. Is the ACL torn or not?

The Lachman test is commonly used to assess the integrity of the ACL. The femur is grasped firmly above the knee, and the other hand is placed on the proximal tibia. With the knee flexed to 20–30°, the lower leg is moved forward. A firm end-point should be felt. The test is positive if the end-point is soft or if there is increased anterior translation of the tibia.

Level of Evidence of Clinical Tests

Three systematic reviews of the accuracy of physical diagnostic tests for assessing meniscal lesions are available in the literature [18, 20, 21]. From these reviews, studies evaluating the value of joint line palpation, McMurray's test, and Apley's grinding test for diagnosing a meniscal tear have been selected (Table 3.1.1).

It is commonly believed that the examination has a long learning curve and that accuracy may increase with experience. Literature data on the reproducibility of the physical tests are unclear and scarce.

All tests have significantly heterogeneous sensitivity and specificity. The McMurray and Apley test could be considered to have high specificity (mean 0.81 and 0.86, respectively) but low sensitivity (mean 0.44 and 0.42, respectively). Joint line palpation tends to be higher in sensitivity (mean 0.69) but lower in specificity (mean 0.55).

A single clinical test is not sufficient to establish a correct diagnosis. Diagnostic accuracy is improved if the results of the three tests are combined. Generally, all clinical tests tend to be less reliable in the presence of concomitant ligamentous injury. Furthermore, physical examination is less accurate in patients with degenerative tears than in young patients with acute injuries [23].

One prospective study reported on the value of physical examination for the diagnosis of unstable meniscal tears in patients with OA of the knee [10]. One hundred and fifty-two patients (mean age 60 years) with symptomatic OA, in whom medical treatment had failed, underwent arthroscopic debridement including partial meniscectomy of unstable tears. The preoperative examination included the McMurray test. The sensitivity was 88%, the specificity 20%, the positive predictive value 62%, and the negative predictive value 53%. Interobserver agreement was poor ($\kappa < 0.4$).

Standard X-Rays

In case of a suspected traumatic meniscal tear in a young patient, X-rays are obtained to look for a fracture that occurred during the injury. Anteroposterior (AP) and lateral views of the injured knee are recommended.

In a patient over 40 years of age with nontraumatic knee pain, X-rays are taken to assess the cartilage and the presence of any degenerative articular changes. A degenerative meniscal tear in an osteoarthritic knee should not have the same treatment as an isolated meniscal tear.

Bilateral weightbearing X-rays including AP, lateral, schuss [16] or Rosenberg [17], and skyline views at 30° of flexion are systematically required in these cases.

The appearance of osteophytes precedes joint space narrowing in the osteoarthritic process. The association of knee pain with the presence of osteophytes has a sensitivity of 83% and a specificity of 93% for the correct diagnosis of OA [2]. Joint space narrowing should be assessed on the AP view in extension and on the schuss or Rosenberg view, since the most frequently involved zones of articular cartilage are the contact areas of knees positioned in between 30 and

Table 3.1.1 Analysis of systematic reviews: value of physical examination for the diagnosis of meniscal tears

Study	Year	Level of evidence	Age	meniscus	N	Test	Sensitivity	Specificity	Positive likehood ratio	Negative likehood ratio
Fowler [11]	1991	1	–	L+M	80	Joint line palpation	0.85			
						McMurray	0.29			
						Apley	0.16	–	–	–
Anderson [3]	1986	4	–	L+M	100	Joint line palpation	0.77	–	–	–
						McMurray	0.58	0.29	0.8	1.5
						Apley	0.69	0.86	4.8	–
Barry [5]	1983	4	–	L+M	44	Joint line palpation	0.76	0.43	1.3	0.6
						McMurray	0.56	1	8.9	0.5
Noble [14]	1980	4	–	L+M	200	Joint line palpation	0.79	0.11	0.9	1.9
						McMurray	0.63	0.57	1.5	0.6
Grifka [12]	1994	4	47	L+M	113	Joint line palpation	0.95	0.05	1.0	1.1
			(15–78)			McMurray	0.66	0.63	1.8	0.5
						Apley	0.58	0.80	2.9	0.5
Steinbruck [22]	1988	3	31	M	300	Joint line palpation	0.73	0.62	1.9	0.4
						McMurray	0.34	0.86	2.3	0.8
						Apley	0.47	0.82	2.6	0.6
				L	300	Joint line palpation	0.53	0.91	5.9	0.5
						McMurray	0.10	0.98	6.5	0.9
						Apley	0.23	0.99	19.5	0.8

(*continued*)

Table 3.1.1 (continued)

Study	Year	Level of evidence	Age	meniscus	N	Test	Sensitivity	Specificity	Positive likehood ratio	Negative likehood ratio
Boeree [7]	1991	4	32.7 (6–71)	M	203	Joint line palpation	0.64	0.69	2.1	0.5
						McMurray	0.29	0.87	2.3	0.8
				L	203	Joint line palpation	0.28	0.87	2.1	0.8
						McMurray	0.25	0.90	2.5	0.8
Saengnipanthkul [19]	1991	4	26 (14–59)	M	73	Joint line palpation	0.58	0.74	2.2	0.6
						McMurray	0.47	0.94	8.5	0.6
Corea [9]	1994	4	25.3 (18–40)	M	93	McMurray	0.65	0.93	9.5	0.4
				L	93	McMurray	0.52	0.94	8.0	0.5

60° of flexion [17]. Because conventional extension weightbearing anterior radiographs may miss slight joint space narrowing (Fig. 3.1.2), an AP view in flexion must be added [24].

The schuss view is a weightbearing posteroanterior radiograph of the knee at 30° of flexion, whereas the Rosenberg view is taken at 45° of flexion.

Because literature data comparing these two views are lacking, either one can be used.

The schuss view has good reproducibility when the joint space is wider than 3 mm [6]. Narrowing of the cartilage space of 2 mm or more is strongly correlated with grade 3 or 4 cartilage degeneration [17]. Moreover, there is no significant difference between pre and post-meniscectomy height of the medial femorotibial space on standing AP and schuss views, meaning that narrowing of the joint space is not due to the meniscus itself but is always pathognomonic of OA [15].

Fig. 3.1.2 Forty-five-year-old patient with right knee pain, referred for meniscectomy. Moderate joint space narrowing on a standard AP extension view, and complete medial narrowing on the schuss view

Joint space narrowing of more than 50% is associated with severe chondral lesions and is indicative of advanced OA [8].

Conclusion

A combination of clinical tests and a careful history taking is required for an adequate diagnosis of meniscal injuries. Traumatic knee pain in a young patient should be differentiated from progressive knee pain in a patient over 40 years of age. Standard X-rays, including AP and lateral views, need to be systematically obtained for the assessment of a traumatic knee injury in a young patient.

Nontraumatic knee pain in a patient over 40 years of age should be assessed primarily for arthritis. Bilateral weightbearing X-rays, including AP views in extension and in flexion, and lateral views and skyline views at 30° of flexion, are required before requesting more sophisticated procedures (MRI, arthro CT…).

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MRI, MR-arthrography and CT-arthrography 3.2

W. C. J. Huysse and K. L. Verstraete

Introduction

Damage to the meniscus is one of the most common causes of pain in the knee joint. Accurate imaging of the meniscus is essential to evaluate the damaged area and to select the most appropriate treatment. Similarly, in the postoperative meniscus, imaging is important for treatment, follow-up and identification of any further injury. A number of factors have to be considered when selecting the most appropriate imaging technique. Currently, magnetic resonance (MR) imaging is the preferred imaging modality for the virgin, operated or transplanted meniscus. MR imaging is a non-invasive but highly sensitive technique for the detection of meniscal lesions. MR arthrography does not improve on the accuracy of MR imaging in the non-operated knee, but the technique is useful for detecting a retear in the sutured meniscus. Computed tomography (CT) arthrography is used less frequently and in situations where MR imaging is contraindicated, e.g. in the presence of orthopaedic hardware. This chapter describes the available imaging techniques for the assessment of the meniscus and reviews the use of MR imaging in both the non-operated and postoperative meniscus.

Standard Radiography and Arthrography

Although the meniscus is not visible on standard radiographs, full-leg radiographs taken in a standing position are useful for the evaluation of knee alignment. Varus or valgus deviation results in abnormal pressure on the medial or lateral meniscus, which can lead to early degeneration and subsequent tearing of the meniscus. In a pre-operative setting, meniscal transplantation is not indicated in knees with significant malalignment because the articular cartilage is usually completely degraded [44].

Plain radiographs can also detect other indicators of meniscal lesions, including joint space narrowing and generalized degenerative changes of the femorotibial joint. Radiographic images taken before contrast injection can help distinguish between a tear and chondrocalcinosis, a pitfall on both CT and MR imaging (Fig. 3.2.1).

Single or double-contrast knee arthrography may be used in the absence of CT or MR imaging to depict the meniscal surface and detect meniscal tears. The accuracy of this technique has been estimated to be between 82 and 99% for diagnosing medial meniscal tears and 68 and 93% for lateral meniscal tears [36]. The technique is, however, technically demanding and should not be used for the evaluation of the meniscus without subsequent CT or MR imaging.

CT and CT Arthrography

A CT scan without a previous intra-articular iodinated contrast injection is no longer considered a good practice. CT arthrography and MR imaging have a similar level of accuracy when used for the detection of meniscal tears [26, 27, 48]. CT arthrography is used less frequently than MR imaging because the technique is more invasive and involves the use of ionizing radiation. Furthermore, a number of risks are associated with direct

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_3.2, © Springer-Verlag Berlin Heidelberg 2010

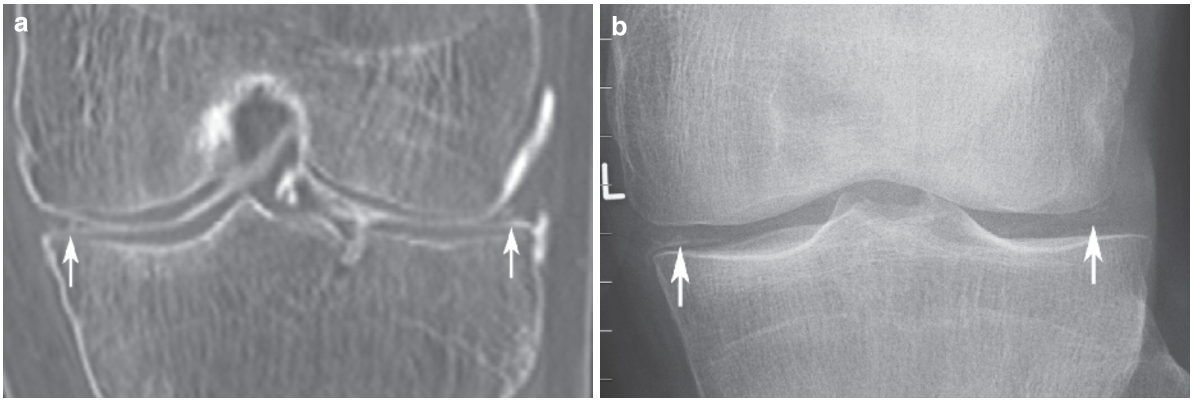

Fig. 3.2.1 (**a**) Computed tomography arthrography, coronal reconstruction and (**b**) plain radiograph, anteroposterior projection. (**a**) The linear areas of high density in the undersurface of the body of both the lateral and medial meniscus (*arrows*) are suggestive of partial-thickness tears. (**b**) Chondrocalcinosis is present in both menisci (*arrows*). Careful correlation between CT and radiography is required to see if all densities are caused by chondrocalcinosis

arthrography, such as septic arthritis and complications related to the iodine-containing contrast media [13].

CT arthrography is, nonetheless, a valuable alternative when MR imaging is not available, in the presence of orthopaedic hardware (Fig. 3.2.2) or in patients with contraindications for MR imaging. It is also indicated for the evaluation of repaired menisci, for largely the same reasons as MR arthrography. This will be discussed further in this chapter.

Developments such as the spiral acquisition mode have increased the spatial resolution of CT arthrography, while multi-detector technology has also increased the speed. Dual-detector spiral CT arthrography has been shown to be accurate for the detection of unstable meniscal tears and displaced meniscal fragments smaller than one-third of the meniscus [46]. It is, however, less accurate in depicting associated lesions such as meniscal cysts and bone marrow oedema [49]. Meniscal cysts are easily recognized when iodinated contrast enters the cyst. It is often best seen as a partially opacified structure adjacent to the meniscus on a delayed scan performed 1 h after contrast injection [25]. If no contrast enters the cyst, it is frequently indistinguishable from the surrounding tissues.

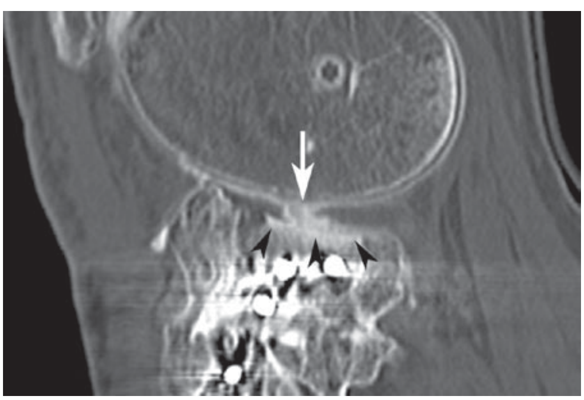

Fig. 3.2.2 CT arthrography, sagittal reconstruction. Even in the proximity of orthopaedic hardware, the gap in the body of the lateral meniscus (*arrow*) and the large cartilage defect on the tibial plateau (*arrowheads*) are clearly visible

Bone marrow oedema is completely invisible on CT arthrography and bone contusion can only be detected if a cortical or subchondral fracture is present (Fig. 3.2.3).

The biggest drawback of CT arthrography is its inability to reliably detect ligamentous lesions, particularly lesions of the posterolateral corner, the lateral collateral ligament and the posterior cruciate ligament (PCL) [47]. Lesions of the medial collateral ligament and anterior cruciate ligament (ACL) can be visualized directly or diagnosed using indirect signs, such as abnormal ACL contours with thickening of the ligament and markedly convex posterior aspects of the ligament.

MR and MR Arthrography

MR imaging of the meniscus is highly effective and is the primary technique for evaluating internal derangements of the knee [46]. The technique is non-invasive and has a high level of accuracy in the detection of meniscal lesions. The sensitivity and specificity for the

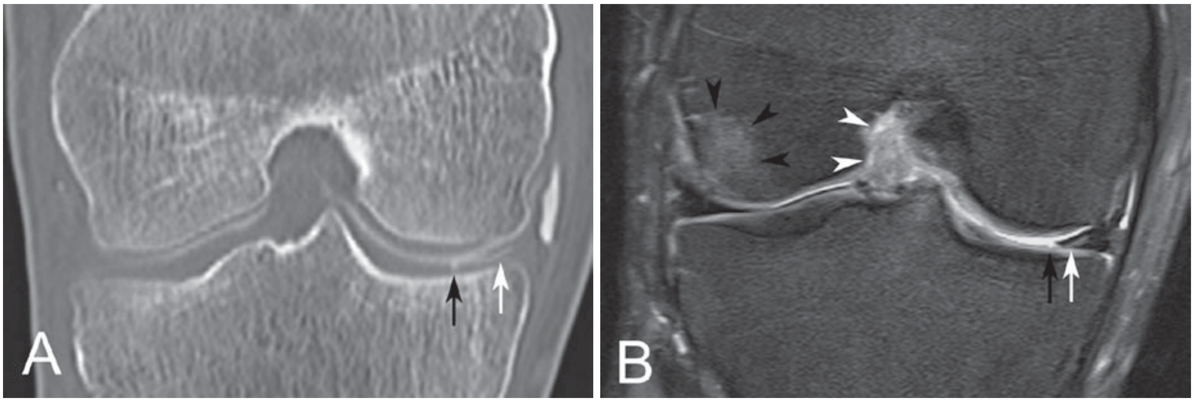

Fig. 3.2.3 (**a**) CT arthrography, coronal reconstruction and (**b**) coronal, T2-weighted FSE sequence with fat saturation. Both imaging modalities depict the oblique tear in the body of the medial meniscus (*white arrow*). However, CT arthrography does not show the area of bone contusion (*black arrowheads*) or the tear of the anterior cruciate ligament (*white arrowheads*), clearly seen on the MR image. The small cartilage lesion (*black arrow*) is more readily seen on CT arthrography

detection of medial meniscal tears are both estimated to be approximately 90%. The same applies to the specificity for lateral meniscus tears, but here the sensitivity is lower (approximately 80%).

The accuracy of detecting meniscal lesions in a non-operated or postoperative knee is not significantly improved by using direct or indirect MR arthrography [57]. However, direct MR arthrography is useful after meniscal repair.

Imaging Technique

A dedicated knee coil is used to provide a uniformly high signal-to-noise ratio without the posterior to anterior signal drop-off that is associated with the use of flat-surface coils. Optimal imaging of the meniscus also requires spin-echo sequences with a small field of view (16 cm or less), a slice thickness of no more than 3 mm and a matrix size of at least 192×256 steps in the frequency and phase encoding directions. For all meniscal tears to be detected with MR imaging, both sagittal and coronal images are necessary.

Conventional spin-echo T1-weighted, proton density-weighted or gradient-echo images are the most suitable sequences for the detection of meniscal tears, primarily due to their high sensitivity [16]. Long echo-time (T2-weighted) sequences are associated with a lower sensitivity and a higher specificity (Fig. 3.2.4).

Reports initially advised against the use of fast spin-echo imaging because the sensitivity (approximately

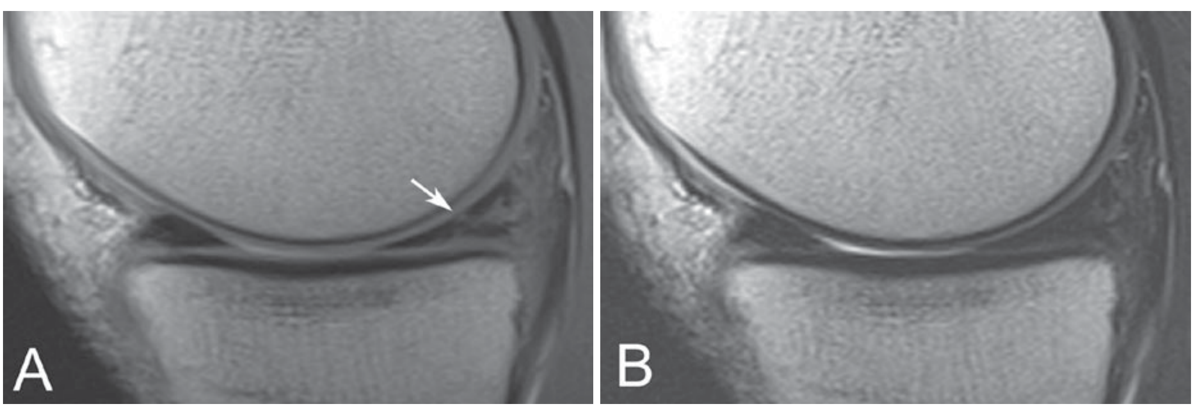

Fig. 3.2.4 (**a**) Sagittal proton density-weighted and (**b**) T2-weighted FSE sequence. (**a**) The image with the short echo-time shows an area of high signal intensity abutting the superior articular surface (*arrow*). This is associated with an arthroscopic tear in over 90% of cases. (**b**) The long echo-time images do not depict this area

80%) was lower than that of conventional spin echo [2], due to the increased blurring inherent in fast spin-echo imaging. Optimization of fast spin-echo imaging by decreasing the echo train length and increasing the matrix size (e.g. up to 384×512) increases the performance of this sequence to the same level as spin-echo images, but reduces the time saved using the fast spin-echo sequence [1, 8, 14, 34].

Fat suppression may be applied to meniscal-sensitive sequences to remove high signal originating from the fatty marrow in the bones and the fat in soft tissues [16]. With fat suppression, the dynamic range of signal in the meniscus increases and tears are more conspicuous. The use of fat suppression is becoming more widespread, although evidence indicating that fat suppression improves the accuracy of tear detection is still lacking [16, 35].

Normal Meniscus Anatomy

The normal meniscus shows uniform, low signal intensity on T1- and T2-weighted images. In the sagittal plane, the anterior and posterior horns are visible as black triangles with the sharp points facing each other. The posterior horn of the medial meniscus is larger than its anterior horn, whereas on the lateral side, both horns are approximately equal in size. Peripherally (medially for the medial meniscus and laterally for the lateral meniscus), the menisci have a bow-tie shape. The anterior and posterior horns are taller than the thinner and interposed body of the meniscus. In the coronal plane, the menisci are triangle-shaped with the pointed apex in the innermost part of the knee.

MR imaging is the modality of choice for confirming the diagnosis of normal meniscus variants, including meniscal flounce and discoid meniscus. A meniscal flounce is an uncommon variant, which is characterized by a single symmetrical fold along the free edge of the meniscus. On a sagittal image, it appears as an S-shaped fold along the free edge (Fig. 3.2.5). On a coronal image, the meniscus appears as a truncated but normal meniscus. The discoid meniscus appears larger than a normal meniscus and can be difficult to distinguish from a normal meniscus. Continuity of the meniscus between the anterior and posterior horns on three or more 5 mm-thick consecutive sagittal sections is indicative of a discoid meniscus.

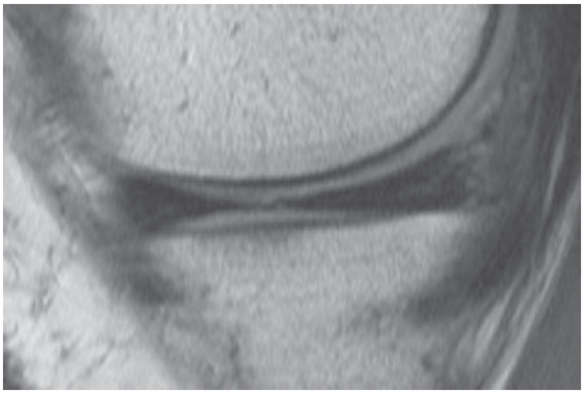

Fig. 3.2.5 Sagittal proton density-weighted FSE sequence. The wavy appearance of a meniscal flounce can be very subtle

Abnormal Meniscal Signals

Abnormally high signals in the menisci fall into three broad categories [23, 39]. Grade 1 represents a focal, increased, globular intra-meniscal signal that does not come in contact with the articular surface of the meniscus. In adults, a grade 1 signal can be associated with mucoid degeneration. In children, however, it may be observed without mucoid degeneration, corresponding to the normal vascularity that diminishes with increasing age. This is most prominent in the posterior horn of the medial meniscus, where a high signal of questionable significance can be seen in many adults [38]. A grade 2 signal is defined as an area of primarily linear signal intensity that does not extend to an articular surface. It is thought to be a progression of grade 1, representing the fragmentation of collagen bundles caused by the difference in frictional forces of the superior and inferior surface of the meniscus. Grade 1 and 2 signals are rarely associated with arthroscopically detectable tears.

A grade 3 meniscal signal refers to a linear, globular or complex area of increased signal intensity with extension to at least one articular surface. Tears are found during arthroscopy in over 90% of cases with a grade 3 signal [9, 21]. In 5% of grade 3 menisci, there is only a closed meniscal tear with intra-substance cleavage, which can be missed arthroscopically without thorough surgical probing.

In some cases, e.g. meniscal contusion and chondrocalcinosis, an abnormal signal in the meniscus does not aptly fall into these categories. Although the increased signal in the periphery of the contused

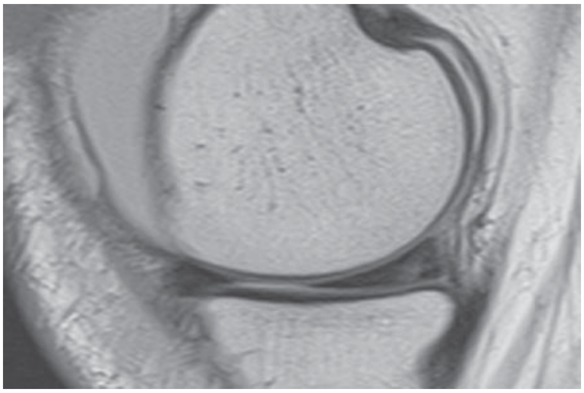

Fig. 3.2.6 Sagittal proton density-weighted FSE sequence. This indistinct area of high signal in the posterior horn of the medial meniscus after a recent trauma represents a meniscal contusion

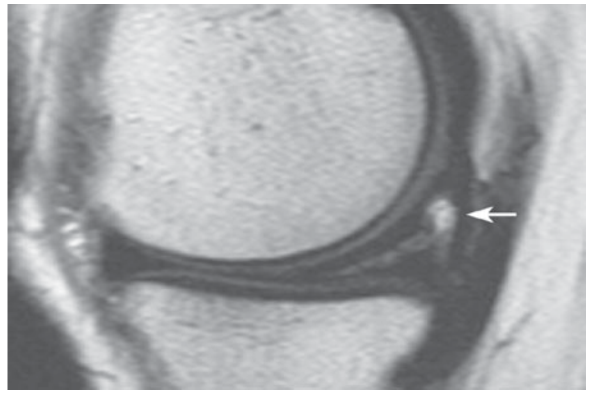

Fig. 3.2.7 Sagittal T2-weighted FSE sequence. A hyperintense line on a T2-weighted image (TR: 4,000 ms; TE: 96 ms) is the most accurate criterion for a meniscal tear. The presence of a meniscal cyst (*arrow*) only confirms this diagnosis

meniscus (Fig. 3.2.6) can resemble a tear, it appears indistinct and amorphous rather than sharp and discrete. Chondrocalcinosis refers to radiographically evident calcium deposits in hyaline cartilage or fibrocartilage. It appears as an area of high signal intensity on T1-weighted or proton density-weighted sequences and can be mistaken for a meniscal tear [16]. In a small number of cases, an abnormal signal does not represent a meniscal tear, contusion or degeneration and is of an unclear cause and significance [21].

Detection of Meniscal Lesions

Meniscal lesions can be detected by MR imaging by the presence of an abnormal meniscal signal and abnormal meniscal morphology. An increased internal signal that abuts an articular surface of the meniscus on a short-TE image (16–20 ms) is a strong indicator of a meniscal tear. The specificity of this criterion is improved if the increased signal is visible on more than one adjacent image [11]. The highest level of accuracy is achieved when the increased signal is evident on T2-weighted images (Fig. 3.2.7). Most meniscal tears are not visible on long TE images unless a cleft filled with joint fluid is present.

An abnormal meniscal shape is an accurate indicator of the presence of a tear in the majority of previously untreated menisci. Exceptions to this rule are a discoid meniscus and a wavy contour or flounce in the medial meniscus. However, these morphologies are still frequently associated with a tear and necessitate careful examination for signal abnormalities.

Meniscal Lesions

Classification of Meniscal Tears

Longitudinal/Vertical Tears

Longitudinal tears run parallel to the outer margins of the meniscus following the longitudinal collagen bundles. They most frequently occur in the peripheral or middle third of the meniscus, usually originating in the posterior horn. Although sagittal images are best suited to demonstrate these tears, coronal imaging is also used to assess extension of the tear into the body of the meniscus.

A meniscocapsular separation is an uncommon but important knee injury, characterized by a vertical tear in the extreme periphery or the junction between meniscus and synovium. As the tear is located in a well-vascularized portion of the meniscus, it may heal spontaneously or be repaired successfully [34]. Differentiation of the vascularized meniscosynovial junction from a tear may be difficult unless fluid is visible within the tear.

A displaced inner portion of a longitudinal tear is described as a bucket-handle tear. In such tears, the fragment usually lies in the inter-condylar notch

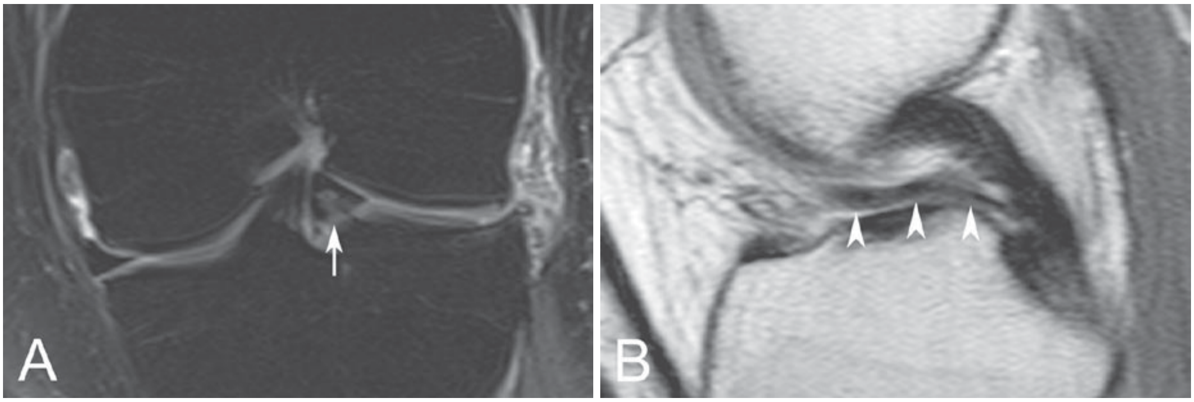

Fig. 3.2.8 (**a**) Coronal fat-saturated and (**b**) sagittal proton density-weighted FSE sequence. (**a**) A long, vertical tear in the periphery has allowed the meniscus (*arrow*) to become displaced. It is now lying against the inter-condylar eminence. (**b**) The dislocated meniscus is seen on sagittal images as a second, hypointense structure (*arrowheads*) paralleling the underside of the posterior cruciate ligament

(Fig. 3.2.8), although a location superior, inferior or posterior to the remainder of the posterior horn is also possible [58]. The sensitivity of MR imaging for the detection of bucket-handle tears has been reported to be only 44–64% [16]. This can be improved by using a technique described as the absent bow-tie sign, where two consecutive sagittal images of the meniscus are taken [17]. In the normal meniscus, two bow-tie shaped images will be seen, whereas in a meniscus with a bucket-handle tear, the second sagittal image fails to have a bow-tie shape due to the loss of tissue in the free edge of the meniscus. A second sign of a bucket-handle tear is the double PCL sign, where an added hypointense structure is seen underneath the PCL (Fig. 3.2.9b).

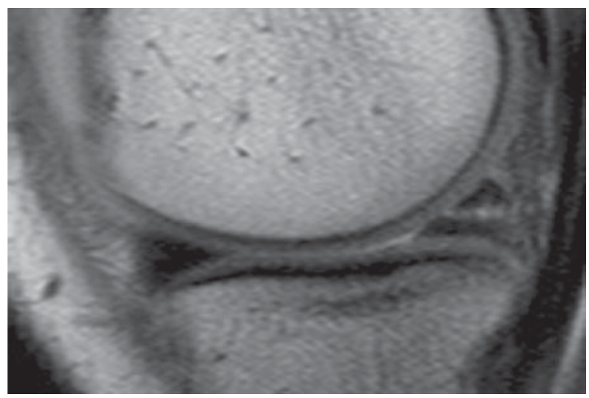

Fig. 3.2.9 Sagittal, T2-weighted FSE sequence. This horizontal tear is found somewhat atypically in a young person and originates from the superior aspect of the meniscus

Horizontal Tears

Horizontal (or cleavage) tears run parallel or at a slight angle to the articular surface of the meniscus and perpendicular to the meniscocapsular junction. They most commonly originate from either the free edge or the undersurface of the meniscus (Fig. 3.2.9). Horizontal tears are often degenerative, occurring in older patients with mucoid degeneration of the menisci. The tear and the mucoid degeneration may have the same signal intensity, making assessment of the depth of the tear difficult on short TE images. Although the extent of a horizontal tear is frequently overestimated, there are exceptions where fluid entering the tear is visible on T2-weighted images. The shape of a horizontal tear can cause it to act as a valve, trapping fluid in the tear until a cyst is formed in the meniscocapsular junction. These meniscal cysts can become very large and compress the surrounding structures [5].

Radial Tears

Radial tears originate from the free edge of the meniscus and extend peripherally, running perpendicular to the longitudinal collagen bundles. They decrease the tensile strength of the meniscus and can cause the meniscus to become displaced. Most radial tears are

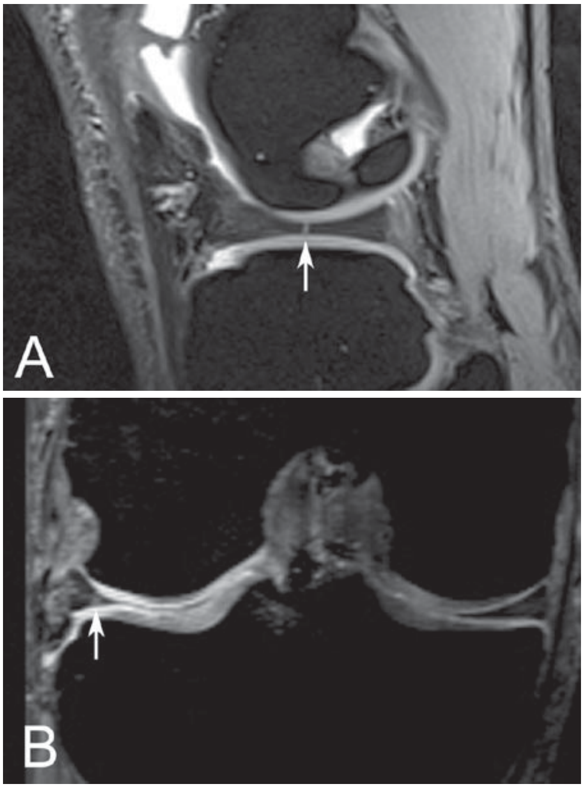

Fig. 3.2.10 (**a**) Isotropic DESS 3D gradient-echo sequence, sagittal reconstruction and (**b**) coronal reconstruction. (**a**) A thin, hyperintense line (*arrow*) in the periphery of the body of the lateral meniscus was the only sign of the full-thickness radial tear in this young soccer player. (**b**) Blunting of the free edge (*arrow*) could only be suspected on the 1 mm-thick coronal reconstructions of the T2-weighted DESS 3D sequence

shallow and do not extend beyond the central third of the meniscus. The appearance of a radial tear on a standard MR image varies with the size, location, orientation and whether the tear is of full or partial thickness (Fig. 3.2.10) [43]. A full-thickness tear that is perpendicular to the circumferential axis of the meniscus is the most easy to diagnose. This type of tear most commonly manifests a complete absence of the meniscus on at least one of a series of images. Blunting of the inner point of the meniscal triangle and interruption of the bow-tie on one or more images are also typical signs.

Oblique Tears

Oblique (or parrot beak) tears are similar to radial tears in that they originate from the free edge and break through the longitudinal collagen fibres of the meniscus. However, they curve into a longitudinal orientation as they extend towards the periphery of the meniscus (Fig. 3.2.11). On at least one image, the free edge appears blunted. On sequential images, a vertically oriented longitudinal tear becomes visible, sometimes with an elongated aspect of the inner point of the meniscal

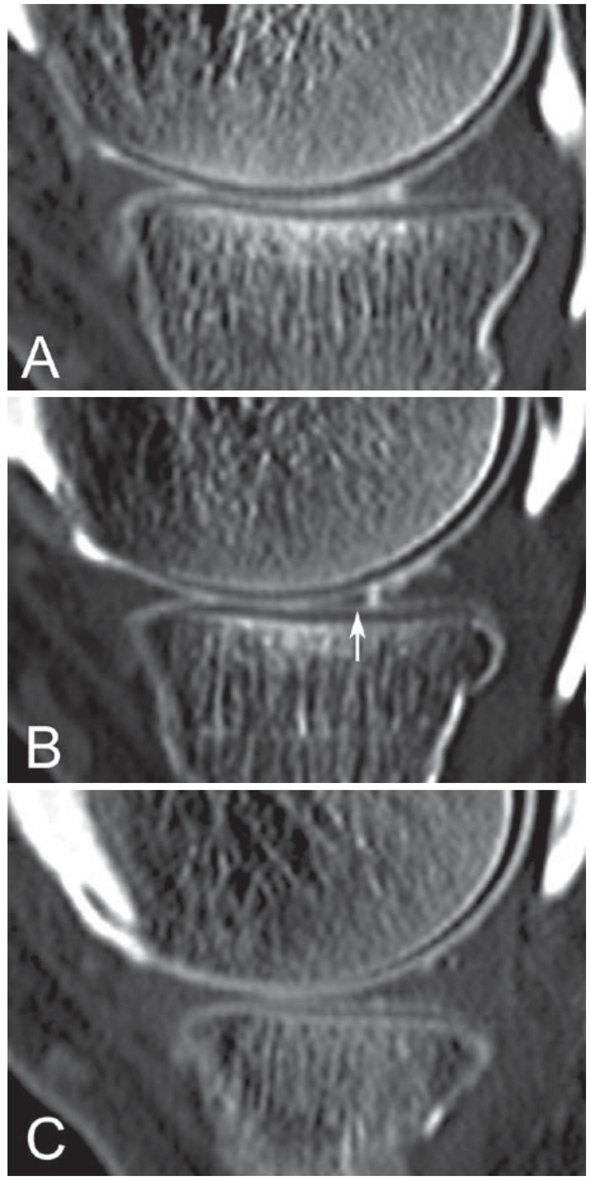

Fig. 3.2.11 Computed tomography, sagittal reconstructions. Sequential images of a oblique tear show (**a**) the blunted edge of the posterior horn, (**b**) a vertical defect in the central edge of the meniscus with a small, displaced fragment (*arrow*) and (**c**) a return to the normal configuration

triangle, indicating that the torn part of the meniscus is displaced towards the centre of the knee compartment. In this case, the tear is unstable and may cause more significant symptoms such as pain and mechanical symptoms, e.g. locking, catching and giving way. Although large displaced fragments are readily seen on imaging, small displaced fragments may be overlooked. Careful examination for displaced fragments should be performed in cases where the meniscus appears abnormally small [17].

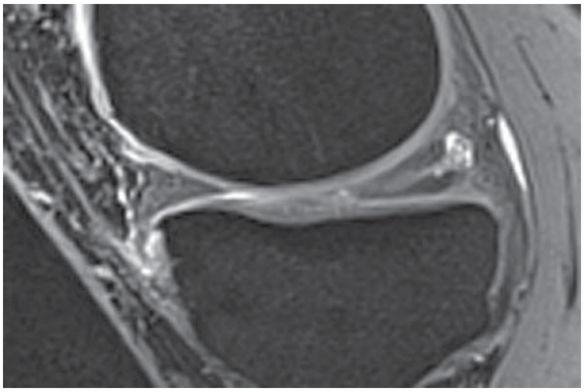

Fig. 3.2.12 Sagittal T2-weighted DESS 3D gradient-echo sequence with water excitation. An undersurface tear in the posterior horn of the medial meniscus has given rise to a parameniscal cyst containing some debris

Complex Tears

A complex tear is a single tear that contains a combination of longitudinal, radial and horizontal cleavage planes. These tears may show characteristics of each of the other tear types, or appear fragmented or macerated. Complex tears are almost always degenerative in origin and are often difficult to differentiate from extensive mucoid degeneration.

Meniscal Cysts

Meniscal cysts occur in 4–6% of knees studied with MR imaging and are found twice as often in the medial meniscus [16]. They are often associated with meniscal tears [7] and may be a source of symptoms. A high MR signal in a swollen meniscus is diagnostic of a meniscal cyst [7, 16]. This high signal is not as bright as fluid on T2-weighted sequences, although under pressure, fluid in the intra-meniscal cyst can be squeezed into the adjacent soft tissues, forming a parameniscal cyst (Fig. 3.2.12), which appears high in signal on T2-weighted sequences. The swollen meniscus decompresses to a shape that is more typical of a normal meniscus.

MR Imaging Pitfalls

MR imaging is very effective for detecting meniscal tears. However, errors may occur in the interpretation of the imaging findings, which results in an incorrect diagnosis. Structures such as the attachment sites of the inter-meniscal ligament to the anterior horns, the popliteal tendon passing next to the posterolateral corner of the lateral meniscus and the origin of the meniscofemoral ligaments from the posterior horn of the lateral meniscus mimicking meniscal tears can result in a false-positive diagnosis [11]. Other potential causes of a false-positive diagnosis are chondrocalcinosis (Fig. 3.2.13), meniscal contusion, healed meniscal tears and degenerative changes in the posterior horns of the menisci [6, 15].

When a short echo-time sequence (e.g. proton density-weighted) is used and part of the meniscus is angled at 55° relative to the static magnetic field, an area of artifactually increased meniscal signal can occur in the posterior horn. This magic-angle phenomenon most frequently occurs in the lateral meniscus and is thought to be one reason why sensitivity for detecting tears in the lateral menisci is lower than that for the medial menisci [30]. One method of eliminating the magic-angle effect in the lateral meniscus is to image the knee in slight abduction. This alters the orientation of the posterior horn, but does not angle the medial meniscus enough to evoke the magic-angle effect.

Tears on the undersurface of the posterior horn of the medial meniscus, particularly those in the periphery, may be correctly demonstrated with MR imaging but missed arthroscopically. To avoid this, the arthroscopist should use additional viewing portals, angled arthroscopes and probing to assist in identifying the

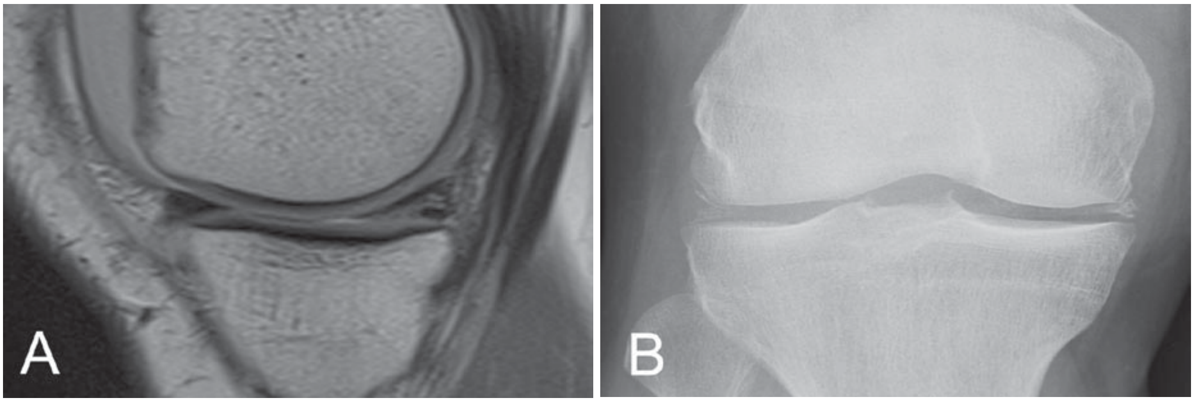

Fig. 3.2.13 (**a**) Sagittal proton density-weighted FSE sequence and (**b**) anteroposterior radiograph. (**a**) Although the MR image shows a grade 3 signal in the posterior horn of the medial meniscus, the calcium deposit seen on the plain radiograph makes the diagnosis of a degenerative tear uncertain

tear. False-negative interpretations include short partial-thickness stable tears, far peripheral tears in the red zone and peripheral tears in the posterior horn of the lateral meniscus [11, 20].

Postoperative Imaging

MR imaging of the operated meniscus is becoming more common due to the increasing number of therapeutic knee arthroscopic procedures [33]. Artefacts resulting from the arthroscopy procedure may be present on MR images (Fig. 3.2.14). Microscopic metallic fragments along the tracts made by the arthroscopic instruments can result in small areas of signal loss on spin-echo and fast spin-echo MR images. These tracts may be more pronounced on gradient-echo images. In addition, small metallic particles may be embedded within the cartilage of the knee joint, particularly in the posterior region of the femoral condyle.

Fig. 3.2.14 Sagittal proton density-weighted FSE sequence. Metallic artefacts can be observed along the arthroscopy tract in Hoffa's fat pad (*arrows*) and around the osteochondral grafts (*arrowheads*) after autologous osteochondral plug transfer

Other possible artefacts include fibrotic scarring along the trajectory of the arthroscope, particularly in the area of Hoffa's fat pad, or strands of high signal intensity on T2-weighted images for a few months post-surgery, indicating the presence of young granulation tissue. Fibrotic thickening or focal defects may be present in the patellar retinaculae and thickening of the patellar tendon may occur as a result of piercing with arthroscopic instruments. After very recent surgery, postoperative seromas or fluid in the arthroscopic tracts may also be observed.

MR Imaging of the Operated Meniscus

Following partial meniscectomy, the morphological appearance and signal intensity of the meniscal remnant can be variable, making evaluation of the meniscus difficult [37]. When only a small portion of the meniscus has been removed, the appearance is similar to that of a pre-operative meniscus. Consequently, the criteria for primary meniscal tears can be applied in cases where there is no marked contour irregularity.

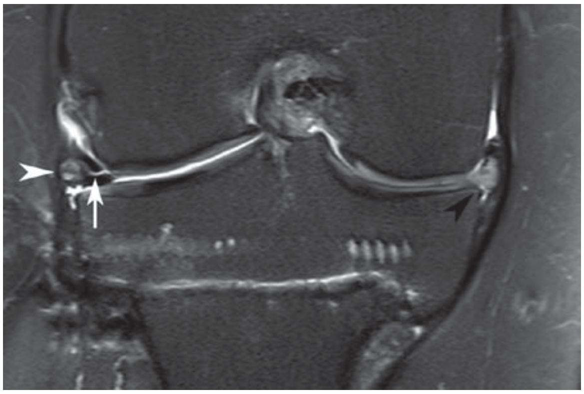

Fig. 3.2.15 Coronal fat-saturated proton density-weighted FSE sequence. The linear high signal in the body of the lateral meniscus (*arrow*) could be attributed to either a residual tear or an area of internal degeneration that has come into contact with the articular surface of the meniscus after resection of the central part of the meniscus. Because of the presence of a meniscal cyst (*white arrowhead*), the former assumption is more likely. Note the artificial meniscus (*black arrowhead*) implanted in the body of the medial meniscus and the tibial osteotomy

Menisci that have undergone extensive resection show much greater signal variation, ranging from homogeneous signal and smooth contour to signal inhomogeneity and marked surface irregularity [37]. The accuracy of tear detection in a postoperative knee is, therefore, much lower (Fig. 3.2.15). In an attempt to improve the diagnostic accuracy of MR imaging, White et al. [57] compared direct and indirect MR arthrography with standard MR imaging. Although the accuracy was slightly increased with direct MR arthrography, the difference was not significant.

Imaging of the Sutured Meniscus

Studies of meniscal repair have shown that linear areas of high signal intensity extending to the surface can persist at the tear site for at least 1 year post-repair [12, 15]. These signals mimic or obscure genuine tears and may lead to a false-positive diagnosis of a retear, or the false conclusion that the repair was unsuccessful. If MR imaging shows a tear at a position that is different from that of the original tear, the diagnosis of a tear may be made. However, if an area of increased signal contacting the articular surface is observed at the repair site, caution should be applied before diagnosing a retear. A more specific but less sensitive sign of a retorn meniscus is the presence of high signal intensity joint fluid extending into a cleft within the meniscus on T2-weighted images (Fig. 3.2.16) [56]. Further indications of a new meniscal tear are marked irregularity with step-like abnormalities, abrupt changes in contour, fragmentation of the meniscus and free meniscal fragments [42].

Direct MR arthrography and CT arthrography are useful after meniscal repair to detect a retear, because pre- and post-interventional findings on conventional MR imaging are often identical [24]. An area of high signal intensity on T2-weighted images after suturing can be classified as scar tissue or a retear, depending on whether or not contrast medium is entering into it. Because CT arthrography does not depict the scar, any contrast entering the meniscus must be considered a tear. However, a small indentation can sometimes be seen where the suture abuts the articular surface. Indirect MR arthrography is not useful, because granulation

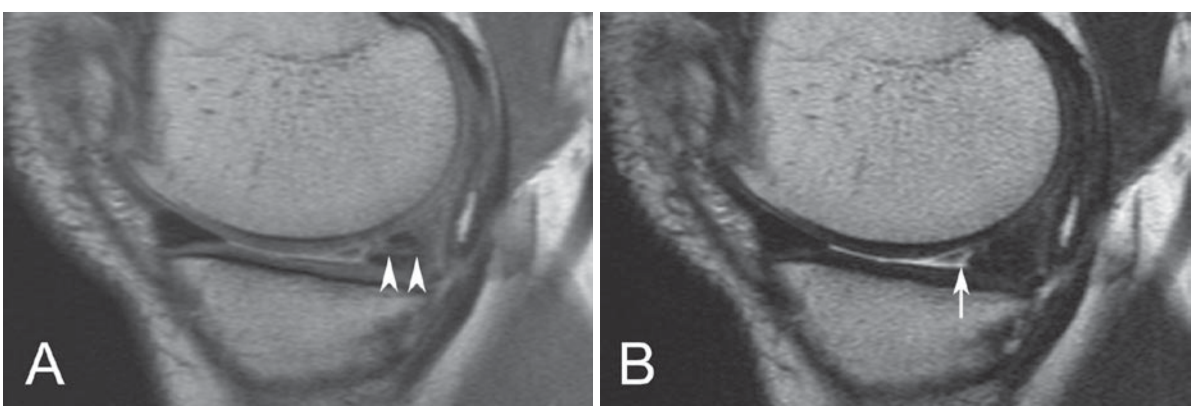

Fig. 3.2.16 (**a**) Sagittal proton density and (**b**) T2-weighted FSE sequence. (**a**) The horizontal high signal (*arrowheads*) in this sutured meniscus should not be considered a tear. However, a small displaced fragment is present at the free edge. (**b**) Fluid can be seen entering the gap (*arrow*) between the fragment and the sutured posterior horn

tissue in the sutured tear also shows enhancement, which can lead to false-positive findings [57].

MR Imaging After Meniscus Transplantation

The aim of meniscus transplantation is to prevent the progressive articular cartilage degeneration associated with total resection of the meniscus. Meniscus transplantation may be considered in younger patients who have previously undergone total meniscectomy and have symptoms such as pain and swelling due to meniscal deficiency [52, 53]. These patients should have a stable, well-aligned knee joint with no more than International Cartilage Repair Society (ICRS) grade 3 cartilage damage. Medial meniscal transplantation may be considered in patients undergoing concomitant ACL reconstruction, because the absence of a medial meniscus results in increased forces in the ACL graft [28]. Prophylactic meniscal transplantation is currently not recommended due to the associated operative risk and limited evidence of a chondroprotective effect [51].

Transplantation of a meniscal allograft requires accurate allograft sizing in order to increase the chances of allograft survival and to maximize the chondroprotective effect in the recipient's knee. A number of imaging modalities have been used to predict meniscus size with varying levels of accuracy. The most commonly used method combines plain radiographs with the technique described by Pollard et al. [31]. With this technique, the width of the meniscus is determined on an anteroposterior view and the length is calculated by multiplying the length of the tibial plateau on a lateral view by a factor of 0.8 for the medial meniscus and 0.7 for the lateral meniscus.

MR imaging is used to determine the status of the transplanted allograft, accurately displaying its position within the femorotibial joint, the capsular attachment, any areas of meniscal transplant degeneration and the condition of the adjacent articular cartilage [29, 32, 54, 55]. A common finding after meniscus transplantation is meniscal degeneration. Fragmentation and separation are less common. Extrusion of the body of the meniscus after meniscal allograft transplantation is frequently detected. This may range from slight lateral displacement to frank dislocation with displacement of portions of the allograft into the peripheral gutters (Fig. 3.2.17) [45, 50].

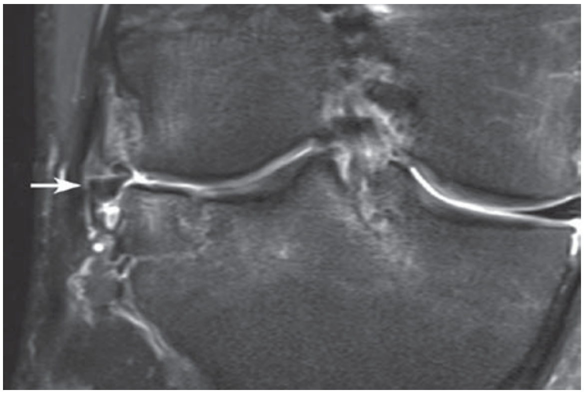

Fig. 3.2.17 Coronal proton density-weighted image with fat saturation. Because the fixation of a transplanted meniscus is less firm than that of a native meniscus, the body of the transplanted meniscus has a tendency to displace. In this case, the body of the transplanted lateral meniscus (*arrow*) has luxated into the lateral recess after recent trauma

The signal intensity of a transplanted meniscus on MR imaging should ideally match that of a native meniscus. However, allografts often show areas of high signal, which appear shortly after the operation and either remain unchanged or show progression at follow-up [39, 41]. Verdonk et al. [51] have suggested that these signal changes represent changes in the water content and extracellular matrix composition of the meniscus, rather than meniscal tears. An increase in signal intensity is also noted at the peripheral capsular attachment. This corresponds histologically to scar tissue with cellular ingrowth and revascularization of the meniscal periphery [29, 32]. Multiple micrometallic artefacts resulting from surgical manipulation may also be present along the meniscocapsular junction, enabling the radiologist to identify the allograft even if the shape, position and signal intensity are normal (Fig. 3.2.18).

Rare complications that have been reported meniscal allograft transplantation include detachment of the allograft from the capsule causing a bucket-handle or flap tear and, more frequently, mild irregularities of the free edge of the meniscal transplant [29, 54, 55].

MR Imaging of the Artificial Meniscus

Meniscal replacement devices based on collagen [40], hyaluronic acid [22], polyurethane [10] and other materials have recently been introduced into clinical

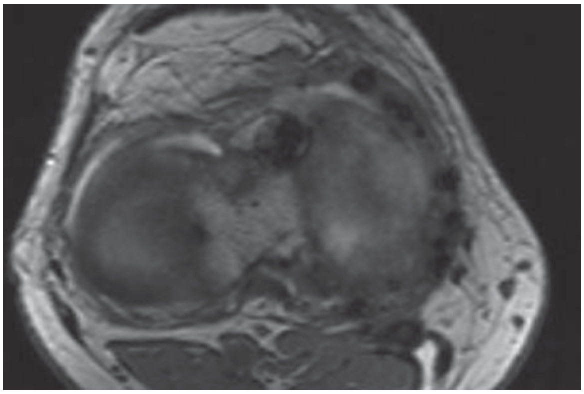

Fig. 3.2.18 Transverse, T2-weighted DESS 3D gradient-echo sequence. The chain of metallic artefacts along the meniscocapsular junction is an unmistakable sign of a transplanted meniscus

practice. The purpose of these scaffold devices is not to replace the meniscus biomechanically, but to provide a matrix for tissue ingrowth and new tissue formation. To obtain stable fixation of the device, implantation is only possible in patients with an intact peripheral meniscal rim. Histological analysis of pre-clinical and clinical biopsies has demonstrated repopulation of the collagen scaffold by host cells and the formation of fibrous tissue, followed by remodelling of the fibrous tissue into fibrocartilaginous-like tissue [4].

To date, little has been published on imaging findings of these implants post-surgery [3, 18]. MR imaging data from patients who received a collagen meniscus implant demonstrated no major changes in the height of the joint space at 3 years post-implantation [40]. Increased signal intensity of the newly regenerated tissue was observed, which was suggested to be a sign of maturation. Imaging of a polyurethane meniscus scaffold also showed increased signal intensity after implantation. MR images obtained 1 week after implantation indicated that the signal intensity of the scaffold was close to that of water on both T1- and T2-weighted spin-echo and turbo spin-echo sequences (Fig. 3.2.19) [19]. Three and 12 months post-implantation, the implant was still clearly visible and had a markedly higher signal intensity than the native meniscus.

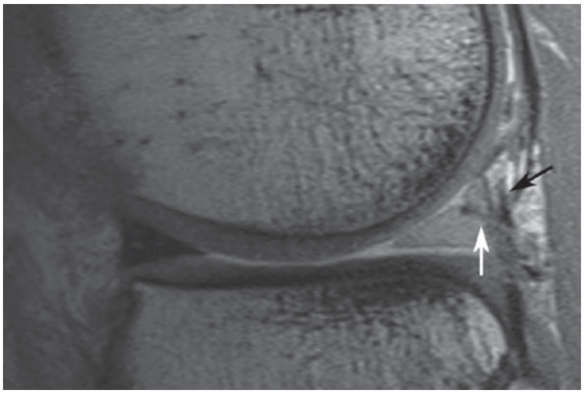

Fig. 3.2.19 Sagittal proton density-weighted FSE sequence. After resection of the posterior horn of the lateral meniscus, a polyurethane scaffold was implanted. The suture (*white arrow*) fixing the device to the native meniscocapsular junction (*black arrow*) can clearly be seen. Note the marked difference in signal intensity between the native anterior horn and the water-filled scaffold posteriorly

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Bone Scan

3.3

S. F. Dye

Most orthopedic surgeons conceptualize musculoskeletal pathology primarily in structural and biomechanical terms. The very lexicon of orthopedic surgery is replete with such terminology (e.g., fracture, tear, rupture, strain, subluxation, chondromalacia, instability, etc.). Even degenerative conditions such as osteoarthritis are characterized by structurally oriented terms (e.g., joint space narrowing, osteophytes, osteopenia, osteosclerosis, subchondral bone cysts, loose bodies, etc.). None of these terms captures the active pathophysiological processes that occur within living joint tissues. The reason for this perspective of musculoskeletal pathology is likely due, in great degree, to the imaging modalities available to most orthopedic surgeons. Plain radiographs, computed tomography, ultrasound, and even magnetic resonance imaging (MRI) provide primarily structural and pathoanatomic data. By contrast, technetium 99m-methylene diphosphonate bone scintigraphy is one of the very few imaging modalities including positron emission tomography (PET) scans, which reveal *metabolically oriented* information regarding musculoskeletal tissues. Technetium bone scans manifest the osseous homeostasis characteristics of living joints [4]. A normal bone scan indicates the presence of tissue homeostasis (normal physiological processes) within volumes of living bone cells. A bone scan showing increased uptake indicates regions of loss of osseous homeostasis reflecting increased metabolic turnover. Such metabolic imaging studies (like thallium heart scans) absolutely require a living individual in order to be performed. It may be surprising to learn that MRIs, as currently configured, are incapable of distinguishing between a living or a cadaver joint [4].

It is well understood that a joint such as the knee with established degenerative changes will manifest increased osseous metabolic activity on bone scintigraphy (Fig. 3.3.1a, b). However, similar loss of osseous homeostasis can be seen with patients with *normal* radiographs. For example, in a patient diagnosed with a torn medial meniscus by MRI and normal radiographs,

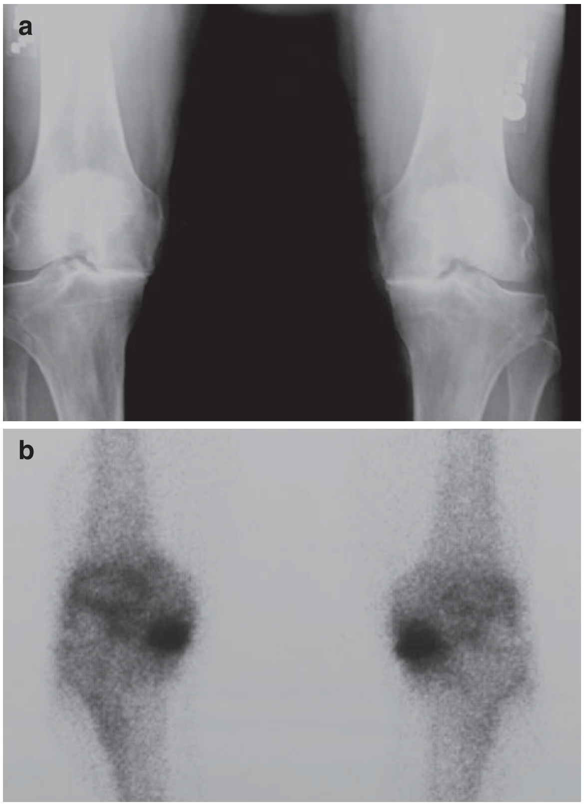

Fig. 3.3.1 (**a**) AP Radiograph showing advanced degenerative changes of the medial compartments of both knees. (**b**) AP bone scan showing intense uptake (loss of osseous homeostasis) in the medial compartments of both knees

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P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_3.3, © Springer-Verlag Berlin Heidelberg 2010

the bone scan is nonetheless abnormal, manifesting loss of osseous homeostasis in the medial compartment (Fig. 3.3.2a–c). In such a patient, most orthopedic surgeons would believe the extant pathology to be strictly limited to structural failure of meniscal fibrocartilage. Because the radiograph and the bone MRI signal are normal, the osseous components are naturally seen as being free of pathology. In such a case, as in 96% of similar cases we have studied, this would be an incorrect assumption. If one obtains a standard technetium 99m-methylene diphosphonate bone scan, the loss of osseous homeostasis of the medial compartment of the knee would be present. The loss of osseous homeostasis occurs in the presence of *normal* structural imaging data of bone. This loss of osseous homeostasis reflects the pathophysiologic effect within the living bone of the medial compartment due to the effects of the torn meniscus. Further, we have shown that this loss of osseous homeostasis (increased osseous metabolic activity as demonstrated on the bone scan) is an early indicator that the joint is "at risk" of developing osteoarthritis in a time when structural imaging studies are still normal [2, 4, 5]. We have shown that if the increased osseous metabolic activity is not reversed to normalcy – reflecting restoration of osseous homeostasis, it is predictive of the early structural changes of osteoarthritis, including joint space narrowing and osteophyte production. We have also shown that if the loss of osseous homeostasis, as demonstrated in a positive bone scan, is eventually reversed to normalcy following meniscal surgery, osteoarthritis can be prevented and the pathophysiologic process leading to the degenerative changes can be aborted at the earliest stages (Fig. 3.3.3a, b) [2, 4].

Envelope of Function

I would suggest that the primary principle of any orthopedic surgical therapy should be to restore tissue homeostasis as safely and predictably as possible. A new method of representing joint function is the concept of the "Envelope of Function" (Fig. 3.3.4a, b). This Envelope of Function [1] describes a range of loading that is compatible with, and even inductive of, tissue homeostasis of an entire joint. If too little load is placed across a joint, disuse changes can occur such as muscle atrophy and calcium loss from bone. If too much energy is placed across a joint (load and frequency are

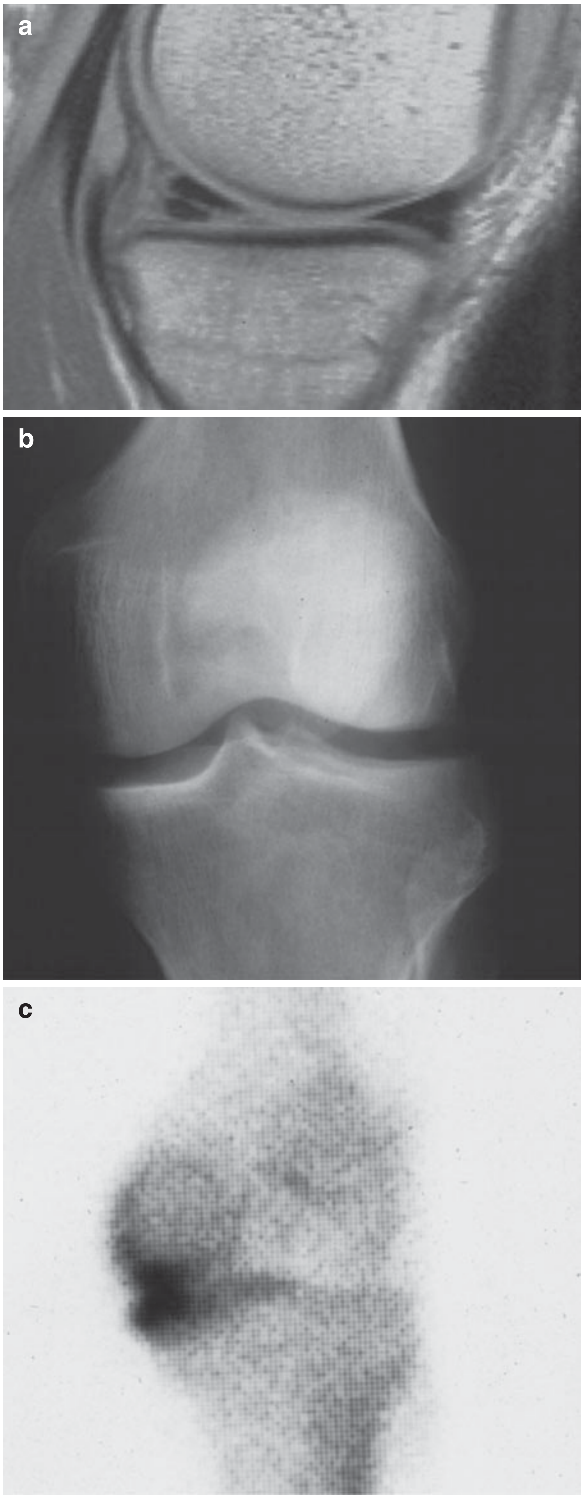

Fig. 3.3.2 (**a**) Sagittal MRI showing a tear of the posterior horn of the medial meniscus. (**b**) Normal AP radiograph of the knee with a torn medial meniscus. (**c**) AP bone scan showing loss of osseous homeostasis in medial compartment despite a normal radiograph and bone signal on MRI

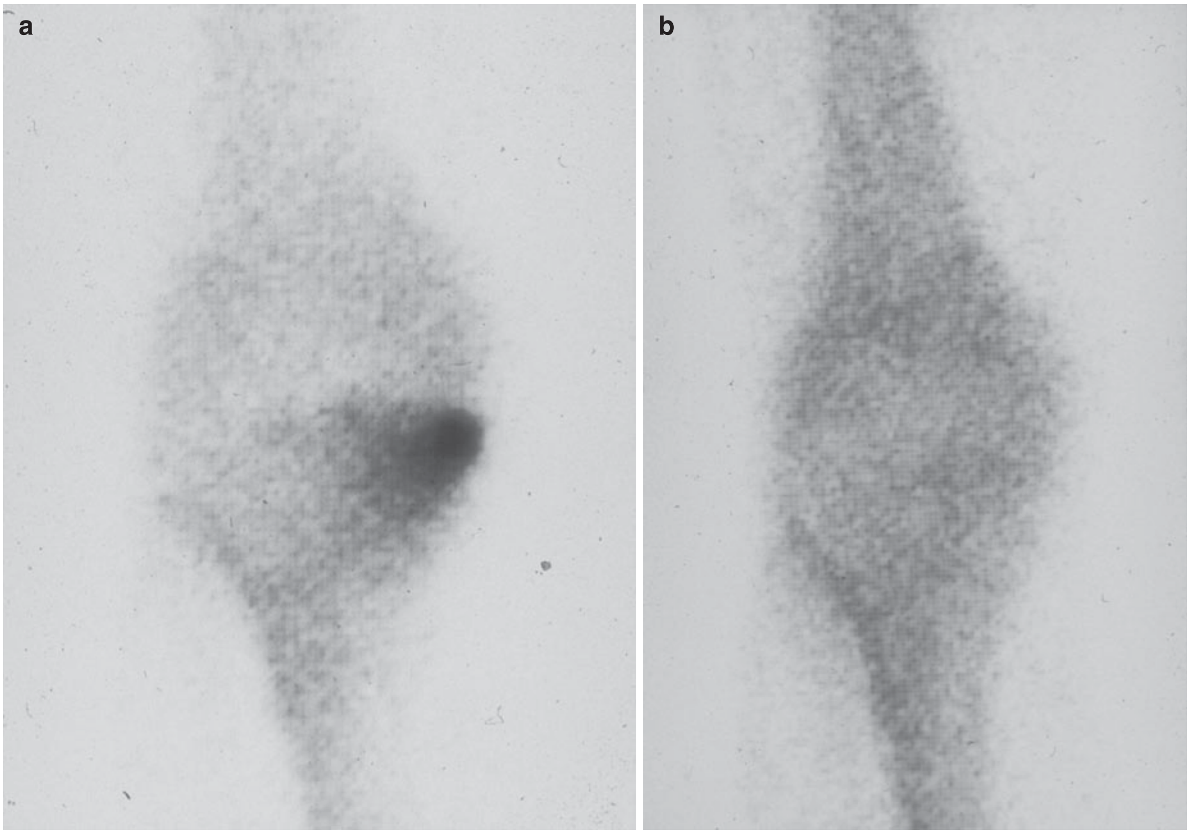

Fig. 3.3.3 (**a**) Preoperative bone scan of a patient with a torn medial meniscus of the right knee and normal radiograph. (**b**) Postoperative bone scan of the patient 7 years following partial medial meniscectomy showing restoration of osseous homeostasis. The radiograph remains normal

equivalent to energy imparted to the joint), overuse changes can occur such as the earliest phases of a stress fracture in a long-distance runner who suddenly upped his running. If excessively high loads are placed across a joint, overt structural changes can occur such as a fracture or tear of ligament or cartilage.

Knees that have undergone surgery, such as a partial medial meniscectomy or even a repair of the medial meniscus, cannot be characterized as having been restored to complete preinjury normalcy. A torn meniscus can be conceptualized as a crack in the bearing of a biologic transmission. No current treatment completely restores normal anatomy to such a joint. No knee is, therefore, structurally "fixed" to a preinjury status. However, if patients remain within their maximal posttreatment Envelopes of Function, *physiological* normalcy of the joint is possible, and osteoarthritis can be prevented if tissue homeostasis is restored and maintained. An example of a patient achieving loading within his/her postoperative Envelope of Function would be by activity modification, such as participating in bicycling and swimming activities rather than high-impact and pivoting sports like basketball or racquet sports.

Recommendations for Use of Bone Scans

I routinely obtain technetium bone scans on every meniscal case I take to surgery, because I wish to understand the pretreatment pathophysiologic status of the joint. In this way a postoperative bone scan can be compared to the preoperative status. I show the patient this preoperative bone scan, which frequently demonstrates the loss of osseous homeostasis, and make it the platinum goal of treatment to restore this loss of homeostasis to normalcy, if possible. Therefore, my patients have a vested interest in doing their part to help restore the joint to normal physiological function, if possible. I also caution them that it takes time – often

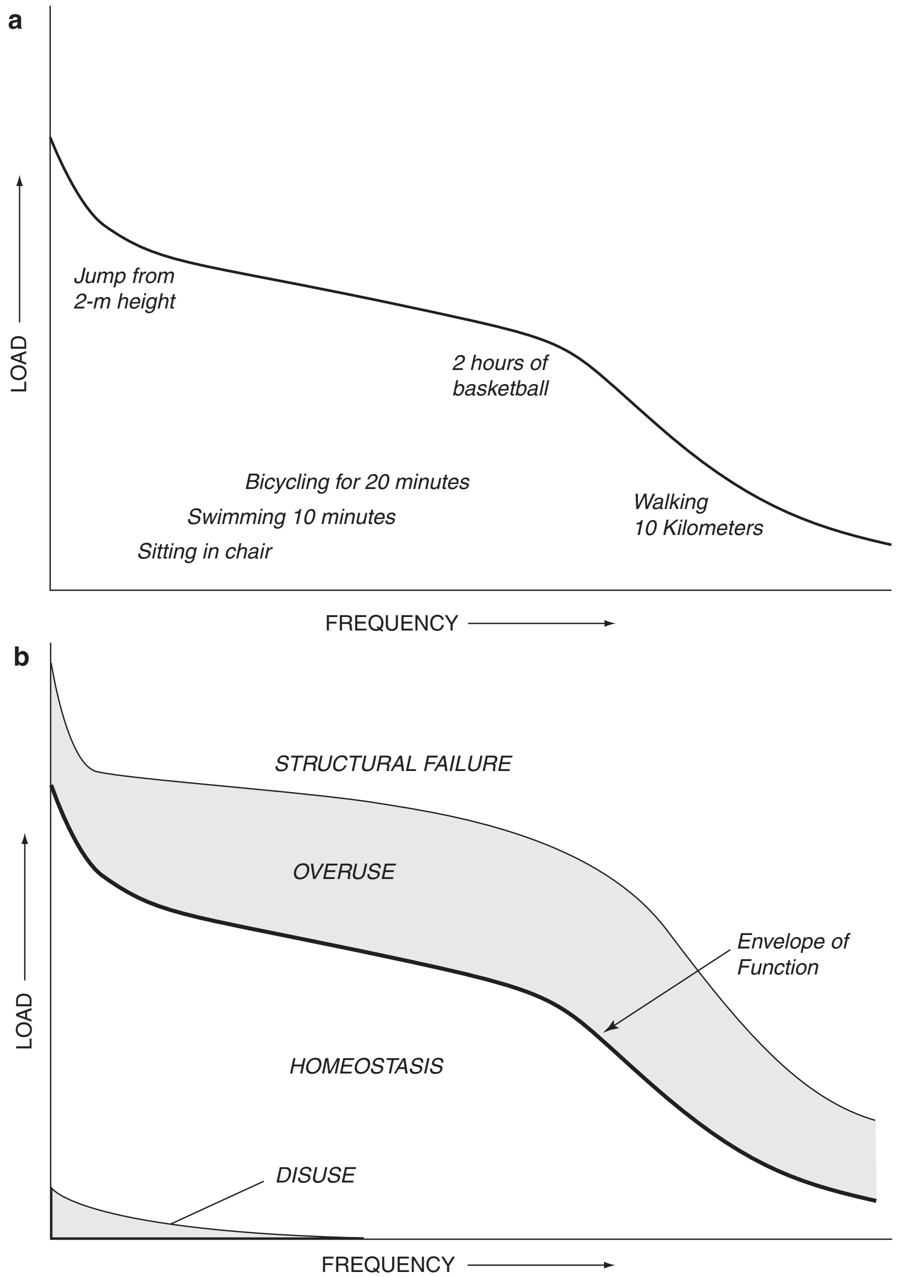

Fig. 3.3.4 (**a**) The Envelope of Function describes a range of loading inductive of tissue homeostasis of a joint or musculoskeletal system. This Envelope represents the idealized capacity for load acceptance of a normal adult knee over a period of 12 h. (**b**) The Envelope of Function is a load/frequency distribution that defines a region inductive of tissue homeostasis for a given musculoskeletal system such as the knee. If too little load is placed across the joint, disuse changes (such as muscle atrophy and calcium loss from bone) can occur. If too much load is placed across a joint, overuse changes can occur (such as seen in a stress fracture). If highly excessive loads are placed across a joint, overt structural failure can occur (such as a fracture, or torn ligament or cartilage)

up to a year and a half or more – to restore loss of osseous homeostasis following surgery.

It is not unusual for patients to come to my office with MRIs in hand that indicate the presence of a torn meniscus whose joint symptoms are unrelated to the structural damage as shown on the imaging. The association of a positive bone scan of the proximal medial tibia and a symptomatic torn medial meniscus is so strong that when a patient with an MRI diagnosis of a medial meniscus tear manifests a normal bone scan, the source of the knee symptoms as caused by the tear must be brought into question [3]. Transient synovial impingement is a common cause for knee pain in my experience, which can exist unrelated to the presence of an asymptomatic medial meniscus tear that may have been identified on MRI.

All extant factors present in a given patient, such as height, weight, sex, general nutrition, age, joint alignment, pathologic anatomy, and neuromuscular control, etc., are summarized at the level of tissue homeostasis or loss of tissue homeostasis. I would urge those with an interest in the management of patients with meniscal injuries and those participating in research into new therapies to add scintigraphic data to their pre and postoperative analysis.

Someday, I believe imaging modalities will be developed to manifest the loss of tissue homeostasis of all components of a living joint including articular cartilage, meniscal cartilage, ligaments, synovium, capsule, muscles, arteries, and nerves. When this information, which is present in all living joints, can be identified and tracked over time, the effectiveness of current and future therapies can be more accurately assessed and therapeutic improvements will likely be achieved.

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Synthesis

3.4

P. Beaufils

The aim of the physical and radiological examination is (1) to accurately diagnose a meniscal lesion and define its characteristics (see chapter: Classification), (2) to search for any concurrent lesions and (3) to provide guidelines for the appropriate surgical treatment, depending on the above-mentioned findings. This issue will be addressed in the chapter on indications.

Two situations which must be clearly distinguished, are a meniscal lesion following a recent or prior injury to the knee, and a symptomatic meniscal lesion in a patient presenting with spontaneous knee pain.

History of Knee Injury

Physical Examination

Meniscal locking is usually easy to diagnose in the presence of popping inside the joint during rotational movements or especially on squatting, impossibility to fully extend the knee and joint line pain particularly on attempting joint extension. If locking has subsided spontaneously, the patient must be carefully questioned about the circumstances in which it occurred and particularly how it disappeared (reduction accompanied by a click and sudden resolution of symptoms). This allows distinguishing true meniscal locking from false locking, which is often described by patients but actually occurs as a result of intense pain irrespective of its cause, patellar instability or less commonly, a loose osteochondral fragment.

Apart from locking of the joint, a meniscal lesion is difficult to diagnose clinically. Physical examination does not allow to draw reliable conclusions. Pujol showed that the Apley and McMurray tests have relatively high specificity and low sensitivity, while joint line tenderness is associated with low specificity and relatively high sensitivity for meniscal lesions.

Associated Lesions

Physical examination is essential to detect and evaluate any concurrent lesions, particularly anterior instability of the joint associated with an anterior cruciate ligament (ACL) tear.

Because of its high specificity and sensitivity, the Lachman test is considered to be the reference test. A positive test with a soft end point allows to establish the diagnosis. However, clinical experience is necessary to detect a delayed stop with a firm end point, which is indicative of a partial ACL tear, distension of the ligament, or a tear followed by partial healing and adherence of the remaining part of the ACL to the posterior cruciate ligament. Physical examination usually provides enough information to suspect a meniscal lesion but not to confirm its existence, while it allows the examiner to clarify the clinical context (stable or unstable knee). A radiological examination is always required to confirm the diagnosis of a meniscal lesion (tears may be asymptomatic, particularly when associated with anterior instability of the joint) and to give detailed information on its characteristics.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_3.4, © Springer-Verlag Berlin Heidelberg 2010

Radiological Findings

Comparative weightbearing X-rays must routinely be obtained. If there is a history of trauma to the knee, joint line narrowing is rarely present. Nevertheless, other pathological conditions can sometimes be detected, e.g. intra-articular loose osteochondral fragments or patellofemoral dysplasia. Magnetic resonance imaging (MRI) is the reference diagnostic modality. In case of a history of a knee injury, it usually confirms the presence of a vertical longitudinal tear and provides information on its characteristics (affected meniscus, length of the tear, its direction, its location relative to the peripheral zone of the meniscus, and possible displacement). It is, therefore, a great aid in planning surgical treatment.

Should it be performed systematically?

In case of acute joint locking, arthroscopy is immediately performed, and it is not recommended to wait for MRI. Surgery allows to unlock the joint and to perform the appropriate treatment (surgical repair or meniscectomy). All equipment required for meniscal repair should, therefore, be available in the operating room.

In case of recurrent episodes of typical joint locking, the diagnosis depends on the clinical findings. MRI is the examination of choice and can help decide pre-operatively whether the lesion should be repaired or excised. It also facilitates the patients information.

If a meniscal lesion is only suspected, MRI should always be performed.

In the particular case of a chronic ACL-deficient knee with no clinical signs of meniscal pathology, MRI is also considered to be the preferred examination. Detection of a meniscal lesion could influence the indications for surgical treatment (see chapter: Indications).

As regards the clinical diagnosis and treatment of a previously unoperated knee, contrast-enhanced computed tomography (so called arthro CT scan) and arthro MRI are seldom indicated when a meniscal lesion is suspected. The advantages of these techniques do not outweigh the specificity and sensitivity of "simple" MRI. They might be applied after "simple" MRI has been performed, when a focal cartilaginous lesion is suspected. They are particularly useful in the diagnostic work-up of a symptomatic post-meniscectomy knee (see the relevant chapter).

History of Spontaneous Knee Pain

A history of spontaneous knee pain is most likely to be associated with a degenerative meniscal lesion and should be differentiated from pain caused by early or advanced osteoarthritis of the knee.

Typically, the pain is mechanical in nature and is localized to the joint line. Factors that might be suggestive of a meniscal lesion include male sex, history of strenuous physical activity, sudden onset of symptoms and localization of pain in the posterior part of the medial joint line. These are, however, only clues and their specificity is low.

Roentgenographic examination, especially the schuss view, is essential to assess the width of the joint space. Any narrowing is indicative of cartilaginous wear. Neither a meniscal lesion nor prior meniscectomy causes joint line narrowing by itself.

If signs of joint line narrowing are present, the diagnosis of knee osteoarthritis can be made. MRI is then unnecessary as it would show meniscal lesions that commonly occur in the course of this disease but are not responsible for the patient's symptoms. It would only be beneficial in case of a sudden deterioration, which could suggest an additional "traumatic" tear. If the joint line is of normal width, MRI should routinely be performed to confirm the existence of a meniscal lesion and to provide information on whether it reaches the meniscal surface (grade 3) and would benefit from surgical treatment, or is confined to the interior of the meniscus and would, therefore, best be treated conservatively. Additional information regarding early signs of chondral degeneration could also be obtained, e.g. extrusion of a meniscus, areas of looking-glass subchondral reaction, local bone ischemia (necrosis). These pathological findings are contraindications to arthroscopic meniscectomy.

Conclusion

History and physical examination play a key role in the diagnostic work-up and assist in evaluating the context. However, they do not provide sufficient grounds to draw conclusions about the characteristics of a meniscal lesion and the indications for surgical treatment. Recourse to imaging techniques is essential, with roentgenographic examination and MRI being the two most widely used methods. Only the combination of the clinical and imaging findings allows to make the correct diagnosis and to select the appropriate treatment.

Part IV

Technique

Meniscectomy: Medial-Lateral

4.1

K. F. Almqvist, A. A. M. Dhollander, P. Verdonk,
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Introduction

The meniscus plays an important role in the function of the knee. The menisci are C-shaped discs of fibrocartilage interposed between the condyles of the femur and tibia. Once described as the functionless remains of leg muscle, the menisci are now considered to be integral components of the complex biomechanics of the knee joint [1, 3]. This has led to a renewed interest in the basic science of the meniscus in terms of its structure, function and physiology. Preservation of the meniscus, if possible, is preferred when deciding to treat a meniscus tear. A thorough understanding of the anatomy, structure and biomechanics of the meniscus and other factors of meniscal healing is critical while evaluating a torn meniscus for a reparative procedure [5].

Treatment by Arthroscopic Meniscectomy

Introduction

Not so long ago, total meniscectomy was advocated to obviate the need for secondary procedures [7]. Trillat [8] stressed the importance of preserving the meniscal wall because this structure reduces the loading stress between femur and tibia by more than 50%. With the advent of arthroscopy, "adequate resection" of meniscal lesions became the gold standard, as confirmed by Northmore-Ball and Dandy [6] and Gillquist and Oretorp [4] in 1982.

Arthroscopic Medial Meniscectomy

Arthroscopic medial meniscectomy is performed with the patient under spinal or general anaesthesia depending on surgeon preference. A tourniquet is usually applied. The leg is positioned in a leg holder, which allows valgus stress to be exerted across the joint to open up the medial compartment for adequate visualization.

Classic arthroscopic approaches are used, sometimes with placement of an accessory transpatellar tendon portal. A suprapatellar pouch outflow cannula can be used at the surgeon's discretion.

Once the lesion is visualized, a probe is introduced into the index compartment in order to manipulate and evaluate the meniscal lesion.

When meniscal suturing is indicated, appropriate techniques are used to stabilize the lesion.

In the presence of a (chronic) flap tear, a radial tear, or an extensive lesion, resection is usually indicated (Fig. 4.1.1).

Pulling on the loose flap allows to properly resect the attachment under direct vision (Fig. 4.1.2). The surgeon must be careful not to lose the fragment inside the knee joint. Should this occur, the water flow can be reversed in order to "suck" the loose fragment in front of the arthroscopic optic. This allows for easier removal.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_4.1, © Springer-Verlag Berlin Heidelberg 2010

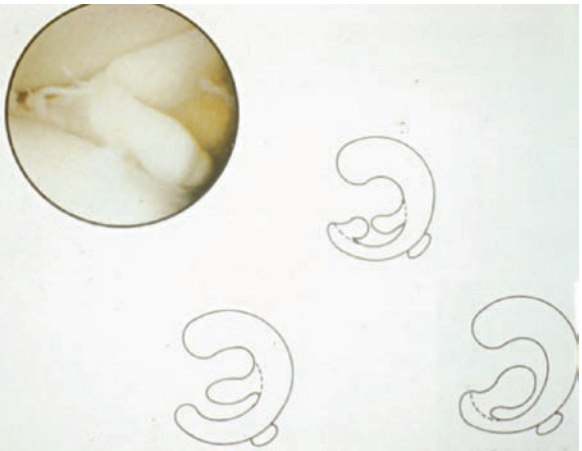

Fig. 4.1.1 Radial tears tend to evolve to flap tears, then becoming symptomatic and necessitating resection

Fig. 4.1.2 Chronic flap tears cause mechanical derangement and may be difficult to resect. After resection, fragments may become loose bodies which cannot easily be removed. Reversing the water flow in the joint is of help in finalizing surgery

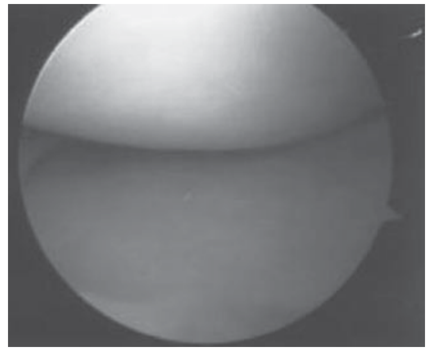

Fig. 4.1.3 After partial meniscal removal, any remaining meniscal wall irregularities may be resected until a smooth surface is achieved (by courtesy of Bell and Glaser [2])

Fig. 4.1.4 The Cabaud position allows for easy lateral compartmental viewing

In case of a bucket-handle tear, the posterior attachment is sectioned using arthroscopic scissors. Under tension (with a grasper) and through a lateral incision, the anterior horn is resected. Again, during manipulation, care must be taken that the fragment does not get lost inside the knee joint. Section through the meniscal wall should be avoided at all costs. In a number of instances, the section sequence can be reversed so that the anterior attachment is resected first, followed by the posterior horn attachment, because this may allow for meniscus removal through the anterior medial portal.

After partial meniscal removal, any remaining meniscal wall irregularities may be resected until a smooth surface is obtained. The stability of the meniscal wall is tested again with the use of the probe (Fig. 4.1.3).

Arthroscopic Lateral Meniscectomy

The standard arthroscopic meniscectomy portals are used, including an accessory transpatellar tendon portal.

An outflow incision can be prepared at the medial or the lateral superior corner of the patella.

For arthroscopic lateral meniscectomy, the lateral skin incision should be superior to the joint line and to the transpatellar tendon portal. Varus stress is applied to improve visualization of the lateral compartment (Cabaud position) (Fig. 4.1.4).

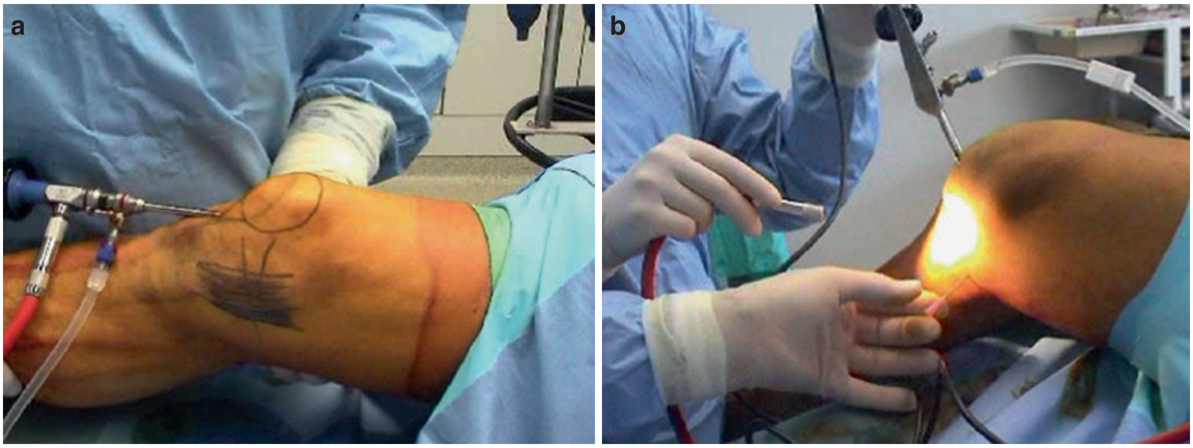

Fig. 4.1.5 (**a**) The joint line and the medial collateral ligament are marked out on the skin for visualization (right knee). (**b**) A needle is inserted through the skin to "puncture" the medial collateral ligament in order to gradually tear its fibres – with valgus stress – so as to obtain proper visualization of the index compartment

A probe is inserted through the lateral skin incision to evaluate the meniscal lesion. In some instances, when visualization is more difficult, a medial skin incision may allow for easier probing.

Lateral meniscal lesions are present in various clinical circumstances. Adequate resection is mandatory to relieve clinical symptoms. Extreme care should be taken not to rupture or incise the lateral meniscal wall more specifically at the hiatus popliteus, which is often degenerative and non-functional. It is common biomechanical knowledge to expect lateral meniscectomy to have poor results when the hiatus popliteus is interrupted.

Flap tears and complex bucket-handle tears of the lateral meniscus are resected according to techniques similar to arthroscopic medial meniscectomy.

Once meniscal resection has been performed, final trimming of the meniscal wall is done.

Specific Cases

If access to the posterior horn of the medial meniscus is difficult, forced extension of the knee by applying manual pressure just distal to the tourniquet or in the posteromedial crease of the knee joint will suffice. However, a peripheral posterior tear associated with anterior cruciate ligament laxity remains difficult to treat. The posterior horn frequently tends to escape behind the femoral condyle. Fortunately, these lesions can be treated with a meniscal suture in a considerable number of patients.

If resection proves to be necessary, the posterior horn can be visualized with the assistant applying a valgus force combined with knee extension and maximal internal rotation. In knees with a tight medial compartment, releasing the medial collateral ligament to open up the compartment is a justifiable option (Fig. 4.1.5). This partial release can be done through skin puncture with a needle. This allows to progressively open up the medial joint compartment from the inside using Steadman's pick instruments without the risk of cartilage damage.

Rehabilitation

The post-meniscectomy rehabilitation protocol is fairly simple. Weight-bearing should be avoided for some days. After 2–3 weeks work may be resumed, depending on the occupation and the intensity of the physical demands. Return to sports activities can be allowed at 3–6 weeks postoperatively.

Complications

Complications are rarely seen. The risk of infection is about 0.1%. Hydrarthrosis is more common after a lateral than a medial meniscectomy. This can be explained by the congruence of the lateral tibial plateau, which is more convex than the medial one. This incongruence increases the mechanical conflict. Contrary to meniscal repair techniques, arthroscopic meniscectomy is very rarely fraught with vascular or nervous complications.

Treatment by Open Meniscectomy

Introduction

Prior to the advent of arthroscopic meniscectomy in the 1960s, meniscectomy was performed through an open arthrotomy. Nowadays, no indications remain for open meniscectomy, because it requires transection of the anterior horn, both medial and lateral, to achieve adequate visualization of the meniscal body. This in itself is deleterious to the hoop stress protection system. In specific instances, a posteromedial approach may be necessary to repair posteromedial meniscal wall discontinuity.

Surgical Technique

Open Medial Meniscectomy

Open medial meniscectomy has been abandoned as a treatment for medial meniscal lesions.

Historically, a 2–3-cm parapatellar skin incision was performed to approach the medial compartment. The anterior meniscal horn was transected to visualize the meniscal body.

In case of a bucket-handle tear, both the anterior horn and the posterior attachment could adequately be resected. The remaining meniscal wall potentially protected from further mechanical loading in the medial compartment.

In case of a posterior horn meniscal wall rupture, a posterior incision could be of benefit. The joint line is identified as a skin incision is made parallel to the medial collateral ligament fibres. The posterior joint is opened through a synovial incision, which allows to visualize the meniscal wall and any posterior horn meniscal dehiscence. To stabilize the posterior horn, vertical sutures can be used. This technique is further described in Chapter 4.3 on meniscal repair.

Open Lateral Meniscectomy

Open lateral meniscectomy is of historical significance. A 2–3-cm lateral parapatellar skin incision was made with the knee in 90° of flexion. The lateral compartment was opened through a synovial incision and the lateral meniscal horn was incised to improve visualization.

In Cabaud position and varus deflection, lateral meniscectomy could be performed. In some instances, lateral meniscal wall continuity could be preserved.

As lateral compartmental overload was found to induce rapid cartilage degeneration following open total meniscectomy, this procedure has been abandoned.

Conclusion

Although open meniscectomy was a frequently performed operation only 30 years ago, it has only few indications under the current standard of care. Many patients with knee pain may have a history of open meniscectomy. From long-term follow-up studies, it is known that specific radiographic signs develop after many years and tend to be progressive. Some studies linked these signs to symptom progression; others showed them to be more significant following open total meniscectomy. In studies with a more than 10-year follow-up, satisfactory results were achieved in only 42.5–61%, a rate lower than that reported at most intermediate-term follow-ups. These long-term studies have identified certain risk factors for a poor outcome. A younger age at operation, concomitant ligamentous injury, knee instability, innate contralateral varus/valgus deformity, lateral meniscectomy and a long preoperative duration of symptoms may all be correlated with a poor prognosis. Head-to-head studies showed that open partial meniscectomy tends to have a more favourable outcome than open total meniscectomy, which was the treatment of choice for half a century. However, very long-term studies are still lacking. It is still uncertain whether with modern arthroscopic techniques Fairbank's changes and other functional consequences of meniscectomy will be reduced or progress in the same manner.

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Meniscal Repair: Biomechanics

4.2

R. Seil and D. Pape

Introduction

In the medium and long term, meniscal repair has been shown to be successful in 70–80% of cases when performed for the right indications. Despite these excellent results, recent data from France showed that meniscal repair is only considered in a vast minority of meniscal surgeries, not exceeding the 3–5% limit [14]. Considering the high educational impact of the French Arthroscopic Society (SFA) among French surgeons, one can assume that this situation is comparable to other countries in Europe. These figures show that there is still room for improvement for meniscal repair, especially with respect to the constantly evolving surgical techniques, which are becoming less invasive, safer and easier to use by the surgical community. Furthermore, early clinical data have shown similar results as with the classical suture techniques.

Indications

Meniscus repair is generally performed for three different indications.

Repair of the main substance of the meniscus is the most frequent indication, mainly for vertical tear types of the posterior horns or in case of bucket-handle tears. Horizontal or radial tears are rarely repaired. Horizontal tear repair is generally only considered for delaminations of the mid-segment of the lateral meniscus, often in conjunction with lateral meniscal cyst debridement. Radial tears are extremely rare and are sometimes reported in children.

Tears of the periphery of the meniscus at the meniscosynovial junction are less frequent in comparison to the previous group. They are more difficult to diagnose at arthroscopy, and therefore may sometimes be overlooked. Repair of these tear types usually requires classical suturing techniques for a good tear site adaptation. Detachments of the meniscotibial ligaments (meniscal root tears) result in a complete loss of the capacity of the meniscus to transform axial compression forces into circumferential forces and are similar to total meniscectomy [2]. These lesions are rare and repair techniques have only recently been described (Fig. 4.2.1).

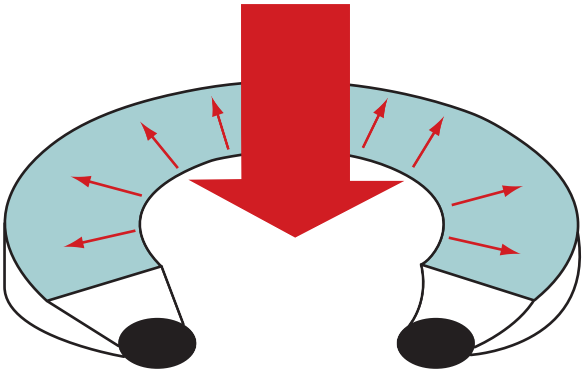

Fig. 4.2.1 The goal of meniscal repair is to restore the biomechanical properties of the meniscus by allowing the transformation of axial compression forces (*large red arrow*) into radially oriented force vectors (*thin arrows*). A prerequisite for this is that both the anterior and the posterior segments of the meniscus must be secured to the tibia (*black dots*) by the meniscotibial ligaments

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_4.2, © Springer-Verlag Berlin Heidelberg 2010

Laboratory Testing of Meniscal Repair Techniques

Biomechanical evaluations of meniscal repairs have analysed only the repair of lesions of the meniscal body by simulating complete vertical tears. The purpose of laboratory testing is to evaluate and improve the mechanical factors of meniscus healing (as opposed to the biological healing factors), either for meniscus sutures or for new meniscus repair devices. Repair procedures include three types of techniques: the first-generation sutures, the second-generation rigid fixation devices and the third-generation flexible suture anchors. Ideally, such biomechanical tests should provide us with information on the following questions: (1) What does the fixation hold? (2) What influences its strength? (3) How much must the fixation hold? (4) For how long does it hold? and (5) Could the type of fixation cause any harm?

In order to replicate as closely as possible the clinical setting of a repair of a complete vertical tear, the biomechanical analysis of meniscus repairs can simulate different time points in the healing process: (1) Immediately after repair ($t = 0$) in the so-called time-zero cadaver studies; (2) During the healing period ($t = 0$–12 weeks). Such studies have been performed either on tissue-culture models or on laboratory animals; and (3) After the initial healing phase ($t > 12$ weeks). So far, the biomechanical properties of meniscus repair at more than 12 weeks have only been addressed in animal studies.

Testing of the Initial Repair (Time-Zero Studies)

The vast majority of studies dealing with laboratory testing of meniscus repair are time-zero studies. Authors have evaluated the tensile fixation strength (TFS) of either sutures [24, 30, 33, 37, 38] Table 4.2.1. or sutures compared to fixation devices [1, 3–8, 11, 12, 15, 18, 31, 40, 42, 43, 45–47] Table 4.2.2.

The TFS was analysed on a materials testing system (INSTRON®, ZWICK®, MTS®). A uniaxial load was applied in tension to the repaired meniscus in an axis parallel to the long axis of the suture or the implant to be tested. The TFS was recorded on a load-displacement curve (Fig. 4.2.2). In most of the studies, a large vertical tear was created at the entire circumference of the meniscus in order to prevent any load transfer at sites other than the repair site. Usually, one suture/device was analysed per test. The tears were standardized in each study, allowing for a comparison within one study.

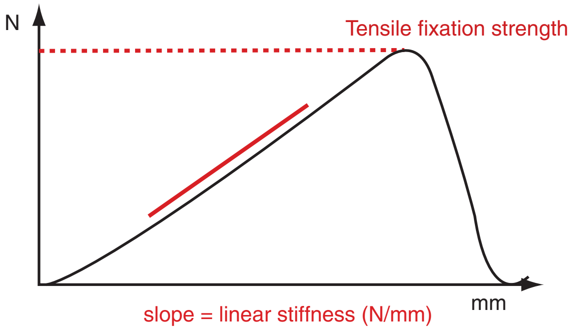

Fig. 4.2.2 The ultimate failure strength is recorded on a load-displacement curve. The slope of the curve indicates the stiffness of the meniscus repair construct

In the first laboratory study on meniscus repair, Kohn and Siebert [24] described the two basic principles of meniscus repair biomechanics. The authors compared open meniscus repair techniques to arthroscopic techniques. They found that the circumferentially oriented horizontal collagen fibre bundles were responsible for the higher TFS of vertical sutures compared to horizontal sutures. They further showed the importance of the superficial, dense layer of thin collagen fibrils, which increased the TFS of mattress sutures compared to sutures including only deeper layers of collagen bundles.

In subsequent biomechanical studies many variables influencing the TFS of meniscus sutures or repair devices could be identified. These variables included the nature of the tested menisci (animal [until today bovine and porcine menisci have been used] vs. human origin; young vs. old specimen) (Fig. 4.2.3), the suture strength, the insertion angle of repair devices, their design (form of head, barbs, etc.), their mechanical properties such as thickness and elasticity, etc. Furthermore, biomechanical testing varies from study to study since there is no consensus regarding the exact testing conditions. This might explain the large variations encountered with some repair devices in different studies and makes a comparison of the TFS between different studies difficult.

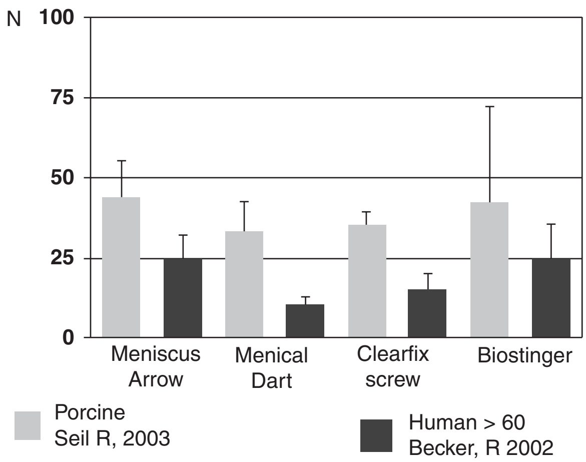

Fig. 4.2.3 The figure shows varying failure strengths of different second-generation meniscal repair devices. It appears that the devices tested in older human cadaver specimens had worse results than those tested in young porcine specimens. This illustrates the influence of the donor tissue when comparing meniscus repair devices

Post et al. [30] and our group [37] showed that the TFS of meniscus sutures was strongly dependent on the suture material. We found no difference for horizontal and vertical PDS 2-0 mattress sutures, but vertical sutures became stronger with increasing strength of the suture material (Fig. 4.2.4). We also found an upper limit of the failure strength for horizontal sutures, which approximated 100 N even if stronger suture material was used. This suggested that the maximum TFS of horizontal sutures depended not only on the suture material, but also on the quality of the meniscus tissue itself. Based on the results of all studies reported in the literature, the TFS of suture repairs varies grossly between 50 and 150 N.

With the second-generation fixation devices, laboratory testing became even more complex as the TFS may be affected by the insertion angle of the device and the number of barbs engaged in the meniscal tissue. Boenisch et al. [12] showed a decrease of the TFS of 66% with a 30% caudal inclination of the Meniscus Arrow® (BionX Implants Inc., Blue Bell, PA). This study showed that the TFS of repair devices can easily be influenced by external factors, which might explain the large variations encountered with some devices in different studies. These variations were especially apparent for the Meniscus Arrow® and the BioStinger® (Linvatec Corp., Largo, FL). Arnoczky and Lavagnino [3] found a mean TFS of 57.7 N (±13.8) for the Meniscus Arrow® and 35.1 N (±6.7) for the BioStinger®, whereas Barber and Herbert [6] found a mean TFS of 33.4 N (±8.4) and 78.3 N (±30.6), respectively (Fig. 4.2.5). Some of these devices reached values that were close to 2-0 UPS sutures. However, the mean TFS of new devices was generally inferior to that of sutures.

TFS is significantly higher for third-generation devices in comparison to second-generation devices. Kocabey et al. [23] and Zantop et al. [45–47] found values that were comparable to PDS 0 or PDS 1 suture repairs in other studies. In both these studies, vertical FasT-Fix repairs showed the highest TFS.

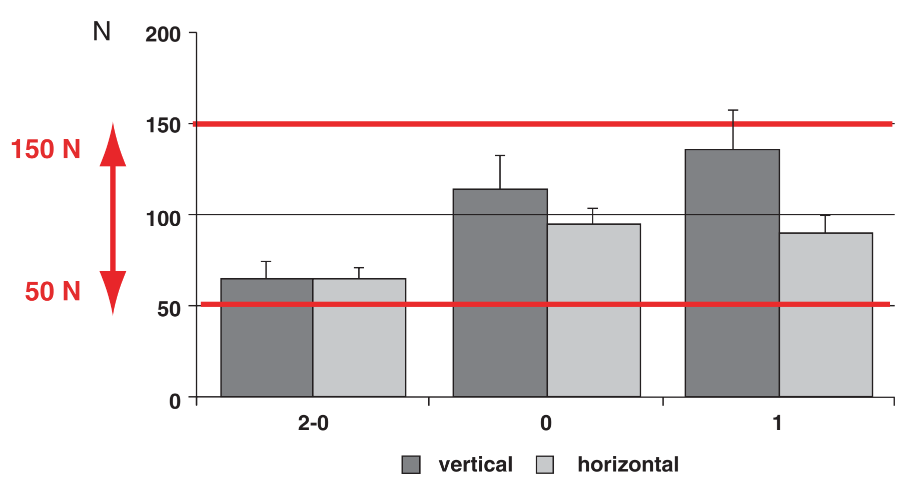

Fig. 4.2.4 The figure illustrates the failure strength for PDS 2-0; 0 and 1 mattress sutures (from Seil et al. [38]). The *red bars* indicate the gross interval of the failure strength of mattress or loop sutures in other studies, independent of the type of suture materials (thinnest = 2-0 USP) or tissues used

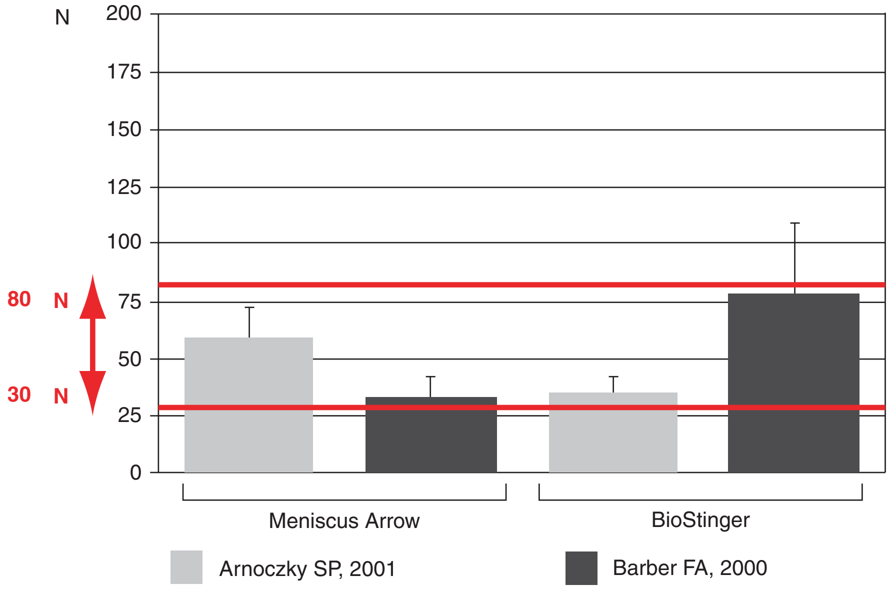

Fig. 4.2.5 The figure illustrates the failure strength of two meniscal repair devices (from Arnoczky and Lavagnino [3] and Barber and Herbert [6]). The results differed significantly for one type of device from one study to the other. The *red bars* indicate the gross interval of the failure strength of meniscal repair devices independent of the type of tissues (human, porcine and bovine) used

Testing Simulating the Early Healing Phase (0–12 Weeks)

During the postoperative healing phase, the operated knee may be protected by a brace and a specific rehabilitation programme is generally applied for a minimum period of 6 weeks. During the following 6 weeks, the goal of rehabilitation is to restore full joint mobility. No sporting activities are usually allowed during the initial 12-week period.

Although it is very difficult to simulate the factors influencing the conditions under which the healing process might affect the biomechanical capacity of the repair in the early healing phase, several individual variables have been identified. Four mechanical factors have been analysed in order to simulate the quality of the repair during this phase: firstly, the evolution of TFS of the sutures/devices over time [3, 16]; secondly, the effect of repetitive loading on meniscus repairs [17, 37, 38, 47]; thirdly, the effect of shear forces on suture repairs [18, 48] and fourthly, the effect of compression on the repair site [41].

Hydrolysis

The effect of hydrolysis time on sutures and repair devices has been analysed in tissue-culture models. In these studies, the repaired menisci were incubated over a defined period, after which the TFS was evaluated. Using PDS sutures, Dienst et al. [16] found a significant decrease of the TFS of nearly 50%, whereas the TFS of non-absorbable suture material remained unaltered. Arnoczky and Lavagnino [3] found no decrease in TFS for the BioStinger®, the Meniscus Arrow® and the Clearfix Screw® (Mitek Products Inc., A Division of Ethicon, Inc., Westwood, MA) over a period of 24 weeks. However, the devices made of rapidly absorbable materials (SD staple®, Surgical Dynamics, Inc., Norwalk, CT, made of PLA/PGA; and the Mitek Meniscal Repair System®, Mitek Products Inc., made of PDS) showed a complete loss of fixation strength after 24 and 12 weeks, respectively.

Cyclic Loading

Cyclic loading of reconstruction techniques has been introduced in biomechanical testing procedures in order to simulate repetitive physiologic loading conditions [35]. Two fundamental findings have been identified in comparison to previous static loading tests: firstly, the appearance of a gap of several milimetres between the two parts of the meniscus [8, 26, 37, 47]; and secondly, the occurrence of failure of the repairs. Furthermore, the gapping or displacement observed during cyclic loading was closely related to the stiffness of the repair construct.

Cyclic testing of second-generation devices showed failures either due to implant breakage [3, 40] or slipping of the device through the meniscus tissue [40]. Several design factors were shown to be responsible for the different behaviour of the devices under these conditions. The number of barbs and the size of the head of the device were inversely proportional to the number of failures. This also accounted for the fact that the BioStinger and Meniscus Arrow had a stiffness which was comparable to mattress sutures [8]. Similar results were published by McDermott et al. [26]. These authors found that arrows gave superior hold under lower loads, with the least gapping across repairs under cyclic loading of the four methods tested (vertical 2-0 PDS suture, Meniscal Fastener, T-Fix and Arrow).

Among the third-generation devices, vertical FasT-Fix repairs showed better biomechanical properties (less gapping and greater stiffness) under cyclic loading conditions in comparison to horizontal FasT-Fix repairs and the RapidLoc device [23, 27].

Shear Forces

To our knowledge, Fisher et al. [18] were the first to evaluate the effect of shear forces on meniscal repair sutures and devices. They noted several, quite opposite effects when comparing the results of simple axial pull-out tests with pull-out in a shear-force scenario. While for the Meniscus Staple the TFS doubled by applying shear forces, it decreased by approximately 40% for the Meniscus Arrow and horizontal PDS 1 sutures.

Zantop et al. [48] quantified the elongation behaviour of horizontal vs. vertical Ethibond 2–0 sutures. In the shear-force test, horizontal sutures were superior to vertical suture techniques. After 1,000 cycles of cyclic loading in the shear force scenario, horizontal suturing revealed significantly less elongation (2.8 ± 1.1 mm) than did the vertical suture technique (4.6 ± 2.0 mm). No statistically significant difference in TFS was found. They concluded that meniscal repair with horizontal suture techniques can withstand elongation due to shear forces more effectively than can vertical mattress sutures. The reasons for this are still unclear.

Compression Forces

Because the use of early second-generation fixation devices gave rise to new complications, including rail-shaped chondral lesions of the femoral condyle [13, 19, 36, 44], new tests were conducted in which tibiofemoral compression forces were applied. In a biomechanical cadaver study, we analysed whether meniscus sutures or different types of devices induced specific medial meniscofemoral contact areas and contact stresses under static (1,200 N) and dynamic loading conditions in full extension, and in 45 and 90° of knee flexion [39]. We found no contact areas/stresses with conventional mattress sutures. However, when the Meniscus Arrow®, the Clearfix Screw® and the Meniscal Dart® were used, contact areas/stresses could be found in 89%, 54% and 29% of the analysed cases, respectively (Fig. 4.2.6). They were significantly smaller/lower for those devices with a small head. Conversely, Becker et al. [9] by using an axial force of 350 N did not find any specific peak loads at the location of the head of the devices.

Compression was also found to have a positive effect on the fixation behaviour and strength of meniscus repairs with the Clearfix screw and the Meniscus Arrow [41]. During cyclic loading, a threefold increase in the number of achieved cycles was found for the Arrow and a 23-fold increase for the screw. The amount of gapping during cyclic loading was reduced as well. The TFS was increased by approximately 50% for both implants. Interestingly, sutures were not influenced by axial compression.

Testing Simulating the Late Healing Phase (≥12 Weeks)

During this phase, laboratory testing of meniscus repair has essentially been performed in animal studies analysing the failure strength of the scar tissue (Table 4.2.3). Even if after 3 months, Kawai et al. [21] found TFS to reach 80% of the intact control meniscus in dogs; most other authors obtained data which were far from normal. This shows that meniscal scar tissue does not reach its initial biomechanical properties after a period of 3–4 months. Koukoubis et al. [25] observed TFS of repaired dog menisci to increase over a 1-year period.

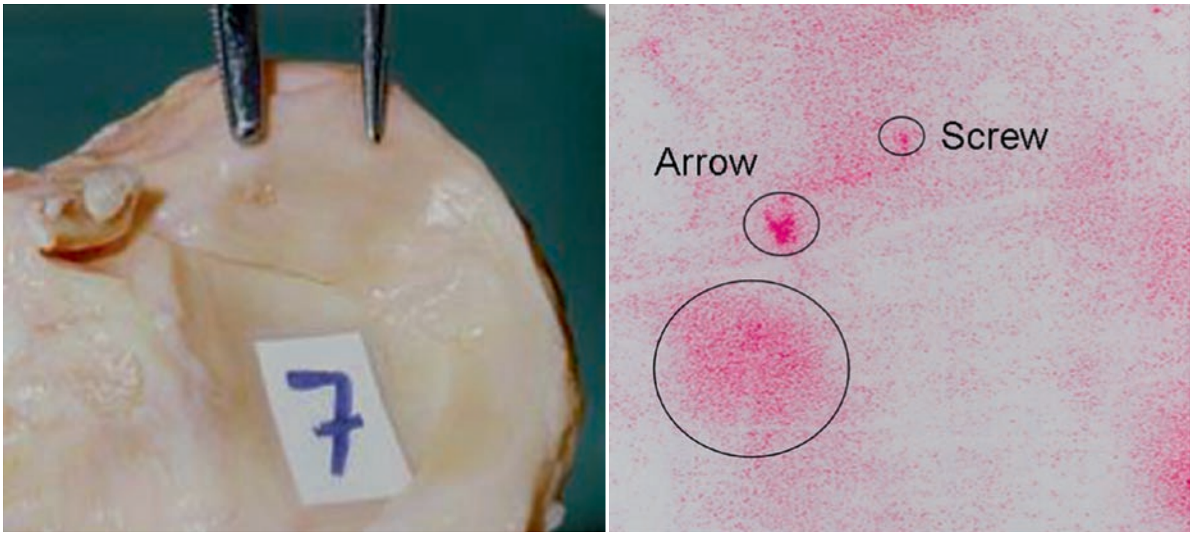

Fig. 4.2.6 The figure illustrates the “footprint” of the head of two second-generation repair devices after knee loading (*small circles*). The *large circle* represents the maximal femorotibial pressure area

Table 4.2.1 Studies analysing the tensile fixation strength of meniscal sutures

Author	Type of meniscus	Suture technique	Suture material	Tensile fixation strength (*N*)
Albrecht-Olsen et al. [1]	Bovine	Horizontal mattress	Maxon-0	49
Asik et al. [4, 5]	Bovine	Horizontal mattress	Prolene-1	98
		Vertical mattress	Prolene-1	130
		Knot-end technique	Prolene-1	64
		Vertical (single loop)	Prolene-1	136
		Vertical (half loop)	Prolene-1	128
Barber and Herbert [6]	Porcine	Vertical mattress	Mersilene 2-0	80
		Horizontal mattress	Mersilene 2-0	56
Boenisch et al. [12]	Bovine	Vertical (single loop)	Ti-Cron 2-0	72.4
		Horizontal mattress	Ti-Cron 2-0	68.3
Dervin et al. [15]	Human (±67 years)	Vertical (single loop)	Ethibond 2-0	58.3
Kohn and Siebert [24]	Human (17–41 years)	Knot-end technique	PDS 0	24
		Horizontal mattress	Ethibond 2-0	89
		Vertical loop	Vicryl 2-0	105
		Horizontal (open technique)	Vicryl 2-0	44
Arnoczky and Lavagnino [3]	Bovine	Vertical mattress	PDS 2-0	52
McDermott et al. [26]	Bovine	Vertical mattress	PDS 2-0	73
Post et al. [30]	Porcine	Vertical mattress	Ethibond 2-0	89.3
			0-PDS	115.9
			1-PDS	146.3
		Horizontal mattress	Ethibond 2-0	59.7
			0-PDS	66.1
			1-PDS	73.81
		Knot-end technique	0-PDS	68.6
			1-PDS	69.3

Table 4.2.1 (continued)

Author	Type of meniscus	Suture technique	Suture material	Tensile fixation strength (*N*)
Rimmer et al. [33]	Human (45–81 years)	Horizontal mattress	Ethibond 3-0	29
		Vertical (double loop)	Ethibond 3-0	63
		Vertical (single loop)	Ethibond 3-0	67
Seil et al. [37]	Porcine	Vertical mattress	PDS 2-0	63
			PDS 2-0	54
			PDS 2-0	61
			Ethibond 2-0	59
			Ethibond 2-0	58
			Ethibond 2-0	64
		Horizontal mattress	PDS 2-0	58
			PDS 2-0	64
			Ethibond 2-0	58
			Ethibond 2-0	57
Seil et al. [38]	Porcine	Vertical mattress	PDS 2-0	62
			PDS 0	112
			PDS 1	131
		Horizontal mattress	PDS 2-0	66
			PDS 0	103
			PDS 1	99
Song and Lee [42]	Porcine	Knot-end technique	PDS 1	54
		Horizontal mattress	PDS 1	75
		Vertical (single loop)	PDS 1	114
Zantop et al. [48]	Porcine	Horizontal mattress	Ethibond 2-0	64
		Vertical mattress	Ethibond 2-0	57

Table 4.2.2 Studies analysing the tensile fixation strength of meniscal repair devices

Author	Type of meniscus	Type of implant	Tensile fixation strength (N)
Meniscus Arrow			
Albrecht-Olsen et al. [1]	Bovine	Meniscus Arrow (13 mm)	53
		Meniscus Arrow + 24 h NaCl	54
Barber and Herbert [6]	Porcine	Meniscus Arrow (13 mm)	33
Becker et al. [7–10]	Human	Meniscus Arrow (13 mm)	25
Boenisch et al. [12]	Bovine	Meniscus Arrow (10 mm)	19
		Meniscus Arrow (10 mm)	35
		Meniscus Arrow (13 mm)	39
		Meniscus Arrow (13 mm)	39
		Meniscus Arrow (16 mm)	53
Dervin et al. [15]	Human	Meniscus Arrow (13 mm)	30
Durselen et al. [17]	Porcine	Meniscus Arrow	52
Fisher et al. [18]	Porcine	Meniscus Arrow	40
Arnoczky and Lavagnino [3]	Bovine	Meniscus Arrow (n.a.)	58
		Meniscus Arrow copolymer	63

(continued)

Table 4.2.2 (continued)

Author	Type of meniscus	Type of implant	Tensile fixation strength (N)
McDermott et al. [26]	Bovine	Meniscus Arrow	34
Seil et al. [40]	Porcine	Meniscus Arrow (13 mm)	44
Song and Lee [42]	Porcine	Meniscus Arrow (13 mm)	38
Bellemans et al. [11]	Human	Meniscus Arrow (10 mm)	19
		Meniscus Arrow (13 mm)	33
		Meniscus Arrow (16 mm)	39
Zantop et al. [45, 46]	Bovine	Meniscus Arrow (10 mm)	49
Other implants			
Barber and Herbert [6]	Porcine	BioStinger	78
		Meniscal screw	33
		Meniscal Fastener	30
		SD Sorb Staple (10 mm)	31
		T-Fix	50
Becker et al. [7–10]	Human	BioStinger	25
		Meniscal screw	15
		Meniscal Dart	10
		Meniscal Fastener	33
		T-Fix	51
Durselen et al. [17]	Porcine	Meniscal Fastener	29
		Meniscal screw	22
Fisher et al. [18]	Porcine	Meniscal staple	4
		T-Fix	45
		Meniscus Arrow	40
Kocabey et al. [23]	Human	FastT-Fix (vertical)	125
		FastT-Fix (horizontal)	90
		RapidLoc	87
Arnoczky and Lavagnino [3]	Bovine	BioStinger	35
		Meniscal screw	35
		Meniscal Fastener	27
		SD Sorb Staple	9
McDermott et al. [26]	Bovine	Fastener	41
		T-Fix	49
Seil et al. [40]	Porcine	BioStinger	42
		Meniscal screw	30
		Meniscal Dart	28
		SD Sorb Staple (10 mm)	37
		T-Fix	31
Bellemans et al. [11]	Human	T-Fix	48
		SD Sorb Staple	4
Zantop et al. [40]	Bovine	FastT-Fix (vertical)	106
		FastT-Fix (horizontal)	87
		RapidLoc	45

Table 4.2.3 Animal studies analysing the biomechanics of meniscal repair

	Animal model	Time after surgery (months)	Tensile fixation strength
Port et al. [29]	Goat	4	30% of normal tissue
Kawai et al. [21]	Dog	3	Up to 80% of normal
Roeddecker et al. [34]	Rabbit	3	Fibrin glue: 42%
			Suture: 26%
			No therapy: 19%
Koukoubis et al. [25]	Dog	12	SD staple > suture
Guisasola et al. [20]	Sheep	1.5	<50% of normal

Forces Acting In Vivo

The tensile forces acting on meniscal repairs in vivo are unknown. Furthermore, besides tensile forces, there are also compressive and shear forces acting on the meniscus. These complex forces are difficult to reproduce in vitro. Only few studies have tried to address this important issue. Kirsch et al. [22] investigated the tensile forces acting on posterior horn sutures of the medial meniscus in a cadaver model. They were lower than expected as they never exceeded 10 N. Becker et al. [9] created a bucket-handle lesion of the posterior horn of the medial meniscus and recorded the tensile forces acting on the repair between 0 and 120° of knee flexion. Distraction forces were evaluated under different conditions (loading, unloading and rotation). The results confirmed the findings of Kirsch et al., showing that the recorded forces were always lower than 10 N. Furthermore, increasing flexion angles did not cause an increase in distraction forces. The authors assumed that other factors such as shear forces might be of greater importance to the mechanical stability of meniscus repair. Limitations of this study were related to the fact that testing was not performed under dynamic testing conditions and with intact ligamentous structures. Knowing that the load on the medial meniscus doubles in the presence of an ACL tear [28], the forces on the repair might also be higher under these circumstances.

Richards et al. [32] evaluated the loads occurring in longitudinal tears of the lateral meniscus in porcine cadaver knees. With a pressure transducer in the tear, the knees were repeatedly cycled through a full range of motion. The authors showed that the tear was compressed throughout the full range of knee motion. At no time were negative intra-meniscal tear pressures registered that would suggest meniscal cut separation. They concluded that the absence of distractive loads across a meniscal cut suggests that the ability of a repair to align the meniscal fragment may be more important than a high load to failure strength.

Conclusions

Since Kohn and Siebert's study in 1989, the biomechanical basis of meniscus repair – and meniscus repair itself – has significantly evolved. Evaluation of the first-generation repair techniques with sutures showed that the biomechanical conditions of meniscal repair were dependent on the anatomy of the meniscus, the quality of this tissue and the type of suture and suture material.

Studies published in the 90s and in the current decade evaluated the second and third-generation repair devices. While the second-generation devices represented a significant step forward with respect to the invasiveness of surgery, their biomechanical properties were generally inferior to those of the "gold standard" sutures. However, as biomechanical testing became more complex with the introduction of cyclic loading, the evaluation of meniscus repair could be extended to include criteria such as the resistance of the repair and gapping of the tear site under more physiologic loading conditions. The third-generation flexible suture anchors meet both the criteria of minimal invasiveness and biomechanical properties, which are comparable to those obtained with suture techniques. These anchors as well as improved all-inside suture techniques will probably represent the first choice of meniscal repair techniques in the coming years.

From a scientific point of view, further studies should be performed to achieve a better understanding of the forces acting on meniscus repair under certain pathologic conditions and of the biomechanical properties of regenerated or "healed" meniscus tissue after repair.

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Meniscal Repair: Technique

4.3

F. Jouve, H. Ovadia, N. Pujol, and P. Beaufils

The interest in preserving the meniscus increased dramatically after the publication of long-term follow-up studies reporting degenerative changes and joint space narrowing following meniscectomy [14, 15]. The biomechanical functions of the meniscus and the consequences of meniscectomy are well established: load transmission, shock absorption, proprioception, and joint stability [1, 7, 17].

Meniscal repair was first reported by Annandale [4], but it was not widely performed and sank into oblivion. Like other procedures in knee surgery, meniscus repair has benefited from advances in arthroscopy. Ikeuchi [16] performed the first arthroscopic repair in 1969.

Arthroscopic techniques include inside-out, outside-in, and all-inside repairs [9, 10]. The first two techniques require the passage of suture through the skin, which exposes the patient to neurovascular complications. In the 90s, various implants were introduced and these procedures became technically less demanding.

Principles

When meniscus repair is carried out under arthroscopic visualization, some common steps, which are independent of the technique, have to be followed.

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Arthroscopic Set-Up

The patient is placed in a supine position. Regional or general anesthesia is induced. Using a standard knee arthroscopic set-up, anterolateral and anteromedial portals are established. In some cases, a central transtendinous Gillquist portal can be useful. Access to the posterior part of the medial meniscus is achieved by holding the knee in slight flexion and applying valgus stress. To access the posterior part of the lateral meniscus, the knee is flexed at 90° and varus stress is applied in the Cabaud position.

Although imaging techniques can be helpful, the characteristics of a tear are best assessed arthroscopically. The final treatment decision is made at the time of arthroscopy. 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. A short tear of 1–2 cm has a better chance of healing.

The peripheral 20–30% of the medial meniscus and the peripheral 10–25% of the lateral meniscus are vascularized [5]. The location of the tear has been 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. De Haven considered meniscal tears within 3 mm of the periphery as vascular, those 5 mm or more from the periphery as avascular, and between 3 and 5 mm as variably vascular [12]. Tears in the red–red and the red–white zone are amenable to repair. Meniscal repair for tears in the white–white zone has poor healing potential.

The macroscopic aspect of the meniscal tissue is assessed (normal or degenerative).

P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_4.3, © Springer-Verlag Berlin Heidelberg 2010

Finally, the meniscus is prepared. If a dislocated bucket-handle tear is present, it is reduced into its anatomic position.

In summary, the ideal candidate for meniscal repair is a young patient with a recent vertical tear within 3–4 mm of the peripheral rim and 1–2 cm in length, in a stable or stabilized knee.

Debridement

To remove the fibrous tissue, the walls of the tear are debrided using a basket punch, a rasp, or a shaver (Fig. 4.3.1). Freshening must essentially be done on the outer part of the meniscus in order to promote the healing response and to preserve meniscal tissue in the inner part. In some cases, multiple perforations can be made with a needle in the meniscal rim to stimulate the bleeding through vascular channels. Debridement of the medial posterior segment can be difficult. The use of a posterior portal improves the accuracy of the abrasion, as proposed by Pujol et al. [20].

Fixation

Whatever the device and location of the meniscal tear (medial or lateral), the implants or the sutures are routinely inserted through the ipsilateral portal for the posterior segment and the contralateral portal for the middle segment. Sufficient sutures or devices need to be placed to avoid gaps of more than 3–5 mm. When using sutures, these should be nonabsorbable (such as Ethibond) or slowly absorbable (such as PDS).

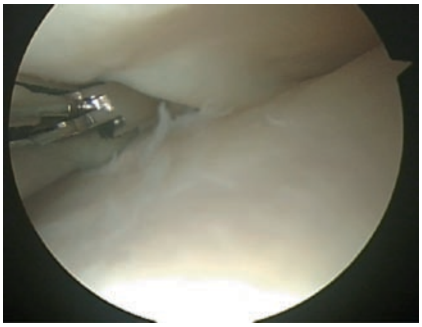

Fig. 4.3.1 Debridement of the edges of the tear with a basket punch

In case of a bucket-handle tear, the reducibility has to be assessed. An old bucket-handle tear can develop plastic shrinkage, leading to redislocation after reduction. The tensile forces are so important that they may compromise the fixation, regardless of the device implanted, and decrease the chance of healing.

For large bucket-handle tears, passing the probe through a transtendinous Gillquist portal permits to hold the inner segment in the proper position. Then, the tear can be fixed with the devices.

Technique

First Generation: Open Technique

The first-generation repairs involve an open procedure [4]. Open meniscal repair has been well described by DeHaven et al. [13] and requires an arthrotomy using a retroligamentous approach (Fig. 4.3.2). The capsule is incised posterior to the collateral ligament and the synovium is opened to give direct access to the posterior segment of the meniscus and the tear, provided that it is a vertical peripheral longitudinal tear. In case of a horizontal tear, the meniscosynovial rim needs to be dissected in order to expose the peripheral meniscal rim and the horizontal cleavage (Fig. 4.3.2).

The repair is performed with vertically oriented, absorbable 4-0 sutures, incorporating the entire height of the meniscal rim and the capsular bed in an anatomic fashion. The individual sutures are placed 2–3 mm apart, beginning with the deepest or more centrally located suture. The repair sutures are tied inside the joint to reapproximate the capsular bed to the meniscal rim. Then, the knee is tested in full extension.

Variations of this technique involve vertically oriented sutures placed through the capsule and tied outside the joint, horizontally oriented sutures placed through the capsule and tied outside the joint, and the use of absorbable or nonabsorbable suture material.

This approach gives good access to the posterior and middle meniscal segments, but is much more difficult on the lateral side, due to the presence of the popliteus tendon. Open repair of the anterior segment (especially on the lateral side) requires an anterior approach.

The ability to achieve a strong fixation is the main advantage of this technique, which is suitable for

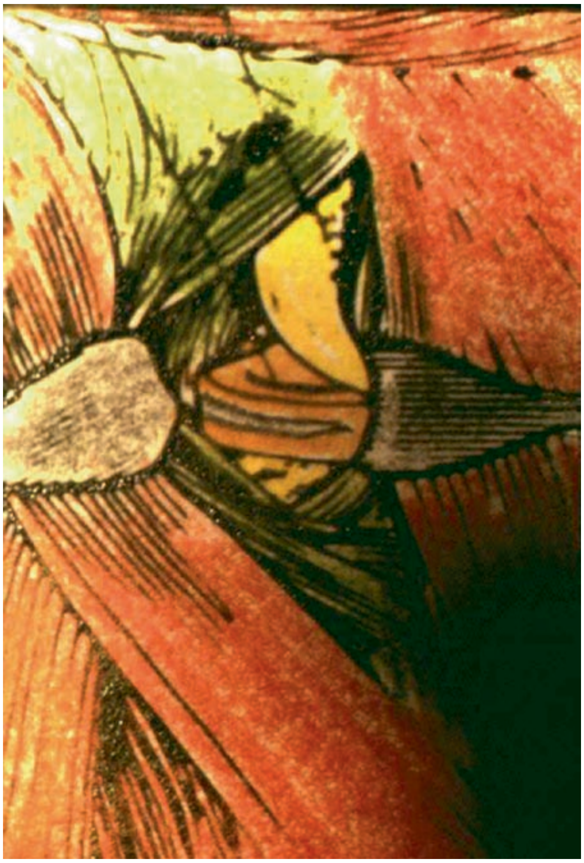

Fig. 4.3.2 Arthrotomy using a retroligamentous approach for a horizontal cleavage tear of the posterior segment

lesions within 3 mm from the peripheral rim. Vertical longitudinal tears in the red–white zone (3–5 mm from the peripheral rim) are difficult to access through the posterior approach. In our opinion, this is the only suitable technique to repair horizontal cleavage tears.

The main disadvantage is the risk of neural damage to the saphenous nerve or its branches.

Second Generation: Arthroscopically Assisted Inside-Out or Outside-In Technique

The second-generation repairs are based on an arthroscopically assisted inside-out or outside-in technique. The goal is to reduce the morbidity associated with the posterior approach and to be able to repair meniscal lesions located in the red–white zone.

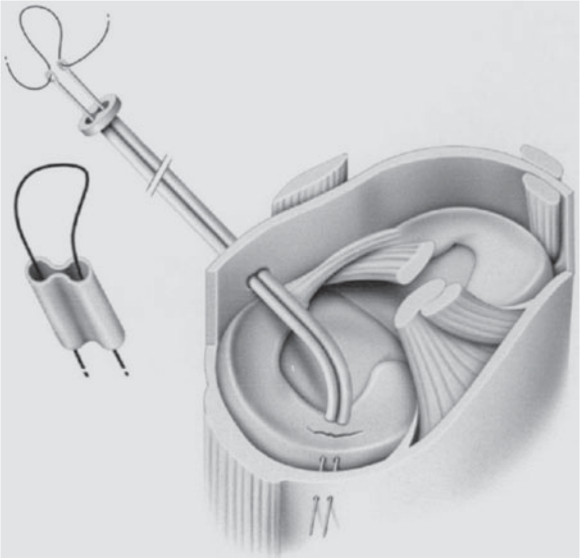

Fig. 4.3.3 Meniscal repair using the inside-out technique with a double-barrel cannula

Inside-Out Meniscal Repair (Fig. 4.3.3)

Several systems have been developed using long curved single or double-barrel cannulas. Absorbable or nonabsorbable 2-0 or 0 sutures are passed from inside to outside, using long flexible needles. Either horizontal or vertical mattress stitches can be done. The sutures are retrieved through an extraarticular posteromedial or posterolateral incision. The posterior neurovascular structures are protected with a large retractor. The knots are tied outside the joint over the capsule.

As with the open technique, the main disadvantage is the risk of neurovascular complications. The peroneal nerve can be injured on the lateral side. The incision must be made behind the lateral collateral ligament and anterior to the biceps femoris tendon. The saphenous nerve and vein are at risk on the medial side. The incision must be made behind the medial collateral ligament.

Outside-In Meniscal Repair (Fig. 4.3.4)

In 1985, Warren [22] introduced an outside-in technique that was initially designed to decrease the risk of peroneal nerve entrapment on the lateral side. A cannulated 18-gauge spinal needle is passed across the tear from the outside-in. Once the sharp tip of the needle is in view, the suture (monofilament absorbable 0-gauge PDS) is passed through the lumen of the needle and pulled through the arthroscopic ipsilateral portal. An interference knot is tied in the end of the suture and the suture is pulled back. The process is repeated and the free ends are tied two by two over the capsule through an accessory skin incision until the tear is stabilized. Sutures may be placed alternately on the femoral and tibial surface of the meniscus in order to balance the repair.

The interference knot inside the joint can be avoided by passing the first suture through the second one tied as a lasso loop (Fig. 4.3.4b). The second suture is pulled back. The two ends of the first suture are retrieved outside the joint and tied over the capsule.

The inside-out and outside-in techniques are complementary. The first one is mainly indicated for posterior and middle segment repairs, while the second allows satisfactory access to the anterior segment of the meniscus.

Both techniques can be associated to repair extended longitudinal lesions.

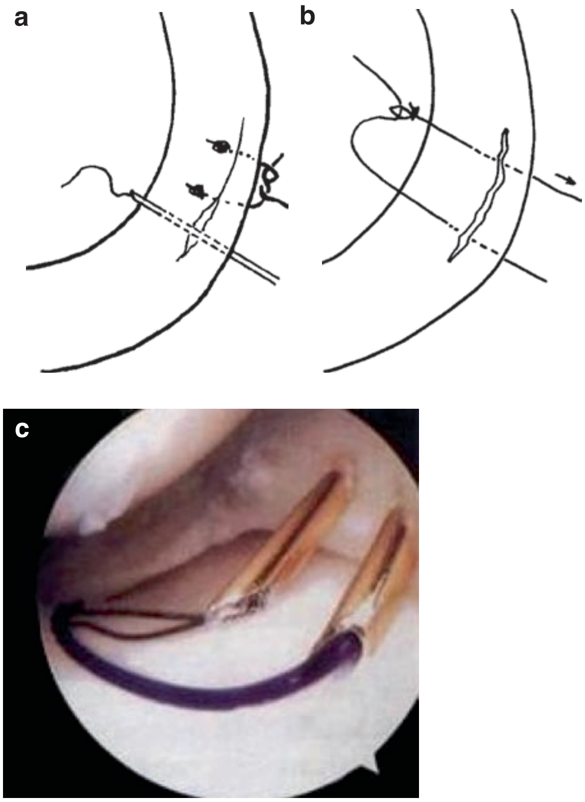

Fig. 4.3.4 Outside-in meniscal repair. The suture is passed through the needle and retrieved inside the joint. (**a**) Interference knots are tied and compress the inner part of the meniscus. (**b**) Variation of the technique: the first suture is passed through the second one tied as a lasso loop, the second suture is pulled back and the two ends of the first suture are tied over the capsule without a knot inside the joint (**c**) Arthroscopic view (courtesy X Cassard)

Third Generation: Devices

Specific implants have been designed to replace the use of sutures and to allow all-inside meniscal repairs without the need for accessory skin incisions [8]. Staples, tacks, anchors, screws, etc. have been proposed (Fig. 4.3.5). Most of the devices are bioabsorbable and composed of rigid poly-L-lactic acid (PLLA).

Albrecht-Olsen et al. [2] were the first to present an all-inside procedure using a bioabsorbable tack, the Biofix meniscal arrow (Bioscience Ltd., Tampere, Finland). The implant consists of a T-shaped arrow with barbs on the stem, resembling a fishing hook. The barbed stem penetrates the meniscus, and

Fig. 4.3.5 Meniscal repair devices, from *left to right*: J Fast (Mitek), Dart (Arthrex), Biomet staple, BioStinger (Linvatec), Meniscus Arrow (Bionx), Clearfix screw (Innovasive), SDsorb meniscal staple (surgical dynamics)

its distal part is fixed in the peripheral part of the meniscus, while the T-head of the arrow is applied to the axial part of the meniscus, usually the upper surface.

A cannula with a blunt obturator is introduced into the knee through the usual arthroscopic portals. When the tip of the cannula is at the proper place, the obturator is withdrawn. A perforator is pushed into the meniscus through the cannula to create a hole for the arrow. While the cannula is held firmly in place, the needle is withdrawn. An arrow is pushed through the cannula to the surface of the meniscus and hammered into the meniscus, fixating the axial part to the peripheral part.

The procedure is repeated every 5 mm. A gun can be utilized to accelerate the procedure.

An accessory incision being not needed and a lower risk of neurovascular complications are the advantages of this technique. Moreover, this technique is fast and easily performed.

The disadvantages are the lower strength of the arrows compared to vertical sutures [6, 18] and the risk of loose bodies, synovitis, cysts, and cartilage abrasion due to the head of the device at the surface of the meniscus [3, 11, 19, 21]. Low-profile heads have been proposed to decrease this risk.

Fourth Generation: All-Inside Technique with Sutures

The newest devices are self-adjusting suture devices, combining the advantages of all-inside meniscal repair (no accessory incision, lower neural complication rate) with those of suture (better strength). They are based on the same principles: an anchor is positioned behind the capsule and a suture compresses and holds the axial meniscal part by using a sliding knot. These implants share the potential ability to deform and move with the meniscus during weight bearing and carry a lower risk of chondral abrasion. The three devices in this category are the RapidLoc (DePuy Mitek Products, Westwood, MA), the FasT-Fix (Smith and Nephew Endoscopy, Andover, MA) and, more recently, the Meniscal Cinch (Arthrex, Naples, FL).

RapidLoc (Fig. 4.3.6)

The RapidLoc device consists of three components: a top hat, a bar, and a 2.0 Panacryl (Mitek, Somerville, NJ) or 2.0 Ethibond (Ethicon, Somerville, NJ) suture. Delivery needles are available in straight, 12 and 27° curved versions. The principle is to compress the axial

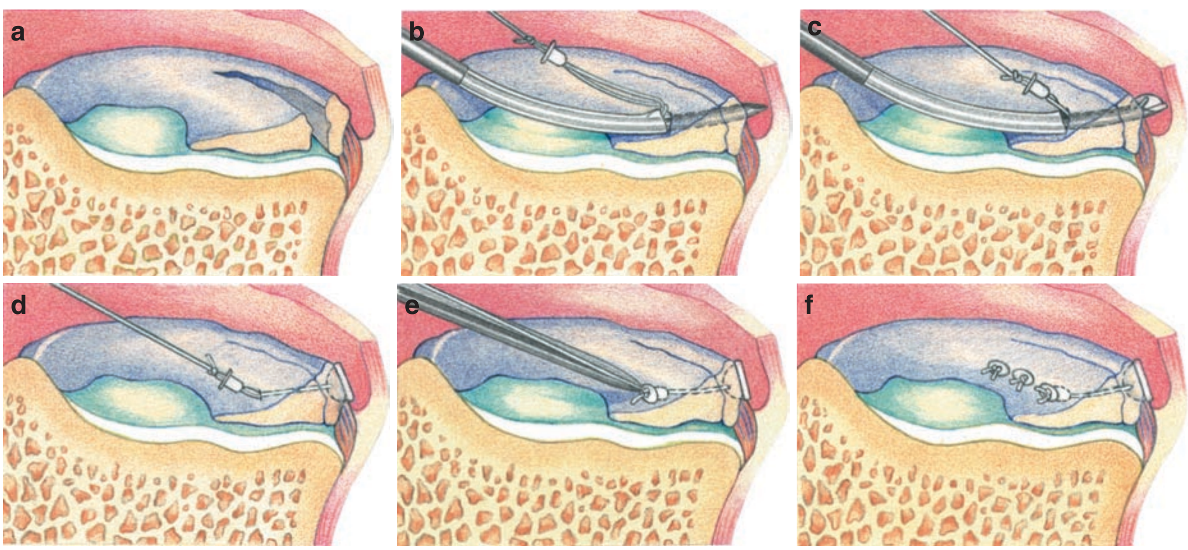

Fig. 4.3.6 Rapidloc (Mitek) meniscal repair. (**a**) Meniscal tear. (**b**) Needle placed across meniscal tear. (**c**)The back-stop is deployed. (**d**) The suture top hat is pulled down to the meniscus. (**e**) The top hat is advanced over the suture with the knot pusher. (**f**) Meniscal tear repaired with three Rapidloc implants (Courtesy of DePuy Mitek)

meniscal part against the peripheral meniscal rim with the top hat.

After debridement, the appropriate angle of the preloaded needle (straight, 12° curved, 27° curved) is selected. The gun is loaded and the needle is inserted through the appropriate portal, protected by the malleable retractor. Once the fat pad is passed, the malleable retractor is removed.

The technique for insertion of the RapidLoc includes piercing the meniscal fragment with the application needle attached to the handle, advancing the needle across the tear to the silicone sleeve (which acts as a depth limiter), and deploying the back-stop. The suture is then pulled to ensure fixation of the back-stop, and the top hat is advanced over the suture with the use of a specific knot pusher until tension is created in the suture. Then, the procedure is repeated to achieve the repair.

FasT-Fix (Fig. 4.3.7)

This device is a modification of the Smith and Nephew T-Fix. Two T-Fix 5-mm polymer suture bar anchors are attached to a No. 0 nonabsorbable braided polyester suture, which – when tightened – forms a tight suture sling between the two bars. The FasT-Fix comes with straight and 22° curved needles. The newest version is the Ultra FasT-Fix with easier knot sliding and stronger suture (UltraBraid). A reverse-curved needle is designed for repairing tears on the inferior surface of the meniscus.

The white depth penetration limiter is cut to the appropriate length, as measured with the meniscal probe (usually 16–18 mm). The cut is made in an oblique manner, which permits parallel positioning to the upper surface of the meniscus. The FasT-Fix delivery system is introduced into the appropriate portal through the blue split cannula to keep it free of soft tissue and to protect the cartilage.

A metallic cannula, which is designed as a gutter, can also be used. The system is positioned in front of the axial meniscal fragment and then passed through both parts of the meniscus and through the joint capsule. It is useful to check the rotation of the needle, in order to be 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. The needle is then withdrawn from the meniscus with a gentle oscillating motion to release the first suture bar behind the capsule. While the tip of the insertion needle is in view, the gold trigger on the handle is slid forward to advance the second anchor. A "click" is heard when this is achieved. The delivery needle is then positioned 5 mm from the first implant in

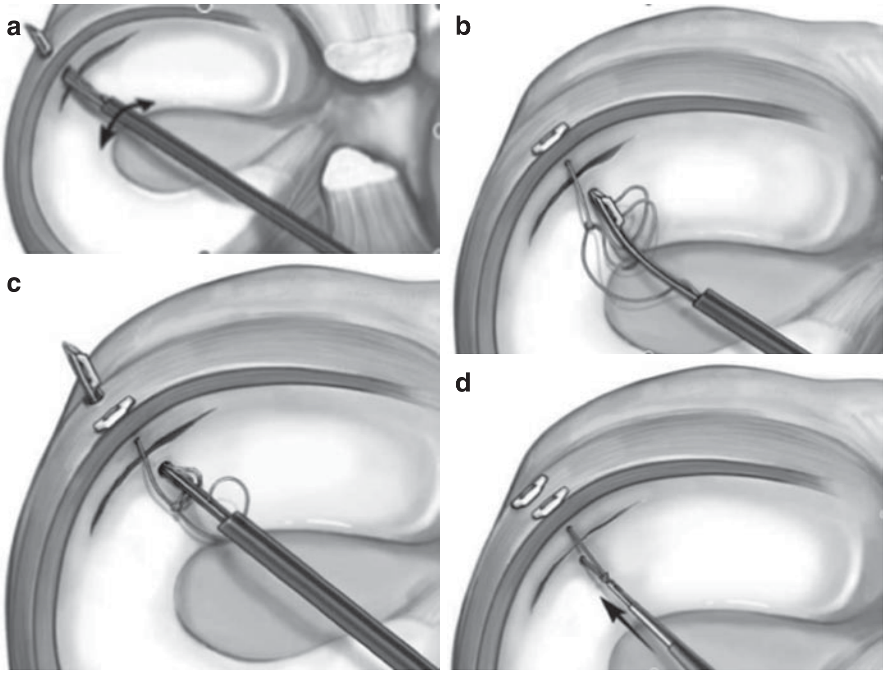

Fig. 4.3.7 FasT-Fix meniscal repair. (**a**) Insertion of the first implant with the needle. (**b**) The needle is positioned in front of the inner part of the meniscus (Arthroscopic view) (**c**) The second implant is passed through the capsule. (**d**) Tensioning of the suture using the knot pusher (Courtesy of Smith & Nephew)

a vertical, horizontal, or oblique plane. Once it is passed through the meniscus and the capsule, the needle is again withdrawn with a rotating motion to release the second implant. The delivery needle is removed from the joint, leaving the free end of the suture out of the knee. The suture is pulled to advance the sliding knot. The probe can be used to exert counterpression on the axial part of the meniscus while the suture is pulled (Fig. 4.3.8). With the knot pusher, the pretied self-sliding knot is tightened. After having checked that the desired tension has been achieved, the suture is cut with the knot pusher. Additional devices are inserted every 4–5 mm until the repair is complete. This device allows the placement of horizontal, oblique, or vertical mattress sutures (Fig. 4.3.9).

The curved needles are useful to achieve a good bite in the corners. For the strategy of the repair, it is more

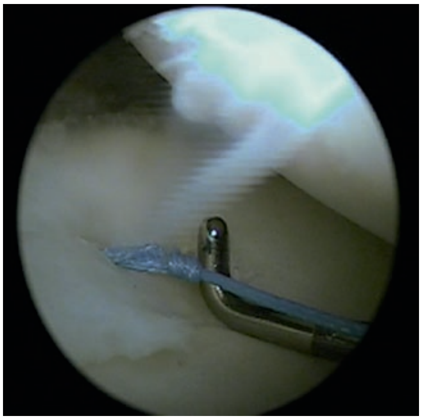

Fig. 4.3.8 The sliding knot is tied by pulling on the free end; the probe can be used to exert counterpression on the surface of the meniscus (FasT-Fix)

Fig. 4.3.9 Horizontal mattress suture on the upper surface of the meniscus (FasT-Fix)

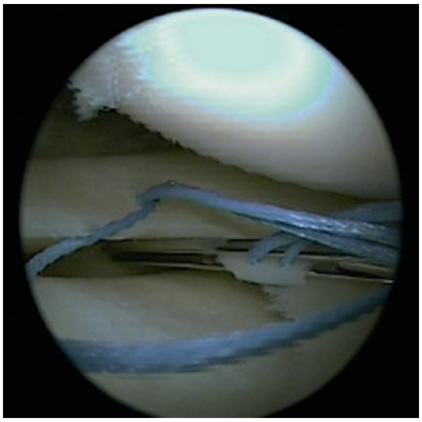

Fig. 4.3.10 The second bar of the FasT-Fix is positioned anteriorly to the first one in order to have a clear view

accurate to insert the second anchor anteriorly to the first one in order to have a clearer view and to diminish the risk of suture tangling (Fig. 4.3.10).

Meniscal Cinch (Fig. 4.3.11)

The newest device of Arthrex is a self-adjusting suture with two anchors. This device shows higher load to failure. The two low-profile PEEK implants are loaded with a pretied sliding knot 2-0 FiberWire suture. A slotted, curved cannula allows easy access to the tear and the graduated tip of the Meniscal Cinch cannula measures the approximate distance from the entry point of the implant to the capsule. The depth stop on the Meniscal Cinch is set by squeezing the tips together and sliding the depth stop forward to a distance equal to the measurement in the first step. Then, the tip of the Meniscal Cinch cannula is placed near the tear. The tip may be used to reduce the tear prior the deployment of the first trocar. The tip of the first trocar is passed through the tear. The first implant is advanced through the meniscus by pushing the trocar #1 until the trocar handle makes contact with the depth stop and the cannula rests on the surface of the meniscus. Trocar #1 is completely removed from the cannula. A slight downward force on trocar #1 during removal ensures that it does not interfere with trocar #2. Trocar #2 is pushed down to release it from the holding position. The tip of the cannula is moved to the second insertion point over the meniscus. Trocar #2 is advanced forward by pushing the trocar handle forward until it

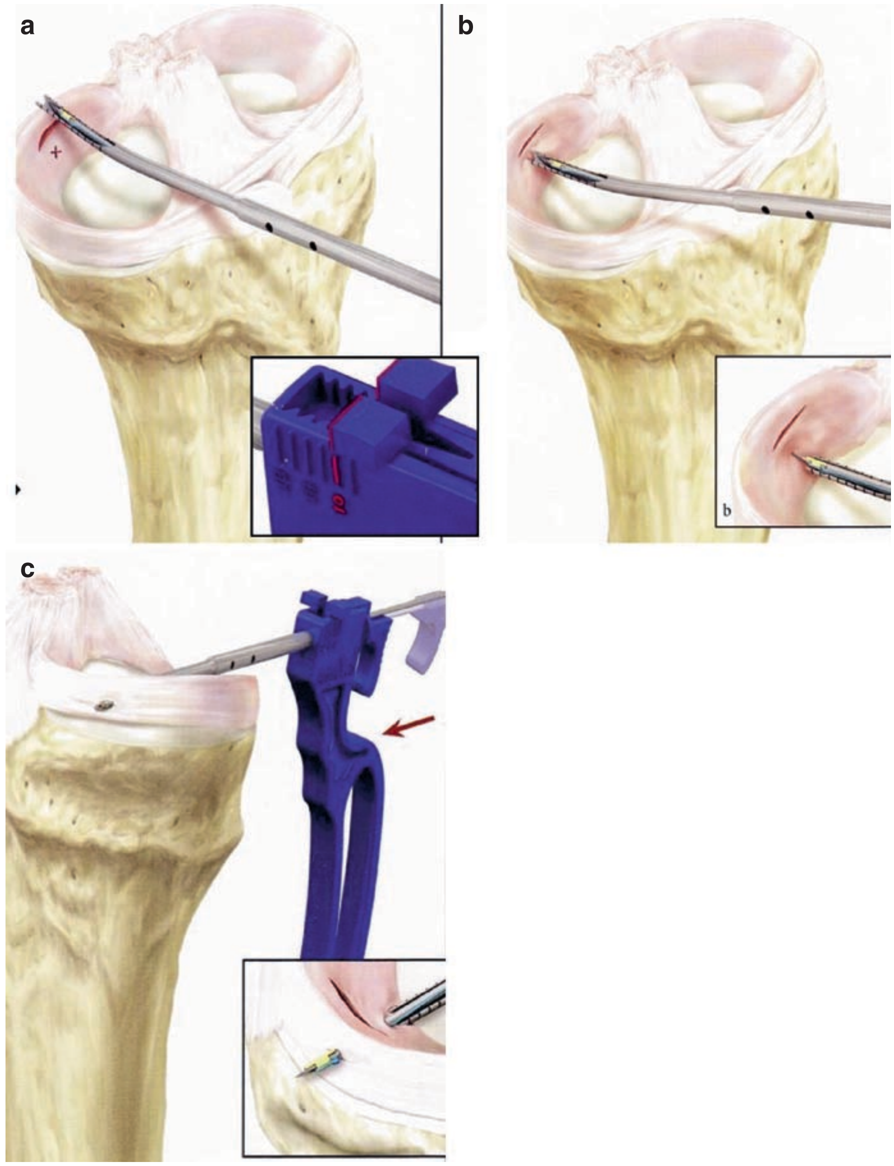

Fig. 4.3.11 Meniscal repair using the Meniscal Cinch. (**a**) After measurement of the meniscal width, the depth stop is set. (**b**) The tip of the first trocar is placed. (**c**) The first implant is pushed through the meniscus. After the removal of the first trocar, the second one is pushed down. Then, the suture is tightened (Courtesy of Arthrex)

makes contact with the depth stop. The suture slack created by advancing trocar #2 may be reduced partially by gently tensioning the external suture near the handle. Then, trocar #2 is pulled out and the Meniscal Cinch is removed from the joint. The external suture is tensioned to advance the knot to the meniscus. The free end of the suture is inserted through the tip of the knot pusher/cutter. The knot is pushed while pulling tension on the external suture. The sliding knot is advanced until it is coutersunk into the meniscal tissue.

All three devices allow an appropriate repair of the posterior segment and the posterior part of the middle segment. They have become the gold standard for the majority of meniscus repairs. However, due to the insufficient curvature of the needle, they cannot be used for the anterior segment.

Specific Cases

Anterior Segment Tear (Fig. 4.3.12)

Arthroscopic access to the anterior part of the meniscus is limited. Isolated peripheral lesions of the anterior segment do occur, especially on the lateral side. To repair the anterior part of the lateral meniscus, the use of all-inside and inside-out techniques is difficult or impossible. An outside-in suture technique is performed.

Sutures are introduced into the knee through a spinal needle (Fig. 4.3.13). The free end is passed again through the axial part of the meniscus by using a shuttle relay. The free suture ends are tied over the capsule.

Fig. 4.3.12 Meniscal tear involving the anterior segment of the lateral meniscus

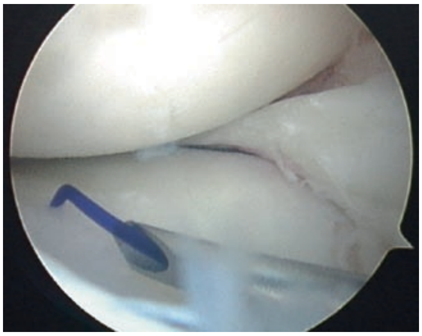

Fig. 4.3.13 Meniscal repair with an outside-in technique

Bucket-Handle Tear

An all-inside technique for the posterior and middle segments and an outside-in technique as described above for the anterior segment can be used to repair bucket-handle tears.

In case of a long tear, the use of a probe inserted through a third transtendinous Gillquist portal permits to hold the axial segment in the proper position. The tear can then be fixed.

Horizontal Cleavage Tear

Meniscus repair is indicated in the vast majority of vertical longitudinal peripheral lesions. However, it can also be proposed in some selected cases of horizontal cleavage tears in young athletes.

These tears are difficult to manage by arthroscopic means. This particularly applies to grade 2 lesions on MRI, where the arthroscopic appearance is that of a normal meniscus. It is, therefore, impossible to debride the lesion, which lies in the intrasubstance of the meniscus. Moreover, it is difficult to place sutures that are perpendicular to the lesion under arthroscopic visualization. This is the reason why, in such cases, we propose an open meniscus repair. First, the absence of a connection between the tear and the articular surfaces of the meniscus is checked arthroscopically, after which an open arthrotomy is performed. The approach is posterior to the collateral ligament. The meniscosynovial junction is opened to give direct access to the posterior rim of the meniscus. The horizontal cleavage tear is exposed and the degenerative tissue is excised with a curette. The two layers of the meniscus are closed with vertical PDS stitches (Fig. 4.3.14). Then, the arthrotomy is closed.

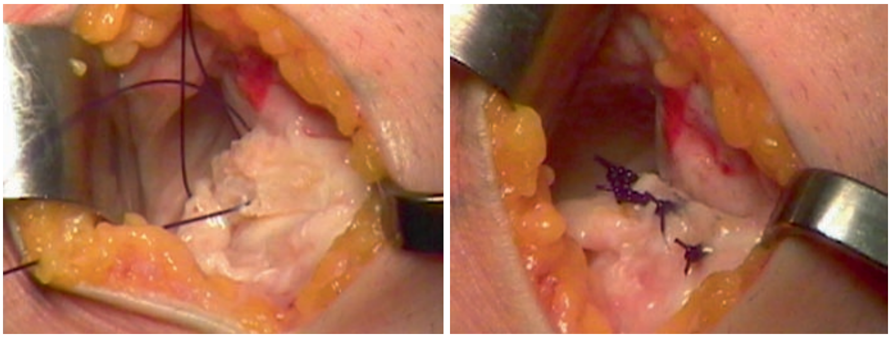

Fig. 4.3.14 Open procedure for meniscal repair using vertical sutures to close horizontal cleavage

Conclusion

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 which are adapted to different indications.

Even if all-inside fourth-generation devices are now the gold standard in the majority of cases, inside-out, outside-in, and even open techniques are still indicated in selected cases. The ultimate goal is to achieve a strong repair.

In the future, the next step will be biological meniscus repair by introducing factors such as stem cells, growth factors, or cytokines at the site of the repair to enhance healing. These can be regarded as biological mediators, which regulate key processes in tissue repair (cell proliferation, directed cell migration, cell differentiation, and extracellular matrix synthesis).

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Meniscal Repair: Enhancement of Healing Process

4.4

M. Jacobi and R. P. Jakob

Introduction

The limited healing potential of meniscal tissue and the importance of preserving the meniscus in view of its important role in load transmission, force distribution, shock absorption, articular cartilage protection, joint lubrication and knee stabilization have led to multiple strategies for enhancing meniscal repair [23, 39, 40, 42]. Loss of meniscal tissue, especially in young patients, has detrimental consequences for the long-term prognosis of the knee joint because it increases point loading and leads to premature wear of the knee due to altered mechanical forces, which ultimately results in osteoarthritis [9, 31]. The healing potential of meniscus tears depends on different factors, such as configuration of the tear, time between injury and repair, age of the patient and location of the tear. An essential prerequisite for meniscus healing is vascular access, which unfortunately is limited in meniscal tissue. The vascular anatomy of the meniscus was described by Arnoczky and Warren, who distinguished the red–red, vascularized peripheral zone with the best healing potential from the intermediate red–white zone and the most central white–white zone [3]. The more central the lesion is located, the worse its healing potential is. A longitudinal red–red peripheral lesion repaired by meniscal suturing has the best chance of healing. Already in 1936, King stated that "for a meniscal tear to heal the torn meniscus must communicate with its peripheral blood supply" [21].

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Prerequisites of Meniscal Healing

Enhancement of meniscal healing is based on some fundamental requirements that are essential to successful meniscal repair.

The proper meniscus suturing technique should be used to provide optimal stability. The stability of different suture techniques and devices has been investigated extensively [1, 5, 6, 10, 43]. The choice of the applied technique depends on the location, size and configuration of the meniscus tear.

Knee instability is a negative predictor for meniscus healing. While healing rates between 20 and 70% have been reported in anterior cruciate ligament (ACL)-deficient knees [2, 20, 25, 33], associated ACL reconstruction increases the healing rate from 80 to 100% [20, 25, 33, 34, 37], and is therefore, indicated when performing a meniscus suture in an ACL-deficient knee.

The meniscus tissue should ideally be without degenerative changes. Often, the division into traumatic and degenerative tears is not as strict. Traumatic tears undergoing delayed surgery often show some degeneration, and menisci with minor degenerative changes can also sustain a traumatic tear. Whether suturing is still feasible in these cases is often a subjective decision. The younger the patient, the greater the interest in preserving the meniscus even if some degeneration is present.

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_4.4, © Springer-Verlag Berlin Heidelberg 2010

Enhancement Techniques

Mechanical Trephination *(Fig. 4.4.1)*

A basic method to promote meniscal healing is mechanical trephination, which has shown some success [11, 24]. This method creates vascular access channels, which improve the blood supply to the healing meniscus. Zhang and Arnold demonstrated better healing rates and fewer symptoms in trephinated patients [44]. They operated on 36 patients by trephination and suturing, with two retears (6%), and on 28 patients by suturing alone, with seven (25%) retears. In this study healing evaluation was based on clinical reporting without arthroscopic control.

Abrasion *(Fig. 4.4.2)*

Abrasion or rasping of the adjacent synovium and the surface of the meniscus stimulates bleeding in the region of repair and may release beneficial growth factors into the healing environment. This is a technically simple method, which is recommended in every case of meniscal repair [7]. In a goat model, it has shown a better outcome compared to fibrin clot [27, 32]. Uchio et al. performed a retrospective cohort study of 47 patients and evaluated them arthroscopically [38]. Forty-five patients were clinically asymptomatic. At second-look arthroscopy, 34 menisci (71%) were healed completely, 10 (21%) partially and 4 (8%) did not heal. At least 32 of the lesions were not in the red–red zone.

Synovial Flaps *(Fig. 4.4.3)*

Free or pedicle flaps are used to cover the meniscus or are transplanted to the meniscal tear. The technique has been widely investigated in animal models, where it improved healing in all zones [12, 13, 36]. Although clinical data are limited, healing of an avascular tear was reported in seven patients [20]. A 3-cm long anteromedial arthrotomy was done and a synovial flap was lifted from the parameniscal synovium, reflected and sutured to cover the torn meniscus.

High-Frequency Current *(Fig. 4.4.4)*

Pavlovich reported on four patients who underwent meniscal repair using high-frequency current [28]: Using a glycine solution for irrigation and the electrocautery tip (high-frequency A/C current), several centripetal movements were performed from the peripheral meniscocapsular junction to the centre of the meniscus, reaching the lips of the tear. Also, the tip

Fig. 4.4.1 Trephination

Fig. 4.4.2 Abrasion

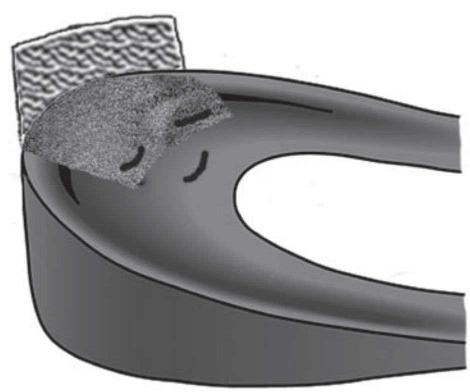

Fig. 4.4.3 Synovial flap

Fig. 4.4.4 High-frequency current

was driven within both lips of the tear. All four cases were evaluated arthroscopically. All of them healed and returned to sports activity. No further report on the use of high-frequency current in meniscal repair was found in the literature.

Gluing *(Fig. 4.4.5)*

Cyanoacrylate glue [22] and fibrin glue [17, 18, 26] have been suggested in the literature as suture or suture reinforcement. Ishimura et al. performed 61 meniscus repairs in 40 patients with fibrin glue, of whom 35 underwent a second-look arthroscopy. Before gluing, arthroscopic rasping was performed. If the meniscus showed some degeneration, two to three additional sutures were placed after glue application. The technique resulted in 77% good, 11.5% fair and 11.5% poor outcomes. Cyanoacrylate glue was tested only under in vitro conditions, where it showed some slight mechanical advantage compared to suture alone [22].

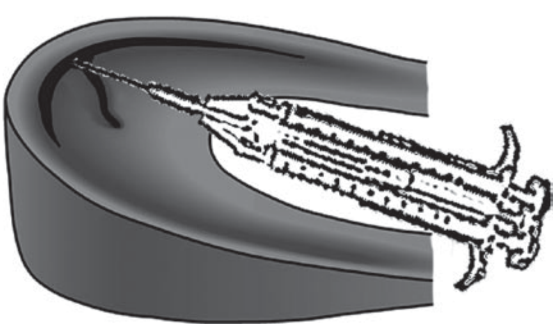

Fig. 4.4.5 Gluing

Exogenous Fibrin Clot *(Fig. 4.4.6)*

Application of a fibrin clot has received ample consideration. The fibrin clot is obtained from the patient's blood, prepared and then incorporated into the repair site through a cannula. The technique is generally performed in combination with conventional sutures. The application of an exogenous fibrin clot may provide a scaffold for cellular ingrowth and growth factors. Its use has been shown to stimulate repair in dogs [4]. It is recommended for complex tears and tears extending into the avascular zone [8, 15, 35].

Fascia Sheath Coverage and Fibrin Clot *(Fig. 4.4.7)*

The technique includes rasp abrasion of the parameniscal synovium, peripheral white rim and tear surface of the handle fragment. The meniscus is sutured first. Then, a rectangle of fascia from the distal anterolateral

Fig. 4.4.6 Exogenous fibrin clot

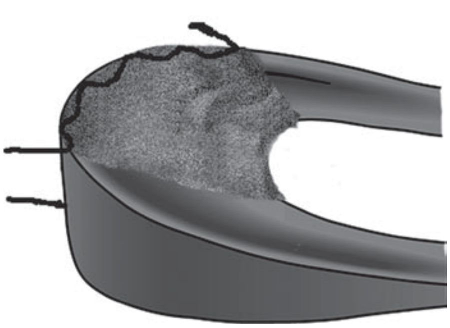

Fig. 4.4.7 Fascia sheath coverage

thigh is prepared with sutures to pull the fascia over the meniscal repair. The exogenous blood clot is injected in the tear under the sheath. The procedure is technically demanding and only one preliminary report is available, suggesting that improved healing rates can be obtained for most complex tears [16]. Repairs of tears in the middle one-third of the lateral meniscus still show a high failure rate. The combination of fascia sheath coverage with exogenous fibrin clot has led to arthroscopically documented healing in 26 of 31 patients with a complex meniscus tear.

Table 4.4.1 Baseline data

Men/women	19/11
Associated injuries	10 ACL lesions (reconstruction) 1 medial meniscus (normal suture)
Medial/lateral meniscus	23/7 all in the red–white or white–white zone
Complex tears	15
Bucket-handle	11
Horizontal	4

Meniscus Wrap Technique *(Fig. 4.4.8)*

The meniscus wrap technique is based on the experience with a technique developed by the senior author (RPJ) and first applied in 2003. Wrapping the meniscus with a collagen matrix might create some kind of bioreactor, guiding cell ingrowth and improving suture stability. Thirty patients with tears in the red–white or white–white zone, complex tears, delayed traumatic tears with degenerative aspects, or repeat sutures were treated with this technique. Baseline data are presented in Table 4.4.1.

Technique: The meniscus is reduced and fixed by preliminary inside-out sutures retrieved through a posteromedial or posterolateral counterincision. A collagen I/III matrix, measuring 20 by 20 mm, is prepared using two 2-0 sutures of different colours fixed at the inferior corners. The matrix is then introduced through a 7–8 mm arthroscopic cannula with the two 20-cm slightly curved needles at the tip ahead. One of the needles perforates the capsule beneath the sutured meniscus in the back and the other one in front. The matrix is pulled and pushed through the cannula with a third suture fixed in

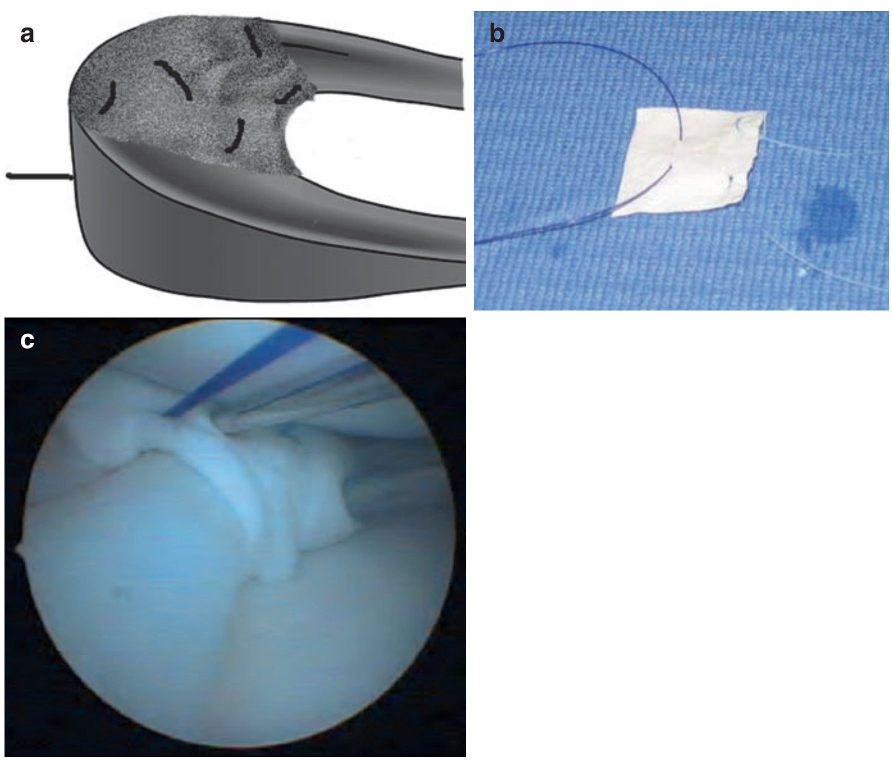

Fig. 4.4.8 (**a**) Meniscus wrap. (**b**) Preparation of collagen membrane. (**c**) Arthroscopic view of meniscus wrap

the middle, i.e. the folding area of the membrane that allows retrieval of the matrix in case of twisting. The inferior half of the matrix is placed beneath the meniscus. Then, the remaining half of the matrix is folded onto the superior meniscal surface and free inside-out sutures are used to fix it as tightly on the meniscus as possible. Multiple sutures are added (up to 10), completing the fixation of the membrane on the meniscus and the meniscus tear. This part is usually done without water expansion, just using room air entering through the cannula, since twisting of the membrane can be a problem in the liquid medium.

Results: After a mean follow-up of 2.5 years (range 1–5), three patients had a symptomatic failure (10%). In two of them, partial meniscectomy was performed, and in the other patient (a 20-year-old female with a second suture of a bucket-handle tear), a third suture combined with an unloading osteotomy was performed, which ultimately led to clinical meniscal healing. All other 27 cases (90%) were asymptomatic. Additionally, the following complications were noted: arthrofibrosis requiring mobilization under anaesthesia (one patient), saphenous nerve entrapment necessitating revision (one patient) and ACL re-rupture after reconstruction and a new trauma, with the meniscus remaining intact (one patient).

Conclusion: This repair enhancement technique seems to improve the chances of healing, even in unfavourable conditions. Although the evaluation did not include a second-look arthroscopy, 90% of patients remained asymptomatic after a mean follow-up of 2.5 years. Similar to fascia sheath coverage, this technique has the disadvantage of being technically demanding and time-consuming.

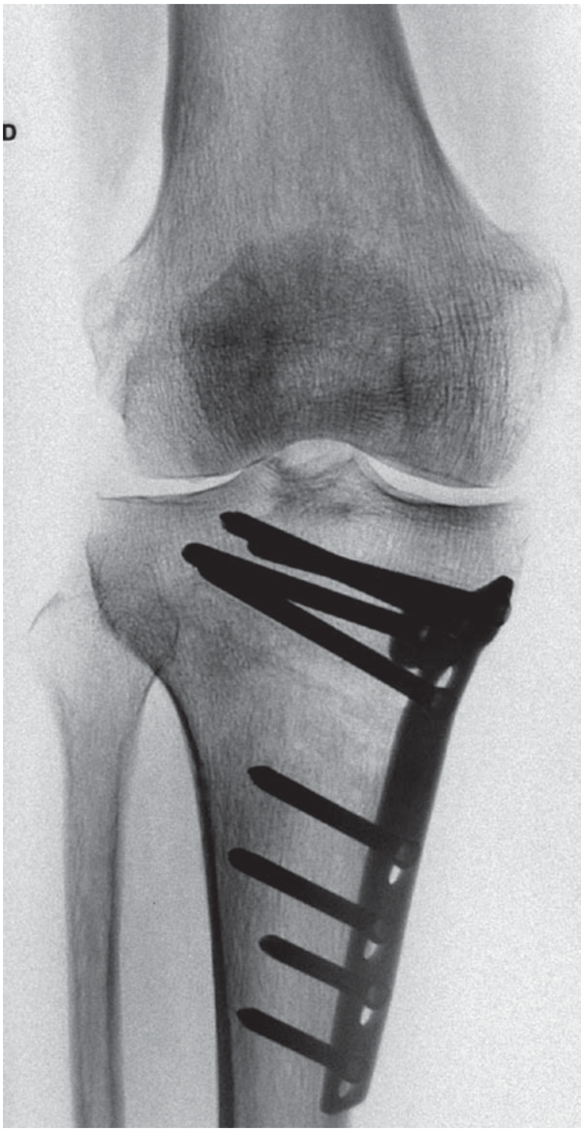

Fig. 4.4.9 Unloading opening-wedge high tibial osteotomy

Unloading the Meniscus (Fig. 4.4.9)

The majority of patients with medial meniscal tears present associated varus malalignment [14]. Although in most cases varus deformity is slight, load transmission will predominantly occur through the damaged compartment [19]. To increase the healing potential, the authors performed an unloading opening-wedge high tibial osteotomy together with repeat meniscus suturing in seven patients presenting a first or second re-rupture of the medial meniscus and associated varus deformity. All of them were assessed arthroscopically after 1 year, when metal removal was performed. All menisci healed completely. Unloading the involved compartment might be a successful treatment option in re-rupture cases, especially in young patients.

Cell-Based Therapy and Gene Therapy

A better understanding of meniscus cell biology, healing response and potential to enhance the intrinsic reparative process might in the near future lead to new treatment options. Much laboratory research and animal studies are being conducted to find such options [29, 30, 41], but these have not yet been applied to humans.

Conclusion

Among orthopaedic surgeons, it is undisputed that as much meniscus tissue should be preserved as possible because removal leads to degenerative changes in the involved compartment. However, the problem of promoting healing of meniscal tears in the avascular area has not been resolved as yet. Different promising approaches have been advanced to improve meniscal healing. Technically simple techniques such as abrasion, rasping or trephination should be adopted whenever possible and are currently widely propagated. Conversely, the technically more demanding treatments, e.g. meniscus wrapping or fibrin clot application, are rarely used. Finally, some other techniques have probably been abandoned (gluing, high-frequency current). All techniques have one thing in common, i.e. the level of evidence of their utility and value in enhancing meniscal repair is low, particularly for clinical application.

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Meniscal Cysts

4.5

C. Hulet, B. Lebel, and B. Locker

Introduction

Meniscal cysts are relatively uncommon. The reported incidence ranges from 0.27 to 5% of meniscal tears. The ratio of lateral to medial meniscal cysts is 5:1 according to Maffuli et al. [26], and 10:1 according to Seger and Woods [39]). In the early descriptions, Nicaise [29] and Ebner [11] considered cysts to be a herniation of the synovial membrane. The aetiology and pathophysiology of meniscal cysts have been the subject of much controversy [38], but most authors accept a "degenerative" origin. The cyst generally develops insidiously, although Locker et al. [23] and Wroblewski [41] reported a traumatic component in a significant number of cases (50%). In our hands [18], trauma was found in only 32%.

The rate of meniscal tears related to meniscal cysts is between 18 and 100%. Reagan et al. [34] described several stages of lateral meniscal cysts relating to the location of the initial tear in the substance of the meniscus and the progression of the tear. It may spread to the periphery of the meniscus and/or centrally to the inner intra-articular surface of the lateral meniscus. In the last century, a wide variety of treatments has been suggested [20, 22, 33, 35], including open meniscectomy and excision of the cyst, isolated open excision of the cyst, steroid injection of the cyst, and more recently, arthroscopic cyst decompression with partial meniscectomy [13] or open excision of the cyst with either partial meniscectomy or meniscal repair.

Magnetic resonance imaging (MRI) is an essential diagnostic modality, giving information on meniscal tissue, location of the cyst and other intra-articular lesions (chondral damage). It is a very important tool for the pre-operative planning. In non-symptomatic patients, conservative treatment is highly recommended. A major study, conducted by the French Arthroscopy Society, of 98 lateral arthroscopic meniscectomies with a clinical and radiographic (including schuss views) follow-up of more than 10 years reported a 38% rate of joint narrowing [9]. Therefore, the concept of meniscal sparing remains the rule in the management of meniscal cysts.

This paper discusses the clinical evaluation of meniscal cysts and their treatment options and provides guidelines.

Clinical Evaluation

History: Physical Examination

Patients with meniscal cysts (Fig. 4.5.1) often present after months or years of symptoms. In our experience [18], the mean age at diagnosis was 33 years (range, 12–69 years). A meniscal cyst is a painful disorder affecting young to middle-aged patients. However, Becton and Young [6] reported one exceptional case in a 5-year-old child. The complaints usually are a dull pain associated with swelling and subcutaneous cyst formation in front of the lateral compartment. Effusion, locking and giving way are less common.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_4.5, © Springer-Verlag Berlin Heidelberg 2010

Fig. 4.5.1 (**a**) Typical clinical presentation of a lateral meniscal cyst (left knee). (**b**) A 32-year-old patient presenting with subcutaneous medial cyst formation (right knee)

Cyst size is often limited to 2 cm in length. Expanding cysts irritating the peroneal nerve or causing compression of the popliteal artery have also been reported. Disappearance of a lateral cyst with knee flexion (Pisani's sign) may prompt the clinical diagnosis. Lateral meniscal cysts are easier to diagnose by physical examination than medial cysts because of their relatively anterior, subcutaneous position. Usually, a lateral meniscal cyst is connected to the junction between the anterior and the middle segment of the meniscus, whereas a medial meniscal cyst is often connected to the posterior horn or to the posterior horn-middle segment junction. Medial cysts are commonly deeper-seated and larger. The differential diagnosis includes a meniscal tear without cyst, loose bodies, exostosis, bursal inflammation, ganglion, tendinitis and tumour.

Diagnosis

Pre-therapeutic imaging is necessary to identify additional disorders and to accurately assess the meniscal tear and cyst. Routine X-rays include anteroposterior and lateral weightbearing views. A schuss view is highly recommended for patients older than 40 years [5] to assess the joint line. Erosion of the tibial plateau (Fig. 4.5.2) or the femoral condyle has been described in either the lateral or the medial compartment, and is probably related to pressure from the nearby cyst [2]. MRI is the first step in the diagnosis and assessment of a meniscal cyst (Fig. 4.5.2), and is critical to precisely define the meniscal tear. It allows a meticulous exploration of the cyst's size, location, extent to the articular surface of the meniscus and the connection between cyst and tear. MRI is very useful to search for associated intra-articular damage (especially articular cartilage lesions) to exclude other diagnoses and to plan the treatment. In the majority of studies, a cyst-meniscal tear relationship has been found in 100% of cases [17, 18, 30, 39]. We agree with Reagan et al. [34] that several stages can be distinguished in the development of lateral meniscal cysts and that a complete meniscal lesion depends on the stage of progression in a given patient.

Horizontal cleavage tears are the most common of all types of meniscal tears [10, 17, 26, 31]. Glasgow et al. [17] identified 72 tears, of which 30 were simple horizontal cleavages, 23 oblique-horizontal cleavages and 4 discoid menisci. Hulet et al. [18] found that a horizontal component (56% horizontal cleavages and 10 complex lesions) accounted for 64% of cases. In the literature, horizontal cleavage tears are most frequently associated with lateral meniscal cysts. Isolated radial splits are rarely observed. Meniscal cysts are located in the mid-portion of the lateral meniscus, with an extension to the anterior portion in 21% of cases. Saidi et al. [36] reported five cases of medial meniscal cysts; all tears were located in the posterior segment. In a retrospective MRI review, Campbell and Mitchell [8] predominantly found a medial meniscal cyst ($N=72$), which was adjacent to the posterior horn in 74% of cases, and a horizontal cleavage tear in 90% of cases.

The management of meniscal cysts depends on the pre-therapeutic planning. As mentioned by Reagan et al. [34], a cyst may be associated with a meniscal tear extending to the knee joint (grade 3) or with a meniscal tear leaving the articular surface of the meniscus intact (grade 2). Symptoms, age and associated intra-articular lesions also play an important part in therapeutic decision making.

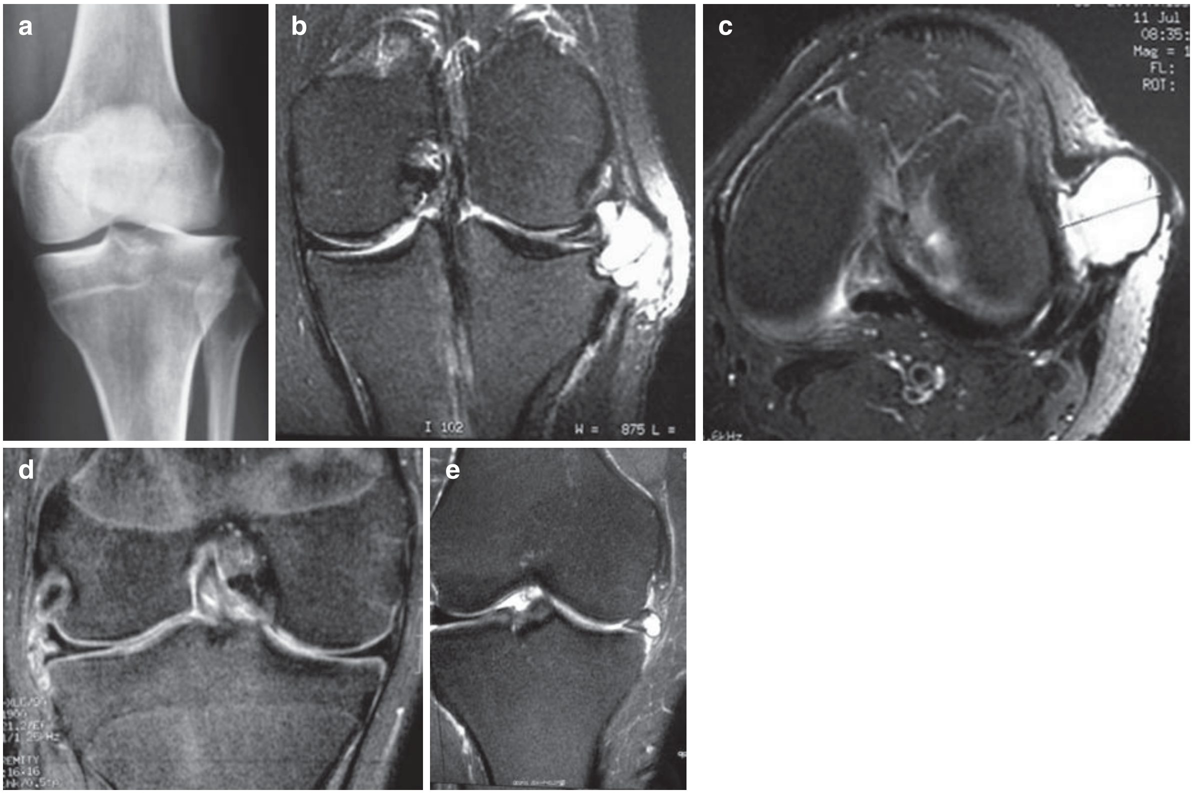

Fig. 4.5.2 Imaging of meniscal cyst. (**a**) Standard X-ray showing an erosion of the lateral tibial plateau. (**b–d**) MRI T2 showing a lateral meniscal cyst and associated meniscal tear. (**e**) MRI T2 showing a medial meniscal cyst and associated meniscal tear

Treatment Options

Conservative Treatment

Two similar approaches have been reported: cyst aspiration followed by steroid injection [4], recently improved by ultrasound-guided percutaneous drainage [28]. It is supposed that steroid injection could induce an inflammatory process with subsequent fibrosis of the cyst [13]. However, according to Mills and Henderson [27], steroid injection only provides pain relief for a few weeks and finally fails. Recently, Macmahon et al. [25] developed ultrasound-guided percutaneous drainage of meniscal cysts. They evaluated 18 cases (13 medial and 5 lateral) with MRI and reported encouraging results. The cysts were injected with local anaesthetic and steroid. Cyst aspiration could be considered in patients unsuitable for surgical treatment because of their age (above 45 years), activity level and associated chondral damage.

Meniscal Tear Extending to the Joint (Grade 3)

Arthroscopic Meniscectomy Combined with Cyst Treatment

This treatment is proposed for grade 3 meniscal tears with a palpable lateral mass of the joint line. It is the most common occurrence. In a retrospective study of 105 lateral meniscal cysts [18], we found a 99% prevalence of meniscal tears extending to the joint. In our experience, a horizontal cleavage tear, isolated or associated with another type of lesion, is most frequently observed. This therapeutic approach has been proposed for the lateral meniscus or the medial meniscus

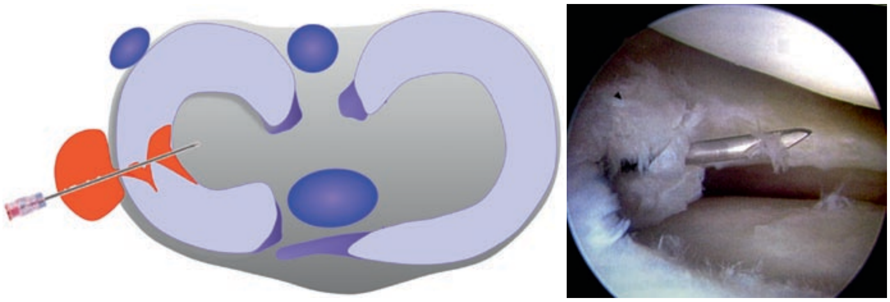

Fig. 4.5.3 A needle is introduced through the cyst to locate the tract junction between the meniscal tear and the cystic mass (as described by Beaufils, Hulet)

by several authors (lateral meniscus [18, 30, 34, 37], medial meniscus [7, 19, 36]).

Technique

Under general or regional anaesthesia, standard arthroscopy portals are created, establishing inflow via a lateral parapatellar portal. Inferomedial and inferolateral portals are then used alternately to explore the joint and perform the surgical procedure. Arthroscopic portals are adapted to the location of the tear and are changed during the procedure as needed. Careful initial probing of the meniscus is performed to clearly identify the extent of the meniscal tear. A spinal needle introduced percutaneously through the cystic mass may help to locate the tract between cyst and meniscus (Fig. 4.5.3).

Radial tears are excised to a stable peripheral rim [10]. The yellowish colour of the pathological meniscal tissue is characteristic of myxoid degeneration (Fig. 4.5.4), which is often found in histological studies [4, 14, 15]. Resection should be sufficiently wide anteriorly and posteriorly to avoid leaving yellowish pathological meniscal tissue and expose macroscopically normal meniscal tissue. Surgical experience is highly important because no arthroscopic criteria are known that can reliably determine the point of transition between healthy and pathological tissue. As for the popliteal hiatus, it is still highly controversial whether the tissue should be removed or a proper meniscal bridge be preserved. Complete excision of the meniscus at the level of the popliteal hiatus will lead to a total meniscectomy.

To decompress the cyst, a punch forceps is passed through the tear into the cyst to widen the tract, so that the contents of the cyst can be evacuated into the joint. Additionally, a small motorized shaver (Fig. 4.5.5) may be introduced into the cyst to assist cystic decompression and stimulate inflammation and scarring of the cyst and its tract. We recommend that special attention be paid to break down the multiple loculi during cyst decompression. In case of a large cyst that cannot be probed and shaved adequately, we recommend a complementary open cystectomy. Alternatively, if a peripheral meniscal rim remains that appears reparable, an arthroscopically assisted repair of the meniscus to the joint capsule may be performed. The knee is then flushed out and the arthroscopy portals are closed.

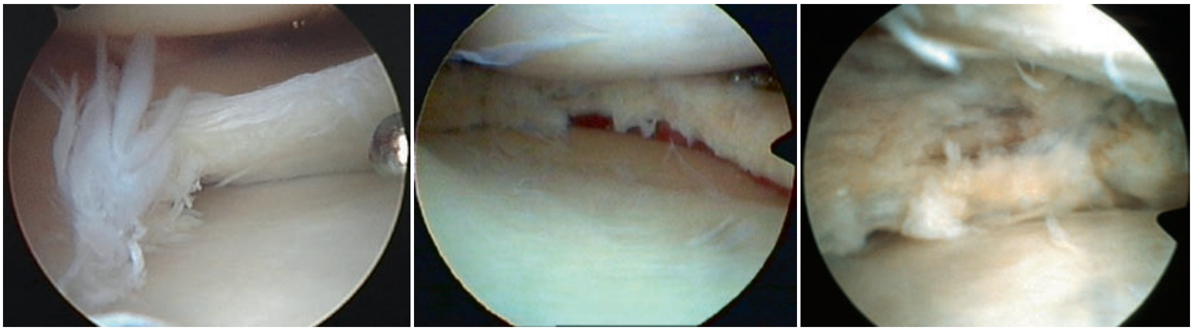

Fig. 4.5.4 Horizontal cleavage tear of the lateral meniscus associated with a meniscal cyst, before (A) and after (B, C) meniscectomy, showing myxoid degeneration (yellowish substance).

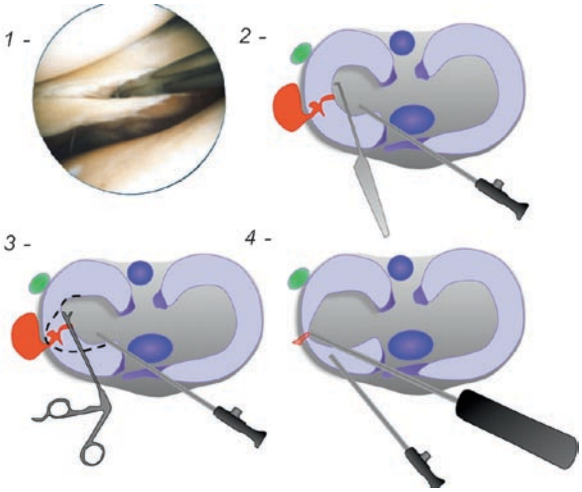

Fig. 4.5.5 Arthroscopic technique in case of a grade 3 meniscal tear. (**a**) Arthroscopic view showing a lateral meniscal tear extending to the joint. (**b**) Exploration of the knee joint and careful probing of the meniscus. (**c**) Meniscectomy. (**d**) Arthroscopic cystic decompression using a shaver

Postoperatively, patients are instructed to perform early isometric quadriceps exercises and immediate full weightbearing is allowed.

Results

Our clinical results at 5 years of follow-up [18] were identical to those reported in the literature [1, 6, 8, 16, 17, 26, 27, 30, 32, 34], with 85% excellent and good outcomes, and to those of arthroscopic lateral meniscectomies [5], demonstrating that functional outcome is related to the meniscal tear and not to the presence of a cyst. Results at the last follow-up were related to former knee pain or an associated medial meniscectomy. Unlike Tabib et al. [40], we did not find age at arthroscopy, morphotype or cartilage damage observed at arthroscopy to have an unfavourable effect on the outcome of our study. Recurrent cysts are not uncommon; according to Maffuli et al. [26], the recurrence rate reaches 9.5% (4 recurrences out of 38 cysts), and to Reagan et al. [34], 15.6% (five recurrences out of 32 cysts). These authors performed a second arthroscopy associated with surgical excision of the cyst. In all cases, an extension of the initial lesion was found whatever the delay to the subsequent procedure. In our experience [18], at an average 5-year follow-up, the incidence of osteoarthritis was 9%. Appel [3] reported the results of 23 cysts (17 lateral, 6 medial) treated by total meniscectomy with a 6–31-year follow-up. Two cases of osteoarthritis were observed. At arthroscopy, an age above 40 years had an unfavourable effect. In addition, Jaureguito et al. [21] reported the results of lateral arthroscopic meniscectomy in 20 patients with a mean 8-year follow-up. Radiographic changes were found to appear at a 5-year threshold. Likewise, a major study, conducted by the French Arthroscopy Society [9], of 98 lateral arthroscopic meniscectomies with a clinical and radiographic (including a 45° weightbearing view) follow-up of more than 10 years found a 38% rate of osteoarthritis.

Cyst Excision Combined with Meniscal Repair

In only few cases is the meniscal lesion a peripheral tear in the red–red zone. The tear is arthroscopically repaired and the cyst managed by aspiration or open cystectomy. Arthroscopic repair is performed using an outside-in technique. Sarimo et al. [37] compared two different operative procedures. In the first group of patients open cystectomy was performed. Then, using the tract to the meniscal tissue, the meniscus was sutured and the meniscocapsular junction reconstructed. In the second group, the entire procedure was performed arthroscopically and the meniscal tear was resected. In both groups there were medial and lateral cysts and the outcome was comparable. Importantly, in both groups, knee arthroscopy had initially been performed to treat any intra-articular disorders, and especially meniscal lesions. In 2006, Lu [24] reported a case of a meniscal cyst arising from the anterior segment of a torn lateral meniscus. The tear was repaired using an outside-in technique and the cyst was aspirated. No recurrence was observed during the 14-month follow-up period. Erginer et al. [12] only performed an arthroscopic decompression for a medial meniscus cyst of the anterior horn, with a good result at 18 months post-surgery.

Meniscal Tear Not Extending to the Articular Surface (Grade 2)

The deleterious effect of meniscectomy have conducted to the concept of meniscal preservation. The same applies to the treatment of meniscal cysts. Historically, meniscectomy was performed in such cases. Because of the biomechanical consequences of partial or sub-total lateral meniscectomy, most authors agree to preserve as much meniscal tissue as possible and advocate meniscal repair.

In case of an intrasubstance meniscal lesion (grade 2) combined with an exteriorized cyst, cyst excision is performed using an open technique for cysts involving the mid-portion or posterior part of the meniscus [7, 31]. When the cyst is located in the anterior horn, Howe and Koh [19] perform an arthroscopic decompression, while Lu [24] recommends arthroscopic outside-in meniscal repair and needle aspiration.

Technique

Both meniscal surfaces are arthroscopically inspected for the presence of a meniscus tear, after which open cystectomy and meniscal repair are performed (Fig. 4.5.6). The tract between the cyst and the peripheral rim is dissected and the meniscus is repaired using either an outside-in or inside-out technique. Surgical approach and repair technique depend on the cyst location and the experience of the surgical team.

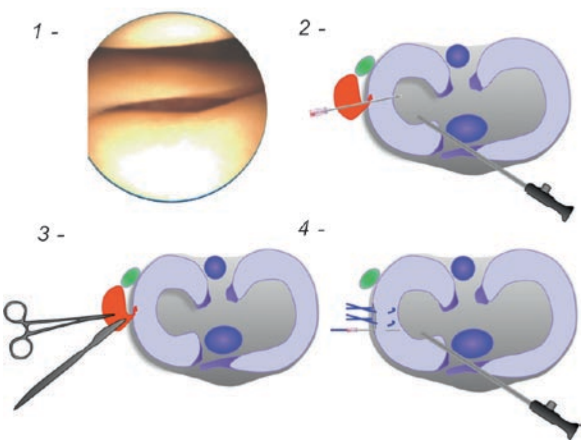

Fig. 4.5.6 Arthroscopic technique in case of a grade 2 meniscal tear. (**a**) Arthroscopic view showing the absence of a lateral meniscal tear extending to the joint. (**b**) Probing of both meniscal surfaces; a needle could be introduced through the cyst tract. (**c**) Open cystectomy. (**d**) Meniscal repair using an outside-in technique

Results

Reports of a meniscal cyst associated with a meniscal tear not extending to the articular surface are scarce. The short and mid-term results of the proposed treatment are good. We reported the case of a 12-year-old patient [18] in whom arthroscopy failed to detect a meniscal tear extending to the joint. Direct approach of the cyst revealed a horizontal cleavage tear originating from a peripheral position. The cyst was excised and the incomplete meniscal tear was repaired. A good result with no recurrence was observed at more than 5 years of follow-up.

Biedert [7] advocated this approach in a randomized clinical trial of the treatment of intrasubstance medial meniscal lesions. Forty patients with a mean age of 31 years presenting a horizontal grade 2 meniscal lesion were included in the study. The author demonstrated that arthroscopic meniscal repair is an effective alternative to meniscectomy. However, the positive early and mid-term results need to be confirmed in longer-term studies.

Clinical and Surgical Algorithm for Treatment of Meniscal Cysts

When a symptomatic lateral meniscal cyst is suspected clinically, X-rays and MRI are the first steps in establishing the diagnosis. Our findings and literature data [32] suggest the following management protocol for the lateral meniscus. MRI is critical to identify additional disorders 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 clearly extends to the joint, arthroscopy is performed first to assess the meniscal tear (Fig. 4.5.7). In case of a small tear, cystectomy should be performed (most often using an open technique) and meniscus repair should be attempted to preserve the meniscal tissue. For large and complex tears, arthroscopic partial meniscectomy and cyst decompression are indicated.

If the tear does not extend to the joint (grade 2), both meniscal surfaces should be arthroscopically inspected for the presence of a meniscus tear, after which open cystectomy and meniscal repair are performed (Fig. 4.5.8).

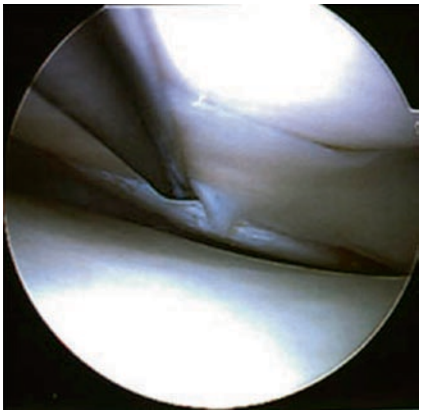

Fig. 4.5.7 Careful examination of the inner and upper surfaces of the menisci, showing incomplete meniscal cleavage at the inner surface of the meniscus

Our therapeutic algorithm is presented in Fig. 4.5.9. Meniscal tissue preservation should always be attempted to preserve the biomechanics of the knee joint.

Conclusion

Meniscal cyst constitutes a specific entity in meniscal tears. When a symptomatic lateral meniscal cyst is suspected clinically, MRI is the first diagnostic step to explore the meniscal tear. An asymptomatic meniscal cyst should be treated conservatively. In all symptomatic cases, meniscal tissue preservation should be the rule to safeguard the future of the knee. Because of the

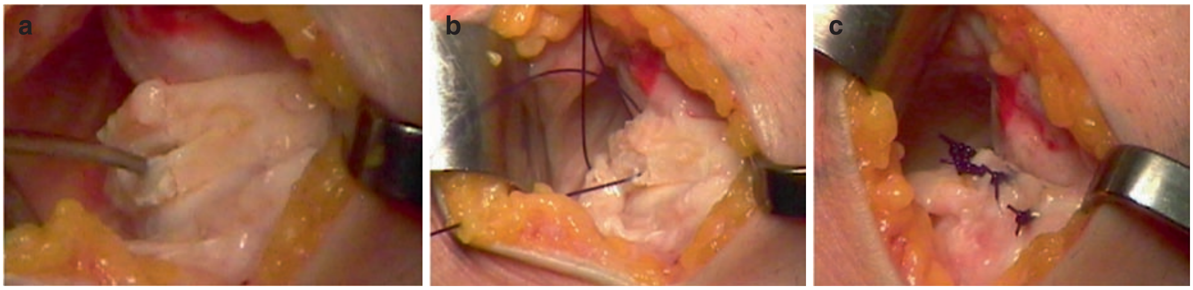

Fig. 4.5.8 Medial meniscal repair after excision of the cyst (Collection, Beaufils with permission). **(a)** Medial meniscal tear of the posterior segment. **(b)** Open meniscal repair procedure. **(c)** Final aspect of the meniscal repair

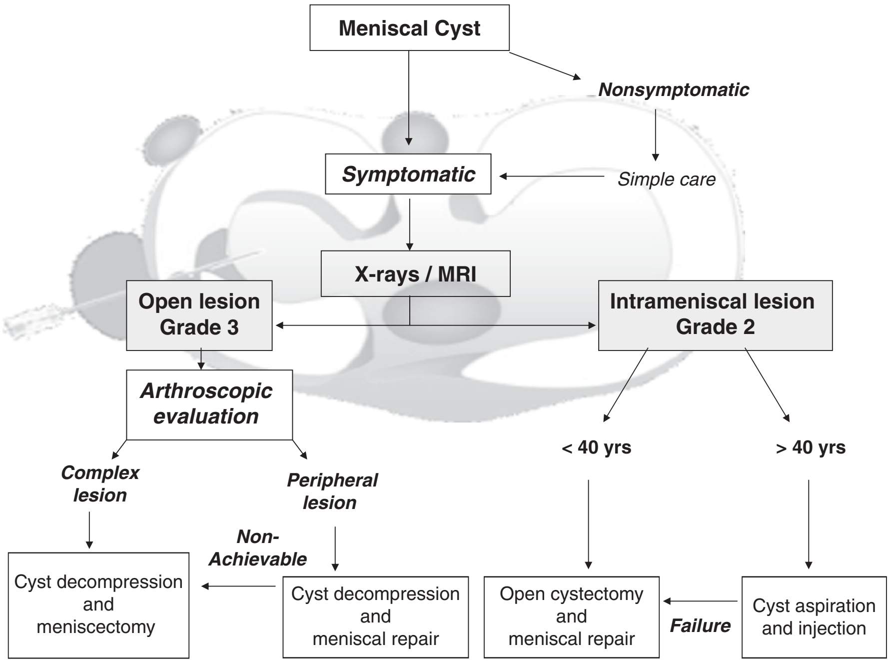

Fig. 4.5.9 Management of meniscal cysts: algorithm

often deleterious long-term results of lateral or medial meniscectomy, attempts to preserve the meniscus are clearly justified. The meniscus tear results from a degenerative breakdown of the ultrastructure of meniscal collagen with myxoid degeneration. Ultimately, referring to Ryu and Ting [35], we believe that it can be questioned 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. However, a meniscus that is functioning to some extent is still preferable to no meniscus at all.

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Rehabilitation 4.6

E. Witvrouw and Y. Thijs

Rehabilitation After Meniscectomy

Introduction

Supervised rehabilitation after partial arthroscopic meniscectomy is frequently considered as nonessential because usually, patients rapidly regain functional autonomy without specific postoperative treatment. However, quantitative evaluations of knee function after arthroscopic meniscectomy have shown recovery to be still incomplete 4–8 weeks after surgery, when the majority of patients already have resumed work and sports-related or other functional activities [11, 24]. Abnormalities in leg movements and muscle activations during submaximal locomotor activities such as gait and stairs ascent and descent have been observed up to 4 weeks post-surgery [12]. At 8 weeks, patients often still walk and descend stairs at a slower pace, suggesting that complete locomotor recovery has not been attained [12]. In addition, strength evaluations have revealed residual deficits of 20–40% in the knee extensor muscles and of up to 20% in the knee flexor muscles, 3 weeks after partial arthroscopic meniscectomy [10, 14, 15].

Since a 10% residual strength deficit of the extensor and flexor muscles has been associated to a higher frequency of knee (re)injury [5], it can be stated that progressive neuromuscular re-education and strengthening of the knee after partial meniscectomy are warranted. Moffet et al. [24] have demonstrated that an early, intensive, supervised physiotherapy programme, applied in the first 3 weeks after arthroscopic meniscectomy, accelerates knee extensor strength recovery.

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Rehabilitation Protocol

Supervised rehabilitation after partial meniscectomy can generally progress as tolerated by the patient with no substantial contraindications or limitations. The main goals of rehabilitation are to control the pain and swelling associated with surgery, restore the range of motion (ROM), restore or maintain isolated muscle function and optimize lower extremity neuromuscular coordination and muscle strength [6].

Early Postoperative Rehabilitation Phase

Immediate weightbearing is allowed as tolerated by the patient. Crutches are advised during the first few days after surgery and can be abandoned when the patient is able to place full weight on the involved leg without pain and has good control over the quadriceps muscle.

Postoperative treatment should initially focus on the reduction of pain and swelling, which may be present to a greater or lesser degree at the operated knee and are normal reactions of the affected tissue to the operation.

Reduction of pain and swelling is imperative for reducing "reflex inhibition", which may be present at the operated knee. "Reflex inhibition" represents a signal which is sent from an injured joint to the surrounding muscles in response to pain and joint effusion and which results in the inhibition of these muscles. This

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_4.6, © Springer-Verlag Berlin Heidelberg 2010

inhibition prevents the injured, weakened joint from being more damaged by excessive pressure in the joint caused by a strong contraction of the surrounding muscles. Hence, reflex inhibition acts as a natural protective mechanism of the body. As a result of reflex inhibition, however, the muscles surrounding the affected joint rapidly lose their strength, especially those that have their insertion closest to the joint, such as the vastus medialis muscle. In addition, the inhibition of the muscles limits their response to strengthening exercises [34].

Rapid reduction of pain and swelling is, therefore, an essential goal during the first postoperative week because strengthening of the muscles surrounding the knee cannot be initiated until reflex inhibition is resolved.

Initially, pain and swelling can be reduced by frequent application of ice (every 2 h for 30 min) and activity reduction. In addition, frequent (high repetitions) low-resistance active and passive movements (e.g. pendulum motions) within the painfree ROM of the knee enhance the nutrition of the joint cartilage, and thus, stimulate joint recovery [21].

Progressive active and passive ROM exercises of the knee can be started immediately post-surgery within the pain limits. Examples of such exercises are heel slides, flexion-extension exercises while standing with the involved leg on a chair or bench (Fig. 4.6.1), stationary cycling and manual ranging of the knee joint. Deep squats are not allowed in the first 4 weeks following the operation to avoid excessive load on the healing meniscus.

The presence of reflex inhibition also causes a disruption of the neuromuscular coordination at the knee [27]. Because of the effects of reflex inhibition, the initial primary focus of muscle rehabilitation is not strengthening of the musculature surrounding the knee, but improving the neuromuscular control of the muscles and the proprioception of the knee.

The neuromuscular coordination of the quadriceps muscle can initially be improved by performing muscle-setting exercises. The patient, lying in a supine position, is asked to perform an isolated isometric contraction of the quadriceps muscle in various knee angle positions. Setting exercises of the quadriceps muscle are, however, not recommended with the knee in full extension because this might cause impingement of the knee capsule. Eventually, the patient should be capable to maintain the isometric muscle contraction for 10 s. Patients are advised to daily perform ten series of ten repetitions until they regain full control of the quadriceps muscle in supine position, after which they can perform the setting exercises in more functional, weightbearing positions such as sitting and standing (Fig. 4.6.2).

Co-contractions of the quadriceps and hamstring muscles in different positions (lying, sitting and standing) (Fig. 4.6.3) at various knee angles are also essential components of the rehabilitation program, because they play an important role in anterior-posterior stability of the knee.

Proprioceptive exercises are essential to improve the functional stability of the knee joint. They can be started immediately after the operation, proceeding from exercises in a lesser weightbearing position

Fig. 4.6.1 Patient performing active flexion-extension exercises

Fig. 4.6.2 Quadriceps-setting exercise

Fig. 4.6.3 Co-contraction of the quadriceps and hamstring muscles

Fig. 4.6.4 Repositioning exercise

Fig. 4.6.5 Patient stabilizing the knee while the therapist moves the ball

Fig. 4.6.6 Balance exercise on an unstable surface

(e.g. repositioning exercises, exercises in lying position) (Figs. 4.6.4 and 4.6.5) to exercises in more weightbearing positions (e.g. unilateral balance exercises on a stable/unstable surface) (Fig. 4.6.6) to optimally facilitate the proprioceptive receptors.

Second Phase

Once the patient has regained good control of the muscles surrounding the knee, muscle strengthening exercises can be initiated. Optimizing quadriceps strength is especially important since, in addition to providing functional joint stability, the quadriceps musculature also has a protective function, serving as shock absorber capable of dampening loads during activity. Poor quadriceps strength decreases this shock-absorbing function and results in increased loading of the meniscus [27].

A combination of open kinetic chain (OKC) and closed kinetic chain (CKC) exercises can be used to improve upper leg muscle strength, but the latter become more important with time because they are more functional for the lower limb.

Depending on how much weight the patient can tolerate on the involved knee, CKC exercises are initially carried out with partial weightbearing and then progressively with full weightbearing. The progression in exercise intensity is guided by the amount of pain and effusion the patient experiences at the knee during or after the exercise, and can be increased when there is no marked reaction of the knee to the exercise. The intensity of the exercises has to be modified so that they can be performed within the pain limits. Examples of CKC exercises that can be performed are leg press exercises, squats, forward and sideways lunges and step exercises.

As soon as patients can tolerate full weightbearing on the involved knee, CKC exercises with the patients' own body weight as load can be started at a frequency of three series of 10–12 repetitions. When these can comfortably be performed, the number of repetitions can progressively be increased to four series of 30 repetitions to enhance muscle endurance.

Subsequently, the intensity of the exercises can be increased by increasing the load. The number of repetitions is then initially reduced to three series of 15 repetitions and can progressively be increased again to four series of 20 repetitions. When there is no negative reaction (pain or effusion) of the knee joint to the intensity of the exercises, loading can be increased to 60–70% of one repetition maximum (1RM) at a frequency of three series of 15 repetitions, and eventually to 80% of 1RM in a series of 8 to 12 repetitions [19].

Third Phase

Functional activities, rotational activities, jumps, running and sport-specific exercises can be integrated in the rehabilitation program 3–4 weeks after surgery.

Patients are generally able to return to work after 1–2 weeks and to resume sports activities and training by 3–4 weeks following the operation [35].

Rehabilitation After Meniscus Repair

Introduction

In the treatment of meniscal injuries, preservation of the meniscus has become a major priority. Consequently, contemporary meniscal surgery is aimed at retaining the structure and function of the meniscus whenever possible. The shift in focus from meniscectomy to meniscus repair noted in the last decade has entailed a change in the rehabilitation protocol because the finest surgical technique can be fraught with frustration if rehabilitation is inadequate or incomplete.

In an attempt to protect the repaired meniscus, a significantly less aggressive approach should be used in the postoperative management and rehabilitation than when menisectomy has been performed.

In one of the first landmark papers concerning postoperative care after meniscus repair, Scott et al. [31] advocated immobilization of the knee in 30° of flexion and no weightbearing during the first two postoperative months. In their opinion, weightbearing significantly increased shear strain within the meniscus, and restriction of weightbearing was critically important to healing, especially of substance tears.

In the following years, other rehabilitation protocols were described, and it is probably the poorly understood healing rate of meniscal repair that has led surgeons to suggest various restrictions. Full weightbearing is postponed for various amounts of time (from 8 to 3 weeks) or is allowed immediately. A similar disagreement is found with regard to the ROM and the return to sports activities.

Despite the conflicting reports in the literature, clinicians and researchers all agree about the time-honoured principles of aftercare for meniscus repair. These include a period of maximum protection to provide the best opportunity for healing to occur, followed by a period of continuing restriction from potentially harmful stresses while the healing process undergoes maturation and becomes sufficiently strong to resist re-rupture under heavy stress.

Simply stated, the rehabilitation program after meniscal repair needs to consider when to allow motion, weightbearing and resumption of activities. In order to answer these questions, we need to know how these activities influence the healing meniscus.

Healing of the Meniscus

Healing Rate After Meniscus Repair

The key question is how long it takes for a meniscus to heal and how strong the healed tissue is. Roeddecker et al. [29] showed in rabbits that 12 weeks post-repair the energy required to tear the suture-repaired meniscus was 23% of the energy required to tear a normal meniscus. This suggests that even after 12 weeks, a repaired meniscus is still significantly weaker than a healthy meniscus. In contrast to this, other experimental studies showed that lesions of the vascular portion of the meniscus heal completely after 10 weeks and that it takes several months for fibrocartilage to regain a normal appearance [1]. Four to five weeks are usually required for early histological evidence of meniscal repair.

However, the question arises how strong the repair needs to be before weightbearing and other exercises can be initiated. Morrison [25] showed that during normal gait, the forces in the human knee can be as high as four times the body weight. However, evidence exists that only compressive, not distractive, forces occur across a peripheral meniscus tear during normal unloaded and loaded knee motion [4, 28].

Extrinsic Factors Influencing Meniscus Healing After Meniscus Repair

Immobilization

Studies have shown decreased collagen content in meniscus repairs subjected to prolonged immobilization [9]. These findings encourage early ROM exercises after meniscal repair. In addition, it has been demonstrated that a rehabilitation program implementing immediate knee motion from the first postoperative day after meniscus repair (with or without anterior cruciate ligament (ACL) reconstruction) is not deleterious to the healing meniscus tissue [7, 30]. As a result, most postoperative rehabilitation protocols now allow immediate mobilization.

Weightbearing

Restricted weightbearing and limited ROM are common in an attempt to avoid undue forces which could impair meniscal healing. However, Staerke et al. [33] showed that compression of the meniscus can substantially increase the pullout resistance of meniscal repair implants, and thus, does not seem to negatively influence the stability of the repair. On the basis of their results, these authors rather support early weightbearing, although some caution is warranted while drawing clinical implications from ex vivo studies. Moreover, these results are in agreement with the fact that the hoop stresses caused by weightbearing are primarily absorbed at the periphery of the meniscus. In addition, it was shown that immobilization and non-weightbearing did not improve meniscal healing in sheep and rabbits after suture repair in the avascular and vascular zone [13, 17].

In conclusion, there is very little evidence showing that weightbearing alone causes significant distension forces on a meniscal lesion. However, scientific evidence proving the opposite is also rather scarce. As a result, it is not very surprising that no consensus has yet been reached in this respect. Many authors do not allow immediate postoperative weightbearing, while others do.

Intrinsic Factors Influencing Meniscus Healing After Meniscus Repair

Intrinsic key factors in meniscal repair include: a) vascular supply (determined by age and localization of the tear); b) suture fixation, which can lead to early failure if too vigorous a program is initiated; c) anatomical site of the tear (anterior, posterior, medial or lateral); d) tear size and type; and finally, e) other intra-articular disorders.

Therefore, it seems evident that a rehabilitation protocol after meniscal repair should take these intrinsic factors into account, and accordingly, provide for some variations. For example, peripheral repairs heal rapidly, whereas complex tears extending into the central avascular region heal more slowly and require greater caution. Radial repairs must be especially protected, as excessive weightbearing in an early postoperative stage can disrupt the repair site. A higher rate of failure of tears has been observed in the medial vs. the lateral meniscus (30–45 vs. 16–20%). Tears longer than 4 cm had a 59% failure rate, which dropped to 15% for tears smaller than 2 cm [37]. In addition, modifications may be required if significant articular cartilage deterioration is present [18]. Obviously, this might affect the design of an exercise program.

Protocol

Conventional Rehabilitation Protocol

In most of today's conventional protocols, weightbearing is not allowed the first 3–4 weeks. A 4-week period of restricted ROM (until 90°) is recommended. Controlled knee extensor-flexor strengthening exercises in an OKC are initiated after 2–3 weeks, and in a CKC after 4–5 weeks. Stationary cycling is allowed at 2 months. Since backward pedalling offers lower tibiofemoral compressive loads compared to normal forward pedalling [26], we suggest that backward pedalling be started 2 weeks earlier. Return to light work and running are allowed at 5–6 months. Full participation in pivoting sports is deferred until 9 to 12 months postoperatively [8, 16, 36].

Accelerated Rehabilitation Protocol

An accelerated rehabilitation program after meniscal repair includes immediate full weightbearing as tolerated. Patients are allowed to actively move their knees within the painfree ROM immediately after surgery. Progressive early motion is permitted as the swelling decreases. Forced knee flexion should be avoided, especially if effusion or soft-tissue swelling is present. Loaded knee flexion should not exceed 90° for the first 6 weeks. Unloaded ROM from 0 to 90° is allowed from the first postoperative day, with flexion advanced to 120° by the third to fourth week. Full knee flexion is permitted after 6 weeks. Caution is used to avoid hyperextension in individuals who have had anterior-horn meniscus repairs.

OKC strengthening exercises are allowed after the first postoperative week, and CKC strengthening exercises from the fifth postoperative week. Low-resistance stationary cycling and swimming are allowed at 6 weeks. When effusion is absent, full extension, full flexion and straight-ahead jogging are permitted 4–5 months post-surgery. Patients are allowed to return to pivoting sports when there is no pain, swelling, or reduced motion despite running and agility training (5–7 months post-surgery) [3, 20, 22, 32].

Based on clinical, MRI and arthroscopic evaluations, several authors reported an 80% success rate after an aggressive rehabilitation program [2, 7, 22, 23]. These results are consistent with those reported after non-aggressive rehabilitation. Although these studies have documented an equal success rate, no randomized control trials have been performed to compare these two rehabilitation protocols.

Individualized Rehabilitation Protocol

We suggest, together with other authors [3, 18], to avoid using a “cookbook” (conventional or accelerated) protocol, but rather recommend an individualized program based on the patient’s intrinsic key factors influencing the healing of the meniscus (vascular supply, suture fixation, anatomical site of the tear, tear size and type and other intra-articular disorders).

The therapist needs to thoroughly evaluate the patient to implement the appropriate protocol. The individualized program will be a mixture of elements from the conventional program and the accelerated program, depending on the patient’s intrinsic risk factors. If more than two risk factors are present (e.g. large tear of the medial meniscus), the individualized program will be similar to the conventional program. In contrast, if less than two risk factors are present, the individualized program will largely correspond to the accelerated program. The initial goal of this individualized program is to prevent excessive weightbearing forces. The limitation is designed to control high compressive and shear forces that could disrupt the healing meniscus repair. The supervised physical therapy program is supplemented with home exercises performed on a daily basis. Patients are warned that an early return to strenuous activities, including impact loading, jogging, deep knee flexion, or pivoting, carries a definite risk of a repeat meniscus tear. This is particularly true in the first 4–6 months postoperatively, where full flexion or deep-squatting activities may disrupt the healing repair sites [18].

Conclusion

Although evolving continuously, concepts of postoperative rehabilitation after meniscus repair still remain controversial. Two rehabilitation protocols, applied in clinical practice, are described in the current literature: the conventional and the accelerated rehabilitation protocol. The optimum rehabilitation is yet to be identified, and the lack of scientific data in the literature does not allow us to endorse a specific rehabilitation program.

However, it is the authors’ opinion that all intrinsic factors should be taken into account when designing a rehabilitation program. Individualizing the rehabilitation according to the size and type of meniscal tear, vascular supply, localization, concomitant procedure and presence of other intra-articular disorders (ACL, cartilage lesions, etc.) seems to be an interesting concept. If less than two intrinsic risk factors are present, healing will occur fairly rapidly and the risk of failure is low, so that an accelerated rehabilitation protocol is recommended. However, the presence of more than two risk factors (e.g. a large tear in a red–white zone) increases the risk of meniscus failure and slow healing, and in this case, a more conservative approach is probably the best guarantee for success.

However, well-designed longitudinal studies are mandatory to determine the actual efficacy of this rehabilitative approach with regard to patient function and satisfaction.

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Synthesis

4.7

R. Verdonk

As the purpose of this book is to document why as much meniscal tissue as possible should be preserved, meniscectomy needs to be kept to a minimum, while duly observing the proper indications and techniques.

Menisci are no vestigial structures, but form an integral part of the "self-maintaining transmission system" which the knee joint is.

Minimal tissue resection, which very often can be described as "adequate," e.g., leaving the meniscal rim, should be the rule. Care should be taken to resect what has been torn and remove meniscal tissue only to avoid any further impingement that may remain sensitive to rotational painful stress and may, thus, produce clinical symptoms.

Arthroscopic techniques allow for repeat surgery, which may be required in case of persistent mechanical derangement. However, the fulcrum to proceed to repeat arthroscopy surgery needs to remain clinical. All too often, repeat surgery does not alter the clinical findings if it is based on needless imaging alone.

Therefore, potential meniscal repair is warranted in all cases where meniscal resection has been considered. Full options remain when, in addition to partial resection, suture of the meniscal remnant to the meniscal wall appears to be required.

Biomechanical investigation and testing of meniscal repair devices have received ample consideration. While tensile forces, which are of lesser importance in clinical practice, have been extensively investigated, shearing forces acting on the meniscus are of paramount clinical importance, but cannot be reliably reproduced in in vitro studies.

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Experience has taught us that a red-on-red tear heals spontaneously within 4–6 weeks, provided that the necessary immobilization is applied. The purpose of meniscal stabilization is to safely bridge this period in order for the scar tissue to heal and stabilize the lesion.

Because in vivo testing is not possible as yet, clinicians investigate implant material by essentially focusing on material properties, safety guidelines, and ease of insertion, with convincing evidence based on physiological meniscal healing.

The implants developed in recent years allow for arthroscopic meniscal suturing all around the meniscal rim. Good stabilization is obtained in the majority of cases. Average results are defined as up to 80% of clinical healing at long-term follow-up. Failures are mainly due to improper indications or knee joint instability. Less well-documented reasons could be poor meniscal tissue, low cellularity, and thus, poor healing response. These findings are obviously difficult to document, but are recognized when at surgery yellowish degeneration of the meniscal core is found, which is often related to age and overload and compromises the healing response.

One of these "degenerative" findings is the meniscal cyst. Prone to increased shearing forces at its fixation around the popliteus muscle tendon, the lateral meniscus may sustain a horizontal tear associated with cyst formation. Depending on its intra-articular "opening," the symptomatic cyst needs to be resected and the torn meniscus repaired. Repair is mandatory at all costs in order to avoid underlying cartilage degeneration.

Obviously, an appropriate rehabilitation protocol may be necessary to optimize the results. A scientific consensus is not available. An individually designed protocol, taking all intrinsic factors into account, potentially leads to a better clinical end result.

P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_4.7, © Springer-Verlag Berlin Heidelberg 2010

Part V

Postoperative Evaluation

Functional and Objective Scores. Quality of Life

5.1

P. Verdonk and R. Verdonk

Summary of knee function/symptoms scoring systems

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
Validated for meniscus-related indications				
Tegner activity level scale Tegner and Lysholm [1]	Patient-reported assessment of sport activity levels	0 points, disability secondary to knee problems; 1–5, work or recreational sports; 6–9, increasing recreational and competitive sports, national or international level soccer	Validated for patients with a meniscal injury of the knee [2, 3]	None identified
Lysholm scale/ modified Lysholm scale/ revised Lysholm scale Lysholm and Gillquist [4], Tegner and Lysholm [1, 4]	Patient-reported scale with emphasis on symptoms of instability. Developed to assess outcome following knee surgery and revised in 1985 Modified Lysholm score developed specifically for meniscal lesions	Eight subscales: limp, support, stair climbing, squatting, instability, thigh atrophy, pain and swelling Thigh atrophy was replaced by catching and locking in the modified and revised Lysholm scales Overall score of 0–100 points. Cut off for excellent and good: 77 for Lysholm scale and modified Lysholm scale and 84 for revised Lysholm scale	Validated in a number of studies of patients with meniscal lesions [2, 3]	Validated for athletic patients with a knee disorder [5], and overall for outcome assessment of various chondral disorders of the knee [3]. Also validated for assessing acute patellar dislocation outcomes [6]

(*continued*)

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P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_5.1, © Springer-Verlag Berlin Heidelberg 2010

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
International Knee Documentation Committee (IKDC) form	Patient-reported knee-specific assessment of symptoms and function in daily living activities	18 questions; raw score transformed to scale with minimum of 0 (worst) and maximum of 100 (best)	Validated for outcome measures of meniscus injuries of the knee [7]	Irrgang et al. [8] validated the IKDC subjective knee form as a knee-specific measure of symptoms, function and sports activity, appropriate for patients with a wide variety of knee problems. Further validation in a population with various knee disorders by Higgins et al. [9]
Knee Injury and Osteoarthritis Outcome Score (KOOS) Roos and Lohmander [10]	Patient-reported assessment of sports injury (e.g. ACL reconstruction, meniscectomy, tibial osteotomy, post-traumatic osteoarthritis)	Five subscales (questions): pain (9); symptoms (7); activities of daily living (17); sports and recreation function (5); knee-related quality of life (4) Scores normalised to 100 for each subscale; each subscale is scored separately. Minimum subscale score, 0; maximum subscale score, 100. The higher the score, the higher the function	Validated for subjects with and without osteoarthritis post-meniscectomy [11]	Validated for subjects following total knee replacement [12], and in subjects undergoing surgical reconstruction of the ACL [13]
Western Ontario meniscal evaluation tool (WOMET) Kirkley [14]	A disease-specific tool designed to evaluate health-related quality of life in patients with meniscal pathology	A total of 16 items representing the domains of physical symptoms (9 items); sports/recreation/work/lifestyle (4 items); and emotions (3 items)	Validated for evaluating treatments for meniscal pathology [12]	Not applicable
Visual analogue scale (VAS) – knee disorders subjective history	Used as an assessment of limitations of knee function	VAS is a patient-reported assessment of a parameter on a 10-cm scale, with the ends of the line representing the extremes of the symptom	Validated to assess the extent of limitations in knee function in patient groups with meniscus lesions [15]	Validated to assess the extent of limitations in knee function in patient groups with insufficiency of the anterior and posterior cruciate ligaments and chondromalacia [15]
No validation for meniscus-related indications identified				
Cincinnati knee rating system Marx et al. [5]	Clinician-based and patient-reported assessment of ligament injury and reconstruction, high tibial osteotomy, meniscus repair and allograft transplant	Six subscales (points): symptoms (20); daily and sports functional activities (15); physical examination (25); knee stability testing (2); radiographic findings (10); functional testing (10). Overall grading from 0 (worst) to 100 (best)	None identified	Validated for athletic patients with a knee disorder [5], and for outcome studies after knee ligament reconstruction [16]

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
VAS – Pain Wallerstein [17]	Commonly used to assess pain [18]	VAS is a patient-reported assessment of a parameter on a 10-cm scale, with the ends of the line representing the extremes of the symptom (e.g. no pain and worst possible pain)	No studies validating scoring system specifically for use in post-meniscus surgery were identified. However, it has been extensively used to measure pain, including in numerous studies of subjects undergoing knee surgery	The VAS pain scoring system is a well-established, validated system for scoring pain [19]
Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Bellamy [20]	Condition-specific assessment for patients with hip and knee osteoarthritis	Three subscales (questions): pain (5); stiffness (2); physical function (17). Minimum, 0; maximum, 96 for global score, subscales normalised to 0–100 score. The higher the score, the lower the function, but frequently transformed to 0 (worst) to 100 (best)	None identified	Validated for patients with osteoarthritis of the knee [21]. Validated for paper, telephone, computer mouse and touchscreen administration [22]
Medical Outcomes Study 36-Item Short Form (SF-36) Ware and Sherbourne [23]	General health outcome measure derived from the Medical Outcome Study and used in addition to disease-specific outcome measures	A multi-item scale that assesses 8 health concepts: (1) limitations in physical activities because of health problems; (2) limitations in social activities because of physical or emotional problems; (3) limitations in usual role activities because of physical health problems; (4) bodily pain; (5) general mental health (psychological distress and well-being); (6) limitations in usual role activities because of emotional problems; (7) vitality (energy and fatigue) and (8) general health perceptions	No papers identified validating SF-36 for meniscal indications; however, used as an outcome measure in a number of studies of outcome following meniscus surgery [24]	Shown to be a responsive measure of outcome of total knee arthroplasty [25]
Medical Outcomes Study 12-Item Short Form (SF-12) Ware et al. [26]	General health outcome measure used in addition to disease-specific outcome measures	12 questions selected from SF-36	No papers identified validating SF-12 for meniscal indications; however, used as an outcome measure in a number of studies of outcome following meniscus surgery [27]	Validated against the SF-36 [26]

(*continued*)

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
Tapper and Hoover system [28]	Grading based on patient's symptoms and disability post-meniscectomy	Grading system with four levels Excellent: The patient has no symptoms and no disability related to his knee Good: The patient has minimum symptoms, such as aching or weakness after heavy use or effusion after heavy exertion, but there is essentially no disability Fair: The patient has symptoms, such as trouble kneeling or climbing stairs; weakness, pain, or discomfort have became enough of a problem to interfere somewhat with everyday activities and the patient feels he has some disability; he is active but cannot participate in vigorous sports (such as skiing, tennis, football and so forth) Poor: The symptoms are severe and include all of those listed under fair as well as the presence of pain at rest, limited motion and locking. The patient is clearly disabled and his activities, including walking, are definitely limited because of his knee	No studies validating this outcome measure were identified	No studies validating this outcome measure were identified
Flandry questionnaire Flandry et al. [29]	Patient-administered questionnaire for assessment of subjective knee complaints	28 items questionnaire with a VAS response format. An average score from 0 to 100 is calculated	None identified	Validated in a clinical study of 182 patients with knee complaints [29]
Activities of Daily Living Scale (ADLS) of the Knee Outcome Survey (KOS) Irrgang et al. [30]	Patient-reported measure of functional limitations imposed by pathological disorders and impairments of the knee during activities of daily living	17 items assessment to determine the impact of symptoms and functional limitations on activities of daily living. Total score ranges from 0 to 100, with 100 representing the absence of symptoms and higher levels of function	None identified	Validated for the assessment of functional limitations that result from a wide variety of pathological disorders and impairments of the knee [30], and validated for athletic patients with a knee disorder [5]

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
Knee Assessment Scoring System (KASS) Mahomed et al. [31]	Subjective and objective assessment of knee function	Subjective (60 points) and objective (40 points) data collected; a successful result requires improvement of the KASS by at least 10 points or, maintenance of a score of 75 points or higher	None identified	In an assessment of KASS by van Arkel and de Boer [32], the authors concluded that they no longer use the KASS because KASS does not add to the Lysholm score; however, the KASS only discriminates between successful and unsuccessful, and the Lysholm score further categorises the successful results into excellent, good and fair
Noyes symptom rating and sports activity Noyes et al. [33]	Assessment of athletic participation before and after treatment or surgery for knee disorders	Assessment of the intensity of sports participation, changes in sports participation, the variables that produced the changes, self-assessed functional limitations and the ability to participate in different types of sports	None identified	None identified
Marx activity level scale Marx et al. [34]	A short, patient-reported activity assessment designed to be used in addition to knee-rating scales and general health outcomes measures	Four questions assessing running, cutting, decelerating and pivoting Items are scored 0–4, depending on frequency performed, from less than once per month (0 points) to more than or equal to four times per week (4 points), with a minimum of 0 to a maximum of 16 points possible	None identified	Validated for patients with knee disorders [33]
American Academy of Orthopaedic Surgeons Sports Knee-Rating Scale Academy of Orthopaedic Surgeons [35]	Part of the musculoskeletal outcomes data evaluation and management system	Five parts; 23 questions in total. Comprises a core section (stiffness, swelling, pain and function), a locking or catching on activity section, a giving way on activity section, a section on current activity limitations due to knee and a section on pain on activity due to knee	None identified	Validated for athletic patients with a knee disorder [5]
The Oxford Knee Scale Dawson et al. [36]	Self-completed patient-based outcome assessment for knee disorders	12 multiple-choice questions, each with five answers	None identified	Validated for patients with osteoarthritis of the knee [37], and for patients undergoing total knee replacement [35]

(*continued*)

Outcome measure	Details of assessment	Scale	Validation for use in post-meniscus surgery	Validation for other indications
Knee Society Score (KSS) Insall et al. [38]	Clinician-completed assessment	Two parts: a knee score that rates only the knee joint itself, and a functional score that rates the patient's ability to walk and climb stairs. Maximum functional score achieved by patient who can walk an unlimited distance and go up and down stairs normally	None identified	Not identified

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Postoperative Imaging: X-Rays, Arthro CT, Arthro MRI

5.2

G. Nourissat, C. Pradel, and N. Pujol

Introduction

Meniscal imaging is an essential element in decision making for surgical management of symptomatic meniscus lesions. Many studies have been reported to explore the importance of the aspect of the meniscus to the surgical indications and outcome of the surgical procedure. When, after surgery, clinical outcome is not perfect and symptoms are not relieved, or when it is necessary to know if the procedure has been efficient, postoperative imaging is the alternative to second-look arthroscopy. While preoperative imaging of the meniscus has received ample consideration in the literature, data on postoperative imaging are less abundant. In the present chapter, meniscectomy, meniscal repair, and meniscus allografting are addressed. The aim is to determine which imaging modality has to be used and how to interpret it, and to help in decision making for revision surgery.

Current Concepts in Postoperative Imaging of the Meniscus

A normal meniscus, without previous surgery and considered as asymptomatic, demonstrates low signal intensity on all sequences [29]. If prior meniscal surgery has been performed, the two accepted magnetic resonance imaging (MRI) criteria for a meniscal retear are straightforward. According to Rubin and Paletta, the first criterion is an increased internal signal on a short-TE image, such as proton density sequences, unequivocally extending to the articular surface of the meniscus; the second criterion is the presence of an abnormal meniscal shape [25].

However, while conventional MRI is an accurate method for diagnosing meniscal derangements, it is less reliable in the postoperative assessment of meniscal repairs [5,29], especially because a scar in a properly healed meniscus mimics the signal seen in meniscal tears [1,6].

Postoperatively, meniscal morphology may remain abnormal for up to 27 weeks [6], and signal abnormalities on proton density images may persist for as long as 13 years [14]. Based solely on signal intensity, a healed tear is therefore often indistinguishable from an acute tear. Fluid extending into the tear on a T2-weighted image is a helpful sign to confirm nonhealing [12,30].

Postoperative Imaging After Meniscectomy

Radiography

In order to assess the outcome of meniscectomy, several imaging techniques can be used. An early radiographic sign of osteoarthritis is joint space narrowing. Prové et al. [21] conducted a prospective study in order to determine whether meniscectomy can be responsible for joint space narrowing. To this end, they performed

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_5.2, © Springer-Verlag Berlin Heidelberg 2010

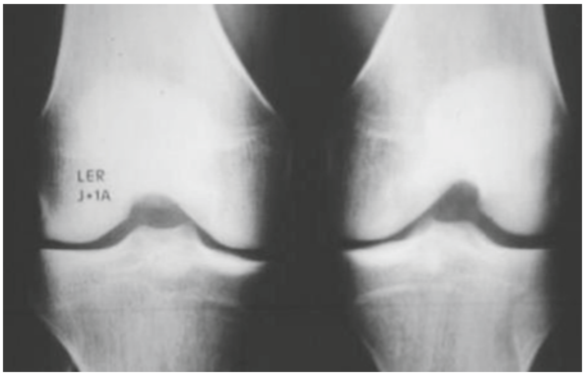

Fig. 5.2.1 Rapid chondrolysis after lateral meniscectomy on the right knee

a computerized analysis of preoperative and postoperative anteroposterior views in full extension and 30° of knee flexion. No significant difference in joint space was found between measurements taken before and after meniscectomy. Regarding those data, it appears that joint space narrowing in a painful meniscectomized knee must be considered diagnostic of chondrolysis and not simply as a consequence of meniscectomy, especially if the patient is young, athletic, and has undergone a lateral meniscectomy [3].

A persistent painful effusion in a knee 1 or 2 months postmeniscectomy should be considered a sign of potential rapid chondrolysis.

In such cases, bilateral standing anteroposterior, lateral, schuss, and skyline views must rapidly be obtained to look for early postoperative joint space narrowing (Fig. 5.2.1).

Double-Contrast Arthrography

Double-contrast arthrography was first used to identify meniscus lesions in the early seventies. Nicholas et al. [15] reported an overall diagnostic accuracy of 97.5% compared to surgical findings, with a 99.7% accuracy for medial meniscus lesions and 93% for lateral meniscus lesions.

Magnetic Resonance Imaging

Postoperative imaging after meniscectomy may be useful to account for pain or recurrent symptoms due to a retear or extension of the tear (see Chap. 3.2). In 1990, Smith and Totty first reported on MRI after partial meniscectomy [26]. They wanted to know if MRI signs defined to describe nonoperated symptomatic meniscus lesions could be found in case of recurrent tears in operated menisci. Fifty-one MRIs of partially meniscectomized knees were studied. Three groups were distinguished. In group 1, at least two-thirds of meniscus length remained, without osteoarthritis; in group 2, less than two-thirds of the meniscus remained, without osteoarthritis; and in group 3, osteoarthritis was present independent of meniscus length. Menisci that had less than one-third resected had a length nearly identical to that of a nonoperated meniscus. They concluded that in many cases it is not possible to distinguish normal from partially meniscectomized knees. However, following extensive resection, the MRI appearance of menisci was more variable, ranging from smooth contours to signal inhomogeneity and irregularity of the surface (30%). When irregularity was present, second-look arthroscopy could in some cases identify tears of the meniscus. The authors concluded that classic MRI criteria can be used to diagnose tears of the majority of meniscal segments that do not display marked contour irregularity. If marked contour irregularity is seen after meniscectomy, it can mask the presence of a tear, especially if the fragment is not displaced (Fig. 5.2.2).

Ciliz et al. [4] compared conventional MRI to MR arthrography in the assessment of postoperative

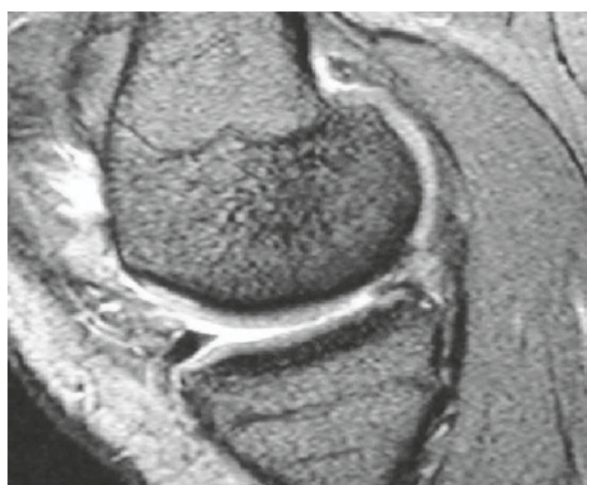

Fig. 5.2.2 Postoperative MRI after partial medial meniscectomy of the posterior segment: note the heterogeneous aspect and the difficulty to assess retears or unstable residual tears

menisci. They looked for recurrent tears in 72 patients with residual pain after meniscus surgery. Forty-five patients underwent second-look arthroscopy. The diagnostic sensitivity for recurrent tears was 54% for conventional MRI and 94.5% for MR arthrography; the specificity was 75 and 87.5% and the accuracy 57.7 and 93.4%, respectively. The authors concluded that the overall accuracy rate was statistically significantly different between the two imaging techniques. They found conventional MRI to be sufficiently accurate when previous surgery had involved a minimal resection of the white–white zone, but MR arthrography to be more accurate when meniscectomy had been more extensive [4].

Arthro CT Scan (*Fig. 5.2.3*)

Mutschler et al. compared the preoperative and postoperative CT arthrographic findings to those at second-look arthroscopy in 20 previously operated menisci [18]. At the initial reading, the sensitivity and specificity for tear detection in postoperative menisci were 100 and 78%, respectively. Criteria for the diagnosis of recurrent tears were usually identical to those used before any type of surgery: intrameniscal contrast material, peripheral meniscus separation, and displaced meniscal fragments.

At the retrospective interpretation, the sensitivity and specificity for tear detection in postoperative menisci were 79 and 89% at reading 1 and 93 and 89% at reading 2, respectively. This interesting study demonstrates that the application of conventional definitions of meniscal tear to arthrographic findings in postoperative menisci can lead to overestimation of the clinical importance of meniscal lesions. The kappa coefficient demonstrated that all radiologists had the same reading of images [18].

Arthro CT or arthro MRI may be recommended to assess retear after meniscectomy.

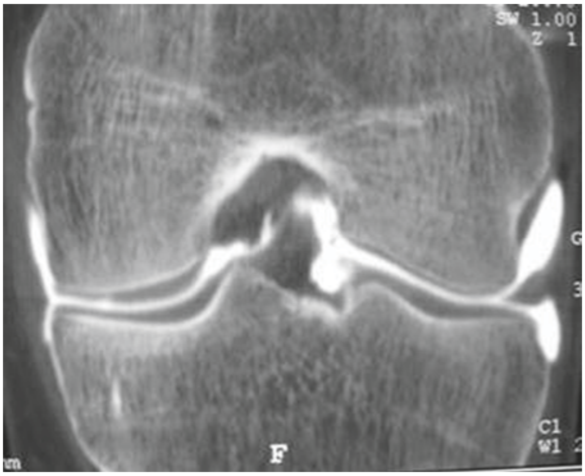

Fig. 5.2.3 Arthro CT after total medial meniscectomy: no meniscal rim remaining, cartilage degeneration on the femoral side

Imaging of Cartilage After Meniscectomy

Smith and Totty found osteoarthritis, evidenced by marginal spurring or cartilage thinning, to be present in 15% of meniscectomized knees, independently of the length of the remaining meniscus [24]. In the literature, progressive degenerative articular cartilage changes have been reported in up to 89% of total meniscectomy cases, as radiographically observed in long-term follow-up studies [11,24,28]. After 21 years, total meniscectomy patients had a relative risk of 14 to present signs of osteoarthritis, compared to nonoperated patients. This was not correlated with sex, compartment involved, or type of meniscal tear [24].

Postoperative Imaging After Meniscus Repair

Arthrography

Arthrography is the gold standard for evaluation of meniscus repair. According to the criteria of Henning et al., a meniscus is considered completely healed if it is healed over the full thickness of the tear. Healing is considered incomplete if it involves at least 50% of the thickness of the tear. Failure to heal is defined as healing over less than 50% of the thickness at any point over the length of the tear [10] (Fig. 5.2.4). In 1991, Farley et al. [7] reported the superiority of arthrography to MRI in the diagnosis of a residual meniscus lesion after repair and considered it to be the imaging modality of choice to assess the healing process. Grade 3 signal intensity on intermediate and T1-weighted images

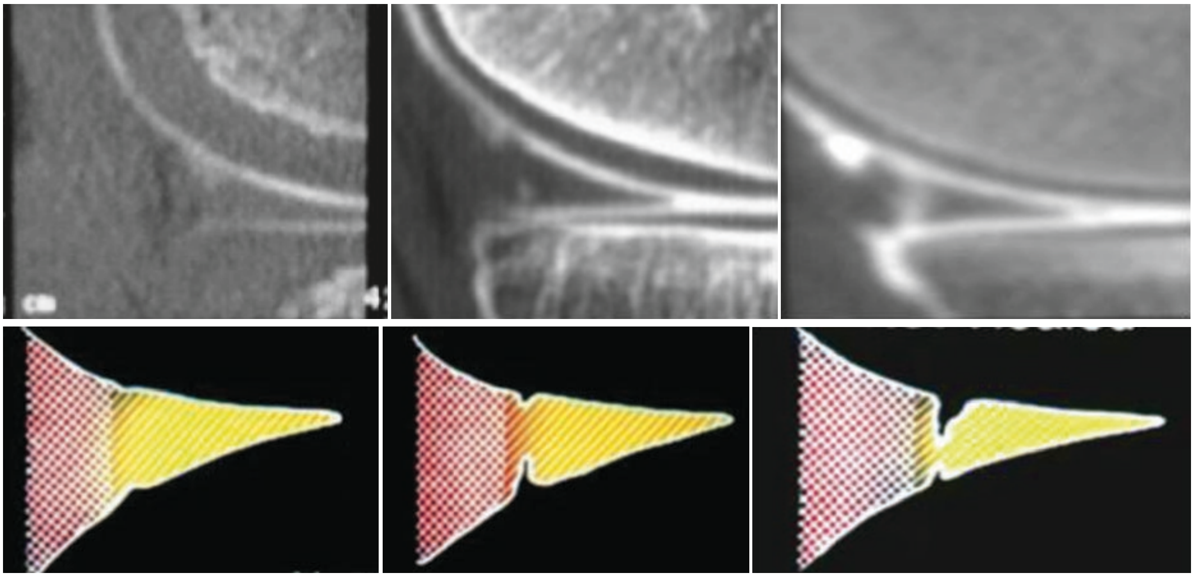

Fig. 5.2.4 Henning's criteria for meniscal healing after repair. Complete healing, partial healing, failure

did not reliably predict a tear, and unequivocal T2 increase had a sensitivity of only 60%.

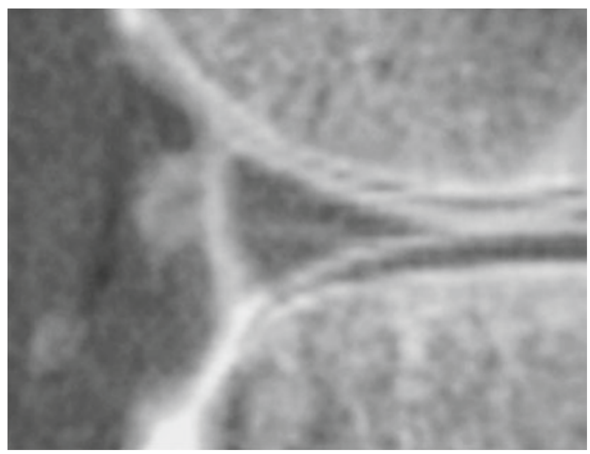

Fig. 5.2.5 Postoperative MRI after repair at 4 months. A non-specific hyperintense signal is seen within the meniscal tear. The suture is also visible. This image should not be interpreted as a failure

Magnetic Resonance Imaging

Imaging is performed to evaluate the healing status of the meniscus, to look for an extension of the lesion, or to confirm a failure of the repair. It does not have to be performed systematically [2], but only to explore abnormal outcomes or for clinical investigation purposes. In 1991, Farley et al. were among the first to study the sensitivity of MRI for the evaluation of meniscal healing [7]. They compared MRI findings of repaired menisci (some of which underwent second-look arthroscopy) with normal asymptomatic menisci and found MRI not to be accurate for the diagnosis of a recurrent tear or healing of previously repaired menisci (Fig. 5.2.5). The only MRI finding predictive of a residual tear in a previously sutured meniscus was unequivocal T2 increase in signal intensity through a full-thickness defect extending to each side of the meniscus. However, this assertion should be ponderated when MRI was performed earlier than 12 weeks after surgery. The sensitivity of this sign remained only 60%. This signal is explained by the authors as the presence of fluid beside the two articular surfaces of the meniscus. The authors compared the findings at MRI and at arthrography, and confirmed that the latter was more accurate in diagnosing recurrent tears after meniscal repair. Almost 10 years later, White et al. prospectively studied the efficiency of MRI, and of direct and indirect MR arthrography for the assessment of 104 meniscal repairs that underwent second-look arthroscopy [34]. They found MRI to have a sensitivity of 86%, a specificity of 67%, a positive prediction value of 83%, and a negative prediction value of 71%

with an accuracy of 80%. For indirect MR arthrography (after injection of gadopentetate dimeglumine), these percentages were 83, 78, 90, and 64%, respectively, with an accuracy of 81%; for direct MR arthrography, these were 90, 78, 90, and 78%, respectively, with an accuracy of 85%. There was no statistically significant difference, demonstrating the usefulness of gadolinium injection. In all three groups, the kappa coefficient was 0.89, showing that the reading was reproducible.

Hantes et al. [9] prospectively compared conventional MRI to MR arthrography in the evaluation of meniscus repair. The patients did not undergo second-look arthroscopy, but were doing well. MRI was performed at 3, 6, and 12 months postsurgery. All menisci demonstrated abnormal signal intensity at the suture site. Interestingly, some differences in imaging findings were observed between arrow repair and suture repairs: foreign body reactions with chronic inflammation or formation of granuloma, and arrows appearing as intraarticular loose bodies [13,19].

Steenbrugge et al. [27] conducted a 13-year follow-up study of 13 knees evaluated with MRI. In all cases, the site of repair was still visible; in five cases, the repair zone presented a hyperintense signal representative of mucoid degeneration or scar tissue. In the same study, cartilage lesions were reported in five cases, but no data were available on the previous cartilage status.

Arthro MRI

Although arthro MRI is not commonly used to evaluate meniscal repair, it can in the future be a very interesting assessment tool because it provides information on the status of the meniscal body [17].

Arthro CT Scan

In our opinion, the most efficient imaging modality to assess meniscus repair is arthro CT scan (CT arthrography). In 2003, the French Arthroscopic Society [2] demonstrated in a retrospective and prospective study that meniscus repair can, in specific protocols, be assessed by CT arthrography with very high sensitivity. They assessed the volume of the healing process and reported the decreasing size of the tear after suturing. This process gives more stability to the meniscus [4]. Pujol et al. subsequently conducted a prospective study of 53 meniscus repairs evaluated by CT arthrography [22] 6 months postoperatively. Sagittal, transverse, and coronal reformations with a 0.45-mm section thickness and 1.6-mm interval were used (Fig. 5.2.6). The criteria for healing were those described by Henning et al. [10] for arthrography.

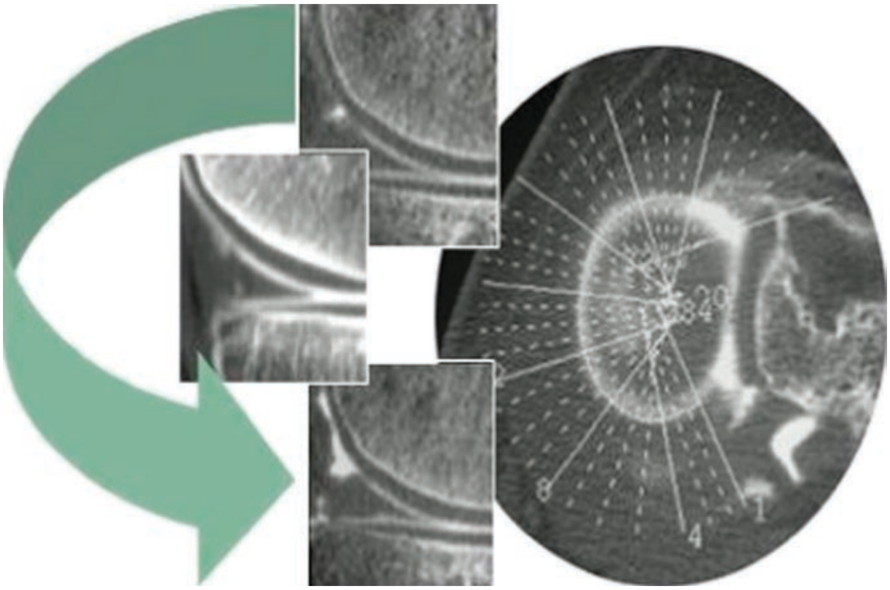

Fig. 5.2.6 Slices selection on arthro CT axial reconstructions corresponding to the anterior, middle, and posterior segments of the meniscus

A very important factor in assessing healing is to reproduce the reading of the images for each segment (anterior, middle, posterior). Furthermore, the overall healing rate can be calculated for the entire length of the tear with radial reconstructed images, perpendicular to the longitudinal axis of the meniscus, and quantified in terms of percentage. In these conditions, it is also possible to measure the meniscal width of each segment, which can provide interesting data for comparison with preoperative measurements.

Postoperative Imaging of Meniscus Allografts or Meniscal Substitutes

Literature data on imaging after meniscal allografting are scarce, because long-term follow-up studies are nearly nonexistent. Plain X-rays are used to evaluate the progression of osteoarthritis, and MRI is mostly used for assessing the healing process and the shape of the graft (Fig. 5.2.7). In the literature we did not find any important study in which arthro CT scan was used to evaluate the healing status.

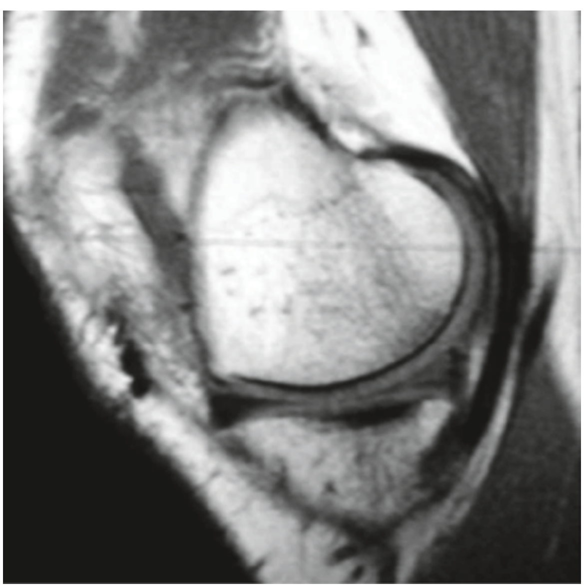

Fig. 5.2.7 Postoperative aspect of a meniscal substitute (collagen meniscus implant). There is important heterogeneity on the posterior segment

Radiography

In the medium-term, few articular cartilage changes were reported after meniscal transplantation [23]. In a long-term study of 42 allografts [25], plain anteroposterior radiographs demonstrated 48% of joint space narrowing with no major signs of OA, even if it was recognized that plain radiography is not the best modality to assess early degenerative changes [28].

MRI and Arthro MRI

In a long-term follow-up study, the signal intensity of the graft was graded 3 at the final follow-up in 59% of cases, but 0 (normal) in all other cases [33]. MRI also allowed to evaluate the position of the allograft. In the same study, allograft position was normal in 24% of knees and partially extruded in 70% of knees. Extrusion mainly involved the midbody and anterior horn of the allograft and seemed to be progressive in nature, because it was not seen in the first 2 years of follow-up [33].

The authors also suggested that meniscal allografts have a potential chondroprotective effect over 10 years, even if they reported 47 and 59% of further degeneration of femoral cartilage and tibial cartilage, respectively. On MRI, 35% of knees did not show any progression of femoral or tibial cartilage degeneration [8, 16, 20, 31–33, 35].

When and Why to Perform Imaging After Meniscus Surgery?

After Meniscectomy

In case of acute pain after meniscectomy, plain X-rays are useful for the diagnosis of postoperative chondrolysis, especially if surgery was performed on the lateral meniscus. Basically, joint space narrowing on the anteroposterior view after partial meniscectomy is suggestive of chondrolysis and MRI may be recommended to confirm the diagnosis. If no joint space narrowing is seen, the tentative diagnosis is a residual tear of the meniscus, and arthro CT scan or arthro MRI has to be performed. If pain appears 6 months after surgery, plain radiographs should be obtained to identify early osteoarthritic changes. However, if a recurrent tear is suspected, arthrography, arthro CT, or arthro MRI are best performed.

Meniscus Repair and Meniscus Transplantation

Imaging is not routinely performed, but only recommended in case of recurrent pain or mechanical symptoms at least 6 months after meniscal repair.

To date, the only imaging technique to assess meniscal healing is arthrography, preferably combined with a CT scan. For the evaluation of cartilage lesions, arthro CT scan is also recommended.

After meniscal transplantation, arthro MRI (Fig. 5.2.8) is the most efficient modality for assessing both the healing process and tissue quality.

Conclusion

Although imaging is becoming more and more efficient in predicting meniscus lesions and the outcome of repair or substitution, it appears that routine imaging is currently not efficient enough to predict failure of previous surgery. Confrontation with clinical data is more than ever necessary in revision surgery.

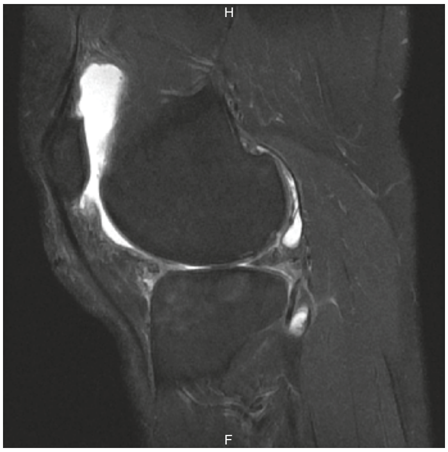

Fig. 5.2.8 Postoperative arthro MRI of a lateral meniscal allograft: complete healing, heterogeneous signal

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Part VI

Results

Meniscectomy: Global Results-Complications

6.1

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In the past decades, partial, subtotal, or total meniscectomy has received ample consideration in the literature. At present, arthroscopic meniscectomy remains one of the most common orthopedic procedures, but may have severe consequences that should not be neglected. The National Center of Health Statistics [45] reported more than 450,000 arthroscopic meniscectomies being performed each year in the United States (US). The first report on degenerative knee joint changes postmeniscectomy was published by Fairbanks [34] in 1948. Since then, many different issues regarding this procedure have been a matter of debate: total or partial excision, open or arthroscopic procedures, and recent techniques of repair, suture, and grafting. The outcome is correlated to cartilage status, anterior cruciate ligament (ACL) efficiency, and amount of resection. The purpose of this chapter is to analyze the global results of meniscectomy and its complications.

History

The first description of a meniscectomy was provided by Broadhurst [12], in 1866 in London. Annandale [7] was the first to describe meniscal repair in 1885. Despite the reports of King [56] and Fairbanks [34], who described the harmful effects of total meniscectomy and the secondary radiographic changes, until the seventies, menisci were considered as functionless evolutionary remnants of leg muscle that could be excised without further relevant consequences for the knee joint [67, 107]. In 1948, Ghormley [37] recommended total excision of any torn meniscus, stating that partial meniscectomy carried a higher risk of joint surface damage. In the fifties, Trillat [111], Trillat and Dejour [112] highlighted the role of the meniscal rim. Trillat described intramural medial meniscectomy [81] through a short anteromedial arthrotomy, preserving the medial collateral ligament and the meniscal rim. Up to 1970, Smillie [107] still recommended total meniscectomy for treating most meniscal tears, as he believed in meniscus regeneration after excision: "When the entire meniscus is excised a new one grows in from the parietal synovial membrane." However, in 1977, McGinty et al. [72] found little scientific evidence supporting such claims. They further stated that Smillie's description of regenerated meniscus closely resembling the original one after total excision was in direct conflict with the observations in their patient population. At second-look arthroscopies of nearly 800 knees, they never found a regenerated meniscal rim wider than 5 mm. From a retrospective evaluation of 136 knees at more than 5 years of follow-up, they concluded that partial meniscectomy had the following advantages: lower postoperative morbidity, earlier rehabilitation, and greater respect for anatomy and joint function.

In the eighties, biomechanical studies stated the importance of menisci to load transfer. Kurosawa et al. [58] showed that total meniscectomy reduced the total contact area by a third to a half in a fully extended knee. Menisci transmit up to 50% of weightbearing forces in extension and about 85% in flexion. In vitro trials reported about 70 and 50% of load transmission

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_6.1, © Springer-Verlag Berlin Heidelberg 2010

through the corresponding menisci in the lateral and medial compartment, respectively.

This combined knowledge stressed the relevance of meniscal preservation, and partial meniscectomy gained ground over total excision.

In Tokyo in 1918, Takagi performed the first arthroscopic procedure in cadaver knees using a cytoscope in a gas medium [108]. However, the first arthroscopic partial meniscectomy is generally attributed to Watanabe (disciple of Takagi) in 1962 [117, 118]. He designed the first practical arthroscope: the Watanabe number-21 arthroscope, which was produced in series and allowed effective intraarticular exploration. Arthroscopy (Fig. 6.1.1) began to assume greater importance in knee surgery mainly after reports of Jackson [47, 49] from Toronto, who repopularized arthroscopy in the Western world. The advantages of closed as opposed to open meniscectomy were stressed by numerous centers in the 1980's [11, 42, 84, 104, 110]. However, these results must be appreciated with caution. Most of the medium and long-term studies of open meniscectomies associated total with partial procedures, unstable with stable knees, medial with lateral tears, thus making it difficult to draw unbiased conclusions. Simpson et al. [104] observed better results with arthroscopic than with open partial meniscectomy, but the follow-up was shorter for the closed procedure (20 vs. 37 years). At a mean follow-up of 4 years Northmore-Ball and Dandy [84] reported similar results of open vs. arthroscopic partial meniscectomy (85% of good and excellent results vs. 90%, respectively). Bergström et al. [11] performed a retrospective randomized study comparing open to endoscopic meniscectomy. They found the short-term results of arthroscopic meniscectomy to be better in terms of recovery, days in hospital and return to work. However, the medium-term functional scores were shown to be similar in both procedures [6]. Nowadays, arthroscopic meniscectomy is considered the gold standard in the treatment of meniscal tears and the aim of this chapter is to present the current knowledge of its implications.

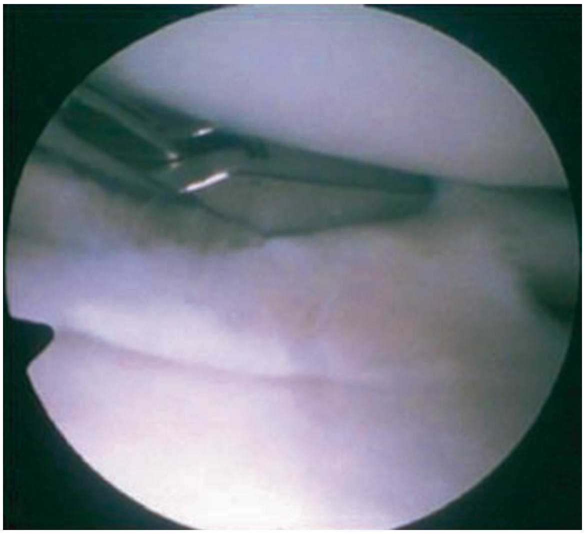

Fig. 6.1.1 Arthroscopic medial meniscectomy

Outcome Evaluation

Clinical results can be evaluated according to the self-satisfaction index, functional scores (e.g., International Knee Documentation Committee – IKDC [27] or Lysholm [19] scores), rate of secondary surgery, or progression to degenerative arthritis. The postoperative radiological evaluation must include standard anteroposterior (AP) single-leg stance views, profile views and particularly double-leg stance AP views at 45° of flexion. Although magnetic resonance imaging (MRI) has good sensitivity and specificity to assess the meniscus, it is not a regular part of the standard postoperative evaluation but is rather performed before surgery. It provides noninvasive assessment of meniscal tears and cartilage characteristics. More recent tools such as arthro-MRI and arthro-computed tomography (CT) scan have improved the accuracy and reliability of knee joint assessment.

Numerous studies have described the results of meniscectomy. However, direct comparison between these studies remains difficult because of the diversity of the procedures performed.

Medial Meniscus

Kurosawa et al. [36, 58] demonstrated the major contribution of the medial meniscus to load transfer and the possible consequences of its excision for the cartilage, subchondral bone, trabecular bone, and cortex of the proximal tibia.

The menisci are not firmly fixed on the tibia and follow AP knee translation during joint motion. Due to its anatomical features, the medial meniscus is less mobile. In a stable knee, the medial meniscus has little participation in anterior tibial displacement constraint. The ACL stops anterior tibial translation prior to significant entrapment of the medial meniscus posterior horn between the femoral condyle and tibial plateau [61].

Lateral Meniscus

Major differences exist between the femorotibial compartments of the knee joint. The lateral tibial plateau has a convex shape, as opposed to the concave shape of the medial compartment. Consequently, loss of the meniscus leads to poorer femorotibial congruence. Furthermore, according to Walker and Hajek [116], the lateral meniscus carries most of the load on the lateral compartment, while on the medial side the load is distributed between the exposed cartilage surfaces and respective meniscus [17].

Meniscectomy in Stable Knees

Because anatomical and biomechanical studies have demonstrated that medial and lateral menisci behave differently during functional knee joint solicitation, different outcomes of medial and lateral meniscal tissue removal are to be expected.

Medial vs. Lateral Meniscectomy (Table 6.1.1; Fig. 6.1.2)

Subjective Results

Subjective results regarding the localization (medial or lateral) remain controversial. In a multicentre study of the French Arthroscopic Society (SFA) [22], no significant difference was found in the IKDC subjective evaluation at more than 10 years of follow-up. In both groups, more than 85% of patients considered their knees as normal or nearly normal and more than 90% were satisfied or very satisfied with their knee. Grana and Hollingsworth [39] reported a similar outcome in their short-term study of arthroscopic partial meniscectomy. Conversely, Bonneux and Vandekerckhove [15] mentioned only 48% of good and very good subjective results after lateral meniscectomy and McNicholas [68] reported better subjective results after medial meniscectomy.

Table 6.1.1 Results of medial and lateral meniscectomies

Studies	Subjective results	Follow-up	Functional results	Degenerative changes
Neyret et al. [80]		20 years		35% after MM, 12% after LM
Ramadier and Beaufils [91]		3–6 months	90% good and very good results after MM, 85% after LM	
Ranger et al. [92]		53 months		38% after MM, 25% after LM
Northmore-Ball et al. [84]		4.3 years	88% satisfied after MM, 95% after LM	
Bonneux et al. [15]	48% good and very good after LM	8.2 years		39% after LM
Hoser et al. [44]		10.3 years	58% good and very good results after LM	39% osteoarthritis after LM
SFA [22]	90% feel normal after MM, 86% after LM	11 years	86% free of symptoms after MM, 80% after LM	22% after MM, 38% after LM
Higuchi and Kimura [43]		12 years	84% satisfied after MM, 73% after LM	60% after MM, 33% after LM
Grana and Hollingsworth [39]	90% very satisfied after MM, 85% after LM	7 months		
Allen et al. [5]		17 years		Higher rate after LM

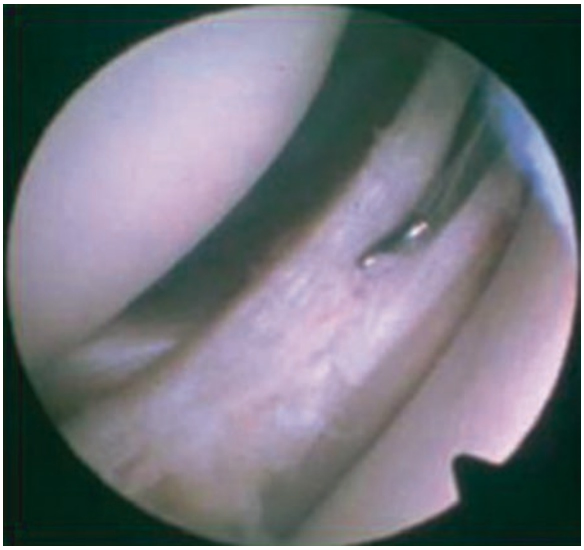

Fig. 6.1.2 Arthroscopic view after lateral meniscectomy

Functional Results

There is also no consensus on the clinical outcome after medial vs. lateral meniscectomy. The SFA [22] did not find any difference in pain, swelling, or giving away. According to Higuchi and Kimura [43], the site of meniscectomy did not affect the functional outcome. These statements were supported by a meta-analaysis conducted by Meredith and Losina [73]. Conversely, Ramadier and Beaufils [91] reported poorer functional results after lateral meniscectomy. These findings were supported by Mac Nicholas et al.'s [68] and Johnson et al.'s [51] observations of significantly worse outcomes after lateral meniscectomy.

Generally, good short-term results can be expected, even allowing athletes to return to preinjury levels of sports. However, in the lateral compartment the results seem to deteriorate with time. Chatain et al. [22] found a higher rate of sports level change after lateral meniscectomy. Jaureguito et al. [50] found that maximal improvement after arthroscopic partial lateral meniscectomy occurred at a mean of 5 months after surgery and lasted for about 2 years.

Moreover, almost twice as high reoperation rates (arthroscopies, osteotomies, or arthroplasties) have been reported after lateral meniscectomy compared to medial meniscectomy [15, 22, 96].

The influence of lower limb axial alignment is still controversial. If we only consider the biomechanical aspects of load transfer, the combination of valgus knee and lateral meniscus tear, or of varus knee and medial meniscus tear, should negatively affect the outcome because it is associated with additional cartilage overload. However, Chatain et al. [22, 23] at 10 years of follow-up and Neyret et al. [79, 80] at 25–35 years of follow-up found no significant difference in final malalignment. More specific studies should be performed to reach a consensus in this respect.

Radiological Results

Degenerative joint changes after meniscectomy continue to be of concern to orthopedic surgeons. In their short-term study, Provè et al. [90] did not find any difference between the height of the medial femorotibial joint space before and after meniscectomy at 1 month of follow-up.

In the SFA study [22] with a minimum follow-up of 10 years, the differences in the clinical and radiological results of partial medial and lateral meniscectomy were compared. Only stable knees with no history of previous injury or surgery were considered. In the radiological assessment, only patients with a normal contralateral knee were considered, because this more closely replicates the natural history of the joint after meniscectomy. This study and others [5, 20, 96] generally reported worse radiological results after lateral meniscectomy.

A fairly high prevalence of previous meniscectomy at more than 20 years of follow-up among patients with knee osteoarthritis requiring treatment, was reported by Neyret et al. [79, 80]. These findings indicate that osteoarthritic changes probably take longer to develop than previously assumed.

Traumatic vs. Degenerative Tears

The type of meniscal lesion is another factor that should be considered in the outcome evaluation. According to the literature, resection of traumatic longitudinal tears would provide better results than when complex degenerative tears are resected. At a mean follow-up of 16 years, Englund et al. [30, 31] found that patients with degenerative meniscal tears had the worst outcome. Osti et al. [86] reported

100% of excellent or good functional results after meniscectomy for longitudinal tears vs. 79% for complex tears. Matsusue and Thomson [70] obtained 74% of excellent results after treatment of traumatic tears and 64% for degenerative tears. According to Saragaglia and Tourne [98], meniscectomy of a degenerative meniscus significantly worsens the final results. Unfortunately, this type of meniscal lesion is most frequently associated with grade III and IV chondral lesions (Outerbridge classification [87]), which represents an additional therapeutic difficulty. Until now, it has not been possible to determine its independent contribution to outcome, because it is difficult to assess the association between meniscal tears and cartilage damage, especially in a degenerative knee. According to Matsusue and Thomson [70], patients with complex degenerative tears more frequently present substantial cartilage damage.

Cartilage damage is the strongest predictor of poor functional results [73]. This was confirmed by the HAS literature analysis in 2008 [40]. In the absence of cartilage damage, the results of arthroscopic meniscectomy seem to be similar for degenerative (48.5–96% of good clinical results) and traumatic (58–95% of good or very good subjective results) meniscal tears. However, in case of associated chondral lesions, arthroscopic meniscectomy for degenerative tears only provides 15–65% of good clinical results. The presence of cartilage lesions, particularly those affecting the patella, negatively influences the final outcome. According to Ramadier and Beaufils [91], femorotibial chondropathy seemed to less significantly lower the rate of satisfactory results. The incidence of postoperative residual pain and recurrent effusion was found to be statistically related to the severity of associated chondropathy [13].

Many authors [13, 22, 63, 98] have reported an age-related progressive deterioration of outcome, with about 85% of satisfactory short and medium-term results in patients less than 45 years old compared to about 75% in older patients. In patients over 55 years of age, less than 60% of satisfactory results were achieved [63]. However, it is difficult to consider it an independent factor for outcome as bias may be introduced once meniscal tear incidence and associated cartilage damage increase with aging [91, 98]. Jackson and Rouse [48] reported that the presence of degenerative changes rather than age at the time of operation seemed to negatively influence the results

Meniscectomy in the ACL-Deficient Knee

The prime passive restraint to anterior displacement of the tibia on the femur is the ACL [103] (Fig. 6.1.3). Secondary meniscal lesions are common after ACL rupture [46]. The cyclic recurrence of instability accidents exposes the meniscus to an increased risk of new meniscal tears and also degradation of the previous ones. Before the advent of intraarticular ligament reconstruction the only therapeutic option was to perform an isolated meniscectomy. Overall, the medium-term clinical and radiological results were far below the initial expectations.

However, in the absence of ACL action, the posterior horn of the medial meniscus acts as a brake to prevent further anterior displacement of the tibia [61]. This exposes the posterior horn to higher stress than usual and may account for the higher incidence of meniscal tears after ACL rupture.

From an anatomical perspective, the lateral meniscus is not fixed as firmly as the medial meniscus is [62]. The lateral meniscus is more mobile, being capable of 9–11 mm translation in the AP plane while this amounts to only 2–5 mm for the medial meniscus [61, 62]. This also implies a lesser contribution to AP motion constraint and accounts for different patterns of injury in the lateral vs. medial meniscus in ACL-deficient knees.

Isolated Meniscectomy *(Table 6.1.2)*

Effect on Sports Level

Several studies have shown that isolated meniscectomy in an ACL-deficient knee is not a benign procedure concerning return to sports activities. Aglietti et al. [2] reported that in the medium term only 31% of patients were able to return to their previous competitive sports level and 25% had to abandon their sports activity. These findings were supported by Hazel and Rand's study [41] at 4 years of follow-up. In the long term, Neyret et al. [78, 80] also reported a significant reduction of sports level after meniscectomy on unstable knees (31% of patients gave up sports compared to 5% when meniscectomy was performed on stable knees). All these results are far inferior to those of meniscectomy on

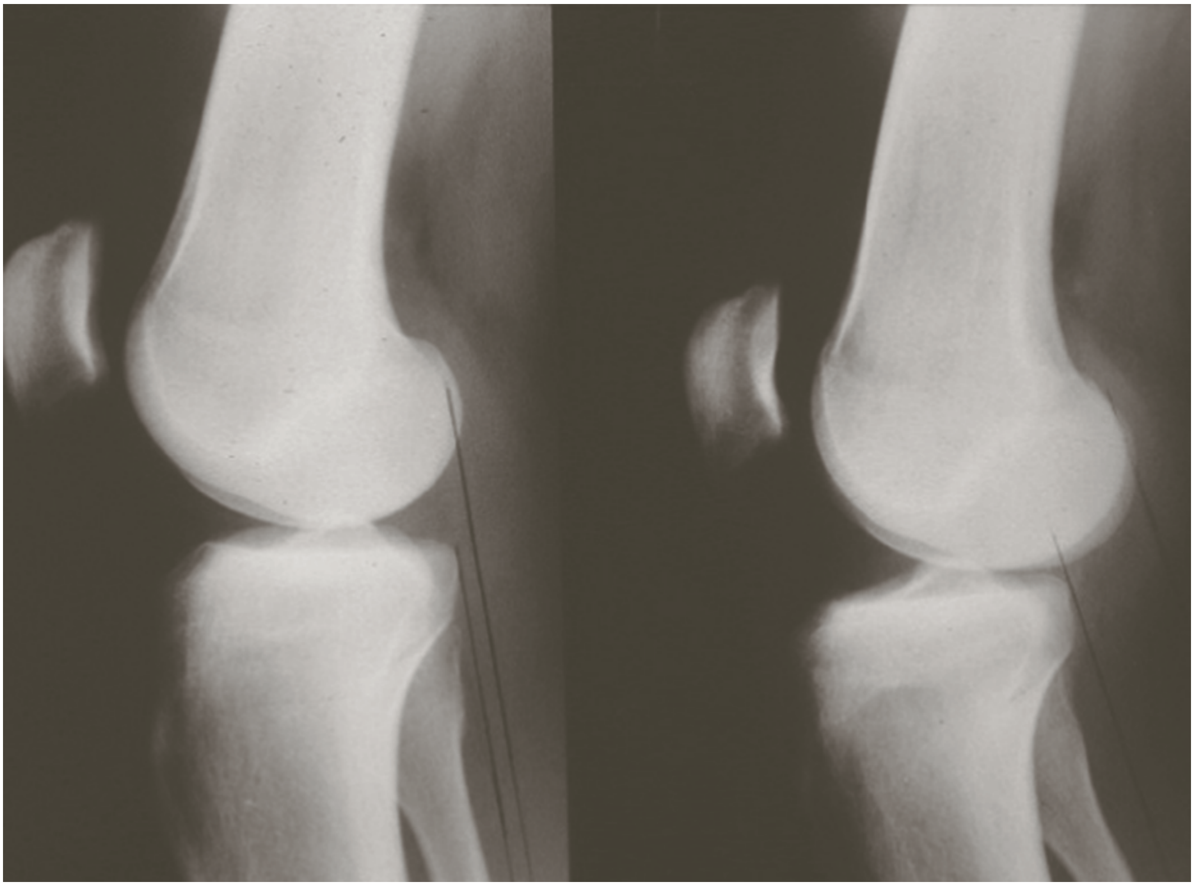

Fig. 6.1.3 Increase of anterior laxity in meniscectomized ACL-deficient knee

stable knees, as demonstrated by Bolano and Grana [12] (74% of patients maintained or increased their activity level 5 years after meniscectomy) and by Higuchi and Kimura [43] (69% returned to the same or a higher level).

Subjective Results

Many studies [1, 2, 41, 78] have shown that the results of meniscectomy are related to the ACL status. Ramadier and Beaufils [91] found the short-term subjective results to be significantly better if the ACL was intact. This was significantly correlated to pain and knee stability.

Functional Results

Several authors have stated that meniscectomy on unstable knees may improve the short-term functional results [2, 35, 91]. However, with time, the outcome progressively deteriorates. In addition, a higher rate of new meniscal and cartilage lesions secondary to instability has been observed, frequently necessitating secondary arthroscopies.

Radiological Results

Radiological evaluations have shown that meniscectomy in an unstable knee predisposes to osteoarthritic changes [3, 12, 28], manifested by hooked tibial spines, osteophytes of the intercondylar notch and the tibia remaining fixed in anterior translation with a "posteromedial cupula" (Fig. 6.1.4). Hazel and Rand [41] found evidence of osteoarthritis in 65% of knees at 4.3 years. Neyret and Donell [78] described a 65% rate of osteoarthritis at 30 years, increasing to more than 85% at longer follow-ups. They found that degenerative changes in a meniscectomized knee were correlated with the ACL status at the

Table 6.1.2 Results of meniscectomies related to ACL status

Studies	Follow-up	ACL status	Sports level	Subjective results	Functional results	Radiographic results
Ramadier and Beaufils [91]	3–6 months	Torn		45% instability	77% good and very good	
		Intact			91% good and very good	
Aglietti et al. [2]	3.5 years	Torn	31% still competitive athletes	53% instability with daily living or recreational activities		
			25% quit sports			
Hazel and Rand [41]	4 years	Torn	35/62 patients quit sport activities	84% improved 68% pain instability	66% effusion	65% osteoarthritis
Bolano and Grana [12]	5 years	Intact	74% same or higher activity level		82% satisfactory	62% degenerative changes
Higuchi and Kimura [43]	12 years	Intact	63% return to same or higher level		79% satisfactory results	
Tapper and Hoover [109]	10–30 years	Intact	25% quit football, skiing			
Neyret and Donell [78]	26 years	Torn	31% quit	7% very satisfied	31% excellent	65% osteoarthritis
		Intact	5% quit	92% very satisfied	68% excellent	
Nebelung and Wuschech [77]	35 years	Torn				10/19 patients had total knee replacement
Von Porat et al. [115]	14 years	Torn				59% degenerative changes after MM

Fig. 6.1.4 Posteromedial cupula

time of surgery. Von Porat et al. [115] reported 59% of osteoarthritis after meniscectomy in ACL-deficient knees, compared to 31% when the menisci were intact. Nebelung and Wuschech [77] found a more than 50% rate of total knee replacement at a mean 35-year follow-up after ACL tears in high-level athletes. All the patients had undergone a meniscectomy.

Meniscectomy Associated with ACL Reconstruction

Subjective Results

According to Kartus and Russell [53], knee pain and swelling with daily activities after ACL reconstruction were more frequent in patients who underwent meniscectomy than in those who did not. Aglietti et al.

[1] noticed statistically significantly more pain in the medial meniscectomy group with concomitant ACL reconstruction. Dejour and Dejour [28] reported a higher risk of residual pain when meniscectomy was performed on the lateral side of the knee and associated with ACL plasty.

Functional Results

Partial or total meniscectomy worsens the functional results of ligament reconstruction. In a series of 281 knees operated on for chronic anterior laxity, Ait Si Selmi et al. [3] found previous meniscectomy to be a risk factor for poor functional results. When assessing knee function following ACL reconstruction associated with meniscectomy or not, Kartus and Russell [53] found worse IKDC scores in the group of associated meniscectomy. Only 22% of patients were rated A compared to 42% in the group without meniscectomy. These results were confirmed by the study of Bouattour et al. [16], in which 48% of nonmeniscectomized patients were rated A compared to 11% in the meniscectomy group. Dejour and Dejour [28] stressed the role of medial meniscectomy in poor functional outcome after ACL reconstruction. Shelbourne and Gray [101] evaluated the results of ACL reconstruction based on meniscus and cartilage status. They found better subjective and objective results in patients with both menisci untouched and normal cartilage at the time of ligament reconstruction. Furthermore, total (as compared to partial) and lateral (as opposed to medial) meniscectomy significantly worsened the results.

Laximetry (Table 6.1.3)

As previously stated, the medial meniscus is one of the secondary restraints of anterior tibial translation. This effect is abolished when meniscectomy is associated with ACL reconstruction. After ACL reconstruction, restriction of AP laxity should belong to the graft alone. However, several authors showed greater residual differential laxity when ACL reconstruction was associated with meniscectomy than when the meniscus was left intact.

Degenerative Changes

Aglietti et al. [1] demonstrated that patients undergoing concurrent meniscectomy had worse radiological results. They found twice as many osteoarthritic changes when a medial meniscectomy was performed. Cohen and Amaro [24] also reported a significant relationship between meniscectomy and degenerative changes. Furthermore, Ait Si Selmi et al. [3] and Dejour and Dejour [28] described the development of deleted medial femorotibial osteoarthritis secondary to ACL deficiency when medial meniscectomy had been associated. Such degenerative changes within the medial compartment of the knee are correlated to anterior tibial translation of the medial compartment. Knees without osteoarthritis presented a mean differential value of 5.7 mm opposed to 8.3 mm for osteoarthritic knees ($p=0.045$). The development of secondary osteoarthritis is influenced by the degree of residual anterior laxity, Laffargue and Delalande [59] reported a higher risk of osteoarthritis when radiological residual laxity exceeded 6 mm. The suppression of the secondary restraint of anterior tibial translation represented by the medial meniscus contributes to such laxity.

Although meniscal tears related to other knee instability patterns have been described, these represent much rarer conditions and are beyond the scope of this chapter.

Complications

Even if arthroscopic meniscectomy can generally be considered a safe procedure with a satisfactory outcome, it requires surgical expertise and scientific

Table 6.1.3 Laxity after ACL reconstruction

Studies	Laxity with intact meniscus	Laxity after meniscectomy
Bouattour and Chatain [16]	1.57 mm	5.18 mm
Ait Si Selmi et al. [3]	3.9 mm	4.2 mm
Laffargue and Delalande [59]	29% rated A (IKDC ligament item)	0.9% rated A
Kartus and Russell [53]	78% negative Lachmann test	64% negative Lachmann test

knowledge. Complication rates ranging from 0.56 to 8.2% have been reported in the literature [25, 102, 105, 106]. Besides the previously described long-term complications, those arising in the short and medium term must also be considered.

Short Term

These mainly include the general complications of any arthroscopic procedure and are not as much strictly related to meniscal tissue removal.

Infections

In the literature, the infection rate varies from 0.04 to 0.42% [8, 52]. At the SFA symposium of 2001, infections were reported in 0.04% of cases [26]. The relevance of such infections is mainly dictated by their deepness. Immediate treatment including urgent articular debridement, collection of various samples for microbiological examination and empiric broad-spectrum antibiotics must be instituted. Antibiotics will be adjusted after identification of the germ and its sensitivity. The most frequently involved agent is *Staphylococcus aureus*.

Intraoperative Material Breakage

Because of the reduced space for maneuvering inside the knee joint and the fragility of the instruments intraoperative material breakage is a real but uncommon complication. In the early days of arthroscopy, loss or breakage of electric light bulbs occurred in about 0.3% of cases [49]. Nowadays, we still find episodic reports of arthroscopic instrument breakage (probe hooks, scissors, or blades) [57, 74, 102]. Recent improvements in materials and the growing technical experience have diminished these complications, but their possible occurrence must be kept in mind during all surgical acts.

Iatrogenic Cartilage Lesions (Fig. 6.1.5)

Cartilage injury during instrument handling cannot always be avoided and little is known about its implications [47, 55, 57]. Lubowitz et al. [64] recently described 28% of "mild" and 3% of "moderate and severe" cartilage damage associated with posteromedial assessment of the posterior medial meniscus horn using the transcondylar notch view. The incidence of this complication is directly related to the adequacy of the instrumentation, the residual laxity of the operated knee and the surgeon's experience.

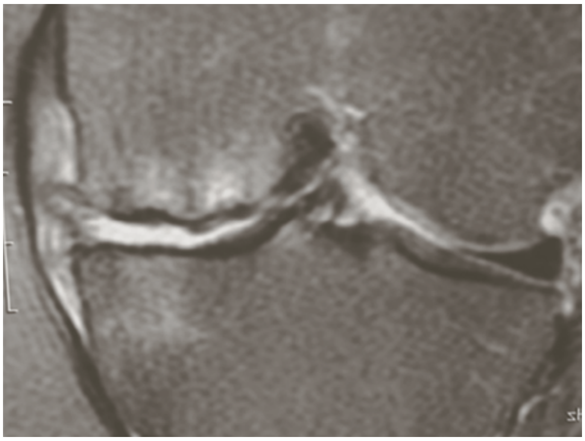

Fig. 6.1.5 Iatrogenic cartilage lesions after medial meniscectomy

Ligament Injuries

Ligament injuries are uncommon complications of arthroscopic surgery. Small [105, 106] reported two cases of medial collateral ligament stretching in a series of 1,184 knee arthroscopic procedures.

Vascular Lesions

Vascular lesions are extremely rare. In 1985, the Committee on Complications of the Arthroscopy Association of North America [25] reported 0.005% of vascular complications after arthroscopic procedures.

However, iatrogenic lesions have been described [55, 75, 102], the most serious of which involve the popliteal artery, resulting in pseudoaneurysms or arteriovenous fistulas.

Neural Lesions

The risk of neural lesions associated with meniscal surgery is known to be higher during meniscal repair than meniscal excision [55, 102]. Even so, portal placement and inappropriate manipulation of instruments may injure the most vulnerable neurological structures around the knee. Sherman and Fox [102] documented 0.6% of postoperative hyperesthesia or paresthesia in the distribution of the sartorial or infrapatellar branch of the saphenous nerve.

Synovial Fistula

If the synovial membrane lining the knee joint fails to heal after surgery, leakage of knee fluid to the skin will occur [85]. This will compromise healing and increase the risk of infection.

Embolic Events

Deep vein thrombosis or blood clots may occur after any lower limb surgery, arthroscopy included. The incidence of pulmonary embolism following arthroscopic knee surgery has not been well established, even if we can find episodic reports in the literature [99].

Medium Term

Early Chondrolysis

The risk of cartilage degeneration is higher after lateral than after medial meniscus lesions [4]. Early chondrolysis is more often related to lateral meniscectomy [21] and develops even in the absence of previous cartilage defects. Clinically, patients present elective pain over the lateral knee and articular effusion within 1 month of surgery.

Cartilage defects affecting the lateral compartment are visible on MRI and will be confirmed at subsequent arthroscopy.

The adequate treatment remains controversial.

Some authors propose joint washout, steroid infiltrations, and joint rest. Others advocate more complex measures such as microperforations, microfractures, or osteochondral grafting (e.g., mosaicplasty, chondrocyte implantation, or even allografting).

Postmeniscectomy Osteonecrosis [88] (Figs. 6.1.6 and 6.1.7)

Postmeniscectomy osteonecrosis was first described in 1991 by Brahme et al. [18]. The etiology of primary osteonecrosis is unclear and its true incidence remains uncertain [33]. However, it is known to be associated with other pathological conditions such as alcoholism, hemoglobinopathies, hyperbarism, chronic corticotherapy, systemic lupus, and Gaucher's disease. Contrary to spontaneous osteonecrosis of the knee, postmeniscectomy osteonecrosis equally affects

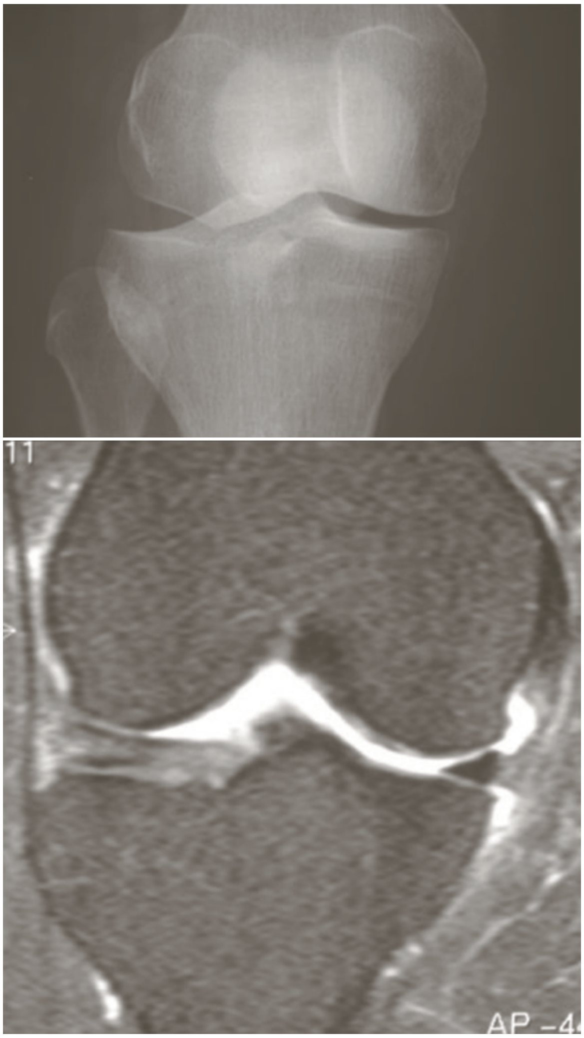

Fig. 6.1.6 Postmeniscectomy osteonecrosis (X-rays and MRI findings before arthroscopy)

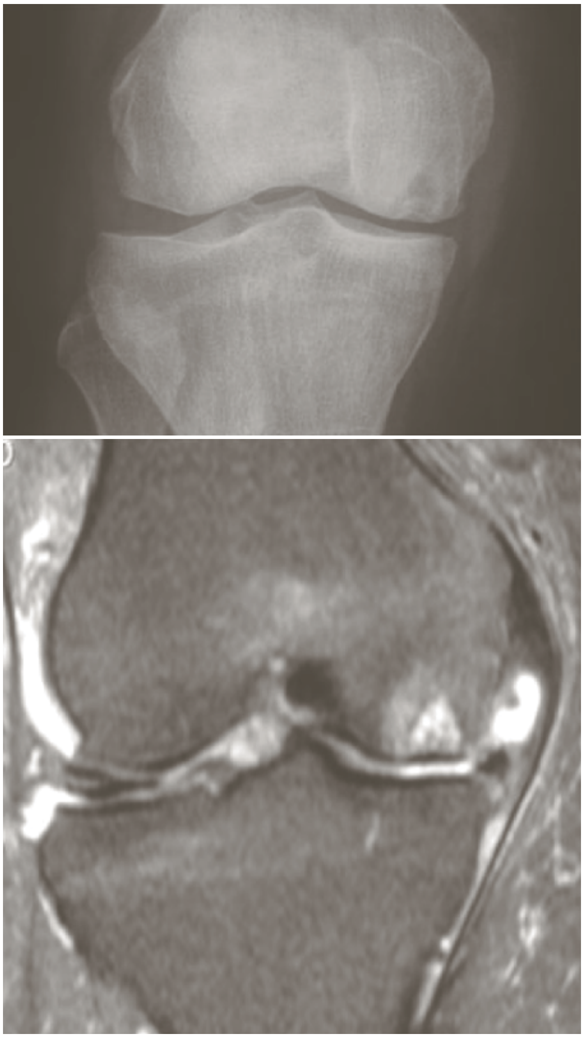

Fig. 6.1.7 Postmeniscectomy osteonecrosis (X-rays and MRI findings after arthroscopy)

both genders, with a mean age of 58 years [89]. The medial condyle is predominantly involved and osteonecrosis always presents in the meniscectomized compartment of the knee. The hypothesis of a vascular mechanism underlying this pathology has gained some support over the years but remains to be clarified. In the last decade, some cases of postmeniscectomy osteonecrosis have been reported. According to some authors, removal of the protective effect of the meniscus on load transfer (as it increases surface for forces transmission dictates lower femorotibial pressure) will lead to subchondral bone injury and finally osteonecrosis. The hypothesis of subchondral edema secondary to an increase of cartilage permeability has been advanced.

The diagnosis is based on the absence of osteonecrosis on preoperative MRI, the presence of bone marrow edema on postmeniscectomy MRI and radiological signs of osteonecrosis. Osteonecrosis has also been described after laser meniscectomy, which is probably related to excessive intraarticular heating [97].

Conclusion

The increasing awareness of the importance of the menisci to the knee joint has led to a higher tendency to preserve their structure. As previously discussed, the long-term results after total or partial meniscectomy are not devoid of complications. Knowledge of anatomy and vascularization [9] combined with recent advances in biology have made meniscal repair more attractive than before [69, 71]. Surgeons tend to adopt a more conservative attitude as they realize that the more meniscal tissue is excised the less congruent and physiological the joint will be. Many suture techniques have proven to be reliable in properly selected cases [29, 32, 95]. The potential use of exogenous fibrin clots [100], stem cells [60], growth factors [54], tissue engineering [76] or gene therapy [38] has been described. The first 10-year reports on allograft transplantation also present encouraging results [14, 82, 83, 93, 94, 113, 114]. Considering all these factors, algorithms for the treatment of meniscal injuries must be regularly revised [10] as scientific knowledge progresses, in order to find the most adequate treatment meeting the patients' expectations (including time to resumption of previous activity) [65, 66] and pattern of lesion.

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Meniscal Repair: Intra- and Postoperative Complications

6.2

M. Katabi, N. Pujol, and P. Boisrenoult

Introduction

Arthroscopic meniscal procedures have a relatively low complication rate. In a large retrospective study sponsored by the Arthroscopy Association of North America (AANA) in 1985, De Lee [15] reported an overall complication rate of 0.6%. In this survey, focusing on diagnostic arthroscopy and first-generation arthroscopic surgical procedures, some serious neurological and vascular complications were identified. This rate was believed to be underestimated, and specific complications of meniscal repair procedures were not considered. Variability in the reported overall complication rate of arthroscopic meniscal surgery depends on the criteria used to define a surgical complication. In a prospective study conducted together with the French Arthroscopy Society (SFA), reporting an overall complication rate of 16%, Coudane and Buisson [14] defined a complication as every phenomenon considered abnormal by the patient or the surgeon during and after an arthroscopic procedure. In a prospective survey of 8,741 knee joint procedures, the AANA evaluated complications in arthroscopic surgery [46]: the overall complication rate was 1.8%, and the incidence of complications was not higher for meniscal repair (1.2%) than for partial meniscectomy (1.7%). An analysis of large surveys of meniscal repair procedures performed by the AANA [45–47] and SFA [28] showed that serious injury involving neurovascular structures was rarely encountered in the most recent studies (Table 6.2.1).

The focus of treatment on preservation and repair of the meniscus whenever possible has led to the development of new approaches to arthroscopic and minimally invasive meniscal repair techniques. In meniscal repair, iatrogenic damage to neurovascular structures including the peroneal and saphenous nerve and popliteal artery, are of utmost concern to both the orthopedic surgeon and the patient. To minimize the neurovascular risks, a number of all-inside devices (arrow, dart, staples, and screws) and repair techniques have been developed, but each has its own specific complications such as cartilage damage or meniscal implant failure. When performing a meniscal repair, the surgeon must keep in mind that each step in this surgery can carry a potential pitfall and be a source of complications: posterolateral or posteromedial approaches, extraarticular knotting, meniscal needles, and all-inside repair devices. Every anatomic structure around or inside the joint can be injured (Fig. 6.2.1a).

Neurovascular and Soft-Tissue Complications

All meniscal repair techniques of the posterior and posterolateral horn of both the medial and lateral meniscus are fraught with the risk of damaging neurovascular structures. Because of their anatomic location (Fig. 6.2.1b, c), the popliteal artery and the common peroneal nerve may be injured when the posterior horn of the lateral meniscus is repaired. Repairing the posterior horn of the medial meniscus carries the risk of saphenous nerve injury (mainly the infrapatellar branch of the nerve). Injuries of the tibial nerve or popliteal vein have not been reported in recent studies of meniscal repair.

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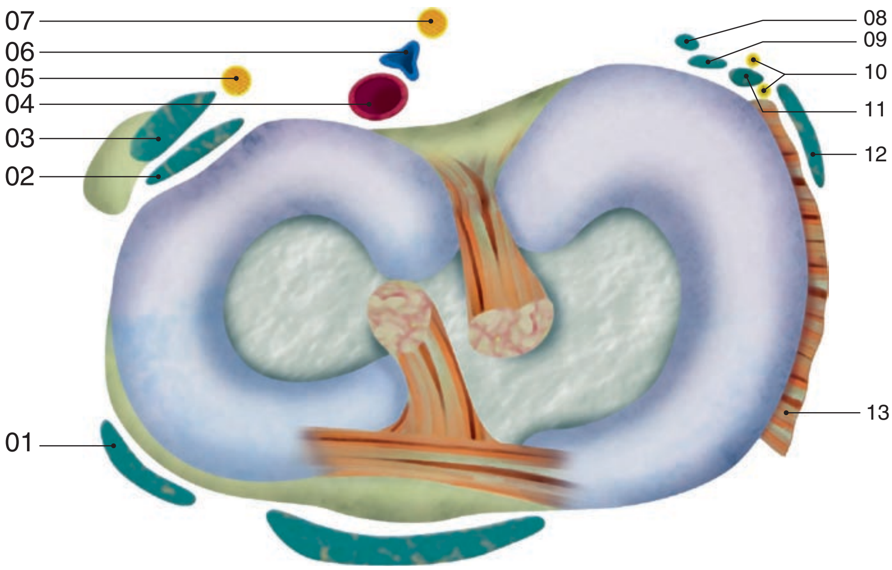
P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_6.2, © Springer-Verlag Berlin Heidelberg 2010

Table 6.2.1 Major complications reported after meniscal repair procedures

	AANA 1986 [45] retrospective *N*=3034	AANA 1990 [46,47] prospective *N*=257	SFA 2003 [28] retrospective *N*=203	SFA 2003 [28] prospective *N*=75
Saphenous nerve injury	30	1	4	0
Peroneal nerve injury	6	0	0	1
Vascular injury	3	0	0	0
Cartilage damage	–	–	3	0
Meniscal damage	–	–	1	0
Synovitis	–	–	1	0



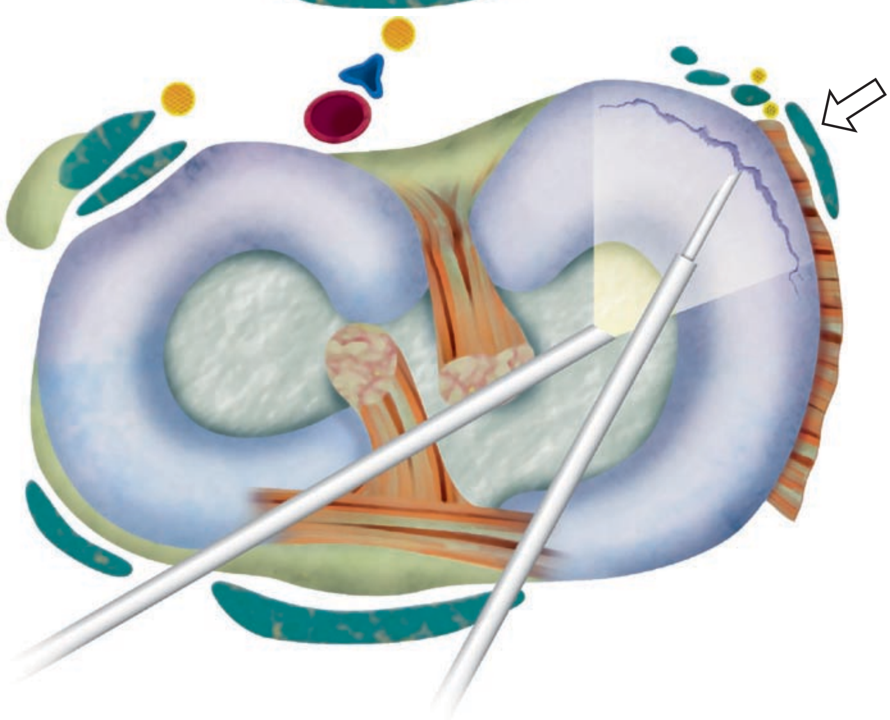
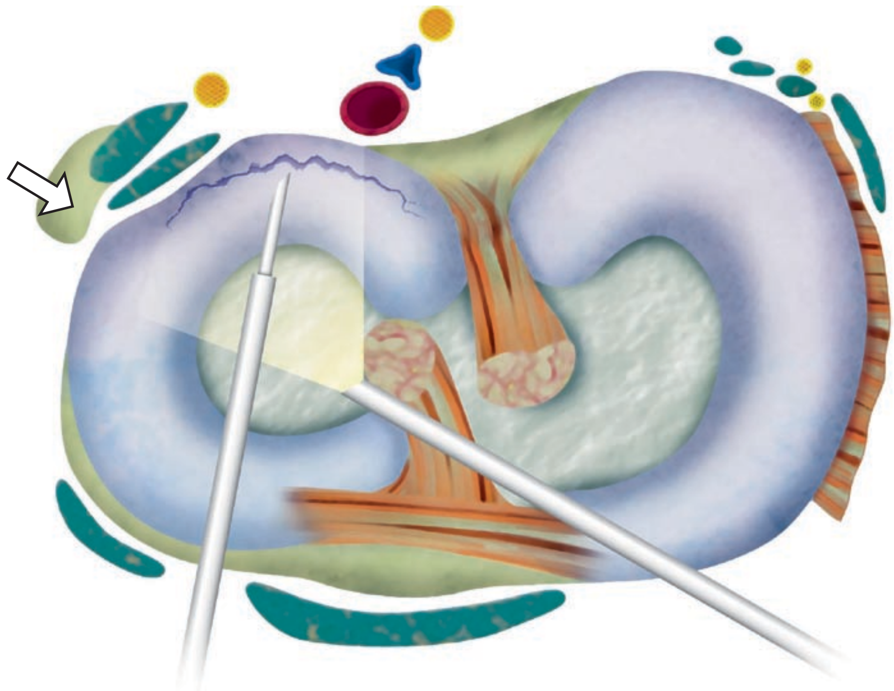


Fig. 6.2.1 (**a**) *1* Iliotibial band, *2* popliteus tendon, *3* biceps tendon, *4* popliteal artery, *5* peroneal nerve, *6* popliteal vein, *7* tibial nerve, *8* semitendinosus tendon, *9* semimembranosus tendon, *10* saphenous nerve, *11* gracilis tendon, *12* sartorius tendon, and *13* medial collateral ligament. (**b**) Structures at risk when repairing the medial meniscus. The *arrow* shows the posteromedial approach. (**c**) Structures at risk when repairing the lateral meniscus. The *arrow* shows the posterolateral approach

Fig. 6.2.1 (continued)



Popliteal artery injury, including pseudoaneurysms and arteriovenous fistulas resulting from laceration or penetration during meniscal surgery, is extremely rare. Several such complications have been reported during arthroscopic meniscectomy [9,11,47], the injury usually being caused by a basket forceps or the use of a shaver without adequate direct visualization. Henning et al. [24] reported a popliteal artery laceration after lateral meniscal repair using a posterior approach. At the proximal aspect of the popliteal fossa, the popliteal artery is located slightly medial to the midline, in front of the popliteal vein and medial to the tibial nerve. At the level of the knee joint, it lies slightly lateral to the midline, in close proximity to the posterior region of the lateral meniscus (Fig. 6.2.2). Because of its anatomic location, the popliteal artery is at risk during lateral meniscal surgery and may be injured during posterolateral surgical dissection or by the posterior exit of a needle or an all-inside device. In a cadaveric study, Cohen et al. [13] referred to the proximity of the popliteal artery with two all-inside repair devices inserted in the posterior horn of the lateral meniscus. Using a penetration limiter and an appropriate needle or meniscal implant of proper length and introducing the device through the contralateral portal (when possible) allows a safer all-inside repair. With an inside-out repair technique, the use of a posterolateral approach is recommended to control the posterior exit of the needles and to safely tighten the knots. Early diagnosis of vascular injury is essential to avoid catastrophic consequences: the surgeon must take care of early and unusual pain after a meniscal procedure. If the clinical examination suggests a popliteal artery injury, the

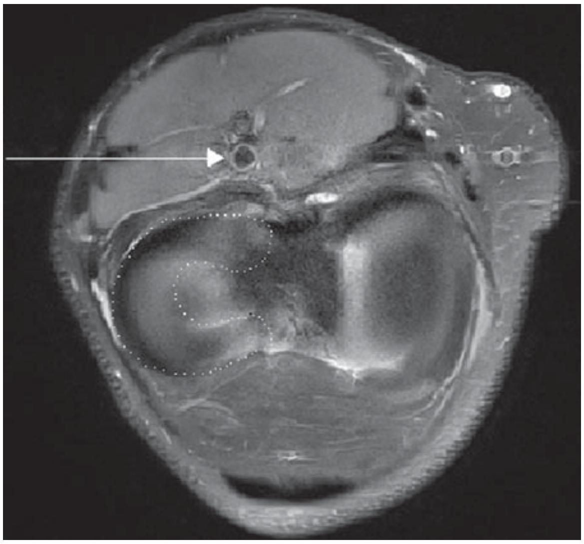


Fig. 6.2.2 Axial MRI view at the knee joint level showing the proximity of the popliteal artery (*arrow*) to the posterior horn of the lateral meniscus (*dotted line*)

diagnosis must be confirmed by ultrasonography or angiography (computed tomographic or catheter-based angiography) prior to surgery.

The peroneal nerve is at risk when the lateral meniscus is repaired near or posterior to the popliteal recess. In an anatomic cadaveric study, Jurist et al. [27] showed that inside-out needles placed into the posterior horn of the lateral meniscus are very close to the peroneal nerve. The nerve runs posterior to the posterior border of the biceps tendon at the joint line level; it then crosses the lateral gastrocnemius and turns around the head and neck of the fibula before entering the anterolateral compartment of the lower leg. Anatomic variability in the course of the peroneal nerve is common and could also be a cause of iatrogenic injury. Deutsch et al. [19] performed a cadaver study of the anatomy of the common peroneal nerve around the joint and described one to five separate peroneal nerve branches at the level of the joint line. The common peroneal nerve divides into its deep and superficial branches at or distal to the fibular neck in only 80% of cases. Krivic et al. [30] reported a case of complete lesion of the common peroneal nerve during inside-out lateral meniscus repair. They found an unusually located common peroneal nerve during revision surgery. Injury to the peroneal nerve is rare during meniscal repair. In a retrospective study of the AANA [45], Small reported six cases in 3,034 meniscal sutures. Boyd and Myers [8] described one neuropraxia of the peroneal nerve in 288 meniscal repairs which resolved after 6 weeks, and Jurist et al. [27] reported one case of complete peroneal nerve palsy after inside-out meniscal repair combined with a posterolateral approach. 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 needle puncture, sutures tied over the nerve, technical error in surgical approach or excessive tension on nerve during posterolateral exposure. The type of injury conditions the quality of neural healing and functional recovery. 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, bearing in mind the anatomic variability in the course of the nerve. Anterior deflection of the needle tip and inserting the needle or suture holder through a contralateral portal, when possible, will avoid posterior exit of the needle towards the peroneal nerve.

Neurapraxia of the saphenous nerve and its infrapatellar branches is the most common neural injury. Barber [4] reported 22% of transient saphenous neurapraxia after meniscal inside-out repair in 24 patients. Stone and Miller [51] reported 43%, of which 8% were symptomatic at follow-up. In a retrospective multicentre study of 203 meniscal repairs using various techniques [28], the SFA reported four cases of saphenous neurapraxia, all associated with the use of a posteromedial approach. The saphenous nerve usually exits the Hunter canal between the sartorius and gracilis tendons along the medial aspect of the knee, and frequently shows anatomic variability in its course and in the number of infrapatellar branches at the knee joint level. The nerve location varies with the degree of knee flexion or extension [36]. When the knee is fully extended, the nerve lies approximately 2 cm anterior to the posteromedial corner; when the knee is in 70–90° of flexion, the nerve lies near the joint, in the posteromedial corner. In order to prevent saphenous nerve injury, Morgan and Casscells [36] described a posteromedial approach located 2 cm behind the posteromedial corner with the knee in only 10–15° of flexion. Conversely, Espejo-Baena et al. [20] recommended a medial incision located more anteriorly and distally, with the knee in 70–90° of flexion. They described a "safety zone" between the surface of the fascia cruris and the medial collateral ligament, where knotting is performed using an inside-out meniscus repair technique. Arthroscopic transillumination at the posteromedial corner can also help locate the nerve [29]. Careful dissection and knotting the sutures directly over the capsule will avoid injury or entrapment of soft tissues and small nerve branches. Saphenous neurapraxia has become a very rare complication since the development of all-inside meniscal repair techniques. Spindler et al. [50] reported a 13% nerve injury rate when repairing the medial meniscus with an 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 [42] or by a prominent meniscal arrow tip [1]. In a cadaveric study of medial meniscus repair using an inside-out suturing device, Espejo-Baena et al. [20] showed that no vascular or nervous structures were pierced by needles. However, on posterior knot tightening, many structures became trapped. In case of persistent saphenous nerve irritation, steroids, or long-acting anesthetic drugs can be locally injected and usually lead to good functional recovery.

Other soft-tissue injuries during meniscal repair could be responsible for residual pain after surgery (Fig. 6.2.1b, c). Anatomic cadaveric studies, in which different meniscal repair techniques (inside-out and all-inside) and meniscal repair devices were used, showed a high incidence of soft-tissue injuries. Entrapment of the popliteal tendon and iliotibial band has been reported during lateral meniscus repair [20,35], Entrapment of the saphenous vein and the different layers of the medial collateral ligament, and tenodesis of the sartorius, gracilis, and semimembranosus tendons have been observed during medial meniscus repair [12,20].

Complications Related to Meniscal Devices and Implants

The objective of all-inside meniscal repair techniques is to minimize surgical incisions and neurovascular risks and to decrease the operating time while ensuring that the biomechanical properties of the repaired meniscus are as close as possible to those obtained with vertical sutures. With the growing development of meniscal devices and implants, new complications of meniscal repair surgery have emerged.

The absorption profile of meniscal implants affects their biomechanical properties and leads to possible fragmentation, which can be a source of some specific complications. A number of meniscal repair implants are made of polylactic acid (Mitek RapidLoc) or its derivatives: poly-L,D-lactic acid (Arthrex Meniscal Dart), poly-L-lactic acid (Linvatec BioStinger, Clearfix Meniscal Screw), and self-reinforced poly-L-lactic acid (Meniscus Arrow). The tensile strength of poly-L-lactic acid decreases significantly after 6–12 weeks. The structural integrity of these polymers declines with time, leading to a decrease of the molecular weight and eventual fragmentation of the implant [21]. A nonspecific foreign-body reaction is induced by lower-molecular weight polymer. When using biodegradable implants, a foreign-body reaction induced by the degradation of the implant can cause aseptic synovitis [2,48]. The mechanism of synovitis is not well understood; the shape and the crystallinity of the implant as well as some other mechanical factors seem to influence the degradation rate of the material and cause synovitis. If this is the case, removal of the meniscal implant and all implant fragments is indicated. Arthroscopic synovectomy is associated in case of severe inflammation with hypertrophy of synovial membranes. Removing all small articular implant fragments can help achieve full functional recovery.

Because the Bionx Meniscus Arrow was the first implant to become popular, its complications have been reported in several studies. Chondral injury is of particular concern and occurs when the head of the arrow is not inserted sufficiently deep in the meniscal tissue. Chondral damage is located in the posterior area of the femoral condyle overlying the arrow; the depth of the chondral groove created by the head of the arrow can vary from partial to full thickness (Fig. 6.2.3). Several cases of chondral grooving have been reported [31,34,39,41,43,44], and have also been observed with other meniscal implants such as Mitek RapidLoc [5], Mitek Meniscus Staple [32], Biostinger bioabsorbable device [2], and bioabsorbable screw. At a second-look arthroscopy, Sarimo et al. found some degree of chondral irritation at the repair site in 7 out of 13 patients [41]. These results are in contrast with the nearly 0% rate of chondral injury with meniscal repairs using traditional vertical sutures or all-inside Fast-Fix suturing devices [22].

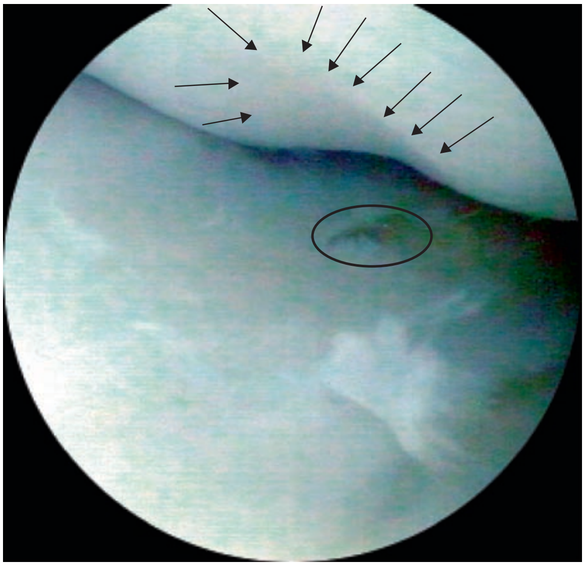


Fig. 6.2.3 Chondral grooving of the femoral condyle caused by the head of a meniscal arrow (courtesy R Seil, J Menetrey)

Other mechanical complications related to the use of bioabsorbable meniscal implants are local irritation at the site of repair usually resolving within 3–12 months [26,31,40,41,52,53], implant breakage [10,31,39], subcutaneous migration [7,32,38], articular migration [52], foreign-body reaction [33,39], cystic haematoma formation [23], and synovial cyst formation [3]. Because all-inside meniscal repair techniques remain technically demanding procedures, some complications are particularly encountered during the learning curve period: intraarticular loosening of the implant, articular deployment of the implant, failure, or section of suture during tensioning (with Fast-Fix and RapidLoc repair systems), and intraoperative meniscal and chondral damage.

Nonspecific Complications

Nonspecific complications are equally prevalent after any type of arthroscopic meniscal surgery. Some of them, e.g., septic arthritis and pulmonary embolism, cause significant morbidity, sometimes leading to serious sequelae, and should not be overlooked.

Infection following arthroscopic knee surgery is relatively rare, with Small [46] reporting a 0.21% rate in 8,791 arthroscopic knee procedures. The most commonly identified germs in septic arthritis after arthroscopic knee surgery are Staphylococcus and Streptococcus species. Long operating times, intraarticular steroid injections, and inadequate sterilization of arthroscopic instruments, especially cannulas, increase the risk of septic arthritis, as was reported by Blevins et al. [6]. Early diagnosis, immediate arthroscopic lavage, and intravenous antibiotics are crucial to achieve full recovery.

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. [18] found that 17.9% of 184 patients presented DVT, documented by venography following knee arthroscopy; 4.9% of them had proximal DVT. There was no clinically suspected pulmonary embolism; 39.4% of patients with DVT were clinically asymptomatic. Delis et al. [17] and Hoppener et al. [25] reported a 7.8 and 5.7% incidence of DVT, respectively, using an ultrasonographic detection device. Hoppener et al. [25] did not identify risk factors for DVT, while Demers et al. [18] found the risk to be significantly higher with tourniquet times of more than 60 min. Delis et al. [17] demonstrated a higher incidence of DVT among patients with two or more risk factors for thromboembolism. Prophylaxis with low-molecular weight heparin significantly reduced the rate of DVT [54] but had some side effects: minor bleeding and transient variations in platelet count in a minority of patients, rarely major bleeding. Pharmacological thromboprophylaxis seems justified after both knee arthroscopy and meniscal repair but a clearly identified high-risk group and a consensus on the duration of treatment are lacking.

Arthrofibrosis sometimes seems to be associated with meniscal repair [29] and can be observed when posterior capsular tissues have been overtightened, limiting the extension of the knee. Morgan and Casscells [36] recommend tying the sutures with the knee in full extension in order to prevent excessive posterior capsular tensioning.

Reflex sympathetic dystrophy (RSD), also known as type 1 complex regional pain syndrome, is a multisymptom syndrome usually affecting one extremity. Symptoms include unusually prolonged pain, vasomotor disturbances, and trophic changes in soft tissues. According to O'Brien et al. [37], arthroscopic procedures were the most common event precipitating RSD of the knee. Because RSD remains poorly understood and often difficult to treat, neural blockade is helpful to obtain resolution of symptoms. Complete functional recovery is usually obtained after a period of 6–24 months. The prognosis seems to be closely related to the presence or absence of a remaining anatomic lesion or a persistent painful stimulus [37]. In the postoperative period, pain can be relieved by intraarticular injection of long-acting anesthetic drugs or morphine, but the effect on reducing the incidence of RSD is not proven. Patellar tendon contracture and loss of patellar height are more uncommon in RSD [49], 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 proposed, as described by Dejour et al. [16].

Medial collateral ligament rupture has been reported during medial meniscal procedures [46] when excessive valgus forces are applied to a tight medial compartment. When visualization of the posterior horn of the medial meniscus is difficult, it is however possible to relax the tight medial ligament by means of several needle punctures. Healing is usually achieved with no residual laxity or local pain.

Several other complications have been reported after arthroscopic knee surgery, such as hemarthrosis, instrument failure, compartment syndrome, and knee fracture.

Conclusion

Meniscal repair surgeries have become minimally invasive procedures with relatively low morbidity, comparable to arthroscopic meniscectomy. Complications are very rare, among which neurovascular damage is the most serious and could lead to definite sequelae. Complications related to the surgical approach and repair technique can largely be avoided with a thorough understanding of neurovascular anatomy and proper surgical planning of posterolateral or posteromedial incisions, when needed. The orthopedic surgeon must be familiar with the method of repair, and with the specific pitfalls and complications of all-inside meniscal devices.

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Meniscal Repair: Results

6.3

N. Pujol, L. Panarella, and P. Beaufils

Introduction

Fairbank [10] was the first to document long-term degenerative changes after subtotal meniscectomy. Since then, meniscus-sparing techniques have been developed, ranging from partial meniscectomy to meniscus repair and replacement.

Many studies about meniscus repair have been published, especially since the advent of arthroscopy. The techniques have evolved from open repairs to all-inside arthroscopic repairs, and the indications have been well defined [4, 6, 7].

Seventy to ninety-four percent good clinical results have been reported at the mid-term to long-term follow-up [8, 11, 20–22, 29, 37, 47, 52]. In these studies, subsequent meniscectomy has been performed in 15–24% of cases.

Studies evaluating anatomical healing of repaired menisci are rare and mainly retrospective. The reported partial and complete healing rate varies from 42 to 75% [1, 4, 6, 7, 17–19, 24, 39, 49], and there is a discrepancy between anatomical and clinical results.

A more accurate analysis of the quality and effect of meniscus repair could provide a better understanding of meniscal pathology and lead to much needed improvements. This chapter discusses the clinical, subjective and anatomical results, as well as the failure rates (i.e. subsequent meniscectomy) of meniscus repair.

Clinical Results

Subsequent Meniscectomy

Subsequent meniscectomy should be considered as the main clinical failure after meniscal repair. Johnson et al. [21] reported a secondary meniscectomy rate of 24% 10 years after open meniscal repair. In Rockborn and Messner's [37] study, this rate was 29% at a mean follow-up of 13 years. Failures included lack of healing in one third of cases, and re-tears after healing in two thirds.

At the French Arthroscopic Society symposium [6] in 2003, 203 cases were retrospectively reviewed. Secondary meniscectomy was performed in 23% of cases at a mean follow-up of 45 months (survival rate, Fig. 6.3.1).

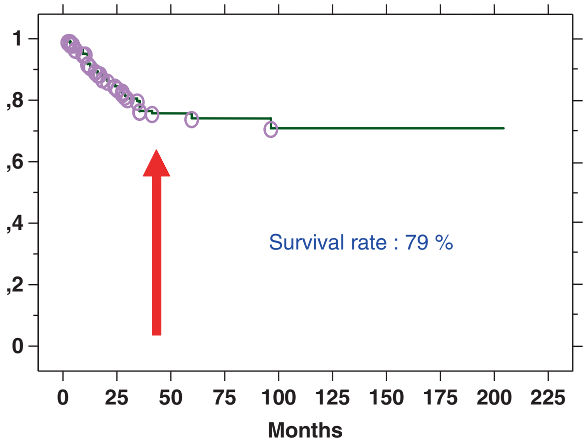

Fig. 6.3.1 Global survival rate of meniscal repairs

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_6.3, © Springer-Verlag Berlin Heidelberg 2010

Twenty-four percent of medial meniscal repairs and 11% of lateral meniscal repairs were converted to secondary meniscectomy, which was performed within the first 2 years in 79% of cases. Siebold et al. reported the same results [42] with 81.5% of failures occurring within 3 years. Moreover, Arnoczky et al. [2] showed that meniscal healing takes place over a period of at least 18 months. 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 frequent between 6 and 24–36 months. They represent real healing failures and should be evaluated separately. After 24–36 months, a failure mainly occurs on meniscal scar tissue and is called a true re-tear. A systematic review of the clinical results of all-inside meniscal repairs has recently been published [27]. The level of evidence was mainly graded IV and the mean follow-up ranged from 3 to 77 months. In some of these studies, different criteria to define failure were used. The clinical failure rate varied from 0 to 43.5%, with a mean failure rate of 15%. In order to more accurately analyse the failure rates due to lack of healing, we selected studies with a mean follow-up of more than 24 months, and the number of patients over 50 (Table 6.3.1). The failure rate ranged from 4.8 to 28% (mean 13%). Differences in study design (often retrospective, or without control group), patient characteristics (medial vs. lateral meniscus, ACL status) and surgical technique (different devices) introduce bias when trying to compare studies.

Functional Results

In the literature, varying global results have been reported, ranging from 62 to 90% of good clinical or functional results at the mid-term to long-term follow-up (2–20 years) [8, 11, 20–22, 37, 47, 52].

At the French Arthroscopic Society symposium, good results (taking into account failures and subsequent meniscectomies) were reported in 62% of patients [6]. The mean subjective IKDC score was 80; the range of motion was normal in 97% of cases. At follow-up, among 103 repairs, 23 patients had undergone secondary meniscectomy, 18 had some residual pain and 62 had a normal knee.

Excluding failures (21/88 cases), Majewski et al. [29] found functional results of meniscal repair in stable or stabilized knees to be good, but not excellent. Nevertheless, Shelbourne and Dersam [41] showed that at 8 years, subjective results of repair were better than those of partial meniscectomy. According to Lee and Diduch, subjective results deteriorated with time: 90% good results at 3 years and only 70% at 6.5 years [26].

Contributing Factors

Numerous factors may influence anatomical and clinical results.

ACL Status

A repairable meniscal tear should be assessed simultaneously with the ACL status. If the ACL is torn, concomitant ACL re-construction should be discussed.

In most recent studies, meniscal repairs in stable or stabilized knees had the same objective and subjective results [1, 5, 6, 33, 47].

Meniscus repair in ACL-deficient knees has been reported in three studies [12, 23, 46]. Thirteen to twenty-seven percent of patients underwent subsequent meniscectomy, 33% of patients secondary ACL re-construction. The results were better in patients who had reduced their activity level.

Table 6.3.1 Literature review: clinical failure rates of all-inside arthroscopic meniscal repairs

Author	*N*	Mean follow-up (months)	Failure (%)	Definition of failure	Level of evidence
Siebold et al. [42]	105	72	27 (28.4)	Meniscectomy	IV
Spindler et al. [45]	85	27	7 (8.2)	Meniscectomy or re-repair	II
Kurzweil et al. [25]	60	54	17 (28)	Clinical failure	IV
Koukoulias et al.[23]	62	73	3 (4.8)	Meniscectomy	III
Quinby et al. [34]	54	34.8	5 (9.3)	Meniscectomy	IV

This procedure is not contraindicated, but indications should be selected with extreme caution, especially in young patients.

Location of the Tear

Meniscal repair should be considered for vertical tears within the vascular zone (red–red or red–white zone), i.e. the peripheral third of the meniscus. Results of repairs in the red–red zone are equivalent to those in the red–white zone [6, 17, 33, 35, 36, 52].

In young patients, the clinical results of repair of meniscus tears extending into the avascular zone were good to excellent in 75–80% at follow-up [32, 38]. Some tears were located in the middle part of the meniscus, and thus potentially in the red–red zone, leading to potential selection bias. Nevertheless, it is difficult to evaluate the limit of the red zone in meniscal lesions located in the middle part of the meniscal body, especially in young patients. In order to preserve the maximum amount of meniscal tissue, meniscal repair could be considered in these cases, despite the increased risk of secondary meniscectomy.

Lateral/Medial Meniscus

Due to highly vascularized areas, lateral tears may heal better than medial tears. Tuckman et al. [48] found a superior healing rate for the lateral meniscus compared to the medial meniscus (80 vs. 56% complete healing).

In the study of the French Arthroscopic Society [6], 24% subsequent medial meniscectomies and 11% subsequent lateral meniscectomies were required after repair.

Age

More than patient age, the quality of the meniscal tissue should be carefully considered. A traumatic vertical longitudinal tear in a macroscopically normal meniscus should be considered for repair, regardless of whether patients are 50 or 20 years of age.

Time from Tear to Surgery

Recent tears (less than 12 weeks) may have a better prognosis. Chronic bucket-handle tears may be difficult to reduce and to repair properly without over-tensioning the sutures to the capsule.

Anatomical Results

Assessment of Meniscal Healing Process

Several studies have reported on the accuracy of MRI, arthro CT and arthro MRI in determining the size of the meniscus, especially for allograft matching in meniscus transplantation [9, 14, 15, 40]. The sensitivity and specificity of spiral arthro CT for the detection of primary meniscal tears are 97 and 90%, respectively [50, 51]. After partial meniscectomy, the sensitivity and specificity for the detection of postoperative meniscal tears are 100 and 78%, respectively [31]. To our knowledge, few studies have reported on the accuracy of arthro CT for the evaluation of repaired menisci, and this has been extrapolated from validated data reported for arthrography [16, 17]. Many authors have found conventional MRI to be unsuitable and unreliable for documenting the healing process of a repaired meniscus [2, 13]. Further comparative studies are needed to assess the accuracy of arthro MRI in the follow-up of the repaired meniscus [28].

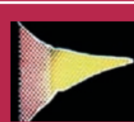
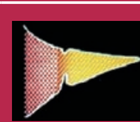
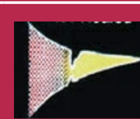
The healing status of repaired menisci can be assessed by second-look arthroscopy, arthrography, arthro CT or arthro MRI. We performed a retrospective, systematic review of the current literature to identify studies describing anatomical outcomes of meniscal repairs (Table 6.3.2). Complete healing was reported in 42–88% of cases.

In studies with arthroscopic second look to assess healing, complete healing was found in 73–88% of cases. In studies with arthrographic or arthro CT assessment of healing, complete healing was found in 45–59% of cases. Despite similar surgical procedures, there is a discrepancy between arthrographic and arthroscopic findings.

Healing Process and Clinical Outcomes

Clinical outcomes of arthroscopic meniscal repair vary considerably, from 70 to 94% good to excellent results

Table 6.3.2 Literature review: anatomical healing after meniscal repair (Henning's criteria)

Anatomical control	Author	N	Results (%)		
			Healed (%)	Healing rate >50%	Healing rate <50%
					
Arthroscopy	Horibe et al. [19]	132	73	17	10
	Asahina et al. [4]	98	74	13	12
	Horibe et al. [18]	36	75	11	14
	Kurosaka [24]	114	79		21
	Ahn et al. [1]	32	82		18
Arthrography	Henning et al. [17]	81	71	20	9
Arthroscopy or arthrography	Scott et al. [39]	178	73	13.5	13.5
			59	18	23
	Cannon and Vittori [7]	69	88		12
		21	62		38
Arthroscopy (15) Arthrography (41)	van Trommel et al. [49]	56	45	32	23
Arthro CT	Beaufils and Cassard [6]	62	42	31	27
	Pujol et al. [33]	54	58	24	18

[8, 11, 20–22, 37, 47, 52]. Morgan et al. [30] reported 84% asymptomatic patients after meniscal repair, of whom 65% had healed and 19% incompletely healed. The failure rate was 16%. All failures were symptomatic, while all healed and incompletely healed menisci were asymptomatic. Cannon and Vittori [7] found 50% of incompletely healed tears to be asymptomatic at more than 6 months after surgery.

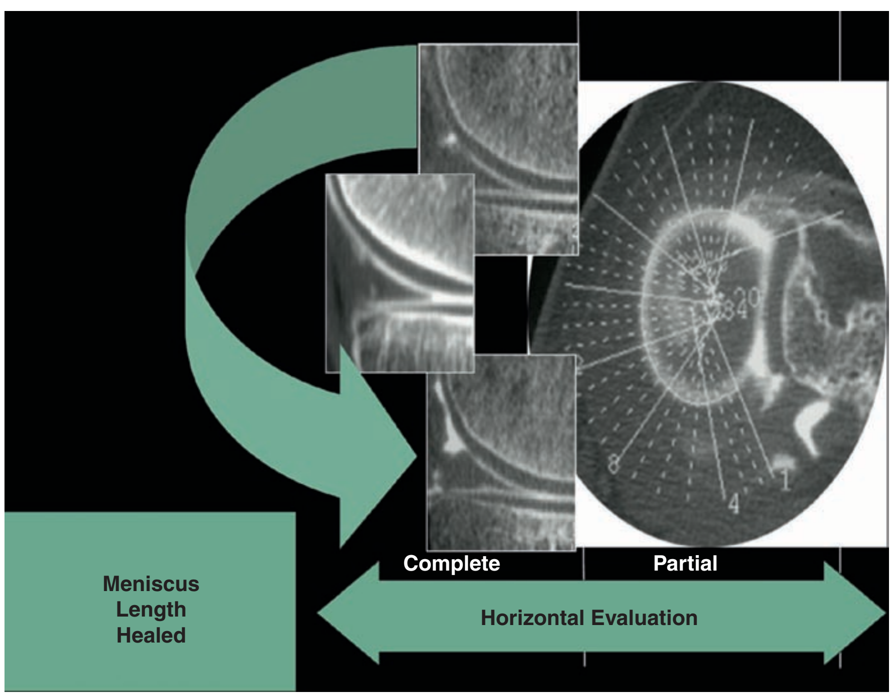


Fig. 6.3.2 Arthro CT axial reconstructions to assess healing by segments, and global or longitudinal healing rate of the tear (after O Charrois)

In a prospective study, including clinical and anatomical assessments, we evaluated 53 arthroscopic all-inside meniscal repairs [33]. Patients were pre-operatively assessed with MRI. Clinical evaluation included IKDC scores before and 6 and 12 months after the procedure. According to the objective IKDC score, 26 patients were graded A, 20 B and 4 C (92% good results). The mean subjective IKDC score was 78.9 (SD, 16.2). According to Henning's criteria, 58% of the menisci healed completely, 24% partially and 18% failed. The overall healing rate was 73.1% (SD, 38.5).

When comparing anatomical and subjective results, we found a correlation between the longitudinal healing rate and the subjective IKDC score ($p<0.03$, $r^2=0.44$). The overall or longitudinal healing rate was calculated for the entire length of the tear with radial reconstructed images, perpendicular to the longitudinal axis of the meniscus (Fig. 6.3.2).

Twenty tears located in the posterior part had a healing rate of 59.8% (SD, 46.0), and 19 tears extending from the posterior to the middle part had a healing rate of 79.2% (SD, 28.2). Isolated tears located in the posterior part had a lower healing rate ($p<0.05$).

Healing rates by zones or segments were also reported by van Trommel et al. [49] in a retrospective study of 51 patients in whom the outside-in technique was used. The evaluation was performed either by second-look arthroscopy, arthrography or MRI. As in our series, poor healing of the posterior third of the meniscus was observed, probably because of the difficulty to perform perpendicular sutures into the posterior segment with an outside-in technique. In our study [33], with current all-inside devices and perpendicular fixation, the healing rate of the posterior segment remained low. We hypothesized that abrasion of the posterior segment is difficult to perform properly by standard anterior arthroscopic approaches. Henning et al. were the first to point out the importance of meniscal abrasion to promote healing [39]. Other methods have been proposed, including trephinations, fibrin clot augmentation, periosteal flaps, and growth factors [3, 44].

The optimal conditions for good healing are difficult to obtain. It may be easier when a posterior arthroscopic portal is used.

Meniscal Shortening

Reduction in meniscal width has already been reported after meniscectomy on MRI and arthroscopic follow-up examinations [43]. We demonstrated significant meniscal shortening (between 10 and 15%) of the repaired middle segments for both menisci, and for the posterior segment of the medial meniscus, (Fig. 6.3.3) [33]. It could not be established yet whether this was

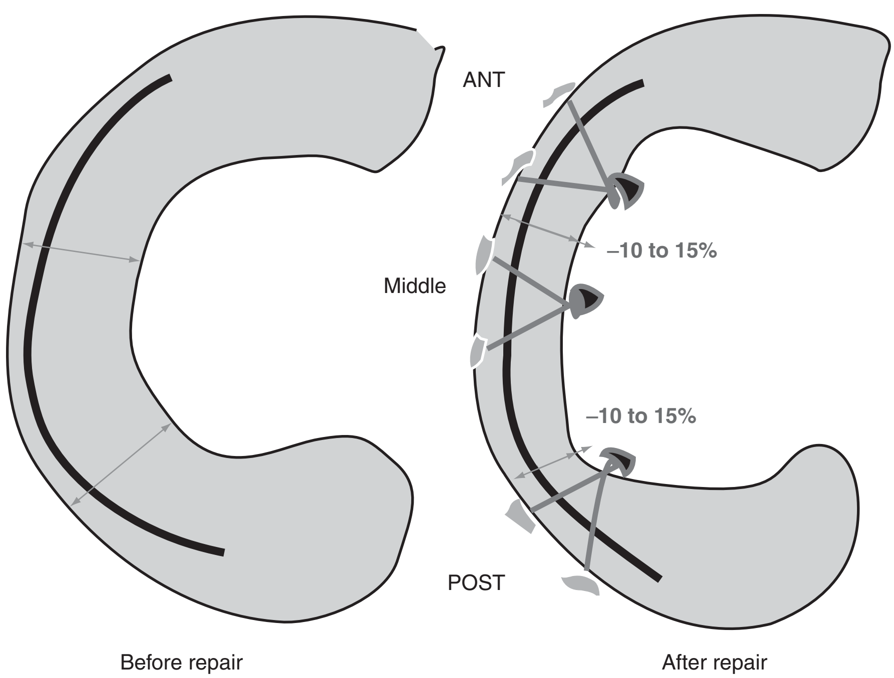


Fig. 6.3.3 Meniscal narrowing after repair

due to meniscal abrasion, suture tightening, or the shrinkage effect of the healing process. Importantly, there was a significant correlation between the rate of shortening and the healing rate, and the best clinical outcomes were obtained in shortened and healed menisci (Figs. 6.3.4 and 6.3.5).

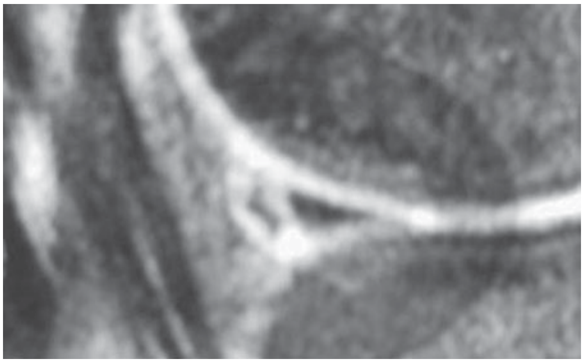


Fig. 6.3.4 Pre-op MRI: complex meniscal tear located in the red–red zone

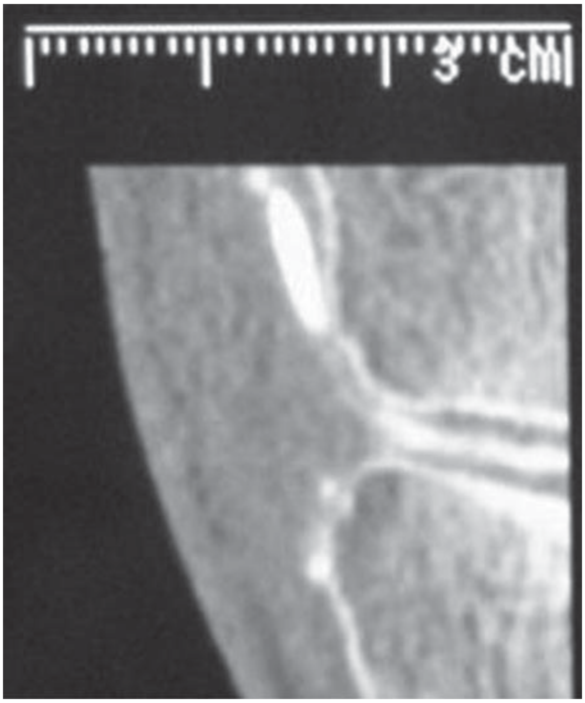


Fig. 6.3.5 Post-op Arthro CT 6 months after repair: complete meniscal healing, but meniscal shortening

Secondary Arthritis

Comparative studies on the incidence of arthritis in repaired menisci vs. meniscectomized knees are scarce. Rockborn and Messner [37] retrospectively compared a consecutive series of 30 patients with open meniscus repair to 30 patients who had undergone arthroscopic partial or subtotal meniscectomy. The groups were matched for sex, age, meniscus lesion and follow-up time. Three patients (10%) with initial repair and 8 (27%) with meniscectomy had minor joint space reduction, but no patient had more severe radiographic changes. After 7 years joint space reduction was more common after initial meniscectomy than after repair ($p<0.05$). After 13 years, the incidence and severity of osteoarthritis did not differ significantly between the two groups, even when only the successful repairs were compared to meniscectomy ($p=0.06$).

In other studies, evaluation of bilateral standing radiographs using Fairbank's classification revealed that, after 10 years, 8–13% of the operated knees had minimal joint changes, as compared to 3–5% of the contralateral, non-operated knees [8, 11, 20–22, 37, 47, 52].

In 2003, at the French Arthroscopic Society symposium, 11% of degenerative changes were reported at a mean follow-up of 4 years in a retrospective study of 203 repaired menisci [6].

Conclusion

Preserving as much of the meniscus as possible is crucial, especially in young patients.

Meniscal function is an integral part of knee function and is related to the integrity of ligaments and cartilage.

It is widely accepted that removal of the fibrous tissue at the tear site and meniscal abrasion, combined with a stable fixation with non-absorbable sutures or devices, are key to reliable techniques of meniscal repair.

Clinical results of meniscal repair are good to excellent in more than 80% of cases. Results are slightly better on the lateral than on the medial side, both in terms of clinical outcome (function and subsequent meniscectomy) and healing rate.

Despite a continual advancement of techniques during the past two decades, the posterior segment healing rate remains lower than that of the anterior and the middle segments, especially for isolated posterior tears of the medial meniscus. This could be due to the lack of abrasion of the tear and the technical difficulty inherent in this procedure. It may be achieved by using a posterior arthroscopic portal, making it possible to rasp and abrase the tear with more accuracy.

Moreover, meniscal repair reduces the tear to a narrower, more stable configuration, with 58% of complete healing. We are unable to say whether incompletely healed menisci continue to function as a load distributor protecting the articular surfaces.

The healing rate is correlated to the subjective outcome. More than obtaining a stabilized meniscal tear after repair, the goal is to achieve maximal healing.

In addition, the width of the repaired meniscus is decreased by 10–15%. This reduction in width is not large, but it seems to be correlated to the healing rate and the subjective functional result. Does a narrowed but completely healed meniscus protect the cartilage from degenerative changes?

Additional studies with a long-term follow-up are recommended to elucidate these questions.

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Part VII

Indications: Adults

7.1 Traumatic Meniscal Lesions in a Stable Knee: Masterly Neglect, Meniscectomy, Repair

K. F. Almqvist, P. Vansintjan, P. Verdonk, and R. Verdonk

Introduction

Over the years, the treatment of meniscal lesions has evolved greatly. Numerous treatment options are available, ranging from conservative treatment to (sub)total meniscectomy and meniscal repair. Before making any treatment decision, it is essential to understand the function and the healing potential of the menisci in the knee joint.

The peripheral meniscal blood supply is a key to healing (Fig. 7.1.1). It is capable of producing a healing response similar to that in other connective tissues [2, 5, 9, 18, 20, 42].

Most studies of meniscal healing have focused on vertical and longitudinal tear types [1, 3, 4, 13, 18, 22, 23, 27, 29, 33, 35]. Radial tears extending to the synovium heal in a similar fashion [29], but may not perform adequately from a biomechanical standpoint. The ability to transmit load is not maintained [24].

A well-structured assessment of the patient and his/her symptoms is mandatory to identify the exact type of lesion and to select the proper treatment strategy.

Evaluation and Decision Making in the Treatment of a Traumatic Meniscus Tear

The menisci have a chondroprotective function in a loaded knee. It is essential that a meniscal lesion be diagnosed because it can lead to degenerative lesions of the knee.

The diagnosis of a traumatic meniscal tear is primarily based on history and physical examination, supplemented with imaging investigations if necessary.

History

Proper history taking is helpful in making an accurate diagnosis of a torn meniscus. A well-known causative mechanism is a flexion-external rotation trauma, resulting in a rupture of the medial meniscus. A bucket-handle tear is produced when the patient rises from a kneeling or squatting position. Obviously, other lesions might accompany or follow the initial trauma to the posterior

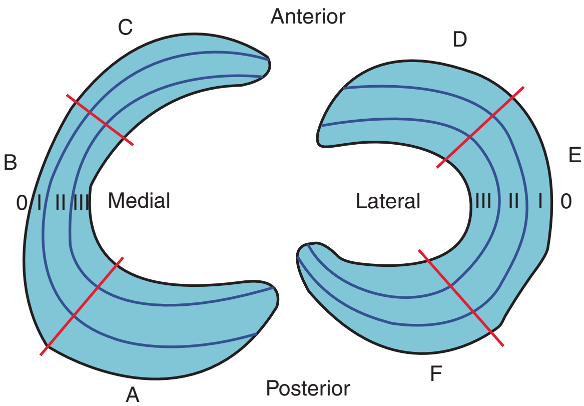

Fig. 7.1.1 Zone classification of the meniscus (modified from Cooper et al.). The most anterior zone of the medial meniscus is labeled C; the most anterior zone of the lateral meniscus is labeled D. *Zero* is the meniscosynovial junction; *I* is the outer third, *II* the middle third, and *III* the inner third of each meniscus. (Redrawn from Newman et al. [29])

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_7.1, © Springer-Verlag Berlin Heidelberg 2010

or anterior horn of the meniscus. The patient reports pain when rotational force is applied to the knee during specific meniscal tests [39].

Physical Examination

The clinical signs of a meniscal tear are not always uniform. The physical examination indicates whether the medial or the lateral meniscus has been injured. The medial meniscus is affected ten times more frequently than the lateral meniscus. The most obvious sign is pain at the joint line with compression. Multiple tests for diagnosing meniscal tears have been described [39].

Imaging

Imaging techniques such as double-contrast arthrography and computed tomography can be used to confirm the diagnosis, but have nowadays been largely replaced by magnetic resonance imaging (MRI) as the method of choice for diagnosing meniscal tears, with an accuracy of more than 90% [14, 26, 32].

Arthroscopy

Arthroscopy is not part of the diagnostic methods, but allows to confirm or adjust a diagnosis based on history, physical examination, and imaging techniques. It permits the surgeon to define the exact size of the lesion and to identify other lesions. Arthroscopy has entirely replaced open surgery for the treatment of meniscal tears.

Classification of the different types of meniscal tears is essential in planning the subsequent treatment. A frequently used classification is that devised by O'Connor [36], in which the following tear types are distinguished: (1) longitudinal tears; (2) horizontal tears; (3) oblique tears; (4) radial tears; and (5) variations, which include flap tears, complex tears, and degenerative meniscal tears [6] (Fig. 7.1.2).

Numerous other factors are also involved in making treatment decisions for a traumatic meniscal tear. The first goal always is to preserve as much viable tissue as possible. Other factors are location, length, tear pattern, stability of the tear, and any damage to the integrity of the meniscus body [11].

When conservative management is not feasible, arthroscopy is the method of choice for the treatment of a traumatic meniscal tear. It is essential to inform the patient about the postoperative consequences of the chosen treatment, with the rehabilitation period being short for meniscectomy, but much longer after repair. The final decision is always based on the intraoperative findings at arthroscopy, taking into account all of the previous parameters [39].

Indications for Treatment Options for Traumatic Tears in a Stable Knee

Conservative Treatment: Masterly neglect

After diagnosing a meniscal tear, the first decision the surgeon has to make is whether it should be treated surgically or left alone.

Cascells [8] showed that not all meniscal tears cause clinical symptoms.

Tears that surgeons should consider leaving alone are partial-thickness split tears and full-thickness but short (5 mm or less) vertical or oblique tears, if the inner portion of the meniscus is stable with probing. This also applies to short (5 mm or less) radial tears. Some smaller lesions can be treated conservatively, especially when the patient does not perform strenuous physical activities [39].

Short inner radial tears (<5 mm) usually do not heal, but can be left alone because they may be asymptomatic [12, 40]. Stable tears, defined as tears in which the central portion cannot be displaced more than 3 mm [40], can be left alone if they are less than 1 cm in length [4, 41]. Stable longitudinal tears in the peripheral two-thirds often can be left alone, particularly if they are less than 5 mm in length [12]. The same applies to less than 5 mm long partial-thickness tears of various types (especially longitudinal) [39].

In a recent review, Pujol and Beaufils found the conservative approach to be more effective for lateral menisci [31].

Some smaller lesions are asymptomatic and, when diagnosed at arthroscopy, can be left alone. Therefore, it is essential that the surgery be performed by the same

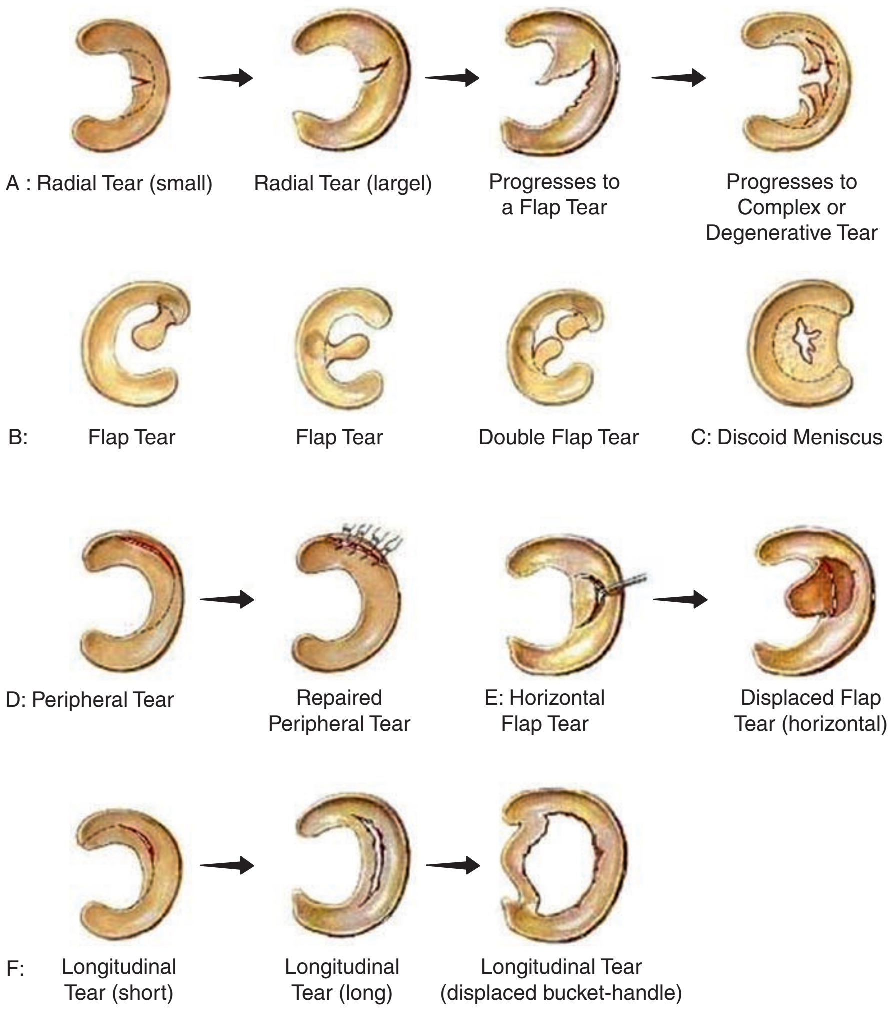

Fig. 7.1.2 Overview of the different types of meniscal tears. (Courtesy of G. Klaud Miller, 2/8/1999, http://www.jockdoc.ws/subs/meniscusrepair.htm)

surgeon who has diagnosed the lesion and has suggested the indication for surgery [39].

Surgical Treatment

When a meniscal tear becomes symptomatic, the decision can be made to treat it surgically. Different types of procedures have been used, from open total meniscectomy to arthroscopic, all-inside repair.

Meniscectomy

Symptomatic lesions in the avascular zone of the meniscus should be treated with meniscectomy [39] (Fig. 7.1.3).

(Sub)Total or Partial Meniscectomy

In the early days of meniscal surgery, little attention was paid to the preservation of healthy meniscal tissue. A tear in the meniscus was generally treated by total or subtotal meniscectomy. In 1948, Fairbank was the first to describe radiological changes in the knee following total meniscectomy, now known as Fairbank's changes (flattening of the femoral condyles, formation of peripheral ridges, and joint space narrowing) [15].

Roos et al. [34] compared knees of 123 patients who had undergone open total meniscectomy 21 years earlier, with normal knees of matched controls. They concluded that meniscectomy represented a significant risk factor for radiographic osteoarthritis of the knee, with the later appearance of degenerative changes being 14 times more likely in meniscectomized knees than in uninjured knees.

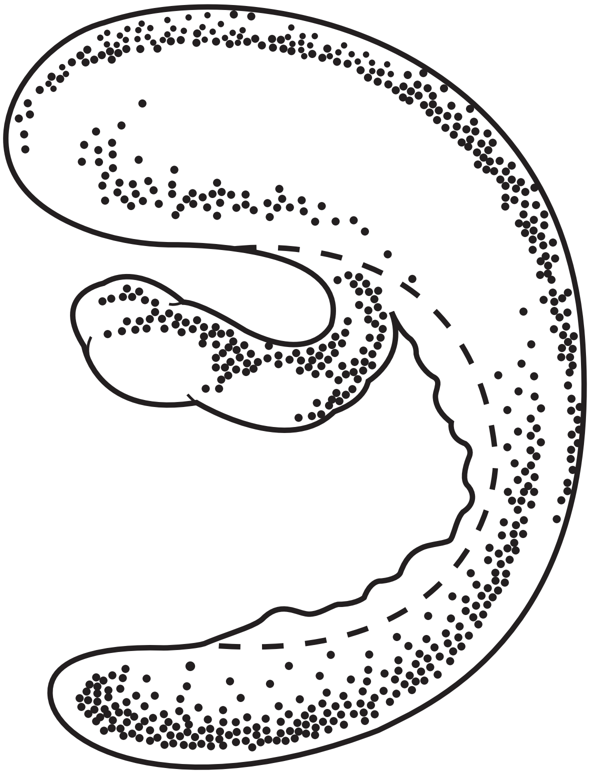

Fig. 7.1.3 Partial meniscectomy: tear in meniscus and area of resection. (Courtesy of www.hss.edu/conditions_14341.asp)

Literature reports had already shown the superiority of adequate partial resection of the meniscus to total meniscectomy [16, 17, 25, 30, 38].

These findings initiated a mentality change and surgeons, nowadays, always try to preserve as much meniscal tissue as possible [21].

Repair of Traumatic Tears

When faced with a torn meniscus, the question arises whether the damaged tissue can be repaired. In the last two decades, different techniques have been developed to repair some, not all, meniscal tears. In the early days, meniscal tears were repaired during an open procedure. Currently, arthroscopy is generally accepted to be the method of choice for repairing a meniscal lesion. The arthroscopic management strategies can be divided into three groups: the inside–out technique, the outside–in technique, and the all-inside technique.

Suitability and Indications for Repair

A thorough knowledge of the meniscus tear is necessary to determine its suitability for repair.

Besides the physical examination and the presence of associated lesions, the location is a critical factor. Only the peripheral third of the meniscus is sufficiently vascularized. DeHaven [11] considered tears within the peripheral third (3 mm) as vascular, 5 mm from the periphery as avascular, and between 3 and 5 mm as variable in vascularity. (Fig. 7.1.1) Current techniques allow some tears of the central and middle third to be repaired.

A more than 1 cm long tear in the vascular zone of the meniscus is an excellent indication for repair by suture [38] (Fig. 7.1.4).

The pattern, length, and stability of the tear are also important. With intact circumferential hoop fibers, the chance of healing is greater [29]. In general, radial tears are less amenable to repair. Complex bucket-handle tears with radial components, often seen in chronic cases, have more difficulty healing with repair than simple bucket-handle tears [4]. The same applies to oblique and horizontal tears. Longitudinal (vertical) tears in the periphery are most amenable to repair [3, 4, 29].

Any significant injury to the meniscus body, such as a complex tear, multiple cleavage tears, or change in the body contour, may compromise repair. Often, the structural integrity of the meniscus is damaged and vascularity may be impaired [11].

Some authors have reported better healing of acute vs. chronic tears [7, 20].

For the medial meniscus, repair of stable peripheral tears may always be indicated to decrease the risk of postoperative pain or subsequent meniscectomy [31].

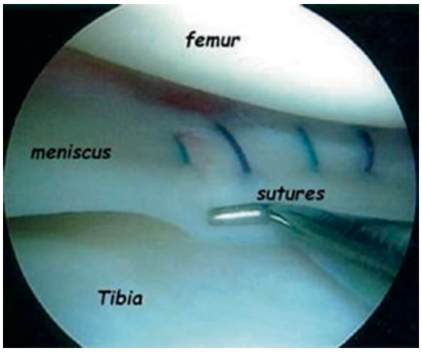

Fig. 7.1.4 Arthroscopic repair of a meniscal tear with sutures. (Courtesy of www.tarlowknee.com/.../knee-arthroscopy.php)

Table 7.1.1 Repair techniques and indications (Courtesy of Sgaglione [36])

Outside–in sutures	Anterior horn tears, midthird tears, radial tears, complex tears, reduction of bucket-handle tears
Inside–out sutures	Posterior horn tears, midthird tears, displaced bucket-handle tears, peripheral capsular tears, meniscal allografts
Fixator implants (first-generation devices)	Posterior horn tears, tears with >2–3 mm rim width, vertical/ longitudinal tears
Suture-based devices (second-generation devices)	Posterior horn tears, midthird tears, bucket-handle tears, radial tears

Sgaglione proposed the indications for the different repair techniques, as shown in Table 7.1.1 [36].

Conclusion

The diagnosis of a traumatic meniscal tear is primarily based on history and physical examination, sometimes supplemented with MRI if there remains uncertainty about the lesion. Classification of the different types of meniscal tears is essential in planning the subsequent treatment. The location in the red, red–white, or white zone is the principal determinant of the further management.

Since all meniscal tears do not cause symptoms, some smaller and asymptomatic lesions can be treated by conservative means, especially when the patient does not perform strenuous physical activities. The clinical observations should be correlated with the arthroscopic findings. Therefore, it is essential that the surgery be performed by the same surgeon who has diagnosed the lesion and has suggested the indication for surgery.

Symptomatic lesions in the avascular zone of the meniscus should be treated with partial meniscectomy, always trying to preserve as much healthy meniscal tissue as possible.

A wide variety of techniques exist to repair a torn meniscus. The pattern, length, and stability of the tear play important roles in the choice of the repair method. Tears in the vascular outer third are most amenable to repair with an inside–out, all-inside, or outside–in technique.

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Traumatic Lesions, ACL Knee: Masterly Neglect, Meniscectomy, Repair

7.2

O. Charrois, A. Podgorski, and P. Beaufils

Introduction

The menisci and the anterior cruciate ligament (ACL) are the main contributors to antero-posterior stability of the knee joint. Therefore, they are frequently damaged simultaneously as a result of a severe trauma. In a retrospective study of 156 cases, Gadeyne et al. [6] observed that 25.6% of medial meniscus lesions, 21.8% of lateral meniscus lesions and 9% of lesions of both menisci were associated with an ACL injury. Consequently, two questions need to be asked: firstly, does the co-existence of a meniscal lesion influence the indications for a ligament reconstruction, and secondly, does the co-existence of an ACL injury influence the indications for the treatment of a meniscal lesion?

Does the Co-Existence of a Meniscal Lesion Influence the Indications for an ACL Reconstruction?

Anterior instability of the knee joint is frequently associated with a meniscal lesion. Meniscal lesions can have two distinct origins. They can be caused by the initial trauma or be a consequence of chronic instability, combined or not with other pathological conditions (chondral damage, ligamentous elongation, etc.)

Indications for ACL Reconstruction in Case of a Co existent Meniscal Lesion and Modifications of the Procedure

ACL reconstruction has typical indications which are related to the patient's age and demands and the functional instability. Theoretically, the presence of a meniscal lesion could alter the choice of the type of reconstruction and the postoperative rehabilitation. When the indications for ACL reconstruction are debatable (low demands, age of the patient and absence of functional instability), the co existence of a meniscal lesion is in itself considered to be a drawback. The short-term functional results of meniscectomy in an unstable knee are worse than in a stable one [7], and arthritic deterioration is much more frequent [8]. An associated meniscectomy remains a negative factor for ACL reconstruction [4] and the long-term evolution of the joint [9, 11]. Therefore, it is imperative to spare as much of the meniscus as possible.

When meniscal repair is planned, joint stability has to be restored. Except for Sommerlath and Hamberg [16] who noticed only 11% of failures of meniscal repair in unstable knee joints, most of the authors agree about the high failure rate of repairs without ACL reconstruction. In a study conducted in 2003 and presented at the French Arthroscopy Society symposium [3], 145 meniscal repairs were performed on initially unstable knees, only 14 of which were left without reconstructing the ACL. The secondary meniscectomy rate in this sub-group was twice as high as when joint stability was also restored.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_7.2, © Springer-Verlag Berlin Heidelberg 2010

Type of ACL Graft

In the above-mentioned study [3], all the ACL reconstructions were single-bundle ones; a bone-patellar tendon-bone graft was used in 63% and a hamstring graft in 37% of cases. The type of the graft had no statistically significant influence on the failure rate of meniscal repair.

Association of a Lateral Peripheral Tenodesis: Double-Bundle ACL Reconstruction

An ACL injury leads to both anterior and rotatory instability. These two factors affect the evolution of the initial meniscal lesion and its ability to heal spontaneously or after surgical repair. While the results of single-bundle reconstruction in terms of restoring antero-posterior stability of the knee joint can accurately be evaluated by means of X-ray (Telos) or instrumental laximetry (KT100), the assessment of rotatory instability and its restoration using a single-bundle technique are more complex to achieve. The first proposal was to add a lateral tenodesis. However, when performed alone, this procedure has been found to lack effectiveness in protecting the menisci [11, 13]. Moreover, its use combined with a single-bundle reconstruction remains controversial [1], and any benefit for the menisci has never been demonstrated. Recent study**,** which focused on the anatomical and functional characteristics of the two bundles of the ACL, provided some interesting information on this subject [19]. The relevance of a double-bundle reconstruction and the particular indications for this procedure cannot be defined by preliminary evaluations of this technique [5, 15]. Its influence on the natural history of co existent meniscal lesions should be assessed and could lead to more specific indications for this technique.

Rehabilitation After ACL Reconstruction

A fast and effective post-operative rehabilitation protocol is essential to the functional outcome of ACL reconstruction. Can the co-existence of a meniscal lesion influence the rehabilitation protocol? In case of a meniscectomy, which does not require immobilization of the knee, the protocol remains unchanged. However, when a meniscal repair is associated, the question is whether to unload and/or immobilize the knee, as these measures are often proposed after repairs in stable knees. In a study presented at the French Arthroscopy Society symposium [3], the large variation in rehabilitation protocols precluded a statistical analysis. Nevertheless, the failure rate of meniscal repair in patients who completed a full rehabilitation programme after ACL reconstruction and who were allowed immediate weight bearing (37 cases) did not differ from the rate in the overall series. This is consistent with the current trend that considers ligamentoplasty to provide the necessary support for meniscal healing. This seems to be applicable to meniscal lesions which are judged to be stable during ACL reconstruction and for which no surgical repair is proposed. Pierre et al. [12] found this to be true for the lateral meniscus, as none of the 35 lateral meniscal lesions of different types that were left unrepaired during ligamentoplasty required additional surgery despite the institution of a standard rehabilitation programme.

Secondary Meniscal Lesions in an Unstable Knee

The occurrence of a meniscal lesion is part of the natural course of chronic instability of the knee and its treatment by meniscectomy negatively affects the articular evolution [9, 11]. A clinical and radiological assessment of the joint status is essential to determine if the meniscal lesion is isolated or associated with other ligamentous injuries or chondral defects.

The treatment of isolated meniscal lesions is the same as that of traumatic lesions and consists of ACL reconstruction and partial meniscectomy. Any distension of the collateral ligaments must be taken into account during ACL reconstruction.

In case of meniscal lesions, most of them being degenerative in nature and associated with serious chondral deterioration, the choice of the proper treatment is more complicated. If chondral degradation is limited (joint line narrowing not exceeding 50% of its width on radiographs taken both in extension and in the schuss position, sub-chondral bone not stripped), a repair can be considered and should be accompanied by ACL reconstruction. However, there may exist indications for a tibial osteotomy (when chondropathy is confined to the medial compartment and occurs in a genu varum) or even a meniscal replacement, because extensive meniscal lesions of this type are rarely reparable. When signs of knee osteoarthritis are already present, neither does ligamentous nor meniscal surgery seem to alter the progression of the disease. In that case, the treatment is essentially the same as for osteoarthritis in a stable knee and may consist of an osteotomy, viscosupplementation and, as a last resort, arthroplasty.

Occurrence of Meniscal Lesions in an ACL-Reconstructed Knee

When a meniscal lesion occurs in an ACL-reconstructed knee, the efficiency of the previous ligament surgery is questioned. Objective assessment of joint laxity (Telos or KT1000) is essential in order to determine if the meniscal lesion is caused by an additional trauma, which would impose the same indications for surgical treatment as in a stable knee, or if it occurred as a consequence of residual laxity. In the latter case, another ligament reconstruction procedure must be considered, especially if the meniscal lesion can be repaired.

Does the Co-Existence of a Ligamentous Lesion Influence the Indications for Meniscal Surgery?

A meniscal lesion cannot be addressed independently of the ligamentous status. Meniscectomy indeed worsens the prognosis of a ligament-deficient or reconstructed knee. Apart from that, meniscal healing is uncertain if the knee remains unstable.

Isolated or Associated Meniscectomy

As already mentioned, meniscectomy negatively affects the articular evolution in unstable knees and compromises the short and long-term results of ACL reconstruction [4, 9, 11]. Isolated meniscectomy should only be considered for symptomatic meniscal tears not amenable to either repair or masterly neglect.

Meniscal Repair

Meniscal repair is favoured because these longitudinal lesions can generally be more easily repaired. In a study presented at the French Arthroscopy Society symposium [3], it was pointed out that of 145 meniscal lesions of comparable size, those which occurred in unstable knees were more often vertical and peripheral than those in stable knees and were, thus, more likely to heal. The overall rate of secondary meniscectomy in ACL-reconstructed knees (25%) was comparable to the rate of repairs in stable knees (23%). An assessment of anatomical healing by arthro CT also demonstrated 25% of failures and showed a strong correlation between failures of meniscal healing and the meniscus involved, because there were 27% of secondary medial meniscectomies and no lateral ones. The other two prognostic factors were the size of the lesion and the technical difficulties during meniscal repair. It is hoped that improvements in surgical instrumentation will eventually lead to a better outcome.

Masterly Neglect

Because articular stability is crucial to meniscal healing, it can be questioned whether meniscal repair should be performed without associated ligament reconstruction. Literature data on this subject are scarce. Beaufils et al. [2] demonstrated that meniscal lesions left untreated may heal spontaneously. Pierre et al. [12] analysed the natural history of 95 stable meniscal lesions (less than 20 mm in length, non-displaceable when examined with an arthroscopic probe), which had been left unrepaired during ligament reconstruction surgery. None of the 35 lateral meniscal lesions required a secondary meniscectomy, whereas 17% of the 60 medial lesions did (Figs. 7.2.1 and 7.2.2). The main prognostic factor was the size of the lesion. Pujol and Beaufils [14] demonstrated in a systematic literature review that the risk of secondary meniscectomy was higher on the medial (0–33%) than

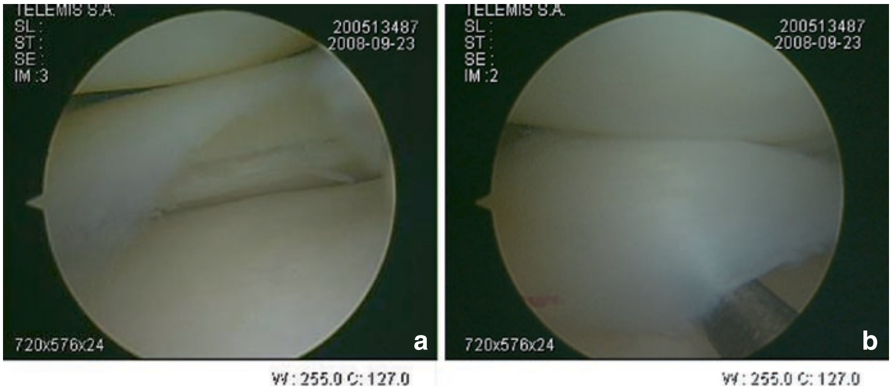

Fig. 7.2.1 (**a**, **b**) Lateral meniscus: typical vertical intra-substance lesion associated with ACL tear: this lesion can be left untreated

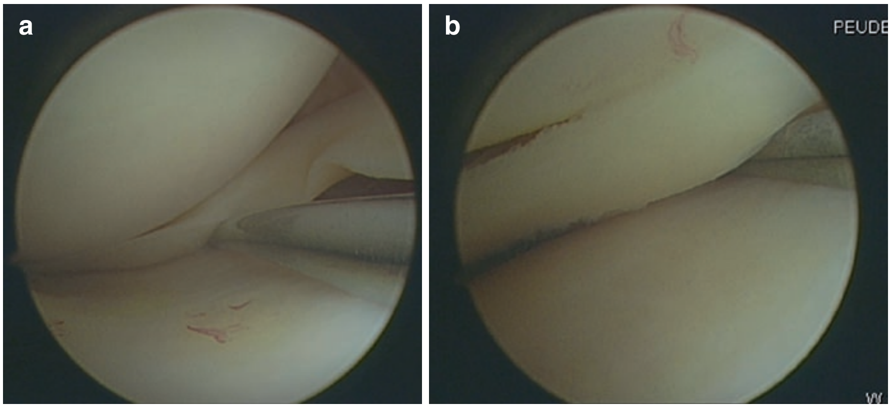

Fig. 7.2.2 (**a, b**) Medial meniscus: unstable vertical lesion of the posterior segment. This lesion should be repaired

Table 7.2.1 Systematic literature review – pre-operative data (Pujol et al.)

Author	Level of evidence	Year	*N*	Mean age at surgery	Meniscus	Time to surgery (months)	Comments
Weiss	IV	1989	32	25.4 (16–47)	L & M	–	80% ACL 20% stable knees
Beaufils	III	1992	31	27 (17–41)	L & M	–	
Fitzgibbons	IV	1995	189	22.4 (13–46)	L	–	
Talley	IV	2000	44	21.9 (13–49)	L & M	–	
Pierre	IV	2001	95	26 ± 1	L & M	24 (1–120)	
Shelbourne	IV	2001	372	23 ± 7.2	M	–	
Yagishita	IV	2004	83	25.4 (14–67)	L &M	–	
Zemanovic	IV	2004	31	28 (14–54)	L & M	18 (1–180)	
Shelbourne	IV	2004	239	22.6 (13–49)	L	–	
Lynch	IV	1983	31	20.1 (10–45)	L & M	40.8 (1–384)	

on the lateral side (0–22%) (Tables 7.2.1–7.2.3). These studies confirm that ligamentous reconstruction improves the healing potential of the lateral meniscus and that the apparent stability of a meniscal lesion is not sufficient to decide on repair or masterly neglect. Beaufils et al. [2] and Pierre et al. [12] advocate not to repair lateral or medial meniscal lesions smaller than 10 mm. Their point of view can, however, be challenged for two reasons. Firstly, we did not observe any distinctive morbidity when meniscal repair was

Table 7.2.2 Operative data and outcomes of medial meniscus tears left untreated

Author	*N*	Mean length of tear (mm)	Type of tear	Selection criteria for treatment	Follow-up (months)	Clinical assessment	Clinical score/100	Pain or mechanical symptoms (%)	Meniscectomy or repair (%)	Anatomical control	Healing	Procedure
Beaufils	23	8	Full thickness tear	Stable	26	Yes		17	0	Arthroscopy (2) or arthrography (11)	61% healing 38% partial healing 1% unhealed	Left untreated
Talley	19	<15	Full thickness tear	Stable	38			0	21	–	–	Left untreated
Pierre	60	9.8 ± 4 (5–20)	Full thickness tear	Stable <20 mm	48	IKDC	–	–	17	–	–	Left untreated
Yagishita	41	12 (5–25)	16 full thickness tears 25 partial thickness tears	Stable <15 mm	16 (7–41)	Yes	–	12	7.3	Arthroscopy	54% healed 7% partially healed 27% unhealed 12% tear extended	Left untreated
Zemanovic	8	–	Partial thickness tear	Partial thickness tear	24.6	Lysholm	92.1	–	0	–		Left untreated
Shelbourne	139	–	Full thickness tear	Stable >10 mm	88	Questionnaire	93.1	5	10.8	–	–	Left untreated
	233	–					95.4	4.3	6	–	–	Abrasion-trephination
Lynch	9	–	–	Stable	45.6 (36–120)	Yes	–	66	0	–	–	Left untreated
Weiss	6	–	Partial thickness tear	Partial thickness tear	21.8 (3–50)	Lysholm	–	0	33	Arthroscopy	50% healed 50% unhealed	Left untreated
	2	–	Full thickness tear	Stable	27.5 (25–30)			0	0		50% healed 50% unhealed	

Table 7.2.3 Operative data and outcomes of lateral meniscus tears left untreated

Author	*N*	Mean length of tear (mm)	Type of tear	Selection criteria for treatment	Mean follow-up (months)	Clinical assessment	Clinical score/100	Pain or mechanical symptoms(%) without treatment	Meniscectomy or repair (%)	Anatomical control	Healing	Procedure
Weiss	9	–	Partial thickness tear	Partial thickness tear	29 (6–79)	Lysholm	–	0	22	Arthroscopy	55% healed 22.5% unhealed 22.5% extended	Left untreated
	15	–	Full thickness tear	Stable	27.3 (6–100)			0	1.3		45.6% healed 40% unhealed 13.4% extended	
Talley	25	<15	Full thickness tear	Stable	38	Yes	–	0	4	–	–	Left untreated
Pierre	35	10±4 (5–20)	Full thickness tear	stable <20 mm	48	IKDC		–	0	–	–	Left untreated
Yagishita	42	10.8 (5–25)	18 partial thickness tears 24 full thickness tears	Stable <15 mm	18.3	Yes	–	7	7.1	Arthroscopy	74% healed 5% partially healed 14% unhealed 7% tear extended	Left untreated
Zemanovic	23	–	Partial thickness tear	Partial thickness tear	24.6	Lysholm	92.1	–	0	–	–	Left untreated
Shelbourne	239	–	Full thickness tear	Stable	79	No, yes	93.8	2.5	3.3	–	–	Left untreated/ abrasion-trephination
Fitzgibbons	189	–	Full and partial thickness tears	Stable	31.2	No, yes	92.2 (48–100)	0	0	–	–	Abrasion-trephination
Lynch	22	–	–	Stable	45.6 (36–120)	Yes	–	18	0	–	–	Left untreated
Beaufils	8	–	Full thickness tear	Stable	26 (12–40)	Yes	–	0	0	Arthroscopy (2) or arthrography (11)	61% healing 38% partial healing 1% unhealed	Left untreated

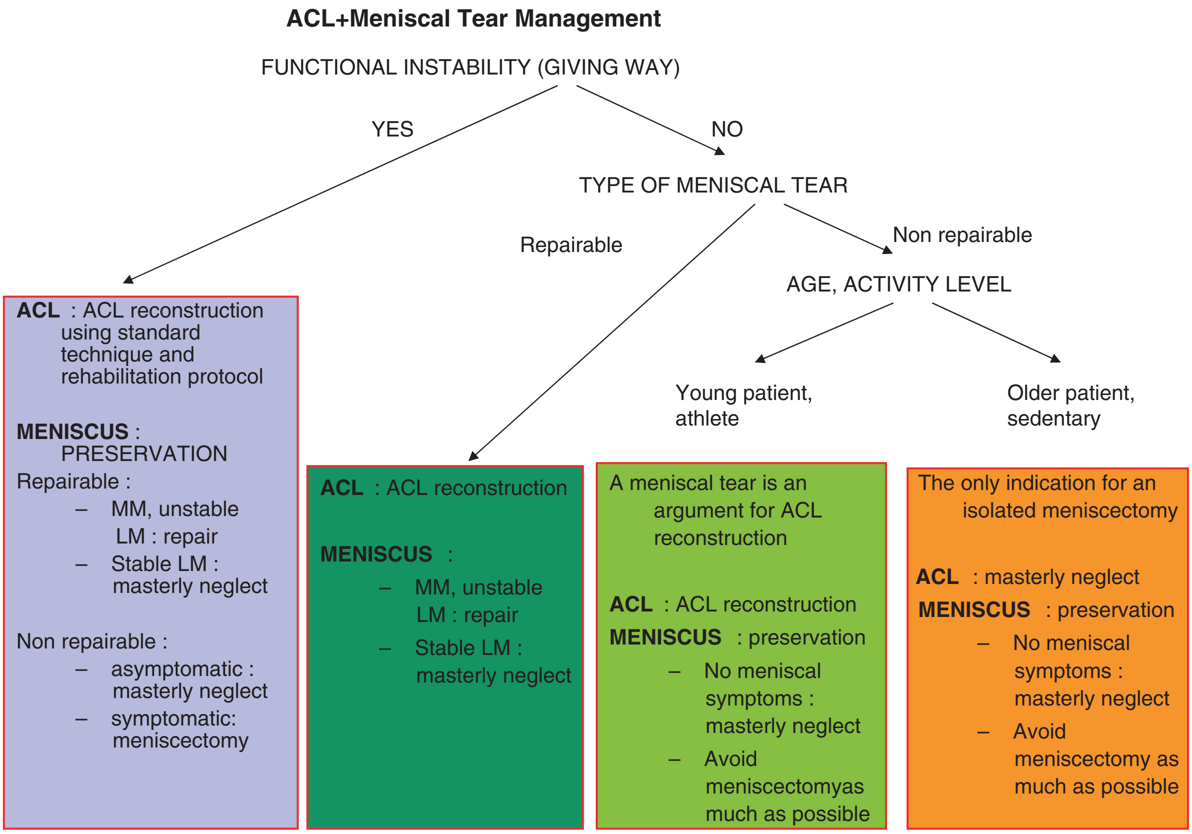

Fig. 7.2.3 Management of an ACL tear associated with a meniscal lesion

performed simultaneously with ACL reconstruction using hybrid devices which facilitate the repair and do not require a counter-incision. Secondly, good functional results and the absence of residual pain were found to be correlated with proper anatomical healing [3]. Therefore, we recommend [14] in association with ACL reconstruction, peripheral detachment of the medial meniscus and unstable tears of the lateral meniscus should always be repaired.

Meniscal Grafts and Substitutes

When a symptomatic meniscal lesion can neither be repaired nor left untreated, the possibility of its replacement with either a graft or a synthetic substitute can be considered in association with ligament reconstruction.

The use of cryopreserved [10, 17] or viable [18] allografts has already been proposed with encouraging results. However, the results of these retrospective studies do not allow to confirm that meniscal substitution compensates the negative effects of meniscectomy associated with ACL reconstruction on the evolution of the joint.

Conclusion

The menisci and the ACL are the key structures providing antero-posterior stability to the knee. This can explain why they are often injured simultaneously, either during the initial trauma or as a consequence of chronic instability.

The treatment of meniscal and ACL lesions is interrelated (Fig. 7.2.3). A literature review does not allow any formal conclusions because specific studies are extremely scarce. Nevertheless, it seems that when these two lesions co-exist, ACL reconstruction plays a key role in the healing of the meniscal lesion and its consequences for the natural history of the joint. The choice of the type of reconstruction does not need to be modified because of the co-existent meniscal lesion.

The rationale of the treatment is to preserve as much of the meniscus as possible, with meniscectomy being justified only if the meniscus cannot be repaired and the tear is symptomatic. When repair is feasible, it should be combined with an ACL reconstruction. The results are then comparable to those of meniscal repair performed on stable knees. When a meniscal lesion is a consequence of chronic instability, the status of the knee needs to be determined prior to performing a functional restoration or continuing with the treatment of an arthritic condition.

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Degenerative Meniscal Lesions in a Stable Knee

7.3

K. F. Almqvist, P. Vansintjan, P. Verdonk, Y. Bohu, P. Beaufils, and R. Verdonk

Introduction

The treatment of meniscal lesions has evolved greatly over the years. Different treatment options can be used, depending on the symptoms of the patient, the extent of the tear, the location in the meniscus, and many other factors.

The management and outcome of a meniscal lesion are very much dependent on the etiology (degenerative or traumatic) and classification of the tear. Traumatic tears have been described elsewhere. This section focuses on the indications for the different treatment options for a degenerative meniscal lesion in a stable knee, including meniscal cysts and meniscal repair of horizontal cleavage tears.

Evaluation and Decision Making in the Treatment of a Degenerative Meniscus Tear

Classification of the different types of meniscal tears is essential in planning the subsequent treatment. Numerous classifications exist, among which the one devised by O'Connor [21] has proved useful. The following tear types are distinguished: (1) longitudinal tears; (2) horizontal tears; (3) oblique tears; (4) radial tears; and (5) variations, which include flap tears, complex tears, and degenerative meniscal tears [4] (Fig. 7.3.1). Another classification of meniscal tears is presented in Fig. 7.3.2.

Degenerative meniscal tears are more common in chronic meniscal lesions and older degenerative menisci. They generally are caused by chronic, long-standing, altered mechanics of the meniscus, and the initial tear may not be identifiable. Degenerative tears often are very complex tears, mostly seen in older patients [4].

Comparable to traumatic lesions, a degenerative meniscal tear can lead to degenerative changes in the knee joint.

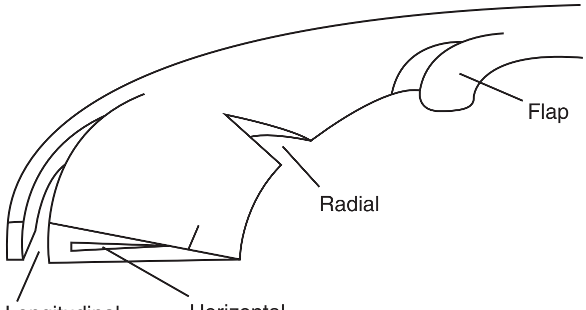

Fig. 7.3.1 Classification of meniscal tears. A longitudinal tear is a vertical tear in the meniscus with a longitudinal direction; it is usually located in the periphery of the meniscus. The longer the tear the more unstable it is, leading to dislocation of the central part of the meniscus – a bucket-handle tear. A horizontal tear is a horizontal cleavage in the meniscal tissue. A radial tear is a vertical tear starting in the free (central) margin of the meniscal tissue. A flap tear is an oblique vertical cleavage producing a flap (parrot beak). A flap tear may also be caused by a horizontal tear. A tear in a degenerative meniscus (not shown) is a tear or multiple tears in meniscal tissue with degenerative changes. (Courtesy of Englund et al. [9])

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_7.3, © Springer-Verlag Berlin Heidelberg 2010

The diagnosis of a degenerative meniscal tear is primarily based on history and physical examination, supplemented with different imaging investigations.

History

Patients presenting with degenerative lesions have no clear history of trauma. They mostly complain of chronic knee pain, swelling, and sometimes locking [24].

Physical Examination

Palpation, joint line compression, rotation with axial loading, and the different meniscal tests are helpful in diagnosing a degenerative tear [24].

Imaging

Conventional X-rays are useful in identifying degenerative meniscal lesions because of the chronic course of the pathology. Comparative standing, weightbearing anteroposterior, and lateral views, combined with a schuss view, are preferably obtained [24].

Single or double-contrast arthrography, computed tomography, and especially, magnetic resonance imaging (MRI) are valuable diagnostic adjuncts [7, 17, 19].

Meniscal cysts may develop from chronic medial or, more commonly, lateral degenerative meniscal tears. Cysts are relatively uncommon, with a frequency of about 1.5%. They can be palpated on physical examination and are most clearly visualized with MRI and during arthroscopic surgery [4] (Fig. 7.3.3).

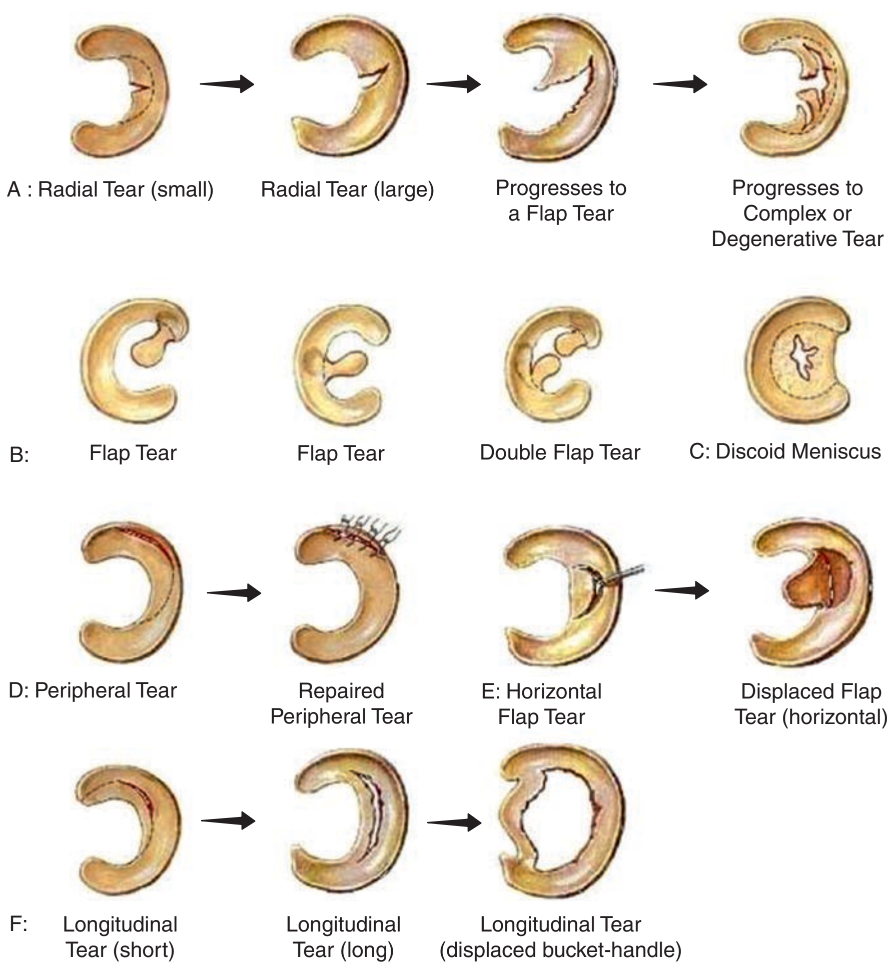

Fig. 7.3.2 Overview of the different types of meniscal tears. (Courtesy of Klaud Miller, 2/8/1999, http://www.jockdoc.ws/subs/meniscusrepair.htm)

Fig. 7.3.3 Meniscal cyst. A cystic structure is seen arising deep to the lateral collateral ligament (*arrow*), intimately related to the lateral meniscus. An oblique tear is seen through the meniscus confirming that this represents a meniscal cyst. (From: www.mdconsult.com; Adam: Grainger & Allison's Diagnostic Radiology, 5th ed, Chapter 50: Joint disease, Fig. 50.29)

Indications for Treatment Options for Degenerative Tears in a Stable Knee

Conservative Treatment- Masterly Neglect

Based on the findings of Herrlin et al., a nontraumatic, degenerative tear of the medial meniscus in middle-aged patients (45–65 years) can be considered as an indication for conservative treatment with an exercise program [13].

Meniscal cysts can be treated conservatively with injections or antiinflammatory drugs, but in most cases these measures only result in temporary relief of symptoms [4].

Surgical Treatment

When a degenerative tear is diagnosed preoperatively or observed at arthroscopic surgery, the same rule as for traumatic tears is applicable: to preserve as much viable tissue as possible. Obviously, patient age, degenerative changes (mucoid degeneration), concurrent intraarticular injuries, the integrity of the anterior cruciate ligament, and the chronicity of the tear should be taken into account.

Other factors are location, length, tear pattern, stability of the tear, and any damage to the integrity of the meniscus body [6].

Meniscectomy

In 1948, Fairbank was the first to describe radiological changes in the knee joint (flattening of the femoral condyles, formation of peripheral ridges, and joint space narrowing) following total meniscectomy [10]. Roos et al. concluded that meniscectomy represented a significant risk factor for radiographic osteoarthritis of the knee, with the later appearance of degenerative changes being 14 times more likely in meniscectomized knees than in uninjured knees [20]. Ever since, orthopedic surgeons have tried to preserve as much healthy meniscal tissue as possible [10, 14].

Partial meniscectomy is the treatment of choice for degenerative meniscal tears. Chronically deformed or degenerative menisci are no good candidates for repair [4].

Studies have shown that partial meniscectomy is superior to total meniscectomy, because it causes less secondary degeneration of the knee [11, 16, 18, 23].

Degenerative lesions have a worse outcome compared to traumatic lesions [8]. Patients with repaired degenerative tears have significantly lower subjective scores than those with nondegenerative tears [22].

Therefore, different authors advocate minimal meniscal resection for the treatment of degenerative tears [9].

Repair

Any significant injury to the meniscus body, such as a complex tear, multiple cleavage tears, change in the body contour, or degenerative tearing, may compromise repair. Often, the structural integrity of the meniscus is damaged and vascularity may be impaired [6].

Complex bucket-handle tears with radial components, often seen in chronic cases, have more difficulty healing with repair than simple bucket-handle tears [1].

Degenerative tears are difficult to hold with repair material. The degenerative portion should be debrided and repair attempted depending on the type of tear and age of the patient. Chronicity also plays a role in the amount of degenerative change present and the complexity of the tear [4, 15].

Some authors have reported better healing of acute vs. chronic tears [5, 12].

Horizontal Tears

Usually, repair of degenerative meniscus tears is impossible or very difficult, with poor results. However, for intrasubstance horizontal cleavage tears (grade 2 or grade 3) in young active patients with a stable knee, repair may be indicated using an open technique as described by Biedert [2, 3] (Fig. 7.3.4). Bohu and Beaufils also use this technique and start with an arthroscopic inspection of the knee joint followed by an open approach through a posteromedial or posterolateral arthrotomy (Fig. 7.3.5). If at arthroscopy a grade 3 horizontal tear is found with an unstable flap, the latter is resected. During the arthrotomy the meniscal rim is dissected, and the torn meniscus is refreshed with small curettes (Fig.7.3.6) and repaired with bioresorbable stitches (PDS), placed perpendicular to the meniscal cleavage tear (Fig. 7.3.7). Any associated meniscal cyst is excised (71%) (Fig. 7.3.8). Their series included 28 patients (30 operated knees) with grade 2 (52%) and grade 3 (48%) horizontal meniscal lesions, with a medial to lateral meniscus ratio of 2:1. All the knees were stable and the patients had been symptomatic for at least 6 months prior to surgery. At 47.2 months of follow-up, only four patients had a failure of the meniscal repair after a complex tear, and subsequently underwent meniscectomy. Twenty-one operated knees were assessed (6 women and 13 men), 7 of them being competitive athletes. Twenty patients resumed their sports activities and 16 patients were satisfied or very

Fig. 7.3.5 Posteromedial approach: the posterior segment of the meniscus is detached from the synovial wall, allowing to expose the meniscal rim with the horizontal cleavage tear

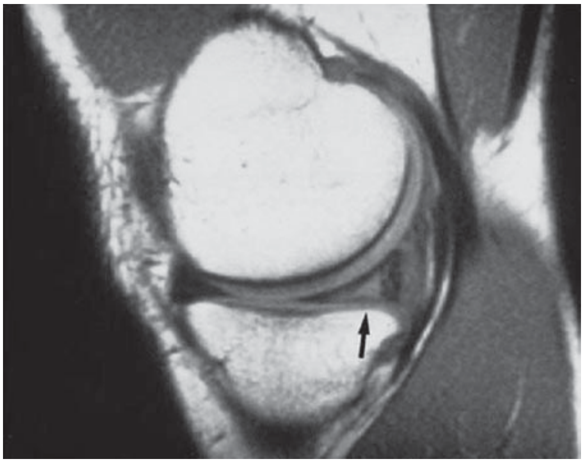

Fig. 7.3.4 Horizontal intrasubstance meniscal lesion on the medial side (*arrow*). (Courtesy of Biedert [3])

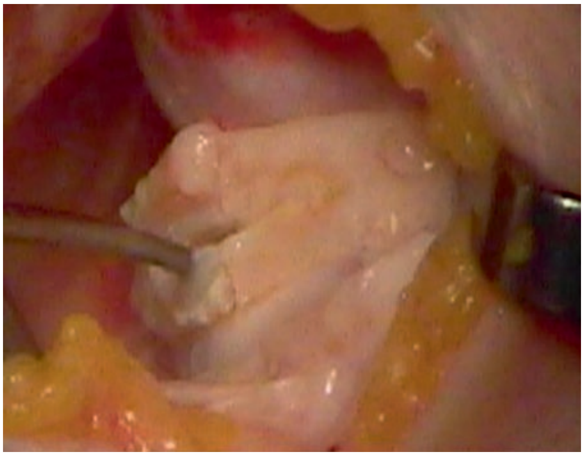

Fig. 7.3.6 View of a horizontal meniscal lesion after posteromedial arthrotomy

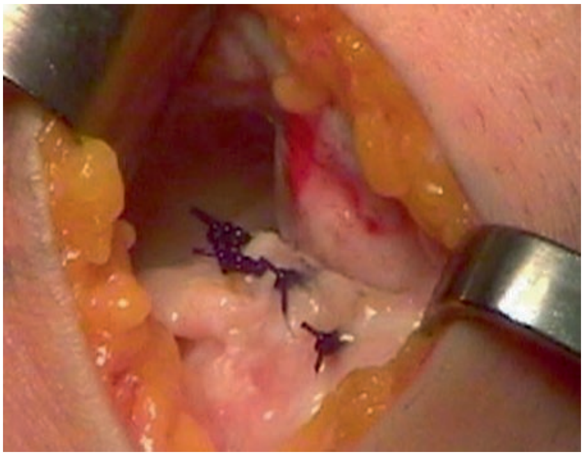

Fig. 7.3.7 Sutures applied perpendicular to the plane of the meniscal tear

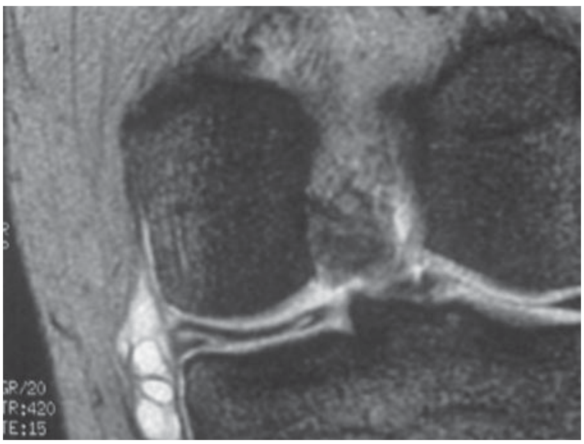

Fig. 7.3.8 Cyst associated with a medial meniscal horizontal lesion

satisfied. The Knee Injury and Osteoarthritis Outcome Score (KOOS) was 87.8%, with 100% representing the best result. Results for the items pain, symptoms, and activities of daily living were good: 89.7, 86.8, and 93.9%, respectively. The items sport/recreation function and knee-related quality of life scored 76.1 and 74.6%, respectively. The International Knee Documentation Committee (IKDC) subjective score was 82.4%. For the items symptoms, sport activities, and function of the knee, the scores were 75.5, 88.5, and 79.7%, respectively. For all items (KOOS and IKDC), results were better in patients under 30 years of age: 94 and 89.6%, respectively.

Meniscal Cysts

Meniscal cysts are good candidates for arthroscopic partial meniscectomy and decompression or excision. The site of the cyst can usually be delineated intraarticularly by probing the meniscal tear fragments and passing through the meniscal body into the central portion of the cyst. The cyst can then be curetted and, with external digital palpation, be compressed into the joint [4]. Cysts usually occur simultaneously with or following a degenerative or complex tear. This might require a large portion of the meniscus to be resected at the same time [4].

Conclusion

Degenerative tears often are very complex tears, mostly seen in older patients. Patients present with a chronically painful knee and the initial mechanism of injury is usually not traceable. The diagnosis of a chronic degenerative meniscal lesion is based on the physical examination supplemented with MRI. Plain X-rays can be used for the evaluation of degenerative knee joint changes. Degenerative lesions are sometimes accompanied by a meniscal cyst, which is most frequently seen in the lateral meniscus.

Partial meniscectomy, with the intent to retain as much healthy meniscal tissue as possible, is the preferred treatment option. Meniscal cysts are a good indication for arthroscopy with decompression or resection of the cyst, usually with concurrent partial meniscectomy. Repair is often not indicated because degenerative lesions are very difficult to hold with the repair material. However, for intrasubstance horizontal cleavage tears (grade 2 or grade 3) in young active patients with a stable knee, repair may be indicated using an open technique.

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Lavage, Debridement, and Osteoarthritis

7.4

N. Pujol and P. Boisrenoult

Introduction

There are many medical and surgical modalities for treating OA, one of which is arthroscopy. Main challenge of a surgeon is to identify those patients who are likely to benefit from arthroscopic treatment and who are not. The first step is to make a correct diagnosis in order to identify the source of pain. Physical examination, standard X-rays, and MRI are useful.

When medical treatment fails to be successful for at least 6 months, surgery may be recommended.

This chapter discusses the diagnostic criteria and reviews the literature on the most common medical treatment modalities and the usefulness of arthroscopy in the management of a painful osteoarthritic knee.

Diagnosis

The cause of knee pain in patients with OA is unclear and probably multifactorial. Pain could stem from bone, synovium, and meniscus. The main goal of the diagnosis is to identify the precise source of pain in an osteoarthritic knee.

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Meniscal Extrusion (Fig. 7.4.1)

Meniscal extrusion is defined as a more than 3-mm peripheral displacement of the middle segment of the meniscus on coronal MRI views. This feature has been strongly correlated to knee OA [6, 9, 13, 16, 18]. A recent prospective study of 205 MRIs reported a strong correlation between meniscal extrusion and the presence of osteophytes or chondral lesions [18]. Another comparative study of 291 cases found meniscal extrusion to be associated with symptomatic knee OA [13]. Meniscal extrusion may be one of the first signs of OA, due to a loss of meniscal function, appearing before cartilage thinning [6, 9, 16].

Fig. 7.4.1 Bone marrow edema and medial meniscal extrusion

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_7.4, © Springer-Verlag Berlin Heidelberg 2010

Bone Marrow Edema

A cross-sectional study was performed of 410 patients (mean age 67 years) with radiographic evidence of knee OA, associated with or without pain [10]. On MRI, bone marrow lesions were found in 272 of 351 painful knees compared to 15 of 50 asymptomatic knees ($p<0.001$). Large lesions were present almost exclusively in patients with knee pain. The severity of bone marrow lesions was not associated with pain severity, suggesting that such pain stems from many other causes [10, 25].

Effusion, Synovial Hypertrophy

A similar study by the same authors assessed the association of joint effusion and synovial hypertrophy with knee symptoms in 381 patients (mean age 67 years) with or without OA, using MRI [14].

Significant effusion and synovial thickening were more frequent in patients with knee pain and OA ($p<0.01$). Synovial thickening was also associated with the severity of pain ($p<0.01$).

Degenerative Meniscal Tear: Symptomatic or Not?

A cohort study of 100 patients referred for suspected degenerative meniscal tears assessed the prevalence of meniscal abnormalities on MRI performed on symptomatic and contralateral asymptomatic knees [25]. Meniscal tears were found in 57 symptomatic and 36 asymptomatic knees. Horizontal medial meniscal tears were found in 32 symptomatic knees and 29 asymptomatic knees. In this study, bone marrow edema and pericapsular soft-tissue abnormalities were most prevalent in symptomatic knees. Radial, complex, and displaced meniscal tears were mostly symptomatic.

In a comparative study by Bhattacharyya et al. [4] of 154 patients with OA (mean age 53 years), the prevalence of meniscal tears was found to be 76% in asymptomatic patients and 91% in symptomatic patients ($p<0.005$). The OA grade was correlated with a higher frequency of meniscal tears. Within the symptomatic OA group, there was no significant difference in pain or subjective scores between patients with or without meniscal tears.

The role of a degenerative meniscus tear in the causation of symptoms among patients with OA is questioned.

Joint space narrowing needs to be radiographically assessed, and an MRI scan be performed to look for bone marrow edema, synovial hypertrophy, meniscal tear, or extrusion, in order to determine the cause of knee pain.

Medical Treatment

Invasive treatment must not be performed until various medical treatments for knee OA have proved to be unsuccessful.

Manual Physical Therapy and Exercise

Few authors have reported on the effectiveness of manual physical therapy and exercise in the treatment of OA of the knee.

In a randomized controlled trial, Deyle et al. [8] randomly assigned 83 patients (mean age 61 years) with grade 1–3 knee OA to receive either physical therapy or placebo. At 1 year, patients treated with physical therapy had clinically and statistically significant improvements in subjective scores and walking distance. In similar trials of exercise programs for OA, dropout rates from 10 to 52% have been reported [11, 17].

Hyaluronic Acid/Steroids

Forster and Straw compared intraarticular hyaluronic acid and arthroscopic lavage for osteoarthritic knees [12]. Thirty-eight patients were randomized into either arthroscopic lavage or medical treatment consisting of five intraarticular injections of hyaluronic acid. Patients with mechanical symptoms were excluded from the study. At 1 year after the procedure, there was no difference between the two groups.

From a Cochrane literature review [2], it was concluded that only the short-term benefits (2–4 weeks) of intraarticular corticosteroids in the treatment of knee OA are well established. The response to hyaluronic acid appeared more durable (14–26 weeks), but no difference in efficacy was found at 45–52 weeks. There was no difference between joint lavage and intraarticular corticosteroids.

According to these studies, exhaustive functional and medical treatment should be tried prior to any surgical procedure.

Arthroscopic Lavage-Debridement-Meniscectomy-Chondroplasty

Surgical Technique (*Fig. 7.4.2*)

Lavage

Several arthroscopic procedures for the treatment of osteoarthritic knees, ranging from simple lavage to formal abrasion arthroplasty, have been described.

The simplest arthroscopic treatment of OA is lavage, i.e., intraarticular irrigation with a saline solution, a simple washout. Dawes et al. performed an observer-blinded, randomized controlled trial comparing lavage with 2 L of saline to injection of 10 mL of saline in 20 patients [7]. The improvement in pain and function seen in both groups decreased at 12 weeks.

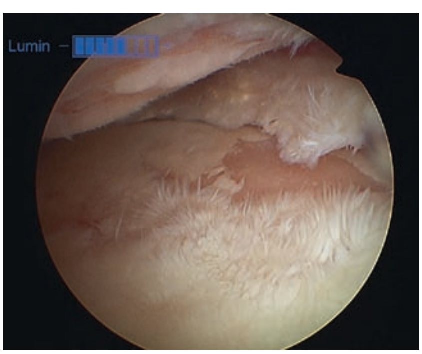

Fig. 7.4.2 Stage IV OA on the tibial side

Debridement

Arthroscopic debridement aims at removing all unstable lesions: loose articular cartilage, chondral flaps, unstable torn menisci, osteophytes, and proliferative synovium. Chang et al. compared lavage with a saline solution to standard arthroscopic debridement and did not find any difference at three and 12 months [5].

The role of resection of degenerative meniscal tears with coexistent articular wear is more controversial and will be discussed later.

Abrasion Arthroplasty

Abrasion arthroplasty involves superficial abrasion of sclerotic articular lesions.

It was first described by Johnson in 1986 [15]. Bert and Maschka reported good results at 5 years of follow-up in 66% of knees treated with debridement alone, compared to 51% of knees treated with debridement and abrasion [3]. At a mean follow-up of 3.8 years, Rand [23] found that the 131 patients who had been managed with simple debridement had better results than the 22 who had undergone abrasion arthroplasty. Fifty-four percent of the patients required a total knee arthroplasty within 4 years. These two retrospective studies with, control groups, evaluated the value of abrasion, and the authors advised against this procedure.

Arthroscopic abrasion chondroplasty is currently not recommended for the management of OA.

Level One Study

Moseley et al. (21) randomly assigned 180 patients (mean age 52 years) with OA of the knee to undergo arthroscopic debridement, arthroscopic lavage, or placebo surgery. Patients in the placebo group received skin incisions and underwent a simulated debridement without insertion of the arthroscope. The mean follow-up was 24 months.

Subjective results including pain and walking ability were not statistically different between subgroups.

Although this is the only Level I study available in the literature, some details require critical evaluation. Of the 324 consecutive patients, 144 declined to participate in the study (44%). No stratification of results by grade of OA was performed. Moreover, a reevaluation of power calculation showed a power range between 14 and 70% for various equivalence factors in the study. All were below a level necessary to claim equivalence (80%) [22].

Other Studies: Review

It is difficult to compare studies because of differences in study design, patient selection criteria, type of procedure, and outcome measures.

In 2007, Siparsky et al. [24] systematically reviewed the literature on arthroscopic treatment of OA of the knee, which yielded 18 relevant studies (1 level I, 5 level II, 6 level III, and 6 level IV studies). They found limited evidence-based research to support the use of arthroscopy as a treatment method for OA of the knee.

Patient Selection for Arthroscopic Debridement

Grade of OA

Matsusue et al. [20] stratified results of meniscus tear debridement by grade of degenerative change and observed worse results with advancing grades of OA. While patients with grade I or II degenerative changes had 87% good results, this dropped to only 7% in case of grade III or IV changes. According to Aaron et al. [1], partial resection of meniscus lesions does not predict the outcome of arthroscopic debridement in patients with knee OA. In this level II cross-sectional study, 90% of knees with mild OA, normal alignment, and a joint space ≥3 mm were improved after arthroscopic debridement. Only 5% with grade IV OA were improved at 34 months of follow-up. Patients with grade II OA had unpredictable results.

Patients with low grades of OA may have acceptable pain relief after arthroscopic debridement.

Type and Location of Meniscal Tear, Mechanical Symptoms

Chang et al. [5] found that patients who underwent arthroscopic meniscectomy for tears located in the anterior two-thirds of the medial meniscus or for any lateral meniscal tear improved more than those with a posterior degenerative medial meniscal tear.

Mechanical symptoms such as catching or locking may be prognostic factors for successful arthroscopic debridement [1, 5, 19].

Location of OA

In the study of Moseley et al. [21], OA was graded for both compartments on a one-to-four scale, meaning that patients with severe changes in one compartment were graded the same as patients with mild to moderate degenerative changes in all three compartments, which makes it impossible to compare the results. In the literature, data on the influence of OA location on the outcome of arthroscopic lavage and debridement are lacking.

Nevertheless, one-compartment OA may have a better outcome than three-compartment OA.

Others Factors

The effectiveness of arthroscopy for knee OA in patients with obesity, frontal deformity, or chondrocalcinosis is not well studied. Prospective randomized controlled trials are needed to assess the benefits or limitations of the procedure in these subgroups.

Conclusion

Meniscal tears are highly prevalent in both asymptomatic and symptomatic osteoarthritic knees. However, osteoarthritic knees with a meniscal tear are not more painful than those without a tear. The presence or absence of meniscal tears does not affect the functional status.

Although Moseley et al. demonstrated that the presence of OA is not a predictive factor for successful arthroscopy, other investigators suggested that certain subgroups may benefit from the procedure.

Patients with well-localized posterior joint line tenderness, mechanical symptoms (catching, locking), and early stages of OA (grade I or II narrowing) may have less knee pain and better function after arthroscopic removal of unstable meniscal tears or chondral flaps.

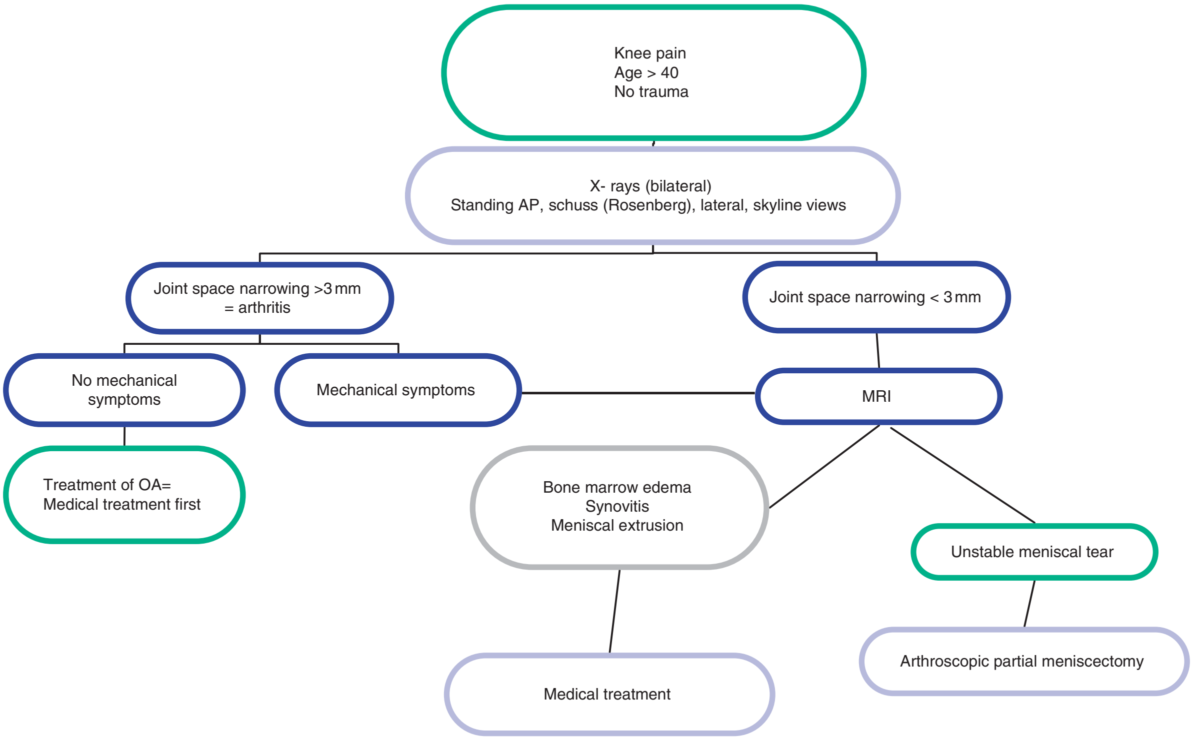

Fig. 7.4.3 Treatment algorithm

In the remaining osteoarthritic patients, the results and their durability are unpredictable and arthroscopic lavage and debridement should be recommended with caution. Finally, patients considering arthroscopic debridement should be counseled regarding potential benefit and the fact that the procedure will not be curative.

Guidelines *(Fig. 7.4.3)*

A few data are critical to the selection of potential candidates for arthroscopic treatment of their knee pain. Bilateral weightbearing X-rays, including schuss (Rosenberg) views, should always be obtained. During physical examination and history taking, any symptoms of mechanical locking or catching need to be elicited.

If the patient has a history consistent with a meniscal tear and presents no joint space narrowing on standing X-rays, MRI is recommended to assess the meniscus, bone, and synovium. An arthroscopy will be considered in case of an unstable meniscal tear. Patients with bone marrow edema, synovitis, or meniscal extrusion will benefit from medical treatment first.

In patients presenting joint space narrowing (>3 mm) on weightbearing X-rays, the first step is to optimize conservative management of their arthritis.

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Synthesis

7.5

P. Beaufils

There is not just one but many types of meniscal lesions.

There is not just one but many methods of treatment.

When an orthopaedic surgeon is faced with a meniscal lesion that is assumed to be responsible for the patient's symptoms, two fundamental questions need to be answered: (1) is it necessary to treat this lesion surgically? Refraining from operative treatment must be seriously considered; and (2) if there is a need for surgical treatment, should meniscectomy or meniscal repair be performed?

The most important guideline in the decision-making process is the principle of meniscal sparing. Therefore, meniscectomy should only be contemplated when neither of the above options is applicable.

Apart from this, the treatment obviously also depends on other factors, such as epidemiologic criteria, e.g. patient's age, activity level, time since injury, or co-existent lesions, particularly to ligaments and joint cartilage, and anatomical criteria, e.g. medial or lateral meniscus, type of lesion, its localization and extension.

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

In clinical practice, one can be faced with four distinct situations, each of which has been discussed in detail in this section: a traumatic meniscal lesion in a stable knee, a traumatic meniscal lesion in an anterior cruciate ligament (ACL) – deficient knee, a primary degenerative meniscal lesion (DML) and a meniscal lesion in an osteoarthritic knee (meniscarthrosis).

For each of these situations, specific treatment is required.

Longitudinal Vertical Lesion in a Stable Knee

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

Meniscal repair should always be considered when the anatomical conditions are favourable (lesion located within the red–red or red–white zone), when the time from injury is less than 3 months, especially if the patient is young and also if the patient's morphotype is disadvantageous (varus knee for medial meniscectomy and valgus knee for lateral meniscectomy). Particular attention must be paid to the possible detrimental effect of lateral meniscectomy on the affected

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_7.5, © Springer-Verlag Berlin Heidelberg 2010

joint as secondary cartilage degeneration is common, not to mention rapid chondrolysis in a young and active patient. Indications for repair should, therefore, be widened for the lateral meniscus (hypermobile meniscus, true traumatic lesion). It is in these cases that the techniques of stimulating healing (fibrin clot, abrasion, synovial or membrane flap) are most applicable, particularly for long-standing, more extensive lesions and red–white lesions.

Traumatic Meniscal Lesion in an ACL-Deficient Knee

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

These lesions fall into one of the following categories:

1. Symptomatic anterior laxity of the knee (functional instability) in an active individual practising sports, in whom ACL reconstruction is strongly indicated. In this situation the meniscal lesion is diagnosed before or during surgery and is treated simultaneously. The post-operative protocol is not altered, regardless of the treatment of the meniscus, which may involve surgical repair or let the meniscus alone. The ACL surgery is aimed at optimally restoring joint function and protecting the cartilage, mainly attributable to meniscal tissue preservation.
2. Anterior laxity of the knee associated with minor symptoms in an active individual who is not engaged in high-demand sports activities. In this case the indications for ACL reconstruction are not straightforward considering the functional limitation of the patient. A diagnosis of a reparable meniscal lesion may be an important argument in favour 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 can only be considered in case of a symptomatic meniscal lesion in a sedentary middle-aged patient who does not present functional instability.

Meniscal Repair or Let the Meniscus Alone

A commonly shared opinion is that unstable or symptomatic meniscal tears should be surgically repaired at the time of ACL reconstruction, while stable asymptomatic tears should be left untreated. However, lesion instability has not been clearly defined and the problem of establishing proper criteria (e.g. size of lesion and abnormal mobility of the meniscus) remains unsolved. At most we can assume that the indications for surgical repair can be widened for the medial meniscus (increased risk of secondary meniscectomy if left alone), whereas for the lateral meniscus let the meniscus alone can be the preferred approach (low risk of subsequent meniscectomy).

"Primary" Degenerative Meniscal Lesion and Meniscal Lesion in an Osteoarthritic Knee (Meniscarthrosis)

The relationship between DML and osteoarthritis of the knee is uncertain. Currently, the question whether DML always leads to the development of osteoarthritis or whether the concept of a "primary" lesion is correct remains unanswered. This problem has been addressed in detail in the chapter on classification of meniscal lesions, and the available epidemiologic information allows to support either of these opinions.

In this context, the results of meniscectomy are generally good, provided that the joint cartilage has not been injured. They are significantly worse in case of damage to the cartilage, and are roughly similar to the effects of placebo when meniscectomy has been performed on an osteoarthritic joint.

The key point for a clinician treating a patient presenting with knee pain is, therefore, to know whether the patient suffers from a DML in a joint with macroscopically intact chondral surfaces or from early-stage osteoarthritis with a co-existent DML. In the first case,

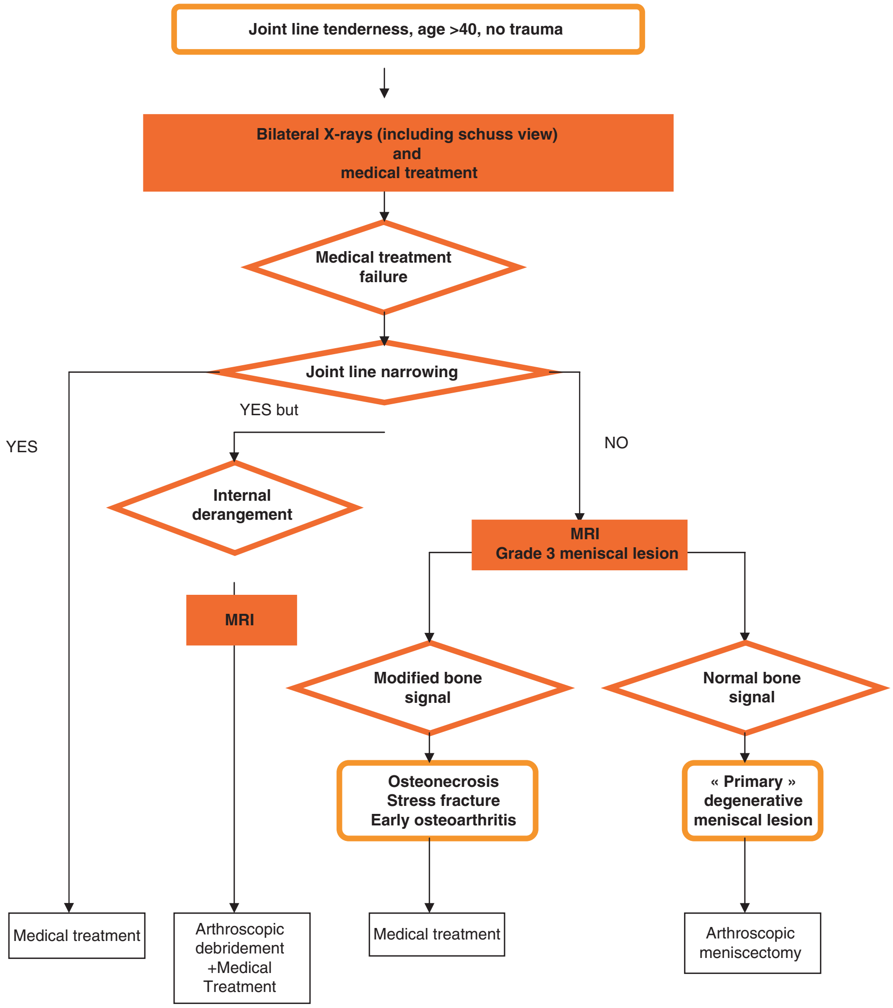

Fig. 7.5.1 Algorithm for the management of knee pain in middle-aged patients

meniscectomy would be assumed to be an "initial" or "curative" procedure, while in the second case it would be palliative. Because in everyday practice it is impossible to obtain direct information on the microscopic structure of cartilage, its condition is assessed by means of standard radiography and MRI.

It is, therefore, possible to establish an algorithm for the management of knee pain in these cases. Treatment consists either of meniscectomy or let the meniscus alone as surgical repair is seldom indicated (Fig. 7.5.1).

The primary treatment of these lesions is conservative and consists of rest, non-steroidal anti-inflammatory drugs and physiotherapy. A substantial number of DMLs respond well to this treatment and the symptoms resolve spontaneously even if the lesions do not heal. If improvement fails to occur within a few months, comparative weight bearing roentgenograms including schuss views must be obtained.

If joint line narrowing is absent, if MRI shows a grade 3 meniscal lesion and the subchondral bone signal is unaltered, and if the clinical findings correlate with the lesion, an arthroscopic meniscectomy can reasonably be suggested. The results of this procedure are good, provided that the above-mentioned criteria have been met.

If there is no evidence of joint line narrowing but the MR image of subchondral bone is abnormal (which can indicate early-stage osteoarthritis, a stress fracture or osteonecrosis), treatment should be focused on the cause of the disease and meniscectomy is not routinely indicated.

If joint line narrowing is present, osteoarthritis of the knee can be diagnosed. Numerous studies, the methodology of which can be criticized, have shown that the outcome of arthroscopic debridement and meniscectomy is roughly similar to the effect of placebo. According to these findings, there is no need for arthroscopic treatment in these patients, with the rare exception of acute trauma to an osteoarthritic knee, which can result in an additional traumatic meniscal lesion.

Consequently, it seems that refraining from surgical treatment should always be considered in this instance and that in the past we may have too often resorted to arthroscopic surgery.

Repair of horizontal cleavage tears can only be considered for a grade 2 or grade 3 lesion in a young athlete under 30 years of age. Moreover, the term "degenerative lesion" is probably misleading in this context and it would be more appropriate to designate it as an overuse injury instead. Surgical treatment, especially in case of grade 2 lesions with or without a meniscal cyst, usually provides good functional results comparable to those of meniscectomy and the longer post-operative management is compensated by the preservation of meniscal tissue.

Part VIII

Meniscal Lesions in Children

Classification: Discoid Meniscus, Traumatic Lesions

8.1

M. T. Hirschmann and N. F. Friederich

Introduction

Children are not small adults. Depending on their age, growth, and developmental stage, children have their own specific physical and psychological characteristics. Compared to adults or adolescents, prepubertal children generally have a more lax knee joint.

In addition, children often have less understanding of the consequences and risks of physical activity, and therefore, are at an increased risk during play and sports.

The ongoing body changes during growth significantly influence the balance, motor skill function, and muscle strength. Since the onset and pace of pubertal development are variable, there are considerable differences in their maturity level.

All these factors have significant implications on the incidence, time, mechanism, and type of knee injury and may at least partly explain why children are more or less prone to specific knee injuries. For example, intrasubstance tears of the anterior cruciate ligament (ACL) are rarely seen, but bony avulsion of the ACL and tibial eminence fracture are more common.

Only few published studies exclusively deal with knee injuries in children [19, 43], most of them being associated with a congenital anomaly such as discoid meniscus [4, 6, 8–10, 12, 15–17, 19, 22–25, 27–30, 32–38, 44].

Knee injuries in children generally have been considered rare when compared to their frequency in adults. Traumatic meniscal injuries in children under the age of 14 years are extremely uncommon [1, 42]. Less than 2% of all meniscectomies are performed in skeletally immature patients [45]. However, not in the least due to recent developments in diagnostics such as more sensitive magnetic resonance imaging (MRI) technology, these lesions in children are being seen with increasing frequency [40]. Another reason may be that nowadays children increasingly participate in more extreme, competitive, and professional sport activities, e.g., soccer or basketball.

Meniscal injuries in children may be purely traumatic or, more frequently, related to abnormal congenital meniscal variants, such as discoid meniscus or meniscal cyst. These anatomical variants often remain unrecognized until the knee becomes injured, and thus, symptomatic. Less common meniscal injuries are associated with ligamentous laxity of the knee.

Traumatic Meniscal Lesions Without Congenital Abnormality

Traumatic isolated meniscal injuries are predominantly located in the periphery and are observed after 12 years of age. In contrast to meniscal lesions in adults, children more often present with an isolated meniscal injury. According to Accadbled et al., 70–100% of meniscal injuries in children were isolated [1]. However, meniscal lesions can also be observed as part of a combined injury, e.g., in conjunction with an intercondylar eminence fracture. Traumatic injuries usually occur on the medial side, in the periphery, or at the base of the meniscus. This is in contrast to meniscal lesions in adults, which predominantly involve the middle part of the meniscus [43].

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_8.1, © Springer-Verlag Berlin Heidelberg 2010

Meniscal Lesions with Congenital Meniscal Abnormality

Discoid meniscus is a well-known abnormal congenital anatomic variant of the fibrocartilaginous meniscus of the knee [4, 6, 8–10, 12, 15–17, 19, 22–25, 27–30, 32–38, 44]. The atavistic anomaly differs greatly in size, shape, extent of peripheral rim instability, and degree of meniscal attachment. Typically, the meniscus is disk-, ring-, or horseshoe-shaped. A discoid meniscus is thicker and covers nearly the entire tibial plateau, which alters the stability and mobility of the meniscus, and thus, predisposes it to injury. The increased thickness of the discoid meniscus, its unstable attachment to the tibial plateau, and its poor vascularization increase the susceptibility to mechanical and shear stress of the meniscus [14, 15].

Most frequently, the lateral meniscus is involved. Discoid lateral meniscus was first described by Young in 1889 [46]. The first authors to describe the anomaly on the medial side were Cave and Staples [10].

The reported incidence of discoid meniscus shows a wide geographical variation. In Europe, it is rather rare, with an incidence between 1.2 and 5.2% [2, 16, 37]. In East-Asian countries, such as Japan [18, 22], Korea [28], and China [30], it is seen more frequently, with an incidence between 13 and 46%.

In 20–90% of cases, a discoid meniscus is present bilaterally. In a Korean series, half of the patients treated for a symptomatic discoid meniscus tear also had a discoid-shaped meniscus on the contralateral side [11]. Bellier et al. [8] found only an incidence of 20%, whereas Fujikawa et al. [17] reported an incidence of 90%. This wide range may be partly explained by ethnicity, cultural habits, and participation in sport activities. Another reason may be that in most studies only symptomatic patients were assessed, whereas a discoid meniscus is often asymptomatic.

No increased frequency with regard to gender or family predisposition has been described so far.

Interestingly, Irani et al. [23] and Mitsuoka et al. [31] found that 15% of patients with osteochondritis dissecans of the knee also presented with a discoid meniscus.

The clinical manifestations of a discoid meniscus vary from no symptoms to severe pain on motion. Locking, clicking, joint line tenderness, giving-way, and extension block of the knee are common symptoms.

The combination of recurrent and often dramatic popping and intermittent episodes of locking has been designated as "snapping knee syndrome," which is almost invariably associated with a discoid meniscus.

The exact etiology of a discoid meniscus remains unclear. Developmental and congenital factors have been described. There are two traditional schools of thought in this respect. According to some authors, discoid meniscus represents a stage during the embryological development of a meniscus. Smillie, as one of the proponents, stated that discoid meniscus represents a failure of absorption during different stages of embryological development [41]. Alternatively, Kaplan in 1957 described how abnormal motion of a discoid meniscus might lead to hypertrophy and result in a discoid shape [25].

Therefore, it may be speculated that its origin could be related to abnormal movement of the meniscus during and after development.

Classification

A large number of different classifications of meniscal lesions in children have been proposed so far [2, 3, 9, 17, 19, 20, 25, 29, 32, 44].

Most of these classifications of traumatic meniscal lesions were typically only based on the location of injury (either medial or lateral and involving either the meniscal periphery or the central part), and for a long time remained the most frequently used. They relied on the belief that the central one-third of a meniscus (white zone) has less blood supply than the middle one-third (red–white zone), and the middle one-third less than the peripheral one-third (red–red zone). This classification helped to determine the healing potential according to the vascularization of the injured meniscus, but it only took the radial tear pattern into consideration (Fig. 8.1.1).

As the knowledge of meniscal injuries increased over the past few decades, the appearance and pattern (radial, longitudinal, horizontal, or circumferential) of a meniscal tear became more important.

A commonly used classification combining meniscal tear location and pattern is that of O'Connor [39]. He distinguished medial from lateral meniscus injuries and categorized the tear pattern as longitudinal, horizontal, oblique, radial, flap, complex, degenerative, or

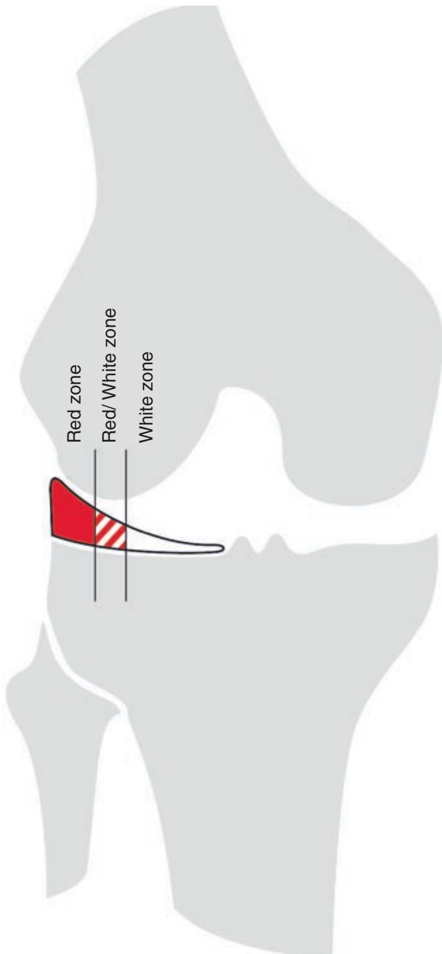

Fig. 8.1.1 Classification of meniscus according to vascularization (*red*, *red–white*, and *white zone*)

interstitial. Some types of meniscal tears are illustrated in Fig. 8.1.2.

Another classification system is that of Cooper et al. [13], which divides the meniscus into three radial (anterior, middle, and posterior-A, B, C, D, E, F) and four circumferential zones (1, 2, and 3). The meniscosynovial junction is referred to as 0 (Fig. 8.1.3).

Like Husson et al. [21], we feel that stability or instability is also an important factor in classifying meniscal tears.

The most frequently used classification of discoid meniscus was introduced in Japan by Watanabe in 1974 [44]. This classification, which is easy and simple to use, is based on the arthroscopic appearance of meniscal morphology and the type of posterior meniscotibial attachment. Depending on the extent of the abnormality, the system distinguishes three subtypes of discoid meniscus (Fig. 8.1.4).

Type I, the Wrisberg type, is characterized by the absence of a meniscotibial attachment of the lateral meniscus. Thus, the meniscus is only fixed at the posterior meniscofemoral ligament (Wrisberg ligament). Typically, the hypermobile posterior horn of the meniscus dislocates in a medial direction into the intercondylar notch during extension. Due to its hypermobility and the associated mechanical stress, it often appears hypertrophic and thickened. According to Kim et al. [26], Wrisberg ligaments in patients with a discoid meniscus are significantly thicker and have a higher attachment on the medial femoral condyle than in patients without a discoid meniscus. Some authors

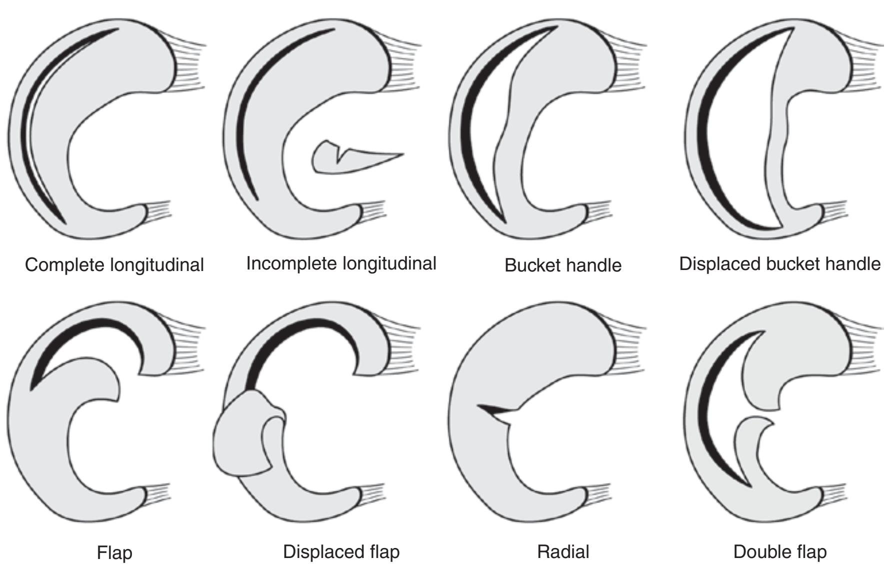

Fig. 8.1.2 O`Connor's [39] classification with description of meniscus location and tear pattern

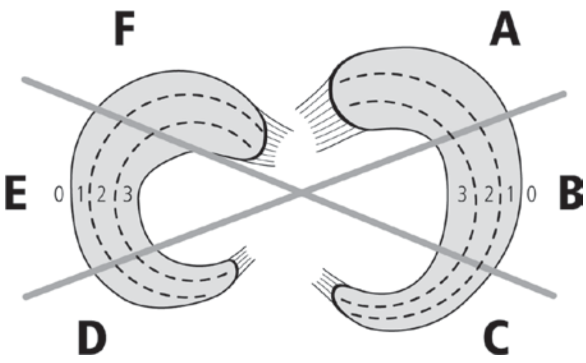

Fig. 8.1.3 Cooper's [13] zone system of meniscal tear classification

speculated that this might be an explanation for the development of a discoid meniscus, while others [9] questioned the existence of this type of discoid meniscus. Still others reported an incidence of 10% of all discoid menisci [36].

Type II is the most common type of discoid meniscus [15]. Because the meniscus covers the entire tibial plateau, it is termed the "complete type" of discoid meniscus. It has a normal tibial attachment. Typically, the meniscus is thickened and hypertrophic.

Type III, the incomplete type, is less frequently seen than the complete type, but more often than the Wrisberg type. It also has a normal tibial attachment, partially covers the tibial plateau, and is generally thickened.

In addition, Monllau et al. [32] described another type of discoid meniscus, which is ring-shaped and has a normal posterior attachment. This finding was confirmed by Arnold and Van Kampen [5].

In 1996, Jordan further modified the Watanabe classification, as he described discoid or semilunar-shaped menisci with and without meniscotibial attachment [24].

A major limitation of the Watanabe classification [44] is the fact that it is only descriptive, and therefore, not helpful to determine the extent of resection in symptomatic lateral discoid meniscus.

With these considerations in mind, Good et al. [19] tried to improve the Watanabe classification [44] by not only classifying a discoid meniscus into complete and incomplete types, but by also assessing the meniscal attachment of the anterior and posterior meniscus with respect to peripheral meniscal rim stability or instability. They found that 77% of all discoid menisci were unstable and that mainly (53%) the anterior meniscotibial attachment was involved.

Husson et al. combined arthroscopic and clinical findings and devised a specific classification system, dividing discoid menisci into complete and incomplete, stable, and unstable. The stable types were subclassified as symptomatic or asymptomatic, and torn or not torn. The unstable types were graded as discoid or normal-shaped [21].

Radiological Classifications

Hall [20] proposed a classification of discoid meniscus based on the arthrography of the knee.

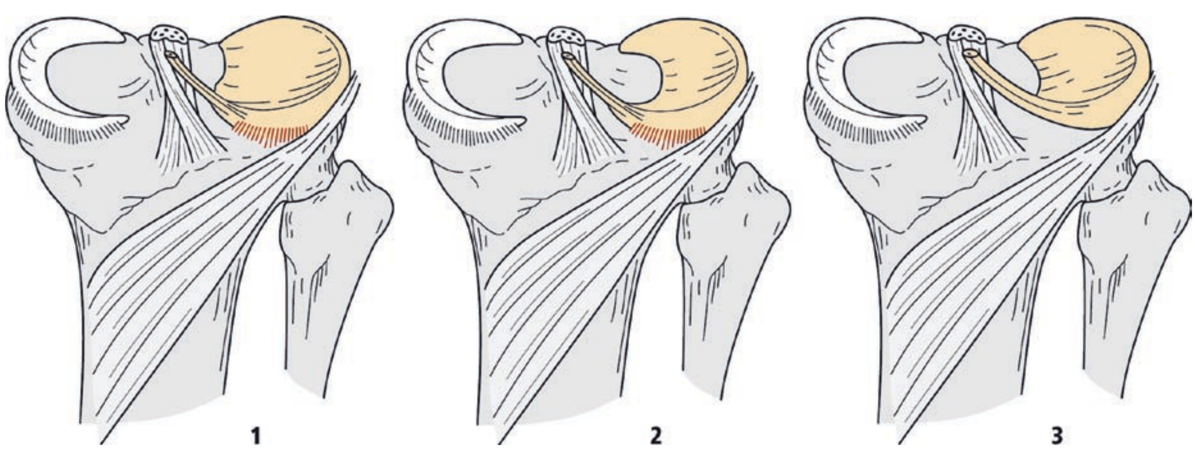

Fig. 8.1.4 Watanabe's classification of discoid meniscus. *1* Complete type. *2* Incomplete type. *3* Wrisberg variant type

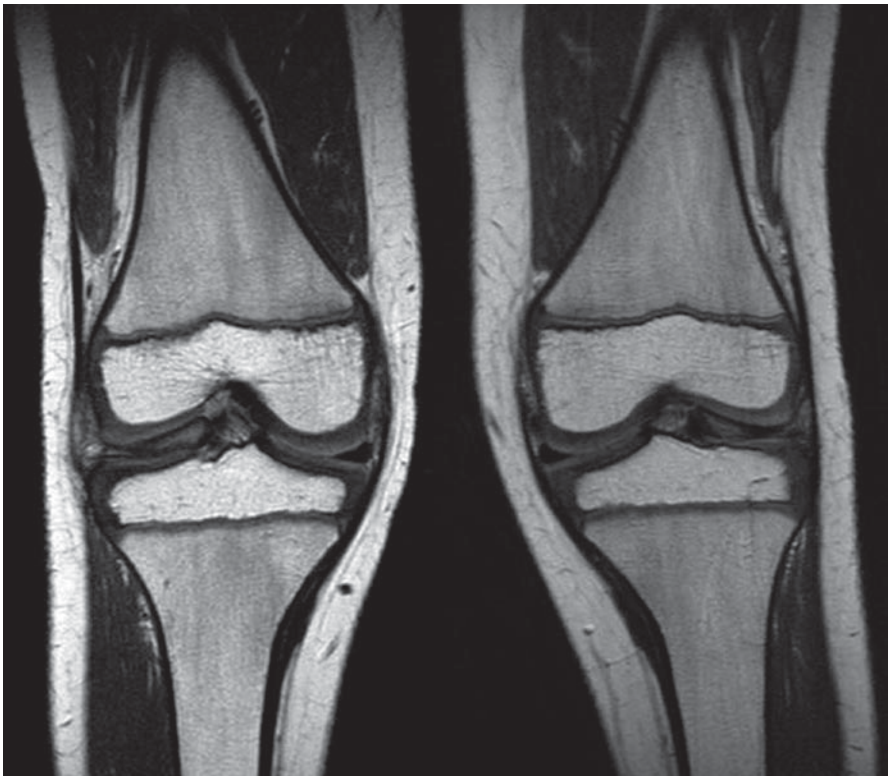

Fig. 8.1.5 Coronal MRI image of an 11-year-old girl with a bilateral complete discoid meniscus

For a long time, arthrography has been considered the most sensitive radiologic diagnostic tool, but with the advances made in MRI technology in the past few decades, MRI has replaced arthrography in the diagnostic hierarchy. A typical MRI of a bilateral discoid meniscus is shown in Fig. 8.1.5.

Ahn et al. [3] used the modified Hall classification and classified the discoid meniscus by MR imaging into three types: the slab (anterior–posterior diffusely hypertrophic) type, the anterior hypertrophy type, and the posterior hypertrophy type. Interestingly, the authors found a significant correlation between the frequency of extension block and the shape of discoid meniscus. Extension block was more frequently encountered in the slab group, with a thickened anterior part.

Correlation Between Type of Discoid Lateral Meniscus and Tear Pattern

Bin et al. [9] retrospectively analyzed the relationship between the type of discoid lateral meniscus and the tear pattern in a consecutive series of 103 patients who underwent arthroscopic partial meniscectomy for lateral discoid meniscal injuries (38 complete and 70 incomplete discoid menisci according to Watanabe). They found a simple horizontal tear only in the complete type, and a radial, degenerative, or complex tear only in the incomplete type. There was no significant correlation between a longitudinal tear pattern and type of discoid meniscus. Although a clear relationship between tear pattern and type of discoid meniscus was observed, their study did not provide any information about the influence on outcome.

Atay et al. [7] found a high incidence of horizontal tears (66%) in the complete type and of radial tears in the incomplete type.

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Discoid Meniscus: Histology

8.2

A. Papadopoulos

The cause of the almost twice as high incidence of tears or degenerative changes in discoid menisci in comparison with normal lateral menisci is not completely understood [1, 4, 9]. Reports of recurrent tears after arthroscopic saucerization and reconstruction sustain the hypothesis that altered biomechanics of discoid menisci due to an increased meniscal size might not be the cause of the lesions observed in discoid menisci [3, 5, 6, 11, 12]. It is well known that the integrity and arrangement of the collagen networks play a crucial role in the determination of the tensile and compressive modulus of a normal meniscus [10, 13]. On the other hand, despite the large number of clinical and arthroscopic studies of discoid meniscus lesions, there is a lack of literature data regarding histological studies of collagen matrix architecture. Atay et al. [2] investigated the ultrastucture of discoid menisci in comparison with semilunar menisci. They observed a heterogeneous course and a decrease in the number of collagen fibres in discoid menisci. The authors recognized several limitations to their study, e.g., the fact that biopsy specimens from torn menisci were used in both groups. Topographic analysis and scoring of collagen fibre network architecture had not been performed and the presence of radially-oriented collagen fibre complexes had not been evaluated either.

In order to investigate the collagen network architecture of discoid lateral menisci, we performed a histomorphologic study of intact complete-type discoid lateral menisci [8]. Our hypothesis was that the decreased resistance of discoid menisci to applied loads, resulting in failure and various tear patterns, might be due to abnormalities in the architecture of the collagen matrix. To our knowledge, our study is the first to topographically analyze and score the two main collagen networks (radial and circumferential fibres) of the ultrastructure of the discoid lateral meniscus. The series consisted of nine discoid lateral meniscus specimens obtained by arthroscopic partial central meniscectomy (saucerization) using the one-piece technique described by Kim et al. [7]. Incomplete and Wrisberg-type variants, as well as specimens with a macroscopic tear or evidence of degenerative changes, were excluded. The mean patient age was 30.2 ± 7.6 years and there were 5 male and 4 female subjects. A series of normally-shaped lateral meniscus specimens excised during total knee arthroplasty procedures served as a control group.

Preparation of the tissue specimens included resection of any capsular remnants, especially in the control group. The femoral surface of the specimen was marked with Indian ink. The anterior and posterior portions of the discoid meniscus specimens were identified by the resection margin and the lesion side, which could easily be recognized. This was followed by formalin fixation, sectioning and staining of representative sagittal and transverse sections with use of the Van Geisen technique. Microscopic evaluation of the slides was performed on 6 and 9 optical fields of sagittal and transverse sections. The presence of radial and circumferential collagen fibre networks was evaluated semi-quantitatively by two independent observers. The following scoring system was used: 0: complete absence of any collagen network; 1: presence of well-arranged collagen fibres in an area less than 25% of the optical field; 2: presence of a collagen fibre system in an area covering between 25 and 50% of the optical field; 3: presence of a collagen

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_8.2, © Springer-Verlag Berlin Heidelberg 2010

network in 50–75% of the optical field and 4: intact collagen network presenting distinct organization occupying more than 75% of the optical field surface. The data were analyzed using the Student's *t*-test. The level of statistical significance was set at $p < 0.05$. Post-hoc analysis of statistical power of the study revealed that the values varied between 74 and 98%.

The evaluation of the radial collagen fibre network was performed on the femoral and tibial surfaces of the anterior, the middle and the posterior portion of the resected specimen. No significant differences in the architecture of the radial system were observed between the discoid and normal meniscus groups ($p = 0.9$ and 0.6, respectively). The network of the radially arranged collagen fibril bundles appeared homogeneous along the femoral and the tibial surface of the discoid menisci.

The circumferential collagen fibre network was studied per third of length and height of the specimen (Fig. 8.2.1). A statistically significant disorganization of these fibres was observed along the entire height of the anterior third (2.2 ± 0.5 vs. 2.9 ± 0.3 in the discoid and normal lateral meniscus groups, respectively; $p < 0.001$) and the posterior third (1.8 ± 0.5 vs. 2.7 ± 0.3, $p < 0.001$). Similar findings were observed close to the tibial surface of the middle third of the discoid menisci (1.6 ± 0.4 vs. 2.8 ± 0.3, $p < 0.001$) (Fig. 8.2.2). The posterior part of the discoid menisci appeared to be the most disorganized segment, demonstrating extensive areas of myxoid degeneration, osseous metaplasia and void spaces. It was not clear whether the abnormality of the central collagen network was congenital or acquired, although the degenerative lesions were indicative of the latter hypothesis. In addition, when the scoring results at various sites inside the discoid meniscus structure were compared, significant differences in the architecture of the circular collagen network were found, indicating heterogeneity of this system. The tibial side appeared to be the most disorganized segment of the meniscus matrix, demonstrating scoring differences as compared to the femoral and middle portions ($p < 0.001$). The best scoring results were observed along the femoral portion of the discoid meniscus specimens, presenting significant differences in comparison with the middle third ($p = 0.03$). Analysis of the scoring results among the portions in the sagittal direction showed that the posterior third presented the lowest scores, with significant differences from the anterior ($p = 0.01$) or middle third ($p = 0.03$). There were no significant differences between the anterior and middle specimens ($p = 0.7$).

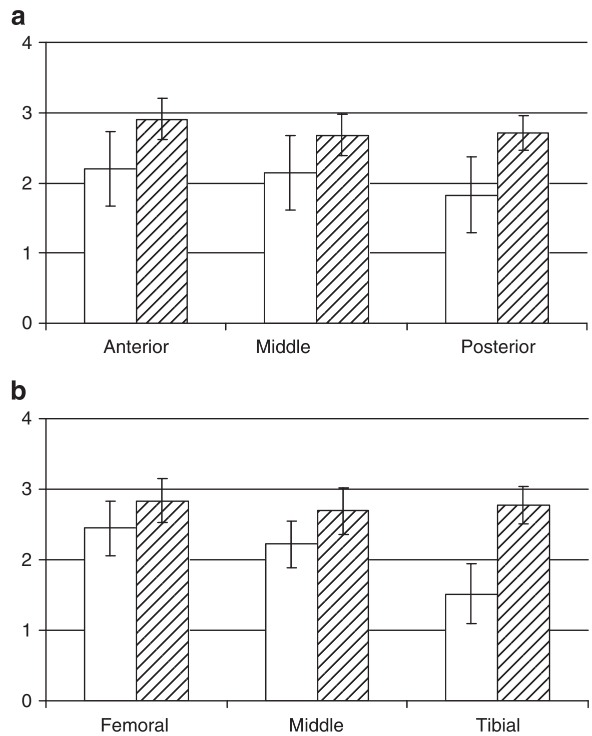

Fig. 8.2.1 Scoring results of the transverse sections demonstrating the architecture of the circumferential collagen network of the discoid (*open bar*) and normal lateral meniscus (*lined bar*) per third of specimen length (**a**) and height (**b**)

In a normal meniscus, the inner circumferential collagen fibres dissipate the hoop stresses on the meniscus structure during weightbearing. Also, an intact collagen network serves as a scaffold to anchor the glycosaminoglycans necessary for normal meniscus function. The finding of a disorganized collagen matrix may contribute to the pathogenicity and the high incidence of tears in discoid menisci. This indicates that the discoid variant of knee menisci does not only refer to abnormally increased meniscal dimensions, but is also accompanied by a disorganization and an inhomogeneity of the circumferential collagen fibre system.

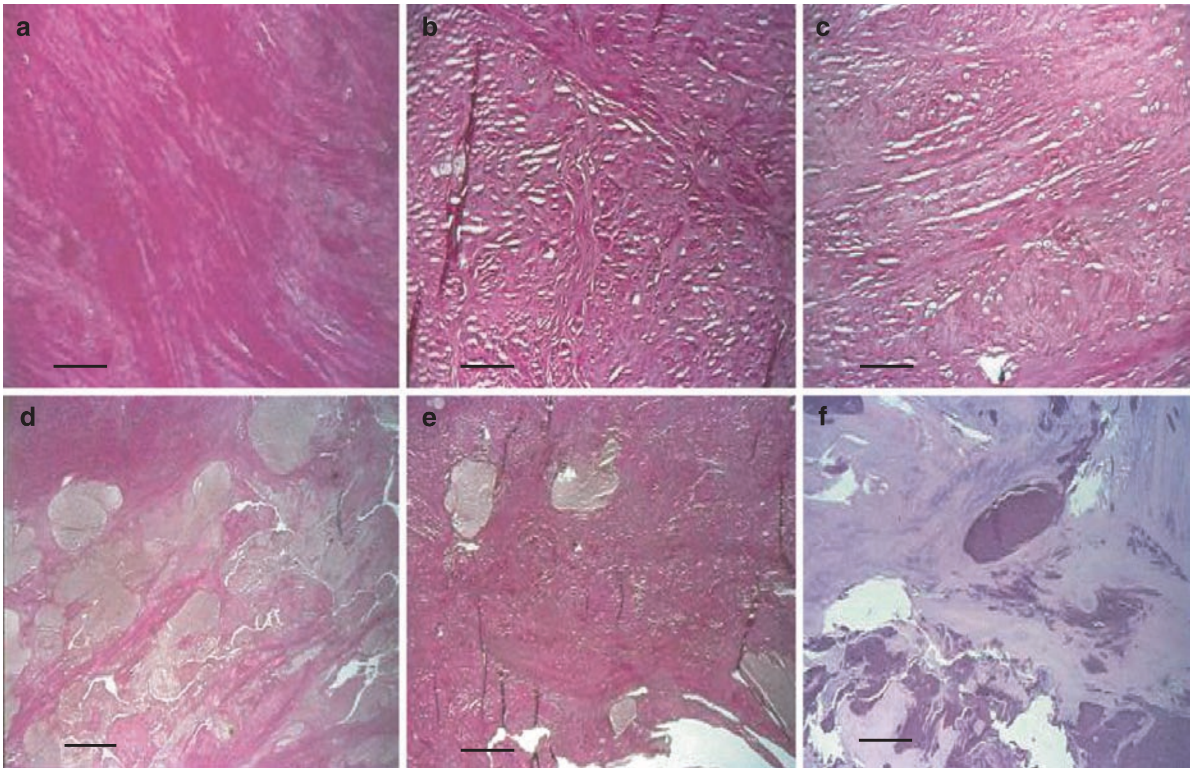

Fig. 8.2.2 Representative photomicrographs of the circularly arranged collagen fibre network of the normal (*upper row*) and discoid lateral meniscus (*lower row*) along the anterior (**a**, **d**), middle (**b**, **e**) and posterior third (**c**, **f**) near the tibial surface (V-G, ×10). Void spaces and areas of degeneration or osseous metaplasia were observed in the discoid meniscus group

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Technique of Meniscoplasty and Meniscal Repair in Children

8.3

X. Cassard

Introduction

Any pattern of meniscal lesion can be seen in younger age groups, and the probability of encountering a lesion increases with age, more often occurring in adolescents than in small children [5, 16]. Meniscal tears in small children are more frequent due to congenital meniscal anomalies, while those in adolescents are more often associated with traumatic lesions of the anterior cruciate ligament (ACL) [5]. Surgical management of such lesions in children poses two additional difficulties when compared to meniscal surgery in adult knees. The first difficulty is to determine the appropriate indication at the right age. In most cases, magnetic resonance imaging (MRI) provides an accurate diagnosis [5], even if clinical presentation is nonspecific and/or difficult to interpret [10]. However, the surgical indication always remains subtle to assert and is sometimes only reluctantly accepted by the child's family. The second difficulty concerns the technical aspect. Because the joint is much smaller in 10-year-old knees and less, the surgeon should be skilled in adult knee arthroscopy before operating on children's knees. The indications for meniscal repair should be extended in children because of the higher healing rate [25] and poor long-term outcome of meniscectomy [1, 23, 30]. Any type of technique can be used and combined to manage meniscal lesions in children: all-inside or other arthroscopic techniques for meniscal repair, meniscoplasty for discoid meniscus, open surgery for meniscal cyst or horizontal cleavage tears and simultaneous ACL reconstruction, with techniques adapted to skeletally immature patients [2, 4, 24] in case of an associated ACL tear.

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Pre-Operative Planning

The pre-operative evaluation should always include an antero-posterior and lateral radiograph and comparison views of the unaffected knee. The latter views may help identify narrowing or widening (Fig. 8.3.1) of the joint space and sometimes early degenerative changes suggestive of chronic meniscal lesions. Other radiographic signs, including cupping of the tibial plateau,

Fig. 8.3.1 Widening of the joint line due to the presence of a thick lateral discoid meniscus

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_8.3, © Springer-Verlag Berlin Heidelberg 2010

flattening of the lateral femoral condyle and elevation of the fibular head and tibial spine hypoplasia, can be seen in discoid meniscus. In the majority of cases, radiographs are normal.

MRI remains the most widely accepted non-invasive technique for evaluation of the meniscus, with an accuracy of more than 90% in determining the presence of meniscal pathology. According to some authors, MRI has better sensitivity and specificity for the detection of meniscal pathology if the clinical-orthopaedic findings are suggestive of a meniscal lesion [29]. The incidence of grade-2 signal changes is high in asymptomatic children [22] and requires careful physical examination of the affected knee to confirm a meniscal lesion. Moreover, MRI can be difficult to perform in very young children, requiring sedation or general anaesthesia during the examination. The ACL status of the knee has to be assessed clinically. Anterior-drawer stress X-rays can be obtained in case of an ACL lesion and/or an uncertain lesion on MRI. Arthro-CT scans can be useful in symptomatic knees with MRI grade-2 lesions that need additional imaging to identify an open crack of the meniscus.

Patient Positioning, Equipment and Arthroscopic Portals

There is no specific surgical setup for children undergoing meniscal surgery. Attention must be paid to the position of the leg holder and tourniquet, if used, in order to allow for a maximum range of motion and access to posteromedial or additional lateral portals (Fig. 8.3.2). Open surgery may also be required, e.g., in case of meniscal cyst. Tourniquet pressure of 250 mmHg is usually sufficient in younger knees. General anaesthesia is preferred because of better cooperation in younger patients.

From the age of 4 years, we find the standard 4.5-mm, 30° arthroscope always useful for performing diagnostic and therapeutic procedures. Some authors suggest to use the 2.7-mm arthroscope for very small knees [9] and the 70° arthroscope for posterior evaluation. An arthro-pressure pump is not essential but can be used with the pressure set at 40 mmHg in order to widen the viewing angle, especially in small knees. The standard arthroscopic tools are adequate: straight and curved basket forceps, rotary 90° side-biting punch, 60° scissors and a mechanical 3.5 mm-diameter shaver. For meniscoplasty in discoid meniscus, we recommend the use of a Beaver knife (Fig. 8.3.3) (BD Beaver™ Mini-Blade, Becton, Dickinson and Company. Waltham, MA), as described further.

Fig. 8.3.2 Position of the tourniquet if a leg holder is used, allowing a good range of motion

Fig. 8.3.3 Beaver knife used in discoid meniscus to start the anterior horn incision under arthroscopic visualization

An image capture device is useful to document an unexpected lesion that could compromise the clinical outcome (e.g., peripheral rim extension of horizontal

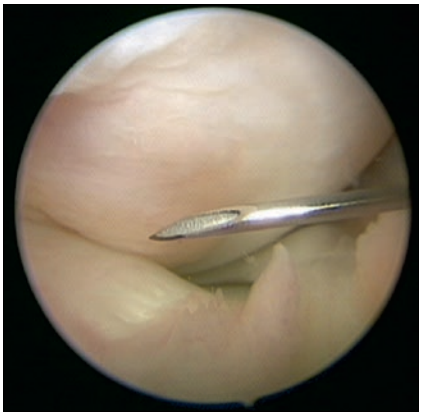

Fig. 8.3.4 An outside–in needle is useful to find the appropriate instrumental portal

cleavage in a lateral discoid meniscus, and/or cartilage damage).

As the joint volume is often much smaller than that in adult knees, particular attention must be paid to portals. The lateral optical portal for the scope is placed first. The medial instrumental portal is ideally made using an outside–in needle (Fig. 8.3.4) to locate the appropriate portal that will allow the tools to reach all parts of the meniscus to be treated. Consequently, the instrumental portal will be different for medial or lateral, anterior or posterior meniscal derangements.

Any treatment should always start with comparative motion and stability testing of both knees under anaesthesia, starting with the unaffected knee.

Discoid Meniscus

Introduction

Surgical management of a discoid meniscus is considered as a highly demanding arthroscopic procedure that includes meniscoplasty, meniscal repair and/or meniscal attachment for peripheral instability. Meniscoplasty implies resection of the centre of the meniscus and peripheral plasty, also called saucerization. Although this morphologic meniscal anomaly almost exclusively occurs in the lateral compartment, it may rarely also be seen in the medial one. A discoid meniscus is thicker and the tissue can be much firmer. It has poorer vascularization than a normal meniscus [18]. Synovial hypertrophy may sometimes be present and there is a high rate of an associated tear [3] or abnormal peripheral attachment [13].

There are many classifications of discoid meniscus. The most commonly used is the Watanabe classification published in 1978. He described three different types of discoid meniscus : type I is a complete disc-shaped meniscus covering the entire tibial plateau (Figs. 8.3.5 and 8.3.6), type II is an incomplete semilunar-shaped meniscus with partial tibial plateau coverage (Fig. 8.3.7) and type III is the so-called Wrisberg ligament type indicating a hyper-mobile meniscus due to a deficient posterior tibial attachment.

Good et al. [13] reported a high rate of peripheral instability and proposed a formal classification in which discoid lateral menisci are classified as complete or incomplete and as stable or unstable, and further sub-classified as anterior or posterior based on the location of instability.

For Klingele et al. [20], the frequency of peripheral instability mandates a thorough assessment of meniscal stability at all peripheral attachments during the arthroscopic evaluation and treatment of discoid lateral meniscus, particularly in complete variants and in

Fig. 8.3.5 MRI of type I discoid meniscus in a 6-year-old boy complaining of snapping knee, with no additional tear

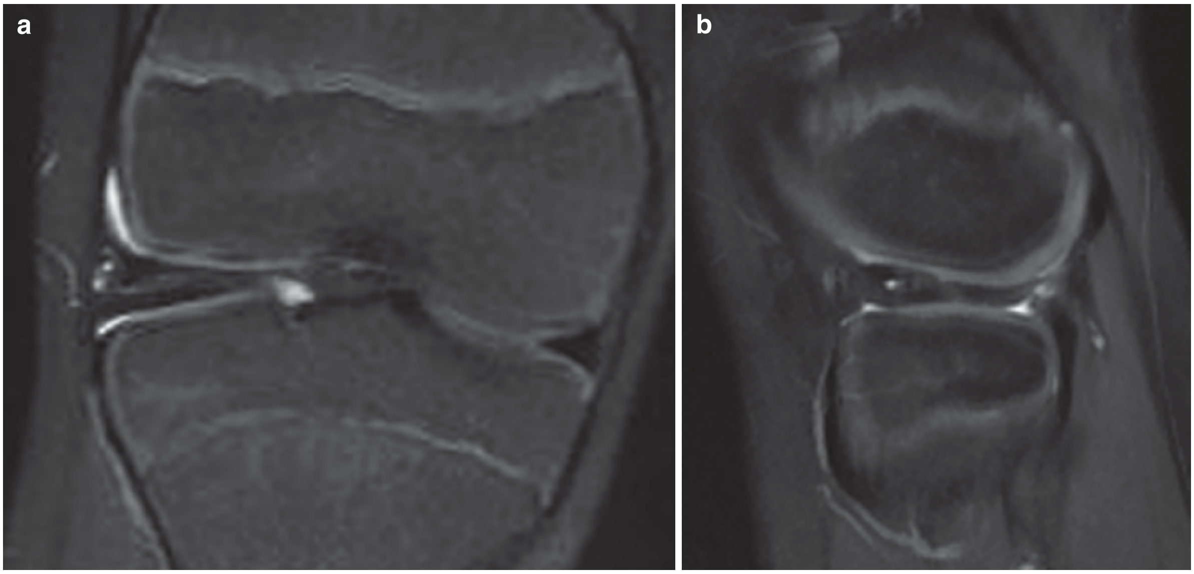

Fig. 8.3.6 (**a**) MRI of type I discoid meniscus in a 7-year-old boy only complaining of pain, showing additional horizontal cleavage and a peripheral meniscal cyst. (**b**) MRI of type I discoid meniscus in the same patient. Sagittal view showing the horizontal cleavage of the anterior horn, an additional vertical lesion of the central part and probable instability of the posterior horn

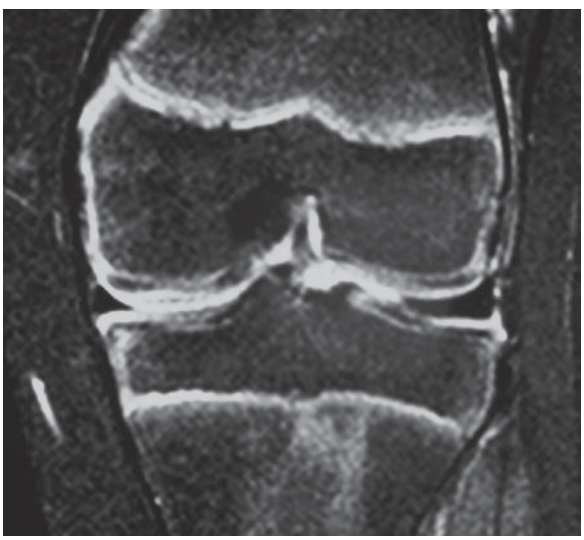

Fig. 8.3.7 MRI of type II lateral discoid meniscus with incomplete coverage of the tibial plateau

younger children. The goal then is to try to shape a "normal" lateral meniscus with saucerization, knowing that results in partially meniscectomized knees are better than those in totally meniscectomized knees [7, 28, 31], and to firmly stabilize all portions of the meniscus. Snapping can result from impingement of the thick central part of the meniscus against the femoral condyle during flexion or from instability of the horns.

Technical Considerations

For the optical lateral portal, we recommend a more proximal and lateral placement than the usual lateral arthroscopic portal (Fig. 8.3.8) in order to have a good view of the anterior aspect of the meniscus. Particular attention should be paid to the instrumental portal, using a needle as described previously.

The knee joint needs to be very carefully inspected for lateral discoid meniscus. First, the inferior and superior aspects of the meniscus are probed (Fig. 8.3.9) for any tear. Then, the peripheral rim is inspected for evidence of detachment, essentially in the posterior horn (Fig. 8.3.10). The anterior margin of the resection is determined using the alignment with the fibres of the inter-meniscal ligament and the anterior fibres of the ACL (Fig. 8.3.11). We recommend the use of a

Fig. 8.3.8 Optical portal situated more proximally than usually for lateral discoid meniscus

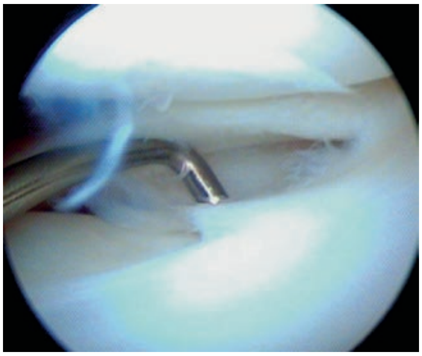

Fig. 8.3.9 Every procedure should start with careful probing, here showing a horizontal cleavage tear in a type II lateral discoid meniscus

Beaver knife, introduced through the medial portal (Fig. 8.3.12), to start the incision of the anterior horn, which can be very thick and strong. Subsequently, resection of the central portion of the meniscus is started using a plain or curved basket forceps, from the anterior to the mid-portion and from the posterior horn to the mid-portion following a circular curve (Fig. 8.3.13).

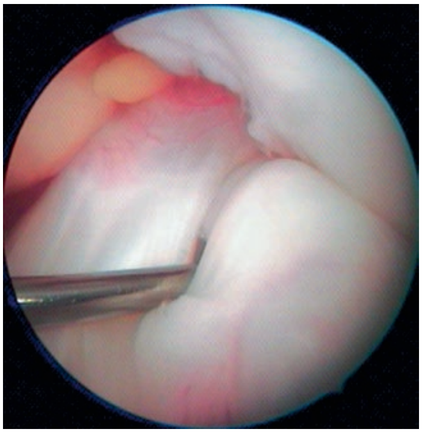

Fig. 8.3.10 The probe is inserted inferiorly and superiorly to the meniscus in order to test peripheral rim stability prior to saucerization

Fig. 8.3.11 Saucerization is limited anteriorly to where the ACL touches the anterior horn

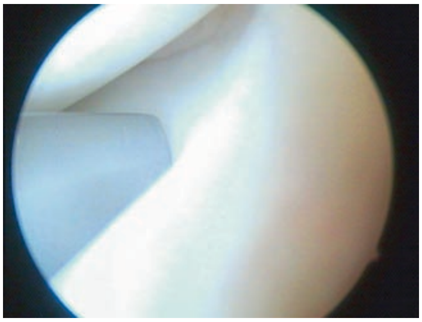

Fig. 8.3.12 A Beaver knife can be used for starting the anterior incision and shaping the meniscus like a regular anterior horn

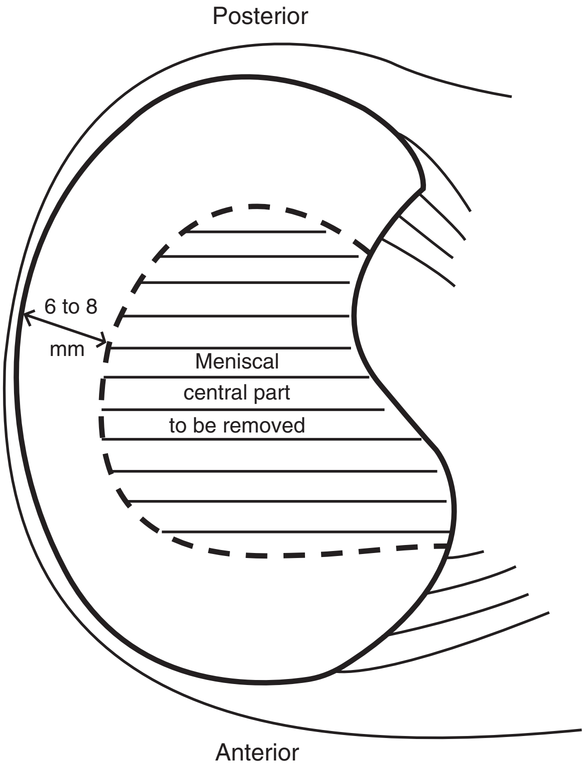

Fig. 8.3.13 This drawing shows the circular curve to follow

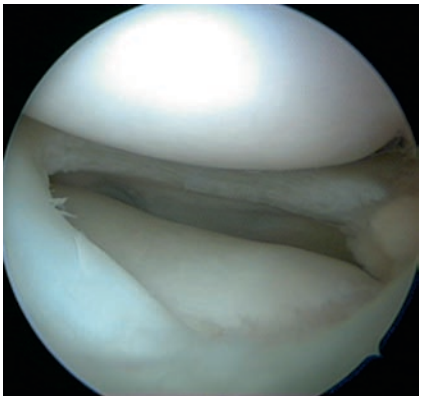

Fig. 8.3.15 Final aspect

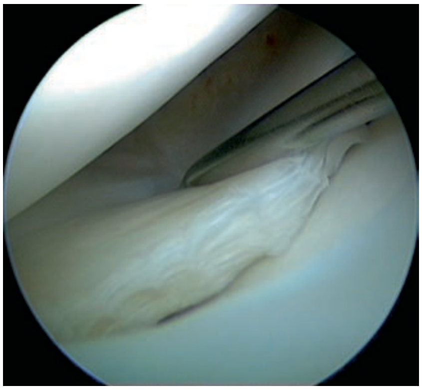

Fig. 8.3.16 Testing of the stability and the size of the remaining meniscal tissue

Debridement and contouring are completed using a right and left-curved basket forceps (Fig. 8.3.14a, b), leaving a 6–8-mm peripheral substance. The peripheral rim may remain thick and does not need additional thinning. A normal thin aspect of the central meniscal border is impossible to obtain, but a shaver can aid in shaping the superior aspect without enlarging the resection (Fig. 8.3.15). At the end of the procedure, the scope is introduced through the medial portal to properly visualize the remaining anterior horn and its contact with the lateral condyle in extension. Final peripheral stability testing is performed, not only of the posterior, but also of the anterior horn (Fig. 8.3.16) to verify the absence of snapping. In case of instability

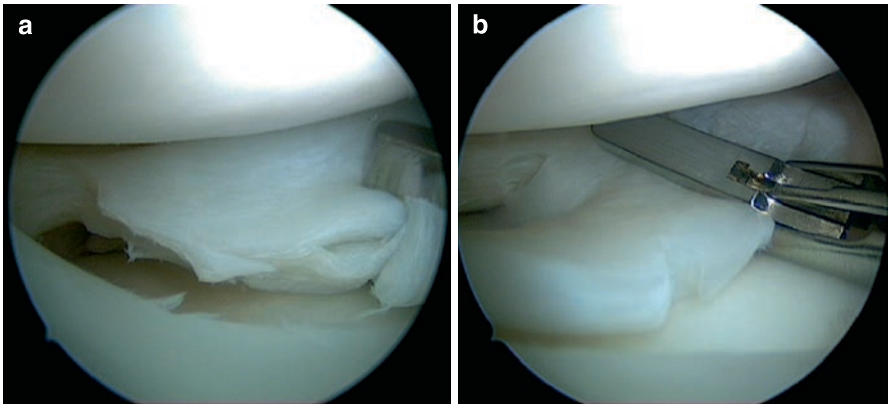

Fig. 8.3.14 (**a**) Saucerization of the anterior portion of the discoid meniscus. (**b**) Saucerization of the posterior portion of the discoid meniscus

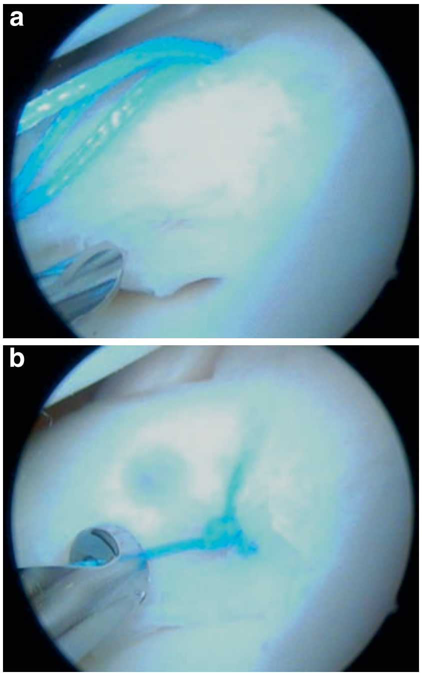

Fig. 8.3.17 (**a**) A vertical suture is placed using a Fast-Fix® device. (**b**) The suture is located anteriorly to the popliteal area

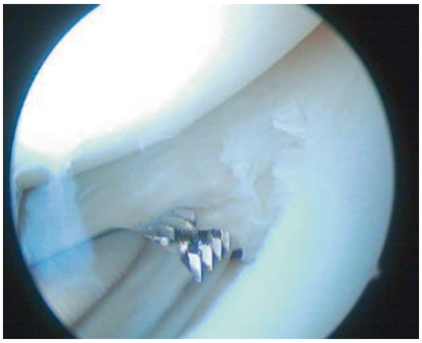

Fig. 8.3.18 A shaver is inserted in the remaining horizontal cleavage for smooth debridement

of the remaining meniscal tissue, a repair can be done using either outside–in sutures guided through needles for the anterior horn or an all-inside suture device (Fast-Fix® or Rapid Lock®) (Fig. 8.3.17a, b) for the middle third and the posterior horn.

In case of a centrally open horizontal tear extending to the peripheral rim, smooth debridement of the damaged central border is performed using a straight or curved basket forceps and a rotary 90° side-biting punch for the medial and the anterior portions. A shaver can also be used for this purpose (Fig. 8.3.18). Another solution is to remove the unstable leaf of the horizontally torn meniscus to the peripheral rim, and to preserve and reshape the stable one until its appearance is similar to a normal lateral meniscus in terms of width and thickness [8].

For a Watanabe type III hyper-mobile meniscus, the technique is the same as for a bucket-handle tear. Suture should only be performed in snapping and painful knees. Freshening of both the hyper-mobile fragment and the meniscal wall is performed using percutaneous needling, and/or smooth resection of the wall is performed with a small synovial resector prior to suturing, as previously described.

Complications

The treatment of discoid meniscus is associated with specific complications. Insufficient anterior resection can lead to residual anterior pain and additional tearing in the anterior horn. Instrument breakage due to the thickness of the discoid portion has been reported. Persistent instability of the peripheral rim can produce snapping symptoms and pain. Long-term follow-up has shown osteochondritis dissecans in the lateral condyle [11, 15, 26] and radiographic changes after saucerization [6].

To our knowledge, no other specific complications of meniscal repair have been reported in younger knees.

Meniscal Lesions in Stable Knees

Introduction

In children, meniscal lesions to be repaired specifically include intra-articular or peripheral open horizontal cleavage tears [17](Fig. 8.3.19) and symptomatic intrasubstance meniscal tears (Fig. 8.3.20), sometimes in association with a meniscal cyst (Fig. 8.3.21).

The treatment of other types of meniscal tears is no different than in adult knees. Particular attention should be paid to popliteal cysts, which typically present as a painless mass in children under 12 years of age. Because they are usually not associated with an internal pathology and often resolve spontaneously, the preferred treatment is observation [21].

Fig. 8.3.19 Symptomatic open horizontal cleavage tear

Fig. 8.3.20 Symptomatic lateral intra-substance meniscus tear

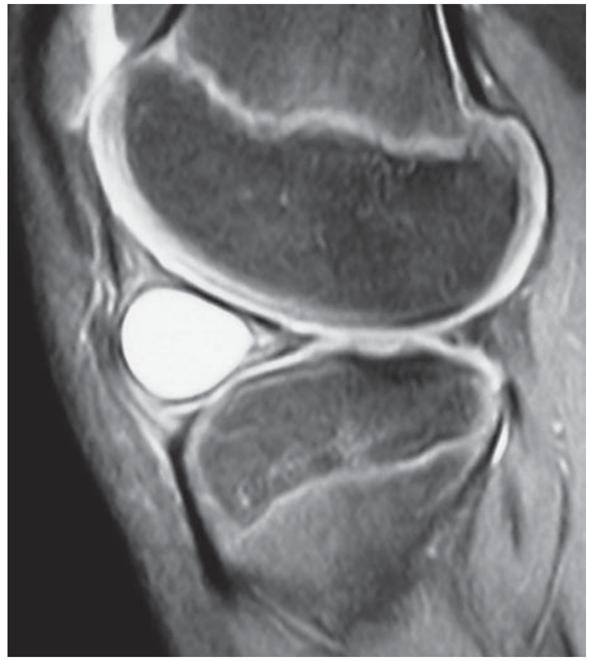

Fig. 8.3.21 Meniscal cyst

Treatment of Horizontal Cleavage Tears with or Without Cyst

The procedure starts with the 30° standard arthroscope using the usual antero-lateral portal for the scope and the antero-medial portal for the probe. Firstly, the entire joint, including the opposite compartment, the anterior and posterior cruciate ligaments and the patello-femoral joint, is inspected using the probe for palpation. The meniscal lesion is then carefully probed to assess the inferior and superior aspects of the meniscus and its peripheral attachment, and the popliteal tendon area in the lateral meniscus [19]. Partial meniscectomy can sometimes be indicated in case of unstable axial lesions, but conservative treatment is preferred whenever possible, combined with an open approach, resection of the cyst (if present) and open meniscal repair.

The peripheral lesion or cyst is located arthroscopically using an outside–in needle, which aids in making a short-centred skin incision on the lateral or medial joint line.

The skin incision is made vertically around the needle location in a 90° flexed knee in order to avoid the saphenous branch medially and to locate the fibular head and biceps tendon laterally for peroneal nerve protection.

At the medial side, the capsular joint is incised posterior to the medial collateral ligament. The meniscal wall is exposed by opening the synovial envelope. The cyst is removed and both faces of the horizontal tear are abraded using a rasp, a small curette or a 2.5 shaver. The horizontal tear is then closed using vertically applied single or double-X PDS-0® sutures. The capsular sheath is closed with separate sutures; no drain is necessary.

In the lateral meniscus, the lesion is most commonly located anterior to the lateral collateral ligament. The skin and capsule are incised anteriorly to this ligament. The technique is the same, with particular attention to the popliteal area, which does not need to be sutured. If the horizontal cleavage runs posterior to the popliteal area, we recommend the use of an all-inside device (Fast-Fix®) for meniscal repair. According to Noyes and Barber-Westin [27], a stable repair of complex meniscal tears extending into the avascular zone can be achieved using a meticulous inside–out vertical divergent suture technique.

Meniscal Lesions Combined with ACL Tears

For meniscal lesions combined with ACL tears, the technique is the same as in adult knees. The question is rather a matter of ACL reconstruction technique adapted to the immature skeleton. The age of the patient is not a decision-making factor. The meniscal tear has to be treated during the ACL reconstruction procedure, with a minimum delay from diagnosis to surgery in order to avoid compounding the lesion [14, 24] and to improve the healing rate [2, 4].

Post-Operative Management: Rehabilitation

On the completion of surgery, a Naropeine injection is administered to relieve knee pain in the immediately post-operative period. This will help the child recover a non-apprehensive knee.

Following isolated meniscoplasty (with no repair), progressive motion is allowed as the swelling subsides after 1–2 weeks of immobilization in a brace. Immediate full weight bearing is allowed, but crutches have to be used in case of pain. Rehabilitation is not necessary and may even have a negative effect if forced flexion is attempted. Full motion is easily recovered in children when pain and snapping symptoms have disappeared. All sports are allowed after a period of 2 months. A minimum follow-up of 2 years is required, ideally until the end of growth.

For all types of meniscal repair, the post-operative rehabilitation programme could be summarized as “gentle and slow” in comparison with “accelerated” in adult knees. On completion of surgery, a brace is applied in full extension. Full weight bearing is allowed; crutches are only necessary in case of pain. No motion is allowed until the third post-operative week, after which progressive flexion is slowly started, not exceeding 90° until the sixth week. We do not recommend physiotherapy and aggressive rehabilitation under the age of 14, in order to avoid pain. All sports including school sports are allowed after 4–6 months.

After simultaneous ACL reconstruction, mobilization is limited to 90° of flexion for 6 weeks and all sports are prohibited until 8–12 months post-surgery.

Conclusion

Meniscal tears in children are uncommon and difficult to treat. However, because of the poor prognosis of meniscectomy at this age and the high healing rate, conservative treatment should always be attempted for symptomatic lesions in stable knees and for all meniscal lesions associated with ACL rupture. MRI should always be performed for the identification and accurate evaluation of additional lesions in discoid meniscus. Treatment should be instituted immediately after the diagnosis has been made, because the risk of secondary meniscal or cartilage injury increases with longer delays to surgery [12].

Arthroscopy should always start with a careful and thorough examination of the involved meniscus, looking for evidence of instability and additional tearing in discoid menisci and an extended lesion in horizontal cleavage tears. An arthroscopic and open surgery technique can be combined to preserve as much meniscal tissue as possible of a normal and stable shape.

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Meniscus Lesions in Children-Indications and Results

8.4

O. Lorbach, D. Pape, and R. Seil

Indications

Symptoms

Especially younger, pre-pubertal children may not adequately describe the severity of their injuries, which makes a subjective assessment unreliable. In these patients, it is more difficult to establish a medical history leading to the definitive diagnosis, and clinical examination of acute injuries may be difficult or even impossible because of pain [55]. Non-specific findings such as pain on palpation of the joint line or locking might be found, and almost one in every three post-traumatic hemarthroses in children is associated with a meniscal injury [55]. An extension deficit without previous trauma often suggests an underlying symptomatic discoid meniscus.

Differential Diagnosis

As in adults, referred pain from ipsilateral hip or spine pathology is not uncommon [23]. For these reasons, typical age-related hip pathologies such as Perthes' disease or slipped femoral head epiphysiolysis, which can be responsible for knee pain, should be systematically ruled out. Painful knee conditions such as patello-femoral disorders (pain and/or instability), osteochondritis dissecans and even knee tumours must also be considered.

Imaging Procedures

Radiographs are typically normal, but can rule out other injuries such as osteo-chondral fractures, other causes of hemarthosis or, in the absence of trauma, osteochondritis dissecans. Plain radiographs should also help rule out patello-femoral disorders such as trochlear dysplasia, which can be responsible for knee symptoms. However, because of the presence of open growth plates, trochlear dysplasia becomes only visible in adolescents.

Early studies reported magnetic resonance imaging (MRI) to be the non-invasive method of choice for diagnosing meniscal injuries [50]. However, Crues et al. [16] and Takeda et al. [52] showed that false-positive results were not infrequent in children, due to a signal alteration caused by hyper-vascularization of the posterior horns of the meniscus (Fig. 8.4.1). Takeda and co-workers found an 85% prevalence of grade 2 and grade 3 changes in 10-year-old children, decreasing to 35% at 15 years.

Surgical Findings

The most common meniscal injuries are discoid meniscus lesions and peripheral tears [55]. The majority of meniscal lesions occur after the age of 12 years [55]. In adolescents, traumatic meniscus lesions usually predominate, whereas congenital anomalies are more common at younger ages (mainly discoid meniscus).

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_8.4, © Springer-Verlag Berlin Heidelberg 2010

Fig. 8.4.1 Sagittal T2-weighted MR image of a 13-year-old high-level female gymnast presenting with posteromedial knee pain related to strenuous exercise. The arrow shows abnormal signal changes in the posterior horn, which may indicate physiologically increased vascularization in children. In this case, arthroscopy confirmed a longitudinal unstable tear, which was repaired with an inside–out suture technique

Medial meniscus injuries seem to be more frequent than lateral ones. Although any type of tear can be found in the different age groups, peripheral meniscal detachment is more common in young children, whereas in adolescents, injuries more frequently involve the central substance [31].

Treatment Options and Criteria for Repair

Four treatment options are possible: partial or total meniscectomy, meniscal repair and masterly neglect [18].

Casscells [13] emphasized that not all meniscal tears produce clinical symptoms. Laboratory studies have shown that torn menisci can continue to function biomechanically if the peripheral circumferential fibres are intact [9]. Therefore, partial-thickness split tears and full-thickness short (<5 mm) vertical or oblique tears can be left alone if the inner portion of the meniscus is stable with probing [18]. For lesions smaller than 5 mm in the avascular area of the meniscus, Vaquero et al. [55] also recommended non-operative treatment because these tears usually are stable and remain asymptomatic for a long period of time. For traumatic longitudinal tears smaller than 10 mm in the vascularized area, immobilization of the knee in a brace might be considered in order to allow for spontaneous healing of the lesion [31]. Longitudinal injuries should be treated surgically either by repair or partial meniscectomy when they are unstable or longer than 7 mm [55]. The basic principle in the treatment of meniscal injuries in children has to be preservation of as much meniscal tissue as possible to minimize subsequent articular cartilage degeneration. Imaging techniques such as MRI or arthrography can be useful in identifying potentially reparable meniscal tears. However, the final decision will be made based on careful arthroscopic evaluation of the tear and probing to determine its stability. Tears definitely suitable for repair are traumatic longitudinal lesions located within the vascular zone, which are longer than 7 mm, clearly unstable, and have not sustained major structural damage [18] (Fig. 8.4.2). Horizontal lesions and bucket-handle tears might also be considered for repair [2].

Relative indications for repair include central lesions with doubtful vascularity or degenerative signs in the meniscus substance [18] (Fig. 8.4.3).

Clark and Ogden reported on a totally vascular meniscus at birth, the vascularization of which had diminished to the peripheral 10–30% by adulthood [15]. As a consequence, the well-known “red–red” and “red–white” zones in adults are less well-defined in a pediatric meniscus and the zone with adequate healing

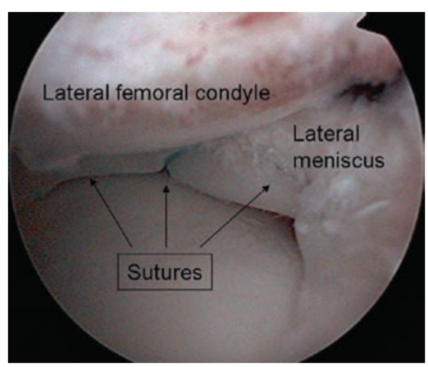

Fig. 8.4.2 View of a lateral meniscus in the right knee of an 11-year-old boy who sustained an ACL tear in a soccer injury. The bucket-handle meniscus tear was sutured arthroscopically, with concurrent ACL replacement

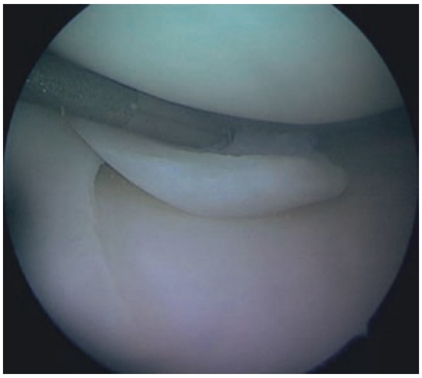

Fig. 8.4.3 Flap tear of the medial meniscus in a 14-year-old ballet dancer treated by partial meniscectomy

potential may be extended towards the central areas of the meniscus in these patients [8]. Repair of meniscal tears in the central, avascular area is generally not recommended in adults. In children and adolescents, however, good results with stable healing can be achieved. Noyes and Barber-Westin [43] examined 71 arthroscopic repairs of meniscal tears extending into the avascular region in children and adolescents between 9 and 19 years of age. They reported 75% of good clinical results without any tibio-femoral symptoms. In the subgroup of patients who underwent meniscal repair and anterior cruciate ligament (ACL) reconstruction, 87% rated their knee as normal or very good at a mean follow-up of 51 months.

Partial meniscectomy might be required in patients presenting irreparable meniscal tears such as radial, flap and complex tears. In these cases the unstable fragment has to be removed, leaving a stable well-contoured wall capable of assuming at least part of the mechanical functions. Total meniscectomy might only be necessary in very rare cases such as intra-meniscal cysts with extensive meniscal degeneration or discoid menisci of the Wrisberg type. It should be avoided whenever possible, because totally meniscectomized children are doomed to develop premature osteoarthritis [1, 34, 35, 56].

Symptomatic discoid menisci are not infrequent. A child may present with an extension deficit not necessarily related to a traumatic event, and may experience popping, snapping and pain (Figs. 8.4.4a,b,c). Discoid menisci are more frequent on the lateral side and uncommon on the medial side [6], with a prevalence of 5% of all menisci in a Caucasian population and up to 17% in a Japanese population. They may either be complete – occupying the entire tibial plateau – or

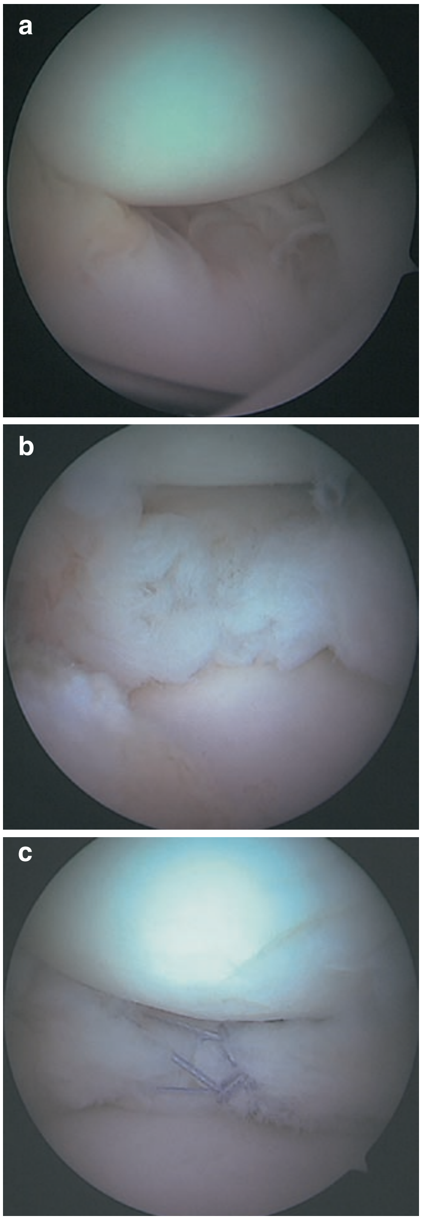

Fig. 8.4.4 Discoid meniscus with a bucket-handle (**a**) and radial tear (b) in a 5-year-old girl. She presented with a long-standing extension deficit of 15°, but no pain. The bucket-handle tear was resected and the deep radial tear was sutured (**c**)

incomplete. Symptoms are often related to tears, which may be complex even in very young children. Surgery requires a three-step procedure with partial meniscectomy and reshaping (saucerization) of the meniscus, stability testing of the meniscal periphery and repair of the detached or unstable meniscus (Figs. 8.4.5a,b,c). Peripheral instability of a discoid meniscus has been reported in 28–77% of patients, either in the anterior,

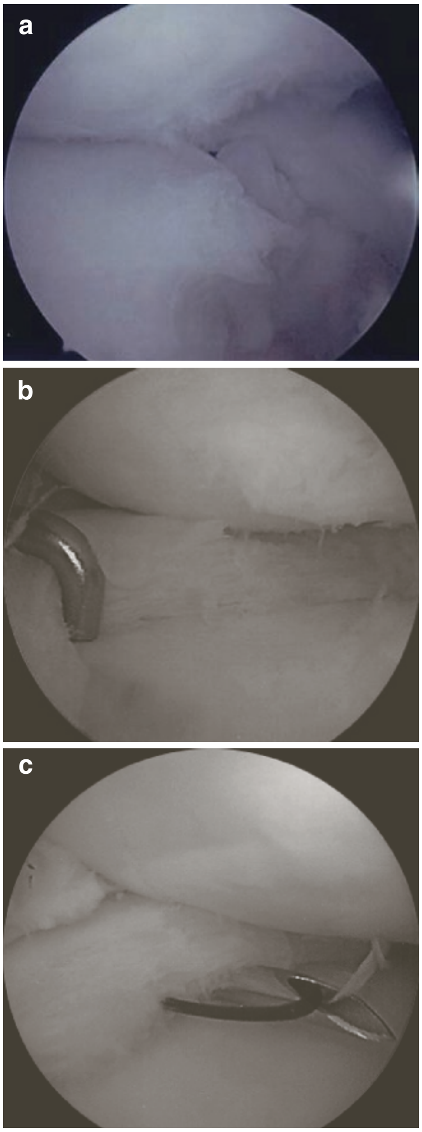

Fig. 8.4.5 Arthroscopic view showing a symptomatic discoid meniscus in a 6-year-old boy. After partial meniscectomy (saucerisation; **a**), the stability of the reshaped meniscus was examined with a probe (**b**). In case of insufficient meniscocapsular fixation, the meniscus needs to be sutured to the capsule (outside– in repair with No. 0 PDS suture; **c**)

the middle or the posterior portion of the meniscus [26, 32]. For the Wrisberg type with no posterior attachment of the meniscus to the tibia, the majority of authors advise total meniscectomy [37, 41].

Cartilage status, mal-alignment and ACL status have important implications for the results of meniscal repair and have to be considered in the decision-making process of partial meniscectomy or repair. If a bucket-handle tear is associated with an ACL injury, we recommend concomitant reconstruction and meniscal repair (Fig. 8.4.2). In chronically ACL-deficient knees, delayed reconstruction is associated with a high incidence of secondary meniscal tears, mainly in the medial compartment [3, 27, 39, 41]. The percentage of reparable tears has been reported to decrease with the chronicity of ACL deficiency [13, 14]. Therefore, meniscal repair and ACL reconstruction should be performed in ACL-deficient knees with meniscal tears to prevent further meniscal damage, using pediatric ACL reconstruction techniques [4, 25, 46, 48].

Results

Limited data are available on the treatment results of meniscal tears in children [8, 40].The results seem to be as satisfactory as in adults [40, 47]. The majority of surgeons reported good initial results in more than 90% of patients after meniscectomy. Radiological degenerative changes were present in a larger proportion than after suture at 5 years of follow-up [33].

Total meniscectomy is characterized by early degenerative changes correlated with reduction of activity [1, 34, 56], particularly when the lateral meniscus is involved [1, 56]. Long-term follow-up studies of totally meniscectomized patients have consistently reported early radiographic signs of knee joint degeneration, in addition to clinical symptoms of premature osteoarthritis and disability [17]. With increasing follow-up, the results worsen [35] and these findings are even more compelling in pediatric and adolescent age groups [5, 11, 34, 36, 49]. Meniscal repair may prevent radiological changes [2]. Manzione et al. [34] investigated the results of meniscectomy in children with a mean age of 15 years at the time of surgery. In 17 of 20 patients, total meniscectomy was performed; only three patients underwent partial meniscectomy. After a mean follow-up of 5.5 years (3–14), only 40% showed excellent (25%) or good results (15%); 80% of the patients showed signs of radiographic changes. These results were confirmed by Raber et al. [45] and Okazaki et al. [44], who also described increased degenerative changes in the femoro-tibial joint in children with a mean age of 9 years (3–14) [45] and 17.9 years (6–55) [44] at the time of surgery. In a prospective longitudinal 30-year review, McNicholas et al. [35] reported the outcome of total meniscectomy in 63 patients with a mean age of 16 years (10–18) at surgery. Seventy-one percent of the patients were satisfied with their knee 30 years after surgery. However, after 17 years of follow-up, osteo-arthritic changes were twice as common as in the non-operated knees. At 30 years, the incidence of osteo-arthritis had increased significantly, being three times higher in the operated knees. The worst results were observed in patients with double meniscectomy, followed by those with lateral meniscectomy, with only 47% good or excellent results. Significantly better results were achieved after medial meniscectomy, with 80% excellent or good results. The long-term effects of meniscectomy were also investigated by Abdon and co-workers [1]. After a mean post-operative follow-up of 17 years, only 52% of the 89 patients with a mean age of 16.8 years (7–18) at surgery had an excellent or satisfactory outcome according to the scoring system of Tapper and Hoover [53]. These results show that osteo-arthritic changes after meniscectomy seem to occur more frequently in children than in adult populations. As a consequence, the basic principle in the treatment of meniscal injuries in children should be to preserve as much meniscal tissue as possible to minimize subsequent degeneration of the knee joint.

Long-term studies of both arthroscopic and open meniscal repair techniques have reported successful healing in 65–92% of patients when the procedure was performed for unstable peripheral meniscal tears [7, 11, 14, 19, 20, 22, 38, 42]. After arthroscopic-assisted meniscus repair in children, Accadbled et al. [2] found seven of nine patients to be completely asymptomatic and two to present occasional pain at a mean follow-up of 3 years. Eight patients had a normal knee according to the International Knee Documentation Committee score (A). The Lysholm score increased from 65.3 to 96.3 points and all but two patients returned to their previous level of sporting activity. Eight patients could be followed up either by computed tomography (CT) arthrogram (3) or MRI (5). In three-sutured menisci, a CT arthrogram revealed complete healing; post-operative MRI showed no abnormality in only two cases. However, a successfully treated meniscus may exhibit grade 3 signal intensity more than 12 months after the tear has healed [21, 24].

Scott et al. [47] described the results of arthroscopic-assisted meniscal repair in 240 patients with a mean age of 22 years (9–53). Arthroscopic or arthrographic follow-up examinations revealed a complete healing rate of 62%. At a mean follow-up of 5 years, Mintzer et al. [40] reported 100% of asymptomatic patients after meniscus repair. The average age of the patients was 15.3 years (11–17). All but two patients returned to their pre-injury level of sporting activity; the two who did not cited reasons unrelated to the meniscal repair. Noyes and Barber-Westin [43] performed 36 arthroscopic evaluations of 71 repairs of meniscal tears in 61 patients with a mean age of 16 years (9–19). They found 13 to be completely healed, 11 incompletely healed and 12 unhealed. Eighty percent of the patients were asymptomatic at 51 months of follow-up.

Any discussion of meniscal repair must also emphasize the significant influence of associated ACL lesions [18], even if meniscal repair also provides satisfactory results when combined with ACL reconstruction [4, 12, 40, 43, 47]. The incidence of re-rupture in repaired menisci has been shown to be higher in unstable knees [19]. On the other hand, ACL reconstruction reportedly improves the healing rate if performed at the time of meniscal repair [29, 30, 47, 54]. Anderson [4] recently described eight meniscal repairs associated with ACL reconstruction in children, and found all patients to be asymptomatic after 4.1 years of follow-up. Because ACL tears are present in approximately 80% of knees with reparable meniscal tears [18], the ACL status must be properly considered in deciding on repair or partial removal. Cannon and Vittori [12] compared the results of meniscal repairs in patients with and without associated ACL reconstruction. Only 54% of patients aged 18 years or younger presented satisfactory healing at follow-up, increasing to 88% when simultaneous ACL reconstruction had been performed. These results were confirmed by Henning et al. [28], who only found a 59% successful healing rate in isolated meniscal repairs and a 94% incidence of satisfactory healing in meniscal repairs done in conjunction with ACL reconstruction. Tenuta and Arciero [54] also reported a better healing rate for meniscal repairs in conjunction with ACL reconstruction, compared to meniscal repairs in cruciate-stable knees. They found a 90% satisfactory healing rate in the ACL group compared with 57% healed menisci in cruciate-stable knees investigated by second-look arthroscopy.

Finally, the time of meniscal repair might also influence the result. Delay between meniscal injury and repair has been reported to negatively affect the healing rate and to compound the lesions [12, 22, 51], whereas other authors have found no effect at all [10, 18, 54]. Especially if an ACL rupture is associated, the healing rates seem to be also satisfactory in meniscal tears older than 8 weeks [12]. ACL surgery results in more intra-articular trauma to the joint, causing more bleeding and fibrin clot formation, which promotes the healing process [47]. Therefore, if a meniscal tear is reparable, ACL reconstruction should also be performed to protect meniscal repair and to provide the best conditions for successful healing.

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Synthesis

8.5

R. Seil

Although many authors have reported an increasing number of meniscal lesions in children, the references cited in this section show that specific reports of meniscus problems in children have remained stable over time. Among the cited references, we counted 12 studies dealing with this subject per decade, starting in the 1980s. Does this mean that there is nothing left to learn about meniscus lesions in children, or that the interest in this subject is fading? I do not think so.

As mentioned by Hirschmann and Friederich [8], children's knees differ in many respects from adult knees in that they are, for example more lax in the prepubertal phase than in adulthood. Baxter [3] showed that they become more resilient with increasing maturation, especially during the adolescent growth period. This physiologically increased knee laxity might explain the high number of traumatic meniscal tears in stable knees identified during an 18-month period in a recent prospective multicentre study by the French orthopaedic society [4]. Of 60 traumatic meniscal injuries in children aged between 8 and 16 years, 55% were found in stable knees whereas 45% occurred in conjunction with a tear of the anterior cruciate ligament (ACL). More than 50% of the lesions were sports injuries. Ninety percent of this paediatric population presented the classical symptoms of pain and/or locking as the main manifestation of their knee problem. The fact that the time from injury to surgery was almost 1 year shows that the diagnosis and treatment of this type of lesions can certainly be improved. Magnetic resonance imaging (MRI) is the best tool to confirm the clinical diagnosis and rule out other lesions such as osteochondral injuries after a knee trauma. However, it should be kept in mind that the prevalence of grade 2 and 3 signal abnormalities in children under the age of 10 years may be as high as 85% in asymptomatic children. At the age of 15, they are still present in one third of the children [18]. The increased hyper-vascularity of children's menisci, which is not limited to the outer third of the meniscal body as in adults, accounts for this finding. However, awareness of potential false-positive cases might lead to a tendency to overlook existing meniscus lesions, especially in children performing strenuous activities as, for example in high-level sports [10].

The tear type observed in the French multi-centre study showed that the lesions generally occur in non-degenerative tissue: 83% were vertically longitudinal tears, and the majority of lesions were bucket-handle tears ($n=25$). Tears in the more mobile lateral tibiofemoral compartment were different from those in the more contained medial compartment, stressing the biomechanical differences between these two compartments. A majority of lesions were lateral (57%), and of the eight horizontal tears, seven occurred in the lateral part of the knee.

When it comes to treatment, the main message of meniscal surgery in children – to save as much meniscus tissue as possible – has been well understood by the majority of surgeons: in 63% of cases, a "preservative" approach was chosen, consisting of either masterly neglect for small and/or stable lesions (15%) or meniscal repair (48%). In times when one might suppose that knee arthroscopy and arthroscopic meniscal repair would be performed by a vast majority of knee surgeons in Europe, it was surprising to see that 41% of repairs were still performed by arthrotomy. These were

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_8.5, © Springer-Verlag Berlin Heidelberg 2010

wise decisions in view of the deleterious long-term effects of meniscectomy in children [11, 12, 17, 21]. Good open repair is better than a poor arthroscopic refixation procedure or a resection. The technique of proper arthroscopic meniscal repair in children has been expertly described in this book section by Cassard [5]. He showed that these procedures are comparable to adult repairs except that the joints are smaller. Nevertheless, “adult” arthroscopic instrumentation can be used in most of the cases. As in adults, approximately 4 of 5 repaired menisci survive in the medium and long term. In a retrospective study of 52 meniscus lesions, Accadbled et al. [1] showed that preserving the meniscus was successful in 79% of cases at 5 years. Three out of four re-operations had to be performed within the first 2 years of the initial surgery, mainly due to less than perfect judgement from the part of the surgeons who performed the eight bucket-handle tear resections (nearly one bucket-handle tear in three!). Unless it is impossible to stabilize the bucket-handle tears in case of long-term chronic dislocation (Fig. 8.5.1: another argument pleading for early diagnosis and treatment), these lesions should have been repaired. The consequences of early meniscal resection are illustrated with the case of an 18-year-old woman who sustained a sports-related lateral meniscus injury at the age of 12 (Fig. 8.5.2). Six years after resection she experienced recurrent episodes of swelling and persistent mechanical pain during activities of daily living. The only anatomic treatment option in these patients – in the absence of ligamentous instability and malalignment – is meniscus transplantation [16]. Fortunately, these cases are rare, but they should always be kept in mind at the time of the index procedure. Total meniscectomy, however, has to be performed in a small category of traumatic meniscal tears. I am referring to complete radial tears, which occurred in only 3% of cases in the aforementioned study. They are extremely difficult to repair and have low healing potential. Reports on such repairs are anecdotal, as illustrated in the previous paper by Lorbach et al. [10].

Fig. 8.5.1 A long-standing dislocated medial meniscus bucket-handle tear in a young patient. The delay between injury and surgery exceeded 1 year. In view of the poor results of meniscectomy in children, this type of tear stresses the need for an early diagnosis and treatment of these lesions. Good short and long-term results have been achieved with meniscal repair. Bucket-handle tear resections in children should be abandoned, especially in the lateral tibio-femoral compartment where symptomatic osteoarthritis often occurs in early adulthood and where no adequate treatment option except probably meniscus transplantation exists

The second large group of traumatic meniscus lesions is due to a major pivoting knee trauma in association with an ACL tear. Forty-five percent of the meniscal injuries in the aforementioned study were related to an ACL tear, either in the acute or the chronic setting. This number is surprisingly high since 10 years ago ACL tears in children were supposed to be very rare. In times of an ever-increasing number of organized pivoting sports – especially in females – and decreasing motor skills in paediatric populations, their incidence might be rising. In our daily practice we still see diagnostic arthroscopies being all too often performed in these cases, but none represents a surgical emergency. This approach should definitively be abandoned, one single exception being a locked knee due to a dislocated bucket-handle or flap tear. There is increasing evidence that ACL reconstruction in a paediatric population provides good results and has only few complications in experienced hands. In previous years, these ACL injuries were either overlooked or “treated” conservatively. This resulted in an inacceptably high number of secondary meniscal tears and even early signs of osteoarthritis [2, 14]. Currently, there is a trend to consider the meniscal status as being the most important determining factor for ACL reconstruction, either in the acute or in the chronic setting. With respect to the growth velocity of the epiphyseal physes which are close to the knee, it is important to differentiate between three categories of children with ACL tears: (1) prepubertal children with a large potential of growth (skeletal age <13 years in girls and 15 years in boys), (2) children with knees nearing maturity (skeletal age of 13–14 years in girls and 15–16 years in boys), and

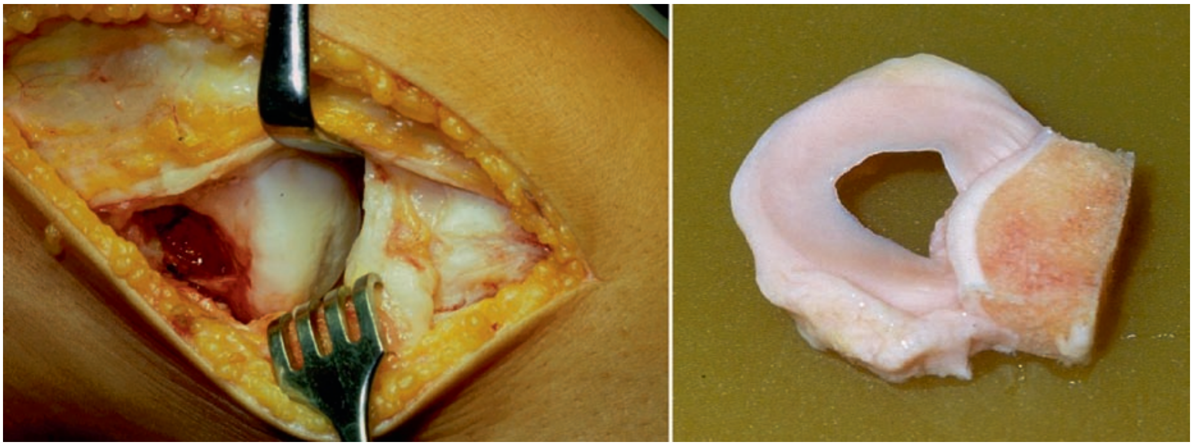

Fig. 8.5.2 Meniscus transplantation procedure in an 18-year-old woman who sustained a sports-related lateral meniscus injury at the age of 12. Six years after resection she experienced recurrent episodes of swelling and persistent mechanical pain during activities of daily living. The left image shows an arthrotomized knee. The joint space has been opened by reflecting the lateral collateral ligament and the popliteus tendon through an osteotomy of the lateral femoral epicondyle. A grade 3 chondral lesion of the femoral condyle can be seen. On the right, a lateral meniscus allograft

(3) adolescents with closed epiphyseal physes (skeletal age >14 years in girls and 15 years in boys). In the third category, meniscus repair can be performed together with ACL reconstruction using adult techniques. In the first category, meniscus repair should be performed in conjunction with ACL reconstruction using specific paediatric techniques, at the latest after the occurrence of a secondary meniscal tear. It is still controversial whether non-operative treatment can be attempted in these patients. However, there is growing evidence that the incidence of secondary meniscus tears, especially on the medial side, increases with chronic anterior knee instability [13]. In a recent study, Woods and O'Connor [20] found no statistical evidence of an increased rate of additional knee injuries in a population that had received optimal non-operative treatment (brace, physiotherapy, regular follow-up visits). However, the number of secondary medial meniscal tears tended to increase, although statistical power was insufficient. Another recent study by Chotel [6] confirmed the occurrence of secondary tears of the medial meniscus with chronic ACL insufficiency in children. In the second category, where the remaining growth potential of the epiphyseal plates is very limited, it might be wise to wait for several months until skeletal knee maturity has occurred.

The third major group of meniscal injuries in children is related to the presence of a discoid meniscus. The clinician must keep in mind that this should be the first condition to consider when faced with an extension deficit in a child. MRI is again the best diagnostic tool to confirm the diagnosis and to rule out other potential knee problems. Hirschmann and Friedrich [8] have provided us with a detailed overview of the epidemiology and the various classifications of these types of menisci. The fact that discoid menisci are more frequent in Asian populations might be of clinical interest. Many classifications have been proposed, among which Watanabe's classification [19] still seems to be most frequently used. In two recent publications, the concept of instability of the discoid meniscus has been added to this classification [7, 9]. Good et al. [7] found that a majority of discoid menisci were unstable (47% in the anterior, 11% in the middle and 39% in the posterior portions of the meniscus). Papadopoulos' study [15] is one of the first to analyse collagen fibre orientation in discoid menisci. He found that the distribution of the circumferential collagen fibre bundles was disorganized and inhomogenous, which might explain the high incidence of tears in discoid menisci. Cassard [5] has described the treatment of lateral discoid menisci with the now widely accepted saucerization procedure, stability testing and suturing of the meniscus to the capsule in case of instability.

In children, rehabilitation after meniscal repair tends to be less aggressive than in adults [5]. Children regain post-operative mobility much more easily than do adults. Even long-standing preoperative extension deficits, which can be seen with symptomatic discoid menisci, usually recover well with gentle physiotherapy. The fact that pre-pubertal children have higher physiologic knee laxity explains why some paediatric orthopaedic surgeons use an even stricter immobilization protocol after meniscal repair than in adults. However, scientific evidence of rehabilitation practices yielding the best results after meniscal repair in children is sparse.

This overview shows that the knowledge and treatment of meniscal injuries in children have undergone dramatic changes over the last two decades and are still continuously advancing. However, many questions still remain unanswered.

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Part IX

Post-meniscectomized Knee

Postoperative Osteonecrosis of the Condyle: Diagnosis and Management

9.1

D. Pape, R. Seil, and D. Kohn

Introduction

Osteonecrosis of the knee comprises two separate disorders. The first one is called *primary spontaneous osteonecrosis* of the knee (SPONK), which was first described as a distinct entity by Ahlback et al. [2]. Two main theories of the etiology of osteonecrosis have been advanced; a vascular arterial insult and trauma, but neither has been conclusively proved.

The second entity of osteonecrosis of the knee is called *secondary osteonecrosis*, which is associated with risk factors and a poor prognosis. Frequently, secondary osteonecrosis is a side effect of prolonged steroid therapy used for many medical conditions, such as rheumatoid arthritis, systemic lupus erythematosus, chronic bronchial asthma, skin lesions, and after renal transplantation. Secondary osteonecrosis is bilateral in 50% of patients and affects the lateral femoral condyle in 60%. Multiple sites (such as humeral head, hip, lateral humeral condyle, talus, etc.) may be involved, but the symptoms are often minor compared to primary lesions that involve an entire condyle. Secondary osteonecrosis may be multifocal (e.g., involving both femoral condyles and the tibial plateau).

A potential third entitiy of osteonecrosis of the knee was described by Brahme et al. [9]. They were the first to report the development of osteonecrosis of the knee after routine arthroscopic meniscectomy. Since then, osteonecrosis of the postoperative knee has been considered as a complication of arthroscopic meniscectomy [13, 28] and has been referred to as "postarthroscopic" [19] or "postmeniscectomy" osteonecrosis of the knee [13, 21, 35].

Since osteonecrosis has also been noted after other arthroscopic interventions, such as cartilage debridement [17] and anterior cruciate ligament reconstruction [6], it might be advisable to refer to this entity as *osteonecrosis of the postoperative knee* (ONPK) to avoid possible medicolegal implications, as previously explained [32].

So far, more than 40 ONPK cases have been reported in the literature [3, 9, 12, 13, 19, 22, 28, 37, 40]. Compared to the high number of arthroscopic knee procedures performed world-wide, the prevalence of ONPK is very low. Several etiological factors for ONPK have been discussed, but its exact cause remains unknown.

However, clinical symptoms and pathognomonic imaging findings for osteonecrosis can be found both in ONPK and in SPONK, which is an important differential diagnosis. Therefore, it has been speculated that ONPK and SPONK could be the same disease, recognized at different perioperative points in time [35]. Both ONPK and SPONK have the potential to progress to irreversible stages. Although this progression can come to a halt at any time, complete resolution seems to be restricted to the early stages of ONPK and SPONK. Consequently, a stage-dependent therapeutic approach – conservative treatment in early osteonecrosis and surgical treatment in advanced stages – has been recommended [19, 40, 41] (Table 9.1.1).

The purpose of this paper is to review the presumed pathophysiology and the clinical and radiographic features, as well as the pitfalls in diagnosing ONPK.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_9.1, © Springer-Verlag Berlin Heidelberg 2010

Table 9.1.1 A modified SPONK classification system by Soucacos et al. [42] combines data from various imaging methods to identify the most appropriate method for diagnosing each of the four stages

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

Studies reporting the associated use of radiofrequency devices or laser techniques for arthroscopic meniscectomy have not been considered in this review, because the suspected principal etiology in these cases is the thermal and/or photoacoustic effect rather than routine arthroscopic meniscectomy performed with hand instruments or mechanical shavers [26, 36]. Studies reporting associated trauma or other risk factors for secondary osteonecrosis have not been considered either.

Epidemiology of ONPK

The exact prevalence of ONPK has never been evaluated, but it seems to be very low considering the large number of arthroscopic meniscectomies [19]. Nine clinical studies including a total of 47 patients have reported ONPK after arthroscopic meniscectomy [3, 5, 9, 12, 13, 19, 22, 28, 37, 40]. In all cases, meniscectomy was performed prior to the development of ONPK. Postoperative MRI always showed signs consistent with ONPK (Table 9.1.2). Both genders were equally affected (24 male, 23 female patients), with a mean age of 58 years (21–82 years, Table 9.1.2). ONPK seems to differ from SPONK in terms of age and gender since SPONK predominantly affects elderly female patients (>60 years, male:female ratio = 1:5 [33]).

Both entities share a striking association of medial meniscal tears and osteonecrosis. Of the 47 patients diagnosed with a meniscus lesion prior to the initial arthroscopy, 41 had a medial meniscus tear (87%) and six had a lateral meniscus tear (13%). Muscolo et al. [29] reported on a series of five patients over 60 years of age who were followed with serial MRI. Each had a symptomatic medial meniscal tear and developed SPONK. Arthroscopy was not performed.

The medial femoral condyle was affected in 82% ($n=39$) of cases, followed by the lateral femoral condyle in 8.5% ($n=4$), the lateral tibial plateau in 2.1% ($n=2$) and the medial tibial plateau in 2.1% ($n=1$). The location of osteonecrosis correlated topographically with the preexisting pathology and arthroscopic procedures in all studies. In case of a medial meniscal tear, MRI signal changes were usually restricted to the medial femoral condyle. No patient developed osteonecrosis in the contralateral compartment to the meniscectomy site. Of the six patients with a lateral meniscal tear, four developed osteonecrosis of the lateral femoral condyle and the other two of the lateral tibial plateau. Sixty-five percent of patients were diagnosed with a concomitant chondral lesion of varying degree. The medial compartment was affected in 33 patients (26 patients with chondromalacia of the medial femoral condyle, 7 patients with medial tibial plateau, Table 9.1.2). ONPK did not differ from SPONK with regard to the location of the lesions. The simultaneous involvement of the medial femoral condyle and either the adjacent tibia or the lateral compartment seems to be very rare in both ONPK and SPONK [9, 41]. However, single lesions other than that in the medial femoral condyle can appear in both SPONK and ONPK [3, 25, 26, 29, 33, 36, 37, 40–42].

Table 9.1.2 Epidemiological data of reviewed studies on progressive osteonecrosis on postoperative MRI after routine 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 their 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 [9]	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
Johnson [19]	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 [37]	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 [40]	2	Retrospective, case reports	1/1	34 (21–47)	2 2 med/0 lat	0	0	0	–	2 MFC
DeFalco [12]	1	Case report	1/0	48	1 1 med/0 lat	0	0	0	–	1 MFC
Kusayama [22]	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 [13]	1	Retrospective, case reports	1/0	66	1 1 med/0 lat	0	0	0	–	1 MFC
Musculo [29]	8	Retrospective, case series	3/5	65 (54–75)	8 8 med/0 lat	4	4 med/0 lat	0	–	8 MFC
Average				58						
Total	47		24/23		47 41 med//6 lat	31 (65%)	26 med/6 lat	7 med/5 lat	15 Chondroplasty	41 MFC (82%) 4 LFC (8.5%) 1 MTP (2,1%) 2 LTP (4.2%)

The location of ON correlated topographically with preexisting pathology and arthroscopic procedures in all studies. In case of a 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 ON of the LFC and the other two of the lateral tibial plateau

MFC medial femoral condyle; *LFC* lateral femoral condyle; *MTP* medial tibial plateau; *LTP* lateral tibial plateau; medically: nonweightbearing for at least 4 weeks with NSAIDs

Etiology

The etiology of ONPK remains unclear. In the majority of studies, degenerative changes of both cartilage and meniscus at the time of arthroscopy were held responsible for the development of osteonecrosis [13, 19, 37, 38, 40]. The meniscal tear itself seemed to be associated with osteonecrosis even before surgery was peformed [7, 29].

Altered knee biomechanics after meniscectomy have also been considered to predispose to osteonecrosis [44]. In these cases, increased tibiofemoral contact pressure might result in insufficiency fracture of the cartilage and subchondral bone with intraosseous leakage of synovial fluid and subsequent osteonecrosis [14, 20].

Other authors hypothesized that pathologic cartilage could have increased the permeability for the arthroscopy fluid, which might lead to subchondral edema and consequent osteonecrosis [37, 38]. Whether an etiologic relationship exists between degenerative meniscal and chondral damage and arthroscopy or whether this is a mere coincidence is unclear because of the high prevalence of degenerative meniscal tears in elderly patients, in whom osteonecrosis is more frequently seen.

It has been suggested that the lesions described as subchondral osteonecrosis following meniscectomy, actually represent subchondral insufficiency or stress fractures [16]. Yamamoto and Bullough [43] came to this assumption on the basis of a careful histologic evaluation of patients with osteonecrosis of the hip and knee. Provided that specimens of advanced and irreversible osteonecrosis were examined in these studies, these findings would question whether SPONK and ONPK actually exist.

Arthroscopy itself has been advanced as a nondegenerative cause of osteonecrosis [21, 37], although the initial reason for arthroscopy was a meniscal tear. Other nondegenerative causes, such as the use of an irrigation pump or tourniquet during surgery and the preoperative intraarticular administration of local anesthetic, have not been associated with subsequent osteonecrosis [13, 19, 28].

Patient History, Physical Examination and Differential Diagnosis

Elderly patients have a high incidence of degenerative meniscal tears [11]. They often present with medial knee pain of sudden onset. On clinical examination, a mild effusion together with medial joint line tenderness can be found. Some patients complain of locking and catching. Conventional radiographs of the knee frequently show a preserved joint space and no signs of osteonecrosis [34]. 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 and symptoms usually resolve. In some patients, however, symptoms persist or even worsen although the degenerative meniscus tear was adequately resected [13, 19, 21, 28, 40]. These patients have similar clinical and imaging findings, which can be indicative of the development of osteonecrosis: postoperative joint line tenderness and effusion consistent with a potential (re)tear of the operated meniscus, and a BME pattern in the meniscectomized compartment on postoperative MRI [9, 13, 18, 19, 21, 28, 35, 40].

The clinical significance of these findings is difficult to interpret since SPONK, ONPK, and chondromalacia can mimic meniscus symptoms and postoperative BME is frequently transient [18, 21].

In patients with persistent or worsening symptoms following knee arthroscopy, one must distinguish between a missed diagnosis of early-stage SPONK, ONPK, a transient lesion presenting a similar BME pattern on MRI [18], and a recurrent meniscal tear.

Establishing a correct diagnosis can be difficult due to the following pitfalls: (1) medial knee pain can be caused by a degenerative meniscal tear, BME, or both; (2) degenerative medial meniscal tears seem to be associated with the development of SPONK [29]; (3) signs, symptoms, imaging findings, and the potential to progress are similar for ONPK and SPONK [13], but additional arthroscopy in the presence of undiagnosed SPONK can accelerate joint destruction [24]; (4) BME on MRI is a frequent but nonspecific signal pattern that can be related to ischemia (i.e., osteonecrosis, BME syndrome, OCD), and mechanical (bone bruise, microfracture) or reactive (osteoarthritis, postoperative BME) causes [18]; and (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) [19, 27, 29].

In the presence of consistent BME changes on pre- and postoperative MRI, the diagnosis of preexisting SPONK is likely. Without BME changes on preoperative MRI, ONPK must be suspected, but SPONK cannot be ruled out. Without a preoperative MRI, SPONK, ONPK, and transient lesions must be included in the differential diagnosis, and a definitive diagnosis may be possible only in retrospect.

Diagnosis of ONPK and Imaging Findings

To diagnose developing osteonecrosis, MRI is mandatory to detect a BME pattern. Since only bone marrow structures are initially affected, plain radiography, CT, or arthroscopy is unable to demonstrate these early changes. Although bone scan is highly sensitive to detect early changes in vascularization by increased tracer accumulation, its spatial resolution is poor and differentiation from other disorders with increased tracer uptake is impossible [18, 38].

According to the literature, the following two prerequisites have to be fulfilled simultaneously to establish the diagnosis of ONPK [19, 23, 29, 34]: absence of osteonecrosis on preoperative MRI obtained 4–6 weeks after the onset of preoperative symptoms, and a temporal association between knee arthroscopy and a suspicious BME 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 has to be present: pathognomonic imaging findings of advanced osteonecrosis on plain radiographs, MRI or CT such as crescent sign or collapse of subchondral bone and articular cartilage, and/or histologic findings consistent with osteonecrosis of the resected lesion during salvage surgery.

Absence of Osteonecrosis on Preoperative Imaging

Normal preoperative MRI findings are mandatory to distinguish ONPK from SPONK. However, in the early stage of SPONK, MRI findings might be normal, because a so-called “window period” has been noted between the onset of symptoms and the appearance of signal changes on MRI [8, 19, 30, 35].

Johnson et al. [19] arbitrarily chose 6 weeks as the minimum time interval between the onset of knee symptoms and MRI examination as an inclusion criteria for their knee patients. This decision was based on a canine model by Nakamura et al. [30], who surgically induced osteonecrosis of the femoral head and demonstrated that it could take up to 4 weeks after surgery for the MRI to become positive.

In a clinical MRI study, Lecouvet et al. [23] described a mean interval of 10 weeks between the onset of symptoms and subsequent MRI changes. Muscolo et al. [29] reported on a series of five patients with a symptomatic degenerative medial meniscal tear followed up with MRI, who developed osteonecrosis without having undergone arthroscopic meniscectomy.The mean interval between initial MRI and onset of symptoms was 2.2 months.

Although the exact length of the diagnostic MRI window period to detect SPONK has not yet been well defined, it appears that MRI findings might be considered as normal only if the examination was obtained at least 6 weeks after the onset of symptoms. Otherwise it might not be possible to distinguish between early SPONK and ONPK.

Temporal Association Between MRI Signal Changes Following Arthroscopy

Nine clinical studies including a total of 47 patients and using MRI as the initial diagnostic imaging method, reported ONPK after arthroscopic meniscectomy [9, 12–14, 19, 22, 28, 40].

In the majority of studies, the diagnosis of ONPK was solely based on a temporal association between osteonecrosis and the occurrence of postoperative MRI signal changes after knee arthroscopy (Table 9.1.3). Preoperative MRI was performed in 44 of the 47 patients (93.6%). In five of the nine studies, the exact onset of clinical symptoms prior to preoperative MRI was not mentioned. In total, up to 28 of the 47 ONPK cases (59.5%) might actually represent preexisting, undiagnosed early-stage SPONK (diagnostic window, Table 9.1.3). In addition, BME on MRI was a common but nonspecific pattern found in several diseases [18]. Postoperative BME is frequently present after arthroscopic meniscectomies [19, 21, 28, 40] or ligament reconstructions [6]. In ONPK, MRI findings seem inconsistent, may resemble SPONK [9, 28, 37] or may even be transient [21] or reactive in nature [10, 17] (Table 9.1.4).

Table 9.1.3 Survey of temporal 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 interval 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 interval between initial arthroscopy and MRI establishing the diagnosis of ONPK (weeks) (range)
Brahme [9]	7	7	Unclear	Up to 7	32 (8–56)
Johnson [19]	7	7	42 (6–144)	0	16 (12–24)
Prues-Latour [37]	9	9	26 (0.4–72)	2	24 (5–48)
Santori [40]	2	1	Unclear	1	4
DeFalco [10]	1	1	3	1	9
Kusayama [22]	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 [13]	1	0	Unclear	1	16
Musculo [29]	8	8	Unclear	4	18 (6–36)
Average			18.3		18
Total	47	44 (93.6%)		28 (59.5%)	

In total, up to 28 of the 47 ONPK cases (59.5%) might actually represent preexisting, undiagnosed early-stage SPONK due to the diagnostic window of the MRI method for detecting SPONK

Kobayashi et al. [21] found postoperative BME on MRI in 34% of partially meniscectomized patients within 8 months after surgery. No signal changes were seen prior to arthroscopy. Postoperative changes were restricted to the meniscectomized 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 or extent of BME and age, gender, or degree of chondromalacia. In addition, Kobayashi et al. did not observe progression of the disease in these rather young patients. Muscolo et al. [28] and Prues-Latour et al. [37] suspected that the risk of progression to ONPK after partial meniscectomy might 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 BME on MRI is common and generally does not lead to ONPK [18, 21].

Imaging Findings and Classification

A classification system for ONPK does not exist. However, because clinical presentation, imaging findings, and the frequent progression to irreversible stages are similar for ONPK and SPONK [13, 29], the current classification systems for SPONK seem to apply also to ONPK. Aglietti et al. [1] proposed a radiographic classification system which is helpful only in the diagnosis of advanced SPONK, since early bone marrow changes of progressive osteonecrosis are not visible on plain radiographs (Table 9.1.5).

Soucacos et al. [41] reported a modified classification system of SPONK, which pairs diagnostic findings with treatment recommendations (Table 9.1.1). In this classification, stages I and II have the potential to resolve with conservative therapy. However, the majority of SPONK patients seem to progress further to irreversible stages (Fig. 9.1.1a, b). Apparently, reversible stages (stage 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 BME. This probably depends on whether the diagnostic

Table 9.1.4 Surgical data of reviewed studies

Author	Total number of patients with ONPK	Number of routine arthroscopic meniscectoies performed 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 [1]	7	7	0		5	0	2
Johnson [19]	7	7	0	3/2	–	Second FU performed in 1 of 7, MRI changes resolved	2 patients lost to FU
Prues-Latour [37]	9	8	1	3/0	–	0	1
Santori [40]	2	2	0	–	–	2 of 2	2, no NSAIDs
DeFalco [12]	1	1	0	–	1	0	0
Kusayama [22]	2	2	0	–	–	0	2
Al-Kaar [3]	10	8	2	3/0	–	0	7
Faletti [13]	1	1	0	Prosthesis scheduled	–	0	1
Musculo [29]	8	8	0	–	–	0	?
Average							
Total	47	44 (93%)	3	9/2	6	Resolving MRI changes in 3	

Table 9.1.5 Five radiographic stages of SPONK have been described by Aglietti et al. [1]

	Findings on plain radiography	Time interval since onset of symptoms
Stage I	Normal	Several months
Stage II	Flattening of the affected weightbearing portion of the femoral condyle	Several months
Stage III	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 IV	Radiolucent area surrounded by sclerotic halo, subchondral bone has collapsed and is visible as a calcified plate	Up to 1 year
Stage V	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 III–V have a pathognomonic appearance on plain radiographs and can easily be recognized. However, the diagnosis may be difficult in early-stage SPONK, since radiographs can be normal or at least inconclusive throughout the course of the disease.

window of the MRI method to detect osteonecrosis has been considered. Moreover, BME cannot be considered pathognomonic of ONPK, since it is frequently seen as a transient lesion following knee arthroscopy [21]. If BME is present in the preoperative knee, abnormalities on T2-weighted images have been related to further progression of the disease (Fig. 9.1.2) [8, 45]. Lecouvet et al. [23] described MRI characteristics that seem to

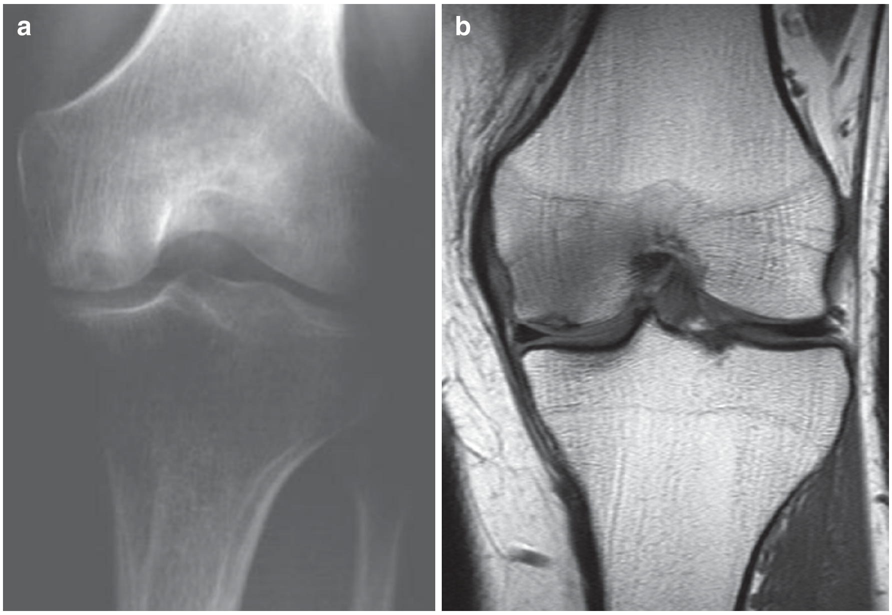

Fig. 9.1.1 (**a**, **b**) Anteroposterior conventional radiograph of a 67-year-old woman with a 4-month history of spontaneous knee pain, showing a radiolucent lesion of the medial condyle (crescent sign) indicating stage III osteonecrosis according to Soucacos et al. [41] (**a**). Coronal T1-weighted MRI shows a subchondral area of low signal intensity consistent with bone marrow edema (**b**)

allow for a differentiation between transient lesions and early irreversible SPONK. These MRI criteria are: (1) a subchondral area of low signal intensity on T2-weighted images, (2) a focal epiphyseal contour depression, and (3) lines of low signal intensity located deep in the affected condyle. The prognostic value of these MRI criteria have been confirmed in just one clinical study [33] and further research is needed (Fig. 9.1.3a, b). BME in the postoperative knee has been reported to be a "normal" and transient finding in 34% of patients after knee arthroscopy [21]. None of these patients progressed to osteonecrosis, nor, of course, did the remaining 66% of patients without signs of BME in the postoperative knee. If BME is absent preoperatively, either no osteonecrosis or developing osteonecrosis not yet demonstrable with MRI (diagnostic window) is present [29]. However, if developing osteonecrosis is suspected, three-phase bone scintigraphy is a reliable diagnostic tool since it has no diagnostic window for detecting early changes. Radionuclide uptake over the lesion is increased up to 15-fold [41], which can be indicative of subchondral bone necrosis [15]. Unfortunately, bone scanning is not a pathognomonic or specific imaging modality and other differential diagnoses, such as chondromalacia or transient BME changes, cannot be ruled out (Fig. 9.1.4).

According to Soucacos et al. [41], stage III and IV osteonecrosis is frequently associated with irreversible destruction of the subchondral bone and articular cartilage and surgery is the treatment of choice. In

Fig. 9.1.2 Bone marrow edema pattern 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 edema

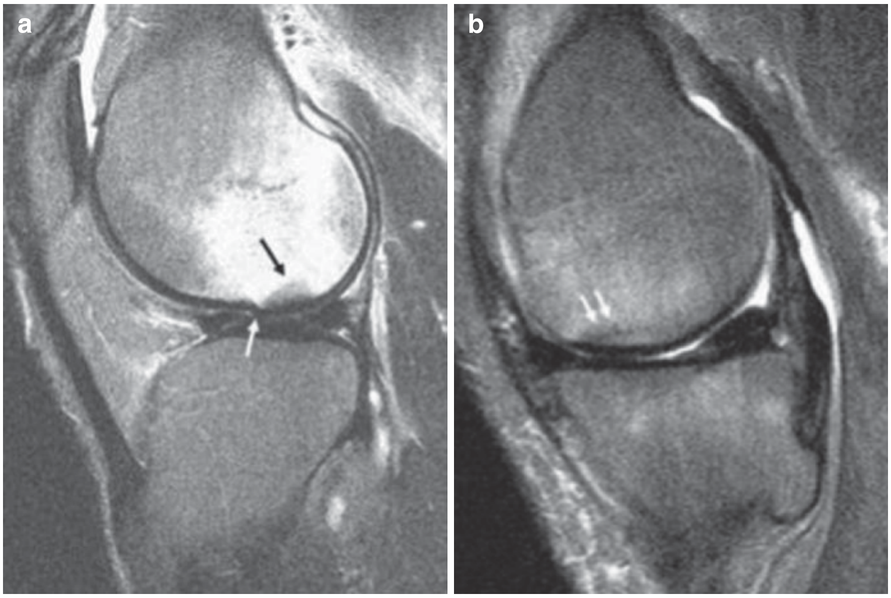

Fig. 9.1.3 (**a**, **b**) On MRI, spontaneous osteonecrosis of the knee shows bone marrow edema and subtle subchondral bone changes. Recently, Lecouvet et al. [23] described MRI characteristics that allow for a differentiation between transient epiphyseal lesions and early irreversible SPONK. For the latter, these MRI criteria were a subchondral area of low signal intensity on T2-weighted images (**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*)

stage III, a radiolucent lesion can be detected on plain radiographs, which is referred to as the crescent sign. This is pathognomonic of segmental necrosis of the subchondral bone with articular cartilage destruction. Other imaging methods, although positive, are not necessary to diagnose 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 to establish the diagnosis.

Histologic Findings

Contradictory reports exist about histologic findings in ONPK. All the cases that were examined histologically required knee arthroplasty. Johnson et al. [19] found clear evidence of osteonecrosis. However, Nakamura et al. [31] reported that MRI findings of osteonecrosis can be present in the absence of histologic osteonecrosis and are described as "osteonecrosis-like lesion." Yamamoto and Bullough [43] reported similar findings in SPONK patients and concluded that the primary pathology was a subchondral insufficiency fracture and that the associated osteonecrotic changes were secondary to the fracture. It remains unclear whether SPONK and ONPK are of different pathogenesis.

Natural History and Prognostic Factors of ONPK

Of the 47 patients diagnosed with ONPK, 44 (93.6%) either had permanent MRI changes or showed a progression to irreversible stages. In 17 of them (36%), further surgery was required. Knee arthroplasty was performed in nine, high tibial osteotomy in two, and repeat arthroscopy in six patients (Table 9.1.4).

If ONPK develops in a compromised knee after arthroscopy, its prognosis is unclear [19]. So far, al-Kaar et al. [3] are the only authors to have correlated MRI changes to different stages of ONPK. In their series of 10 patients, a large area of nonspecific intramedullary edema with low signal intensity on T1-weighted images and with heterogeneous high signal intensity on T2-weighted images was observed at the onset of the disease. Approximately 3 months after surgery, edema decreased and a clearly defined central area of necrosis appeared. This area showed 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. In the following stages, bone sequestration occurred (low signal intensity on T1- and T2-weighted images with a complete rim of very high signal

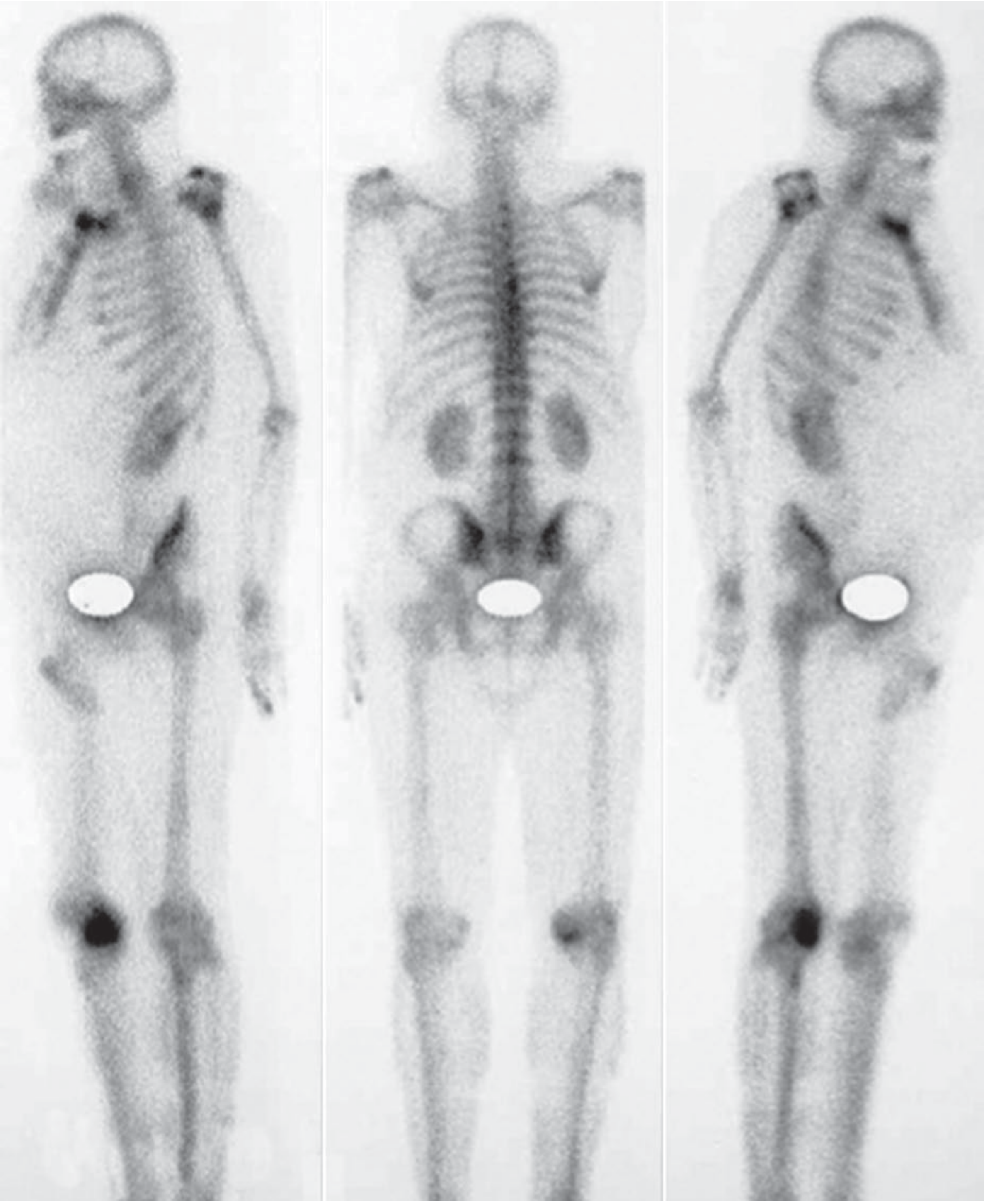

Fig. 9.1.4 Three-phase bone scintigraphy (^{99m}TC-MDP) at 4 weeks after onset of symptoms in an elderly patient with early-stage spontaneous osteonecrosis of the knee [39] (incipient stage), showing a typical distribution pattern of radionuclide uptake in the right medial femoral condyle several hours after radionuclide injection, demonstrating increased metabolic activity in the entire femoral condyle

intensities), and loose bodies or residual flattening of the articular surface were observed. al-Kaar et al. believed that the subchondral band of osteosclerotic bone had prognostic significance and that its thickness was proportional to the risk of bone sequestration [3]. However, these findings mainly depend 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 [9, 18, 21, 23].

The size of the lesion in SPONK is a well-documented prognostic factor and determines the treatment [24]. 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 expressed as a percentage of the diameter of the medial femoral condyle [4, 8, 24]. 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 [9].

In ONPK patients, the size of the lesion has rarely been correlated with outcome. Johnson et al. [19] found five of their seven patients with ONPK to deteriorate rapidly and to require subsequent surgery at an average of 7.6 months after arthroscopy (range: 5–9 months). In all the five patients, the size of the lesion was greater than 40% of the area of the medial femoral condyle on postarthroscopy MRI. Muscolo et al. [28] described five ONPK patients with an average lesion size of 24% (range: 12–30%). In another study of medically treated patients with a degenerative meniscal tear and newly developed BME lesions (not associated with arthroscopy), they described nearly the same size of bone marrow changes in the femoral condyle (21% on average, range 17–26%) [29]. However, the authors did not mention whether the relatively small size of the lesions in both the SPONK and ONPK patients was correlated with a benign course of the disease.

These findings relating to lesion size in ONPK do not confirm the prognostic value of lesion size in 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 mandatory.

Treatment Options

For proper treatment recognition of osteonecrosis is essential. If diagnosed early, osteonecrosis can run a benign course and satisfactory knee function can be achieved with conservative therapy [35]. In the 47 patients mentioned above, the abnormal BME pattern on the first postoperative MRI was diagnosed 18 weeks on average after initial surgery (range 3–176 weeks, Table 9.1.2). In three [19, 40] of these patients (6.4%), signal changes resolved completely after a 6-week period of nonweightbearing. However, potentially preexisting SPONK was not ruled out in two of these three patients, since preoperative imaging consisted of a CT in one patient, and in the other patient, no preoperative MRI was performed [40].

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 weightbearing for 6 weeks, antiinflammatoy medication, and analgesics is frequently propagated [13, 28, 37, 40]. A second postoperative MRI for follow-up evaluation of the BME pattern has generally been recommended. It showed a persistent or progressive lesion in the majority of studies cited, except for 3 [40] out of 47 patients (Table 9.1.4).

A variety of surgical treatments for advanced/irreversible lesions has been proposed, such as arthroscopic debridement, osteotomy, drilling, and total knee arthroplasty [12, 13, 37, 40]. Of the 47 patients diagnosed with ONPK, 17 underwent revision surgery (36%). Of these 17 patients, 11 (64%) were treated with open surgery (nine arthroplasties, two high tibial osteotomies) and 6 (36%) had arthroscopic revision surgery (Table 9.1.4).

Conclusion and Medicolegal Implications

Little is known about the etiology of ONPK. Its prevalence is probably very low. The most important differential diagnosis is preexisting and undiagnosed early-stage SPONK [2, 6, 9, 12, 13, 22, 32]. From a medicolegal point of view, orthopedic surgeons need to be aware of the diagnostic pitfalls in differentiating between ONPK and SPONK, and understand that both may be nonpreventable conditions.

If pain persists after an arthroscopic procedure such as meniscus resection, cartilage debridement, or other intraarticular procedures, it may be more prudent to first perform MRI to look for a BME pattern, in which case nonweightbearing for 6 weeks would be recommended, than to rapidly perform another surgical intervention with the potential of accelerated joint destruction.

In addition, elderly patients with meniscal tears and chondral lesions should be alerted to the rare risk of osteonecrosis following knee arthroscopy [28].

At this stage, surgeons can neither predict nor prevent this disease. Even if arthroscopy is associated with the development of osteonecrosis and adequate preoperative imaging has ruled out preexisting SPONK, ONPK should be considered to be a nonpreventable complication.

We thus suggest that the descriptive term "osteonecrosis in the postoperative knee" be used rather than "postarthroscopic osteonecrosis."

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Management of Early and Late Failure of Lateral Meniscus

9.2

P. Chambat, B. Sonnery-Cottet,
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In this chapter, isolated lateral meniscectomy performed on patients with otherwise relatively healthy cartilage will be discussed. Lateral meniscectomy is technically a relatively simple procedure because the lateral compartment can easily be opened, but problems may arise in the short, medium, or long-term follow-up.

Defining the Problem

Lateral meniscus (LM) resections are far less prevalent than medial meniscus (MM) resections, with ratios of 2.3 MM:1 LM in the study of Allen et al. [3] and 3:1 in that of Chatain et al. [8].

Long-term radiologic changes mainly occur in the LM group. In a 10-year minimum follow-up, Chatain et al. found significant joint space narrowing in 21.5% of the MM and 37.5% of the LM patients. This was consistent with the findings of Burk et al. [5] and Englund and Lohmander [12].

The consequences of lateral meniscectomy are different from those of medial meniscectomy, which is most obvious at the long-term follow-up. This can be explained by anatomical differences between the medial and lateral compartments of the knee and between the MM and LM. Mc Dermott and Amis [20] showed that the LM carries 70% of the load in that compartment, whereas the MM carries only 50%.

Also, in the sagittal plane on the medial side, the convexity of the medial condyle and the concavity of the medial plateau give some degrees of congruity, even in the absence of a meniscus. On the lateral side, however, the convexity of the lateral condyle is mirrored by a convexity of the lateral tibial plateau. Absence of the LM considerably increases the peak stresses on the lateral tibial plateau. With respect to contact surfaces, Kurosawa et al. [19] showed that removal of the menisci decreased the femorotibial contact area by 33–50%, resulting in a 200–300% increase in contact stress. Seedhom and Hargreave [24] calculated that with intact menisci, stresses on the areas of direct articular surface contact were between 0.82 and 1.67 MN/m^2 on the medial side and between 0.88 and 1.18 MN/m^2 on the lateral side. Removal of a bucket-handle tear increased stresses to 2.32 and 3.22 MN/m^2, respectively. They estimated that complete meniscectomy would increase articular surface stresses to 5 MN/m^2.

Biomechanical studies on the consequences of lateral meniscectomy for the evolution of the knee joint do not provide reassuring data, regardless of the length of follow-up.

Clinical experience shows that lateral meniscectomy can be a continual source of problems. The number of repeat surgeries is a good indicator of problems encountered, because at the 10-year follow-up, the reoperation rate after lateral meniscectomy was found to be 11.9% compared to 4.7% for medial meniscectomy [8, 14]. Hoser et al. noted 29% reoperations after lateral meniscectomy at the 10-year follow-up [16].

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_9.2, © Springer-Verlag Berlin Heidelberg 2010

Short and Medium-Term Complications

Postoperative complications may occur early or after a symptom-free period of several weeks. They present as an effusion, which, depending on its size, will limit flexion. The pain is secondary to the persistent suffering of the lateral compartment and to the increasing pressure in the capsuloligamentous envelope generated by hydrarthrosis. This pressure is further raised by flexion, which diminishes the size of the envelope. Often, hydrarthrosis does not respond to treatment and is associated with even minimal physical activity.

The frequency of this complication is difficult to determine. A study performed in 1993 by Tabib et al. [27] reports a 28% incidence of prolonged hydrarthrosis in a series of lateral meniscectomized patients under the age of 30. The postoperative management of hydrarthrosis persisting for more than 2 or 3 months is challenging. During this period of time the radiographs remain entirely normal. MRI evaluation of a lateral meniscectomized knee is difficult because of its altered appearance. In some cases, as shown by Kobyashi et al. [18], MRI can document juxta-articular bone marrow signal abnormalities. For the LM these are mainly seen in the tibia, especially if the meniscectomy has been extensive. This data supports the concept that altered biomechanics of the knee after meniscectomy cause bone ischemia through microfractures and vascular insufficiency of the subchondral bone. MRI occasionally allows visualization of rapidly progressive cartilaginous lesions, which could be confirmed by an arthroscan.

What should be done when one is faced with this problem?

The first step should be to administer intraarticular steroids as needed, to combat the effusion. This wait-and-see policy is not always easy, especially when dealing with high-performance athletes who are engaged in sports activities requiring pivoting maneuvers with the knee partially flexed.

If effusion is still present 6 months postoperatively, a second-look arthroscopy seems justified in order to assess the condition of the LM and of the femoral and tibial articular surfaces (which always seem to be at the root of the problem), and to wash out cartilaginous debris. Postoperative rehabilitation will be focused on progressive cyclic activity and nonweightbearing for 4 weeks. Second-look arthroscopy frequently alleviates the problems, but can be poorly accepted by the patient, who frequently associates it with an initial error in technique.

Persistent effusions can result in true chondrolysis within the first postoperative year, as reported by Charrois et al. [7], Alford et al. [2], and Ishida et al. [17]. In these three studies, the patients were all highly active athletes, who had undergone a lateral meniscectomy with intact cartilage, and experienced pain and swelling on their return to sports. A repeat arthroscopy after several months showed major cartilaginous lesions with, at times, exposed subchondral bone. Also equally noted is the presence of loose cartilaginous debris in the joint. Radiographic evidence of lateral compartment joint space narrowing usually becomes apparent within 1–3 years. These complications may occur as a result of trauma, in which the meniscal lesion is associated with cartilaginous damage. On preoperative MRI, they present as bone bruises. These difficult postoperative complications are frequently accompanied by an inflammatory syndrome, as evidenced by increased radionucleotide uptake on a technetium bone scan. Initially, surgery should be minimally invasive and limited to microfracture, performed at the time of arthroscopy, followed by temporary restriction of weightbearing. A slow, regular, progressive rehabilitation program seems essential. The inflammatory component needs to be evaluated regularly and an osteotomy should be considered only when the knee has regained a more or less normal aspect.

In view of these complications, a number of rules should be observed with respect to indications.

- In the presence of an LM lesion, caution should be exerted in proposing a surgical intervention, especially when dealing with high-performance athletes.
- The use of corticosteroids should be considered to improve the symptoms prior to surgery.
- On preoperative MRI, possible subchondral impaction lesions should be looked for in case of traumatic injuries or excessive sports activity.
- Patients should be informed of the potential risk that might delay their return to sports.

Long-Term Complications

Long-term complications essentially involve osteoarthritis. While radiographic changes may be present at 10 years postmeniscectomy, pain frequently does not arise until the twentieth year. Reoperation is usually required at an average of 30 years postoperatively [10]. The iatrogenic origin of lateral osteoarthritis implies a healthy medial femorotibial and patellofemoral compartment and a normal lower extremity morphotype. The postoperative sequelae depend on the initial type of lesion (a complex tear is disparaging compared to a simple one), the morphotype in valgus, the patient's weight/BMI, and the overall use of the knee. Lateral femorotibial osteoarthritis is usually secondary to traumatic injuries, affecting the meniscus and perhaps the cartilage itself. It thus mainly affects relatively young people.

Knee Osteotomies

Consequently, conservative surgical interventions and osteotomies, rather than prosthetic joint replacement, are indicated. Although valgus osteotomy for medial compartment osteoarthritis restores an acceptable knee biomechanics, tibial or femoral varus osteotomy is not the treatment-of-choice for lateral femorotibial osteoarthritis. A varus osteotomy aims at reducing lateral biomechanical constraints by transferring them to the normal medial compartment, which should provide relief in flexion and extension and create a horizontal joint line (Fig. 9.2.1).

Femoral Varus Osteotomy

A distal femoral medial closing-wedge or lateral opening-wedge varus osteotomy is most commonly advocated in the literature. It allows correction of the valgus deformity in extension by acting at the level of the distal femoral condyles. However, when the knee is in 90° of flexion and the weight is on the posterior condyles, the varus action disappears since the procedure does not modify the position of the posterior condyle [6]. At 90° of flexion, a distal femoral varus osteotomy provides an internal rotation of the distal femoral epiphysis with respect to the femoral diaphysis.

A femoral varus osteotomy is effective in extension, ineffective at 90° of flexion and, as the knee is flexed progressively from 0 to 90° of flexion, a gradual diminution of the varus component and an increase of the distal epiphyseal internal rotation component with respect to the diaphysis are observed. This corresponds to the

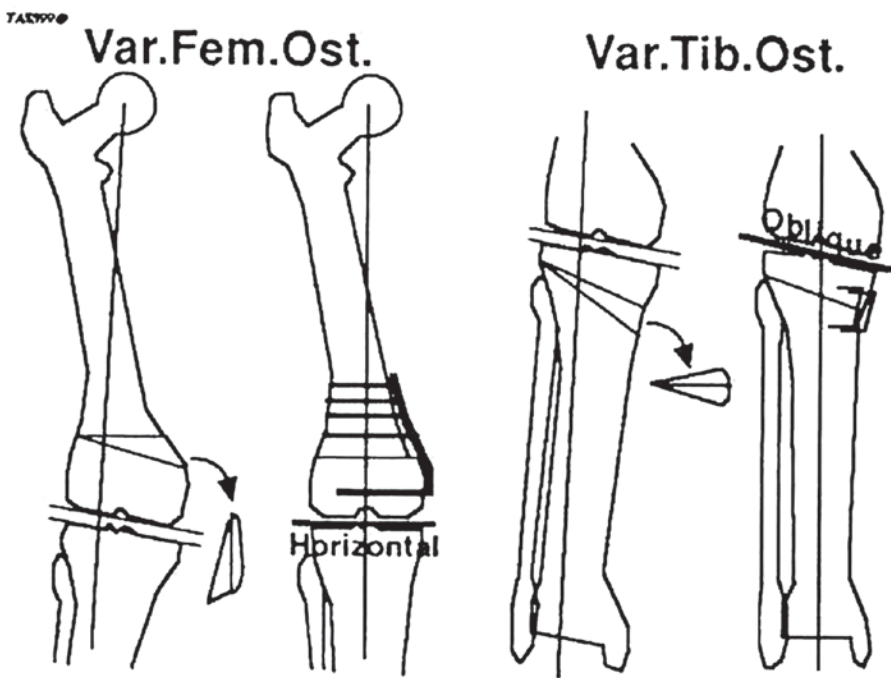

Fig. 9.2.1 Varus osteotomy. A femoral varus osteotomy does not change the orientation of the joint line. A tibial osteotomy produces an oblique joint line due to a change of the mechanic axis of the tibia

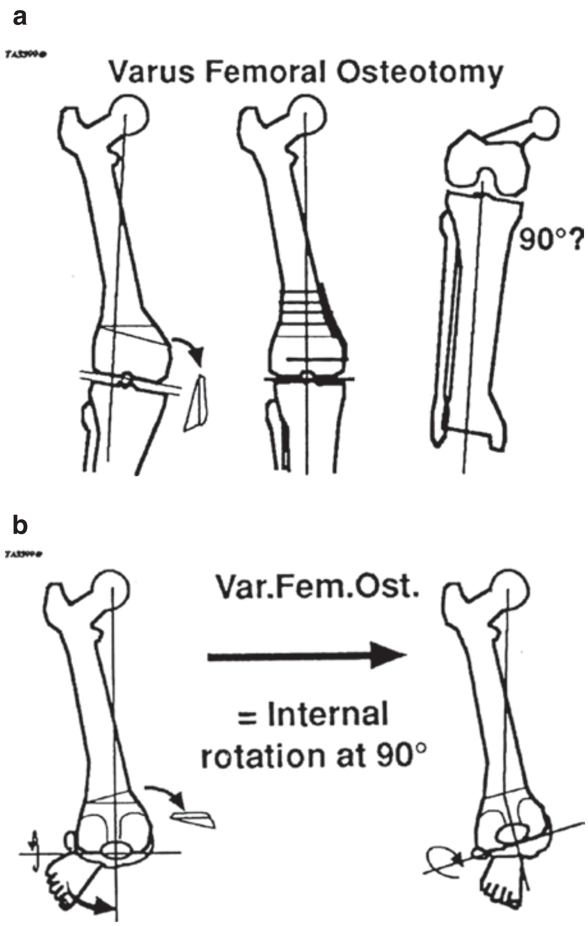

Fig. 9.2.2 (**a**) A femoral osteotomy corrects the valgus deformity in extension, but has no effect on the varus at 90° of flexion. (**b**) At 90° of flexion, a femoral varus osteotomy creates an internal rotation of the epiphysis

progressive shift of distal femoral condylar loading to posterior condyle femoral loading, which is not modified by the osteotomy. It is at this level that a varus moment of the femoral osteotomy in flexion should be achieved. To this end, an external epiphyseal rotation with respect to the diaphysis must be performed [6] (Fig. 9.2.2a). Under these conditions, a positive moment in flexion is achieved, but at the expense of an external rotation component in extension. An osteotomy can effectively treat a valgus knee or lateral femorotibial osteoarthritis only if it consists of a varisation and a distal external rotation component. On the other hand, a distal femoral varus osteotomy does not modify the position of the joint line, the latter being determined by the tibial mechanical axis, which, in this case, is unchanged.

Tibial Varus Osteotomy

A tibial medial closing-wedge or lateral opening-wedge varus osteotomy [6] is inappropriate for different reasons. It changes the orientation of the joint line, which becomes oblique since this surgical correction adds to the constitutional varus of the tibia. Hence, an oblique distal and medial joint line, and thus a tibia vara is obtained. It is this modification of the tibial axis that explains why this osteotomy is effective in flexion and extension (Fig. 9.2.2b).

Choice of Osteotomy

Clinically, if we consider the initial stage of lateral femorotibial osteoarthritis, the problem is seen in flexion since lateral compartment joint space narrowing is greatest during weightbearing at 30° of flexion. Weightbearing X-rays show a relatively normal joint space in extension.

Narrowing in flexion is caused by wear of the posterior aspect of the lateral femoral condyle and lateral tibial plateau. Tibial wear presents as a depressionon lateral views and it is the roll-back phenomenon in flexion that makes the condyle fall back in this small depression.

Since the problem arises in flexion, it seems logical to perform a surgical procedure that effectively works in flexion. If a distal femoral varus osteotomy combined with an external rotation is, biomechanically speaking, appropriate regarding the lateral loading, it would cause some inconveniences in extension. As a first step, we would advise to explore the possibility of a procedure on the tibia, because this has the least detrimental biomechanical consequences.

The final goal of a varus osteotomy is to achieve a femorotibial mechanical axis of 0° [9, 10, 21, 25]. In addition, joint line obliquity should be less than 10° [9, 10, 21] and the mechanical tibial axis thus between 80 and 90°. Joint line obliquity and tibial axis can be estimated from preoperative X-rays. The final axis will correspond to the addition of the angle of joint line obliquity to the angle measurement necessary to correct the femorotibial mechanical axis to 0°. The lesser the degree of constitutional tibial varus, the higher the tolerance for angular corrections. Tolerance is maximal in cases of tibial valgus, which is rare in iatrogenic lateral osteocartilagenous lesions. If these criteria are not met and if the tibial varus morphotype is predicted to be inferior to 80°, a distal femoral osteotomy is recommended.

The paradox of this discussion is that the measurements are made in extension, despite the fact that initially we wish to be most efficient.in light flexion. Computer-assisted navigation should enable us to solve this ambiguity and to perform a double femoral and tibial osteotomy.

Surgical Techniques

Tibial Varus Osteotomy (Fig. 9.2.3)

Tibial varus osteotomy has already been performed for a number of years. The ideal indication involves cases in which wear is located very peripherally with good cartilaginous stock near the lateral tibial spine, at the axial level of the lateral compartment. Under these conditions, the translation forces linked with the joint line obliquity produced by valgus correction will impose load on this axial zone of good-quality cartilage.

Preoperative planning includes a standing anteroposterior X-ray to determine the femorotibial mechanical axis. After correction, this axis should be 0° and the varus tibial end point equal to or greater than 80°. To achieve this, a landmark, as a reference of the osteotomy hinge,is taken at the proximal tibiofibular joint.

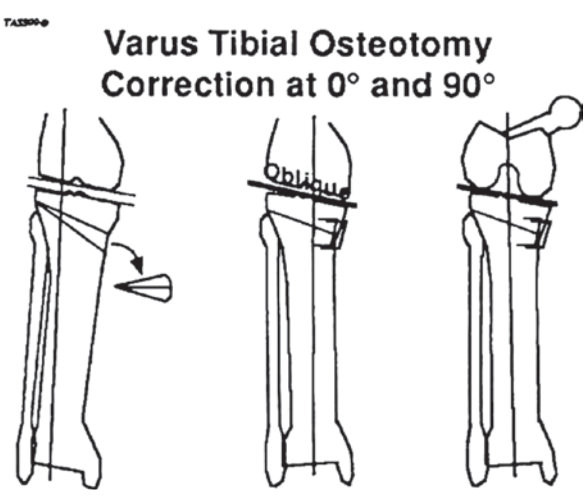

Fig. 9.2.3 A tibial varus osteotomy creates an oblique joint line, but is efficient in extension and in flexion

A medial closing-wedge osteotomy is usually performed. First, the cartilaginous lesions are evaluated and debrided arthroscopically. Then, a vertical midline incision is made, which can later be used for a total knee replacement (TKR), because a tibial varus osteotomy is considered a temporary measure. The medial subcutaneous area is undermined and the pes anserinus is elevated at its distal attachment. The lower end and middle of the medial collateral ligament (MCL) and the distal insertion of the patellar tendon are exposed. The tendon must be protected during the osteotomy. The osteotomy site is localized with a Kirschner wire and with the aid of fluoroscopy. The most important area is the hinge area at the lateral cortical epiphysis. It has to be localized just above the tibiofibular joint, so that the fibula does not impinge upon the varus correction. The Kirschner wire is therefore passed from the middle part of the MCL above the tibial tuberosity and at the level of the proximal tibiofibular joint space.

A horizontal incision is made through the capsular and MCL and semimembranosus. The osteotomy is done using an oscillating saw, which is cooled in water in order to prevent burning of the bone. The osteotomy line ends at 1 cm from the lateral cortex. This will be the hinge necessary to ensure good stability of the osteotomy. The osteotomy is performed underneath the guide wire so as not to enter the epiphysis or the joint space.

Resection has to be minimal and can be done progressively under fluoroscopic guidance or in accordance with the preoperative calculations. Two guide wires are used, which have to be parallel once the osteotomy has been completed.

The weak mechanical resistance of the medial metaphyseal cortex allows bone impaction with good bone contact, which improves correction and promotes union.

A final check can be performed by comparing the intraoperative to the preoperative X-rays and through perioperative and intraoperative measurements, using an EKG pad, fluoroscopically positioned on the center of the femoral head at the start of the procedure and intraoperative fluoroscopy to identify the center of the knee and ankle. Care should be taken to not only verify the frontal plane but also the sagittal plane, which corresponds to the tibial slope. The tibial slope has to be evaluated preoperatively and considered in the preoperative planning if it needs to be decreased in cases of a real or relative flexum. The goal is to improve extension and mechanically delay the angular moment at which the posterior condyle will fall into the tibial depression. Under no circumstances should the tibial slope be increased.

Whereas the initial fixation was with a cast or staples, a more solid construct with plate and screws is currently advocated. Referring to the techniques used for medial opening-wedge valgus osteotomies that allow immediate weightbearing [26], this system of locking screws through a plate could be an option for the closing osteotomies.

This would considerably improve the fixation and allow immediate postoperative mobilization and possibly weightbearing.

Marti et al. [21] proposed an opening-wedge osteotomy with a subtibial tuberosity cut, very slightly oblique, proximal and medial, with a fibular osteotomy in the mid-diaphyseal region. However, this technique essentially addressed posttraumatic valgus deformities.

The results of medial closing-wedge varus osteotomies are difficult to evaluate because the studies are old and include elderly patients (60 years or more) [9, 10, 25] with less than perfect fixation techniques (staples and cast). In two studies [9, 10] with a follow-up of 8 and 9 years, approximately 70% good to excellent results were achieved, with significant pain relief. In case of a preoperative valgus deformity of approximately 10° which had to be reduced to 0°, the persistence of slight valgus was more favorable than slight varus alignment. They stressed the importance of a joint line obliquity not exceeding 10° [9, 10]. Despite these promising results, tibial varus osteotomies for lateral femorotibial osteoarthritis have almost completely been abandoned. It would seem that, when scrupulously respecting the aforementioned defined angular values, tibial osteotomy is a viable procedure, technically easy and reliable with respect to union.

Femoral Varus Osteotomy

Femoral varus osteotomy represents a much more difficult option with regard to technique and postoperative sequelae. In our opinion, candidates for this procedure are patients in whom the goals of tibial osteotomy cannot be adequately achieved. The preoperative radiographic measurements are identical to those previously described, the axis of rotation and the hinge being situated on the medial or lateral condyle depending on whether an opening or closing-wedge technique is used. A medial closing-wedge osteotomy transfixed with a compression plate is most commonly performed [23]. The procedure begins with an arthroscopic inspection and debridement of the lateral compartment of the joint.

The osteotomy is performed through a medial incision, allowing for easy conversion to a subsequent TKR. A 5–10-mm medially based wedge of bone from the distal part of the femur, just proximal to the adductor tubercle and the anterior part of the femoral articular surface, is removed with an oscillating saw. The lateral part of the cortex is perforated at several points with a drill bit or an osteotome. This facilitates correction and prevents lateral displacement of the proximal fragment. A 90° offset dynamic compression blade plate is inserted in the femoral condyle, parallel to the joint line. The osteotomy site is closed with the plate in contact with the medial diaphysis of the femur. If this proves to be impossible, more bone is removed from the base of the wedge until contact is made. The medial part of the femoral cortex and the transcondylar distal line are at 90° to each other and the mechanical tibiofemoral axis is approximately 0°, which is the desired position.

More recently, a technically less demanding technique has been proposed, utilizing a locking plate to fix a femoral closing-wedge varus osteotomy with equal stability as the blade plate. Using the same technique, it has been proposed that a femoral lateral opening-wedge varus osteotomy be performed. It is important that the medial hinge be situated in the region of the proximal attachment of the MCL and the defect filled with an iliac crest autograft.

The use of staples with or without a cast does not provide adequate stabilization and exposes the patient to an increased risk of loss of correction and pseudarthrosis [11].

The results of distal femoral closing-wedge varus osteotomies with blade plate fixation are well-documented. They should be interpreted with caution since postmeniscectomy lateral compartment osteoarthritis cannot be assimilated with all cases of lateral compartment osteoarthritis, which have multiple etiologies. If we consider all series with a follow-up of more than 9 years, two series have 77% [1] and 83% [28] of good to excellent results, three series have between 60 and 64% of good to excellent results [4, 13, 15], and one series 40% [29]. The survivorship at 10 years is 80% for two series [4, 15] and 64% for one series [13]. The survivorship rate drops dramatically from 80 to 45% at 10 and 15 years, respectively [4].

If the preoperative femorotibial angle exceeds 10°, the final postoperative alignment should be 0°. Contrary to tibial osteotomies, the authors rather prefer a slight overcorrection to undercorrection, because the risk of an excessively oblique postoperative joint line is nonexistent.

Tibial and femoral osteotomies in cases of lateral femorotibial osteoarthritis enable us to improve patient function, even though these interventions are not mechanically correct. We should aim at a combination of tibial varisation with femoral varisation, more or less associated with distal femoral epiphyseal rotation. The use of a computerized navigation system should allow us to perform these procedures without too many problems.

Conclusions

Lateral meniscectomy is not a benign procedure. The postoperative complications include persistent effusions, which prolong the time to return to sports and carry the rare risk of rapid chondrolysis. Additionally, lateral meniscectomy compromises the long-term future of the meniscectomized knee because it almost invariably leads to lateral compartment osteoarthritis, the management of which is by no means straightforward. Efforts should be made to enhance our techniques: double osteotomies, rotational osteotomies based on preoperative radiographs and CT scans, surgically assisted by computer navigation.

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Synthesis

9.3

Philippe Beaufils

The results of meniscectomy do not always come up to our expectations, even when indications have been carefully considered and previous evaluation and treatment of the patient have been conducted correctly, including proper radiologic assessment.

It must be kept in mind that 6% of medial meniscectomies in a stable knee and 14% of lateral meniscectomies are followed by second-look arthroscopy.

In more than 20% of lateral meniscectomies, the postoperative course is complicated by persistent pain and joint effusion requiring an intraarticular corticoid injection.

Moreover, in more than 28% of medial meniscectomies and 40% of lateral meniscectomies, joint line narrowing is apparent on schuss view roentgenograms within 15 years of surgery.

This is why meniscectomy is not a minor procedure, but potentially has negative consequences.

The risk of early or late failure primarily depends on proper preoperative evaluation, in which meticulous radiographic assessment plays an important part. It should comprise standard roentgenograms to search for signs of other pathologies, especially joint line narrowing suggestive of early osteoarthritis, and magnetic resonance imaging (MRI) to obtain valuable information on the condition of joint cartilage and subchondral bone. This allows identifying the osteonecrosis or stress fracture, which may clinically mimic a meniscal lesion. Performing a meniscectomy in these cases would affect the evolution of the joint.

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It is essential that full information be provided to the patient, explaining his or her knee condition, proposed treatment and its possible consequences.

Early Complications

Treatment of early complications arising within the first 30–45 days of arthroscopic meniscectomy is primarily symptomatic and consists of relative rest, oral nonsteroidal antiinflammatory drugs (NSAIDs), and intraarticular corticoid injection in case of joint effusion.

This usually leads to the resolution of the clinical and functional symptoms, but if they fail to improve within 3–4 months, additional tests must be performed to confirm or rule out three possible conditions: (1) persistence or recurrence of the symptomatic meniscal lesion, (2) postoperative chondrolysis, and (3) general inflammatory reaction of the knee and particularly complex regional disease.

It is therefore essential that the following diagnostic examinations be performed.

Standard comparative roentgenograms including schuss views must be obtained. They allow prompt visualization of joint line narrowing, which is associated with rapid articular chondrolysis usually accompanied by chronic joint effusion. This process, which is more common in the lateral compartment, is a serious complication since it predominantly occurs in young patients whose cartilage was initially intact. Other radiologic examinations highlighting the remainder of the meniscus must also be performed, e.g., contrast-enhanced computed tomography (CT), MRI or contrast-enhanced MRI. Contrast CT provides thin sections and high-quality information about the condition of the meniscus, but it is an invasive examination

P. Beaufils and R. Verdonk (eds.), *The Meniscus,*
DOI: 10.1007/978-3-642-02450-4_9.3, © Springer-Verlag Berlin Heidelberg 2010

which does not permit the assessment of subchondral bone. On the other hand, MRI is a noninvasive method offering information about all structures of the joint, but it is less accurate than contrast-enhanced CT in assessing the meniscus. Contrast MRI combines the advantages of these two methods, but the sections are much thicker. Regardless of the method used, assessment of the remaining meniscal tissue is difficult and confronting the clinical with the radiological findings is of prime importance.

What should the diagnosis and subsequent treatment be?

Persistent joint effusion associated with early joint line narrowing, a stable remaining fragment of the meniscus and no signs of osteonecrosis is diagnostic of rapid articular chondrolysis. Treatment consists of rest, intraarticular needle or arthroscopic lavage and viscosupplementation with hyaluronic acid, and is continued until the symptoms have subsided. Eventually, if joint line narrowing has stabilized and symptoms persist (which is uncommon) a realignment osteotomy may be considered.

Absence of joint line narrowing on anteroposterior views and of subchondral bone signal alterations on MRI, and the finding of a substantial meniscal lesion on postoperative roentgenograms suggest a residual or a new lesion, particularly if the symptoms have recurred some time after the meniscectomy and if signs of internal knee derangement (popping, joint locking) are present.

This is one of the very few situations in which a repeat arthroscopic procedure may be considered, possibly with good results. At the French Arthroscopic Society symposium of 1991, Frank stated that he had encountered significant meniscal lesions in 58% of cases and had obtained good results in 84% of these. This dropped to 39% if grade 3 chondropathy was present.

If joint line narrowing is absent but MRI shows an intraosseous pathology, a subchondral bone disorder (stress fracture or even osteonecrosis) must be considered even if there is evidence of a persistent lesion of the remaining meniscal tissue. This is even more likely if the arthroscopic surgery was performed on an elderly patient. The treatment is strictly conservative, consisting of rest, restricted weightbearing, and NSAIDs in case of pain. Repeat arthroscopic surgery would not be justified in these cases but further surgical treatment may be necessary in the aftermath of the disease.

In case of a hot, stiff and painful knee, complex regional disease should be taken into consideration. MRI, CT and possibly standard roentgenograms may document this condition, which is treated conservatively, sometimes requiring the assistance of pain specialists. In this situation it is crucial not to propose further arthroscopic treatment as one may be tempted to do so when faced with MRI evidence of a residual meniscal lesion.

Late Complications

These may be related either to other meniscal lesions or, most commonly, to pathologic changes caused by increased stress transmission. This process can eventually lead to the development of osteoarthritis, which is usually confined to one of the compartments.

Radiologic tests should again include standard roentgenograms to assess joint line narrowing, and contrast-enhanced CT or contrast-enhanced MRI to assess the remaining part of the meniscus.

A partially meniscectomized patient presenting joint line tenderness with no standard roentgenographic evidence of joint line narrowing, but in whom a lesion of the remaining meniscal tissue has been demonstrated, is routinely subjected to a second-look arthroscopy and meniscectomy, which usually gives good results. A more modern approach to this situation would include the implantation of a meniscal substitute. This issue is discussed further in the next chapter.

When subtotal or total meniscectomy has been performed and no or only minimal joint line narrowing is visible, the orthopedic surgeon can decide between traditional treatment (high tibial osteotomy, unicompartmental knee arthroplasty) and the innovative technique of meniscal transplantation in a young patient. The latter option will be discussed in the next chapter.

Osteoarthritis of the knee is an absolute contraindication to meniscal replacement.

The therapeutic options are limited to high tibial osteotomy and unicompartmental knee replacement, the latter being applicable only to patients of a certain age.

Realignment osteotomy is the only surgical option in a young patient. If the medial compartment of the knee is involved (following medial meniscectomy), a valgus tibial osteotomy is performed. This procedure usually has well-defined indications and is technically not too demanding since the morphotype of the knee is habitually varus due to the constitutional characteristics of the patient and also the cartilage wear. The results are good, as are those of the same operation for primary osteoarthritis. The medial compartment is considered to be the compartment of stability and osteoarthritic changes in this compartment develop as a result of abnormal stress transmission. High tibial osteotomy allows reducing the stress transferred by the medial compartment by redistributing it to the lateral side of the joint.

Treatment of lateral compartment disorders is fraught with many problems, owing not only to the presence and severity of osteoarthritis, but also to the biomechanics of the knee. This issue has been analyzed in detail by Chambat in Chap. 9.2. First of all, the morphotype is not necessarily valgus (particularly in the early stage of the disease) in spite of lateral compartment osteoarthritis. The fact that lateral compartment osteoarthritis also occurs in a varus knee shows that its development is not only associated with compression forces but also, if not predominantly, with shear forces due to the rotational mobility of this compartment. Varus osteotomy is not an option in these cases.

Chambat also showed that if there were indications for an osteotomy for a valgus knee deformity, it would not necessarily need to be a femoral (as in case of primary knee osteoarthritis and femoral dysplasia) but rather a tibial osteotomy, the postoperative course of which tends to be less complicated and the recovery more rapid. Tibial osteotomy is efficient in both flexion and extension, while femoral osteotomy is efficient in extension only. It can, however, lead to an oblique orientation of the joint line, which has an unfavorable effect on the long-term outcome of the procedure and a possible conversion to total knee arthroplasty.

Preoperative planning is therefore of vital importance. If a less than 10° obliqueness of joint line orientation is anticipated for a mechanical angle of 180°, tibial osteotomy is a more reasonable choice, because it is biomechanically more efficient, technically easier and has a relatively simple postoperative course. In the other case, a femoral osteotomy should be considered.

Conclusion

Because of the substantial rate of postmeniscectomy complications, the prevalence of secondary osteoarthritis and the therapeutic difficulties, the indications for meniscectomy, particularly of the lateral meniscus, should be carefully considered and alternative treatment options (masterly neglect and meniscal repair) should be promoted.

Patients should always be provided with full information on their knee condition, proposed treatment and its possible consequences.

New techniques of meniscal replacement give promising results in the treatment of difficult cases, but are applicable only if the joint cartilage is intact.

Part X

Meniscal Reconstruction – Allograft

10.1 Basic Science

G. von Lewinski and C. J. Wirth

History of Meniscal Transplantation and Replacement

The concept of meniscal replacement can be traced back to Lexer and Gebhardt, who, in an attempt to replace a meniscus, performed fat tissue interposition arthroplasty in 1908 and 1933, respectively [17].

Almost a century ago, the first meniscal allograft procedures were performed in combination with complete knee transplantation during limb-sparing reconstructions [37, 73]. Locht et al. [38] transplanted parts of the tibial plateau which were destroyed by injury with osteocondral allografts including the meniscus, and reported encouraging results. In 1984, the first free meniscal allograft transplantation in humans was reported by Milachowski et al. [46]. The series included 23 patients who underwent medial meniscal allograft transplantation with deep-frozen and lyophilized allografts. In the following years, replacement of meniscal cartilage by autologous and artificial material, xenografts, or meniscal scaffolds was performed with little success [19, 33, 34, 43, 58–60, 62, 63, 65, 66].

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Animal Models

Type of Animal Models

Meniscal transplantation has been investigated in various animal models, including rabbits, sheep, dogs, goats, and monkeys. Some aspects have been found to be important in choosing an animal model. One such aspect is, e.g., the occurrence of spontaneous meniscal regeneration [47, 59]. Furthermore, a large animal model is necessary to perform an adequate surgical procedure and the material properties of the animal meniscus should be comparable with those of a human one. Joshi et al. [27] found sheep menisci to have similar compressive biomechanical properties as human menisci.

The early animal models used to investigate meniscal allograft replacement, primarily focused on the status of the meniscal graft tissue and on variables such as graft healing, blood supply, cellular repopulation, composition, and structure. Later on, the chondroprotective properties of the transplanted meniscus became more and more important.

Evaluation of Transplanted Meniscal Allografts in Animal Models

Macroscopic Assessment

Milachowski et al. [46] used lyophilized, gamma-sterilized and deep-frozen meniscal transplants in a sheep model.

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.1, © Springer-Verlag Berlin Heidelberg 2010

Uneventful capsular healing of both lyophilized, gamma-sterilized and deep-frozen allografts was found 6 weeks after transplantation. Arnoczky et al. [6] replaced 14 medial menisci using a cryopreserved allograft in dogs. The transplanted menisci appeared grossly normal and healed to the host tissue without incident. In three of the specimens, the posterior horn attachment of the meniscus was disrupted and healed with a gap. In an experimental study in sheep, Aagaard et al. [1] found ingrowth of the transplants in only 50–75% of the periphery in three specimens. The menisci tended to extrude peripherally toward the capsule, with the suture anchor being partially pulled out especially in the posterior horn. In addition, macroscopic signs of degenerative changes, such as a change in tissue consistency, color, and shape were seen in some of the transplanted menisci. These observations were consistent with the findings of Mikic et al. [45]. Jackson et al. [25] described only minimal changes in the gross appearance of transplanted menisci in a goat model. Szomor et al. [64] and Cummins et al. [11] found that only the color of the transplanted sheep menisci was less shiny in comparison to the sham group. In a canine model, Elliot et al. [14] found by gross inspection that the meniscal allograft transplants appeared to have healed and attached to the joint capsule after 12 weeks. However, the gross morphological evaluation of the medial meniscus was normal in only one subject. In conclusion, it can be stated that healing of meniscal allografts has been found in most experimental studies, but degenerative changes are present in the meniscal tissue itself.

Histological Assessment

The histological assessment of meniscal transplants after the animals had been sacrificed, included several aspects such as number, type, and localization of cells, histological evidence of rejection, blood vessels, collagen architecture, and assessment of the posterior and anterior attachment of meniscal transplants. Most studies showed a decreased number of cells in the meniscal transplants in the first months [4, 25, 45]. The cells were located at the allograft surface and in the capsular insertion area, whereas the central part of the meniscus was acellular [25, 45, 48]. Jackson [26] could demonstrate that 4 weeks after transplantation, no more donor DNA could be found; it was all of host origin. The repopulation took place from two sources – synovial tissue and parameniscal connective tissue [52]. The type of cells found in the repopulated meniscal transplants are named as resembled fibrochondrocytes [4] or chondrocyte-like cells [48]. With only one exception [28], a reduced viability of the cells is described [25, 48]. Histological evidence of rejection is not described in animal models [25, 46]. This might be explained by the rapid loss of donor DNA [26], suggesting that the donor meniscal cells die before traditional immunological reactions take place. Graft revascularization has been demonstrated [6]. A manifest loss of the normal orientation of the collagen architecture in the superficial layers of the transplanted meniscus has been reported [45, 48, 64]. A relation to the depopulation of cells is suspected, with fibrochondrocytes being responsible for the extracellular matrix synthesis maintaining the distinctive material and structural properties of a normal meniscus [4, 26]. In addition, Rijk and Van Noorden [54] found delayed meniscal allograft transplantation to cause distinct structural damage to menisci in comparison to immediate transplantation. Besides the architecture of the meniscal tissue itself, the attachment zones at the anterior and posterior horn are important to the function of a meniscal transplant. Kelly et al. [28] described fibrous tissue which was loosely integrated into the recipient bone. Gao et al. [16] stated that the tissue architecture of a normal meniscal insertion could not be reestablished.

Microangiography

Microangiography was performed in several experimental studies [6, 25, 28, 48]. Vascular ingrowth with normally appearing peripheral vascularity was always seen. Milachowski et al. [46] found that lyophilized grafts were completely revascularized, but deep-frozen transplants only in the periphery.

Evaluation of Cartilage After Meniscal Transplantation

Macroscopic Assessment

Arnoczky et al. [6] and Mikic et al. [45] reported some degree of cartilage protection after meniscal allograft transplantation in animal studies, but did not grade or compare their observations with those in meniscectomized joints [64]. In the literature, differences in macroscopic cartilage assessment between meniscal transplantation groups and sham groups have been reported in all animal experiments [1, 6, 25, 61, 64, 71]. Even fixation of meniscal transplants with bone plugs could not restore the natural state of the knee joint [25]. The actual goal of restoring a normal knee by meniscal transplantation is difficult to achieve. The results observed in the sham-operated group in this study further demonstrate that the surgical approach alone can lead to degenerative effects. The ability of the meniscus transplant to provide some chondroprotective effect is well illustrated by the comparison with meniscectomized knees.

Histological Assessment

In accordance with the macroscopic findings, most of the histological studies reported in the literature demonstrated that knee cartilage cannot be restored to normal by meniscal transplantation. There is only one exception, in which a lateral meniscal transplantation was evaluated after a relatively short follow-up of 4 months [28]. Some animal studies [2, 11] dealing with histological cartilage evaluation after meniscal transplantation showed a chondroprotective effect, while others found no significant difference in comparison to meniscectomized knees [14, 48, 64] (Table 10.1.1).

Radiographic Evaluation

In the literature, different opinions exist on the relevance of using radiographs for the evaluation of degenerative cartilage or osteoarthritic changes after meniscal transplantation in animals. One of the arguments pleading against their use is that weightbearing X-rays are required. Edwards et al. [13] constructed a special jig to provide a constant compressive force and to standardize the radiographs in sheep, but in a rabbit model no correlation with the histological cartilage changes could be found, not even with

Table 10.1.1 Literature review of the histological evaluation of cartilage degeneration after meniscal transplantation according to the criteria of Mankin and a modification of these criteria

Author	Specimen	Time (postoperatively)	Comparison of treatment groups	Difference	Side
Aagaard et al. [2]	Sheep	6M	Sham:ME Sham:MTX ME:MTX	Significant Significant Significant	Medial
Szomor et al. [64]	Sheep	4M	Sham:ME Sham:MTX ME: MTX	Significant Significant Not significant	Medial
Mora et al. [48]	Sheep	6M	Sham:ME Sham:MTX ME:MTX	Significant Significant Not significant	Medial
Kelly et al. [28]	Sheep	2M 4M	Sham:ME Sham:MTX ME:MTX	Significant Not significant Significant	Lateral
von Lewinski et al. [71]	Sheep	6M	Sham:ME Sham:MTX ME:MTX[a]	Significant Significant Not significant	Medial
Cummins et al. [11]	Rabbits	3M	Sham:ME Sham:MTX ME:MTX	Significant Significant Significant	Medial
Elliot et al. [14]	Dogs	3M	ME:MTX	Not significant	Medial

MTX meniscal transplantation; *ME* meniscectomy; *M* month

[a]MTX with higher levels of intraoperative pretensioning, revealing a tendency to less cartilage degeneration compared to meniscectomized knees

weightbearing radiographs [42]. Furthermore, the duration of the animal experiments was usually relatively short for definitive radiological changes to occur. None of the published animal studies showed a significantly better radiological result of knees with a meniscal transplant compared with meniscectomized knees [48, 53].

Effects of Nonanatomic Positioning and Incongruent Meniscal Transplants on Articular Cartilage

Because proper size matching, anatomically correct positioning, and congruency of the transplants are essential factors influencing the outcome of meniscal transplantation, an experimental study of an ovine model was performed [35, 72] to compare these factors. The animals were subjected to either meniscectomy, medial meniscal autograft transplantation with nonanatomical insertion of the anterior and posterior horn, or meniscal autograft transplantation from the opposite knee as an incongruent meniscal autograft. After 6 months, radiographic, macroscopic, and histological evaluations and scanning electron microscopy of the articular cartilage were performed, all demonstrating that nonanatomical insertion of meniscal transplants resulted in the highest amount of degenerative cartilage changes. The histological assessment revealed significantly greater cartilage damage for the nonanatomically positioned meniscal transplants in comparison to the meniscectomized knees. Furthermore, the cartilage status was significantly better for incongruent meniscal transplants than for nonanatomically inserted meniscal transplants.

Effects of Intraoperative Pretensioning of Meniscal Transplants

In all of these studies investigating cartilage degeneration, a fixation without intraoperative pretensioning of the meniscal transplants was used. Since the ability of the meniscus transplant to effectively transfer load depends on its ability to bear circumferential loading, the influence of intraoperative pretensioning on the chondroprotective effect of meniscal transplants was investigated in a sheep model [71]. Adequate intraoperative pretensioning was shown to have a significant influence on the chondroprotective effect of meniscal transplants but did not prevent the development of articular cartilage degeneration (Fig. 10.1.1).

Preservation Techniques

The clinical success of meniscal transplantation is partially dependent on the effects of preservation techniques on the biological, biochemical, and biomechanical integrity of the tissue. Several techniques of meniscal allograft processing have been introduced: fresh, deep- or fresh-frozen, cryopreserved, and lyophilized (freeze-dried), each having its pros and cons. Fresh allografts may be the ideal type of transplant because fresh tissue contains a large number of viable cells. Verdonk [68] uses viable allografts in a medium that maintains fibrochondrocytes during prolonged storage.

Research results support the concept insofar that viable cells may enhance the maintenance of the extracellular matrix and thus the allograft's mechanical integrity following transplantation [39]. On the other hand, Jackson et al. [26] showed that in a goat model donor cells did not survive and were repopulated by host cells within 4 weeks.

The most commonly implanted meniscal allografts are deep- or fresh-frozen and cryopreserved allografts [39]. Deep- or fresh-frozen allografts are frozen at −80°C after harvesting. They are easier to store but the freezing process destroys the donor cells. Further advantages are the relatively low costs and the apparently favorable clinical results [57]. However, some caution should be exerted. Gelber et al. [19] recently demonstrated that freezing alters the meniscus collagen net. A further study [36] showed that repeated freeze-thaw cycles lead to biochemical and biomechanical alterations of meniscal allograft tissue.

Cryopreservation using dimethyl sulfoxide or glycerol for freezing prevents the formation of intracellular ice crystals, which otherwise rupture and kill the cells, but is an expensive procedure. Cryopreservation worked well in clinical and experimental studies, but no significant differences with deep- or fresh-frozen techniques could be found [15].

Lyophilized or freeze-dried meniscal transplants result in the decay of the entire ground substance and the destruction of all antigens and enzymes. Only a collagen network serves as a scaffold for the ingrowth

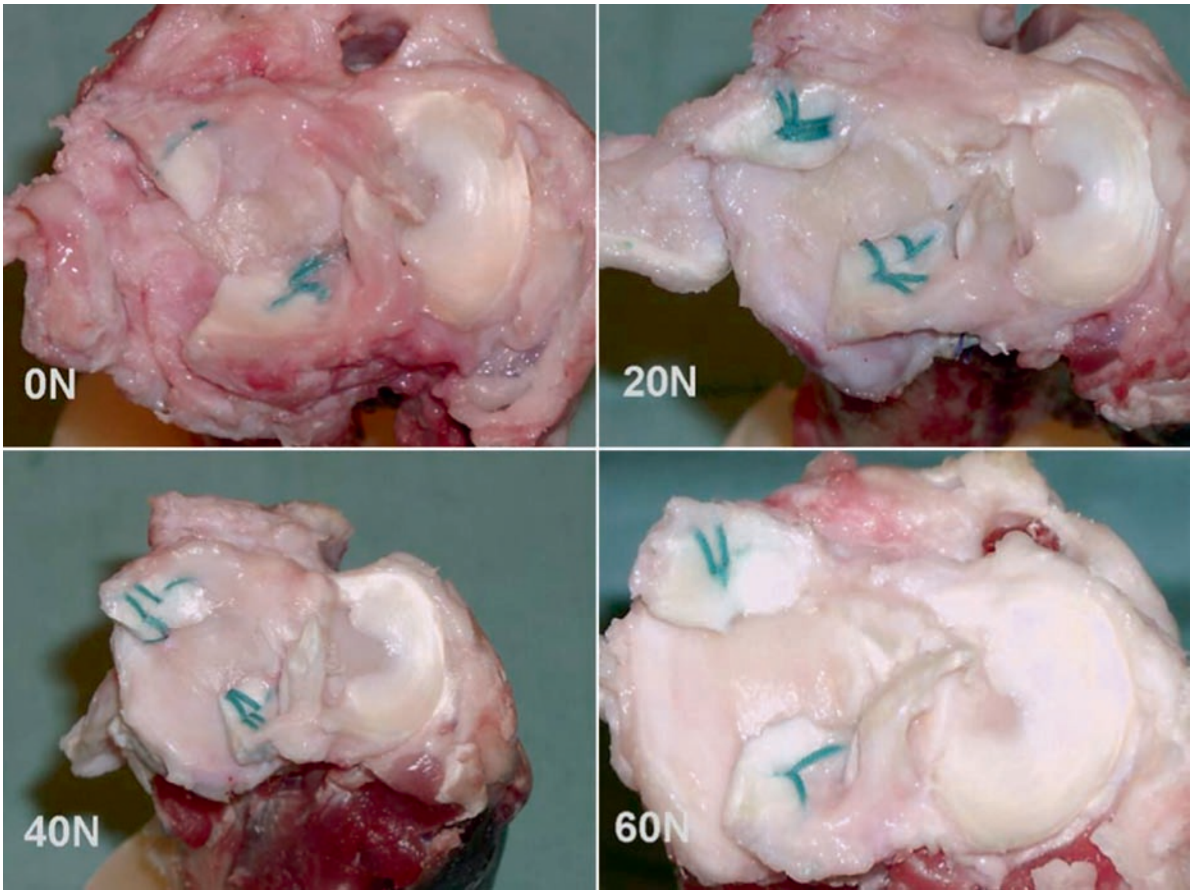

Fig. 10.1.1 Examples of macroscopic cartilage evaluation of the medial tibial plateau after meniscal transplantation with intraoperative pretensioning (0, 20, 40, and 60 N). The plateaus with higher levels of intraoperative pretensioning demonstrate less cartilage damage

of host fibrochondrocytes. Lyophilized meniscal transplants demonstrated early shrinkage in clinical use (Figs. 10.1.2 and 10.1.3). In a clinical follow-up study of 14 years after meniscal transplantation, patients with deep-frozen meniscal transplants had better results than patients with lyophilized meniscal transplants (Figs. 10.1.4 and 10.1.5). Deep-frozen meniscal allografts were found to be more comparable with control knees having an intact meniscus, and lyophilized meniscal allografts with meniscectomized control knees. Therefore, they are no longer recommended for clinical use [74].

Furthermore, the use of gamma irradiation induces mechanical weakening of meniscal allografts.

Yahia and Zukor [76] studied fresh, fresh-frozen, and frozen irradiated meniscal allografts at 6 months postoperatively in a rabbit model and found a significant reduction in compliance to long-term creep compared with nonirradiated fresh and frozen transplants. This was supported by a clinical study of Noyes and Barber-

Fig. 10.1.2 Second-look arthroscopy 14 years after lyophilized meniscal allograft transplantation. The meniscus is reduced in size down to the former rim of the original meniscus

Fig. 10.1.3 MRI of a lyophilized meniscal allograft at 14 years of follow-up. The medial joint space (right) is reduced and osteophytes indicative of degenerative arthritis are seen

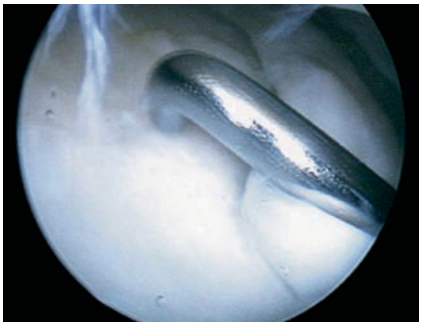

Fig. 10.1.4 Second-look arthroscopy 14 years after deep-frozen meniscal allograft transplantation

Westin [49], who observed a 44% failure rate in 67 meniscal allograft transplants, partly related to the use of a deep-frozen irradiated meniscal allograft.

A number of studies used glutaraldehyde to preserve meniscal allografts. However, in the animal models, less postoperative healing, recurrent joint effusions [8], significantly lower strength and tensile modulus, and significantly higher compressive stiffness were found for the glutaraldehyde-cross-linked menisci compared to fresh specimens [75].

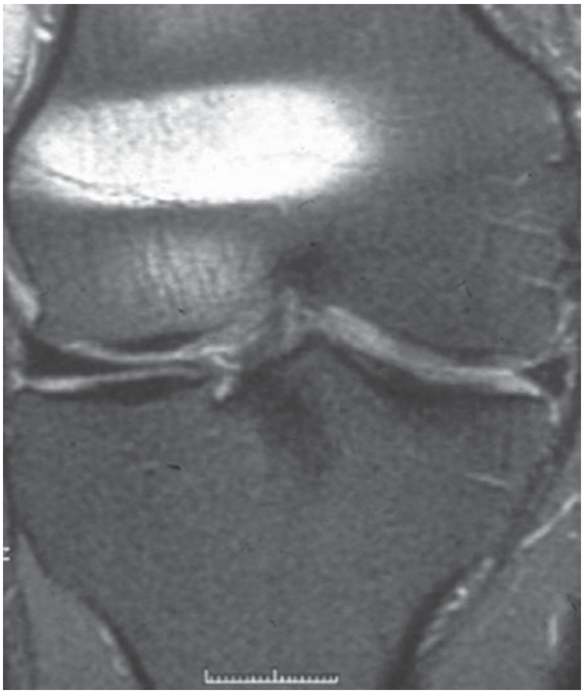

Fig. 10.1.5 MRI of a deep-frozen meniscal allograft at 14 years of follow-up. The meniscal transplant is shown in the medial joint space (*right*). In comparison to the lateral meniscus, there is a minor reduction in size, but the meniscus shows homogeneous signal intensity on MRI

Biomechanical Studies

In vitro biomechanical studies of cadaveric knee joints and biomechanical evaluations of knee joints of sacrificed animals have been performed, including the assessment of the material properties of the meniscal allograft itself and of the insertion sites, biomechanical testing of cartilage, and the tibiofemoral contact mechanics of the knee joint after meniscal allograft transplantation.

Biomechanical Evaluation of the Transplanted Meniscus in Animal Models

A few studies have reported on biomechanical testing of allograft menisci after surgery. Experimental studies of dogs failed to detect any effect of cryopreservation on meniscal tensile properties such as differences in load to failure and elastic modulus, and resistance to hoop stress on the meniscus during loading [5]. Milachowski et al. [46] evaluated meniscal allografts using a standardized traction device in a universal testing machine.

The tensile strength of deep-frozen meniscal transplants corresponded to that of lyophilized transplants at 6 and 12 weeks. However, even after 48 weeks, the tensile strength of a normal meniscus was not reached. Kobayashi [29] described a time-dependency of the material properties of transplanted menisci. He found a decrease of the dynamic stiffness after 1 month. After 3 months no difference was observed between allografts and controls. The initially prolonged stress relaxation seemed to normalize with time. Furthermore, graft preservation techniques such as gamma-irradiation and glutaraldehyde, have been found to negatively affect the material properties of meniscal allografts [75, 76].

The fibrochondrocytes of the meniscus are responsible for the matrix collagen-proteoglycan meshwork and biochemical composition, which in turn are responsible for the biomechanical properties [30]. Transplanted menisci demonstrate repopulation with cells from the synovium and the parameniscal connective tissue. The collagen architecture, which is disturbed initially after implantation, may remodel [4, 15]. Whether the cellular repopulation of the meniscal allograft is sufficient to restore the biomechanical properties remains an important topic for investigation, especially with regard to engineering of meniscal tissue.

Biomechanical Testing of Cartilage

Biomechanical testing of cartilage has become a focus of interest in recent experimental studies. In a canine model, Elliot et al. [14] found the tensile modulus of the surface zone cartilage to be significantly lower than in nonoperated controls 12 weeks after either meniscectomy or allograft transplantation. Kelly et al. [28] measured the cartilage stiffness over the central weightbearing zone of the lateral tibial plateau using a cartilage indentation probe in a sheep model. Compared with meniscectomy, there was a significantly improved maintenance of cartilage stiffness at 2 and 4 months. However, cartilage stiffness was significantly lower at 4 months than at 2 months. After 4 months, the allografts were significantly worse than the nonoperated controls.

Contact Mechanics After Meniscal Allograft Transplantation

Effects of Positioning and Size Matching

The early experiences with meniscal transplantation already emphasized that fixation of the anterior and posterior horn insertions of the transplant at the wrong tibial location may be a cause of failure [31, 32]. Furthermore, congruence and proper size have been recognized as crucial outcome factors [13, 23, 32, 59]. A biomechanical study of Sekaran et al. [55] clearly demonstrated that placement of the posterior horn in a nonanatomic medial location caused a significant increase of the normal maximum pressure over all flexion angles. The authors recommended that the posterior horn tunnel of a meniscal transplant should be placed within a tolerance tighter than 5 mm medial and 5 mm posterior to the anatomic location because nonanatomic placement significantly alters the contact pressure distribution. Too small a graft can be trapped under the femoral condyle and thus subjected to disproportionately high forces that predispose to failure. Conversely, a large graft may have a loose fit around the femoral condyle, and therefore can be mechanically ineffective [41]. Dienst et al. [12] demonstrated in a biomechanical in vitro study that only a mismatch of less than 10% of the original meniscus might be acceptable. Various preoperative measuring techniques for accurate size matching of meniscal allografts have been reported in the literature [9, 20, 23, 51, 56, 67]. An anatomic study of meniscal allograft sizing showed that the meniscal dimensions can be accurately predicted from tibial plateau measurements [41].

Effects of Fixation

The method of fixation to the surrounding tissues is another factor affecting the ability of a meniscal transplant to restore normal contact mechanics at the time of implantation and is a controversial issue in meniscus transplantation [44]. Biomechanical investigations have shown that meniscal transplants require firm bony fixation in order to function well in load transmission.

The results of meniscal transplants fixed only with sutures were inferior to those of meniscectomized knees [3, 10, 21, 50]. In contrast to these earlier studies, a recent biomechanical investigation showed that with suture fixation alone, restoration of joint contact mechanics was not significantly different from normal, although some advantage was found for the grafts with bony fixation [40]. Furthermore, no difference was observed in the pull-out strength of medial meniscal allograft fixation with bone plugs and suture fixation via bone tunnels secured over a screw on the proximal tibia [24, 69]. Additionally, investigations of contact area and pressure considering the healing and ingrowth process, should be taken into account. Biological processes observed immediately postoperatively, such as remodeling, healing, and inflammation of bone and soft tissue, can alter the contact area and lead to different conclusions than purely in vitro cadaver studies. Bylski-Austrow et al. [7] demonstrated this effect by measuring knee joint contact pressure after chronic meniscectomy compared to acutely meniscectomized joints in an animal model at 4 and 8 months postmeniscectomy. The biomechanical evaluation of an ovine model [70] demonstrated that biological ingrowth and intraoperative pretensioning of meniscal transplants applied on the tag sutures passed through the bone tunnels, had a positive effect on the contact biomechanics of the knee joint. Contact area and peak contact pressure with higher levels of intraoperative pretensioning showed significantly better results in comparison to meniscectomized knees (Fig. 10.1.6).

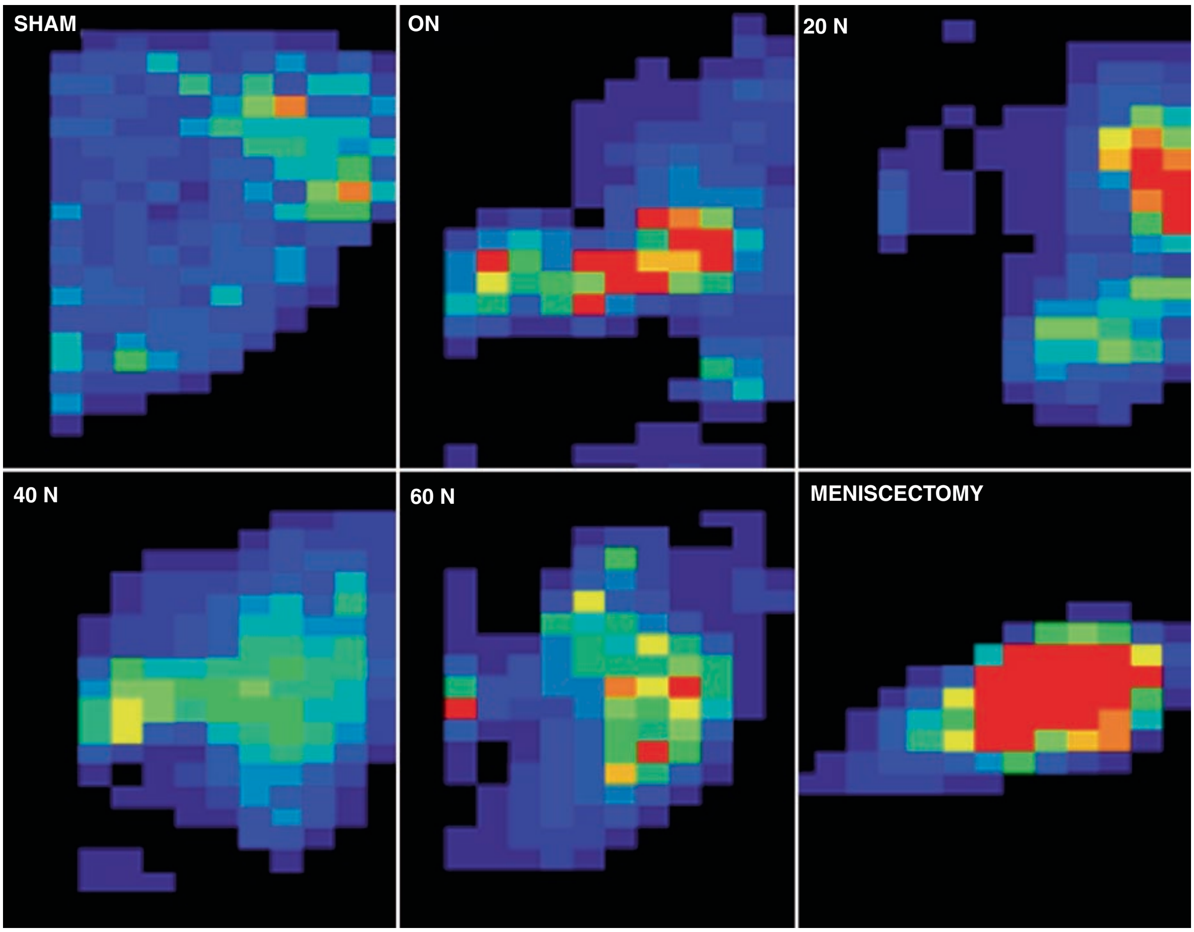

Fig. 10.1.6 Example of pressure measurement with Tekscan® pressure sensitive film at 60° of flexion and 500 N compressive load. Pressure increases from *blue* to *red*. The medial collateral ligament is located on the right hand of the figures and the cruciate ligaments on the left hand

Conclusion

From the available experimental studies, it can be concluded that the ovine model seems to be adequate for investigating meniscal allograft transplantation. Animal studies have provided evidence of meniscal allograft healing, but concerns regarding graft hypocellularity, material properties, and long-term functional survival still remain. Macroscopic and histological cartilage assessments have shown a chondroprotective effect compared to meniscectomized knees. However, experimental studies have also demonstrated that the cartilage status of the knee cannot be restored to normal by meniscal allograft transplantation. Biomechanical investigations confirmed that precise size matching and positioning as well as firm fixation at the anterior and posterior horn are mandatory for meniscal transplants to have an adequate loadbearing function.

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Organization: Type of Grafts, Conservation, Regulation

10.2

T. Schubert, O. Cornu, and C. Delloye

Introduction

Joint degeneration following complete meniscus removal has been documented and recognized as a major cause of osteoarthritis [1, 24, 35, 40, 49]. The meniscus at the knee has been shown to serve various functions such as load distribution, shock absorption, joint stability, knee proprioception and joint lubrication. A deficient meniscus implies a decrease of surface contact area with a subsequent increase of contact pressure, leading to wear and gradual disappearance of cartilage within a decade [4, 36, 38, 45]. The basic principle underlying meniscal transplantation is to restore the joint anatomy and to relocate an implant that will serve and perform in a similar fashion as the original one.

An allograft should delay or better still, prevent osteoarthritis of the knee.

The demand for meniscal allografts has recently increased because of the improvements in graft fixation and the extended indications for meniscus allografting.

Limitations to musculoskeletal tissue donation and donor age contribute to the shortage of available meniscal tissue. Optimal handling and fixation of a meniscus allograft during surgery will avoid tissue wasting and improve the surgical outcome.

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Tissue Banking Organization

Meniscus transplantation deals with human tissues, and as such, is regulated by the European directive on human tissue, which sets the standards of quality and safety for the donation, procurement, testing, processing, preservation, storage and distribution of human tissues and cells [20–22]. Most large tissue banks are involved throughout the whole process from harvest to graft delivery [25, 51].

Donor Selection

Consent

The procurement of any human tissue is framed by European directives on human tissue, covering donation, donor selection and tissue safety. In each country, the European directive must be translated into a national law of at least the same level of requirements. Each country has the possibility to reinforce one or more legal aspects. A national authority controls tissue banking activities in each European country.

Menisci 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.

Anonymity between donor and recipient is a key principle, whereas traceability is maintained by a unique donor coding number [22].

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.2, © Springer-Verlag Berlin Heidelberg 2010

Donor Selection

Donor suitability is determined in compliance with the standards and guidelines developed by European or national authorities, or tissue banking associations such as the American Association of Tissue Banks and the European Association of Musculo Skeletal Transplantation. Those standards list a series of conditions that might indicate a donor at risk for disease transmission [2, 3, 19, 21, 22]. Thorough examination of the medical files and donor physical assessment are imperative.

European standards differ from American ones in two specific points [2, 3, 20, 21]. A past history of cancer is an exclusion criterion in Europe, but not necessarily in the United States. In Europe, the donor's body must be refrigerated within 6 h for a procurement to occur within 24 h after death, whereas in the United States an interval not exceeding 15 h prior to body cooling can be accepted before procurement.

The donor is screened for disease transmission prior to tissue harvesting. If the potential donor has been transfused with a large volume (>2,000 mL) of blood, blood components or plasma volume expanders within 48 h prior to death, a pre-transfusion blood sample is required for testing, because dilution of donor plasma carries a risk of false-negative results.

HIV-1 and 2 (two antibodies tests and *P24* antigen detection), HTLV-1 (antibodies), hepatitis B (surface antigen *HBs* and core antibody *HBc*), hepatitis C (antibodies) and syphilis (antibodies) are systematically screened. Additional safety measures can be taken to screen for potentially false-negative results during the incubation period of a virus, by using nucleic acid testing for hepatitis viruses and HIV (NAT). This type of assay allows significant reduction of the serological window period [8, 19, 37]. Furthermore, another safety feedback is possible for tissues procured from an organ donor as organ recipients can be screened for disease transmission 3 months after having been grafted [19].

The value of blood cultures is still a matter of controversy [13, 14].

During and after harvesting, samples of the procured tissues are placed in a thioglycolate broth culture medium in order to exclude bacteriological contamination [51, 52]. They are cultured for aerobic and anaerobic bacteriae and fungi for at least 7 days.

Harvesting

Harvesting from a multiorgan donor is performed under sterile conditions in the operating theatre by a team of three to four trained individuals, one being an orthopaedic surgeon. When selecting viable meniscal or osteochondral allografts, the donor should preferably be under 45 years of age. Close examination at the time of procurement will determine the quality of the surface of the cartilage and of the meniscus. In daily practice, donor age is certainly not the main critical factor: post-traumatic or osteoarthritic changes may be present in younger patients, whereas suitable cartilage or meniscus might sometimes be found in donors above the age limit of 45 years.

At our institution, a 1 cm-thick section of the tibial plateau is removed (Fig. 10.2.1). Then, the plateau is in its central aspect separated into two parts, taking care not to damage the insertions of the menisci (Fig. 10.2.2).

Risks and Recommendations

Bone and tissue allografts are capable of transmitting virus and contaminating the recipient [7, 9, 10, 12, 43, 46, 47, 50]. The risk of viral disease transmission through tissue is very low, provided the guidelines for donor selection have been strictly followed and the donor has been screened by medical history-taking and blood testing. For HIV, the theoretical risk of transmission has been evaluated to be less than one in a million, and for HCV one in 200,000 for an unprocessed

Fig. 10.2.1 Menisci harvested. Aspect prior to bone sawing

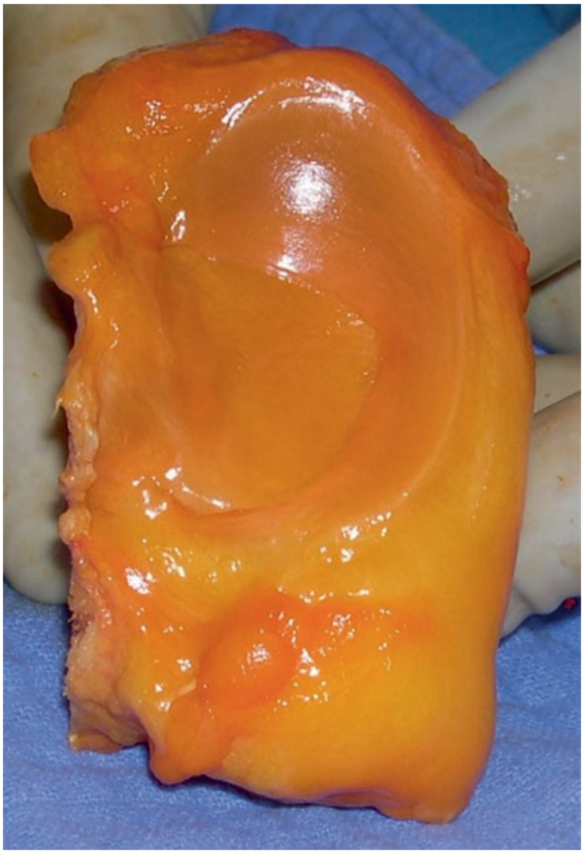

Fig. 10.2.2 Meniscus harvested with its osseous support

tissue from a selected and serologically screened donor [6, 16, 18].

For a processed tissue such as cancellous bone that has been subjected to thorough saline washing and solvent-detergent exposure with a final irradiation, the theoretical risk is much lower, with an average decrease of two orders of magnitude [12, 16].

The surgeon using the graft must verify the bacteriological and serological results himself and inform the patient of the use of an allograft.

ABO blood group typing is not required prior to a bone or soft-tissue grafting procedure. On the other hand, the Rhesus factor has to be determined if the recipient is a female with a potential of becoming pregnant [33, 34]. It has been shown that 0.5 mL of bone marrow is sufficient to induce Rhesus immunity in a Rhesus-negative patient. Soft tissue such as meniscus does not carry this risk.

Graft Sizing

Sizing is usually based on peroperative measurements and standard X-rays.

For peroperative sizing of the graft, the antero-posterior and latero-medial dimensions are

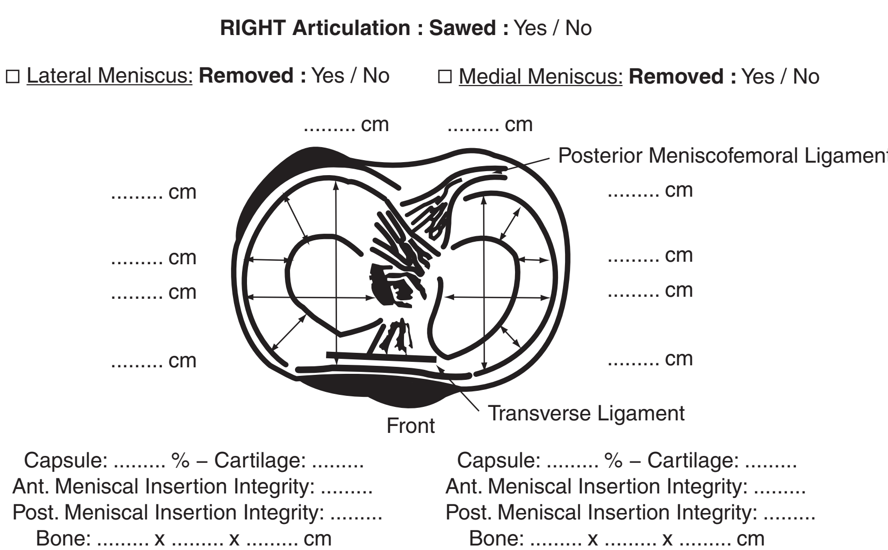

Fig. 10.2.3 Graft sizing. Standard sizing chart used in the operating theatre

Fig. 10.2.4 Standard AP view of a procured tibia with menisci

measured, as well as the width of the meniscus at its anterior, medial and posterior parts [39]. All measures are recorded on standardized charts and are catalogued in our tissue bank inventory, providing a wide range of meniscal transplants (Fig. 10.2.3).

Standard X-rays are difficult to obtain. If true anteroposterior or lateral images are lacking, the inaccuracy of the measurements is significantly increased (Figs. 10.2.4 and 10.2.5) [44].

Magnetic resonance imaging (MRI) is not used by bone banks because its superiority has not been clearly demonstrated. Moreover, MRI is not easily applicable in a routine tissue bank protocol or pretransplantation planning [28, 44, 48].

A successful transplantation requires precise matching of the size of the donor meniscus and the recipient. The use of digital imaging during procurement might be helpful [17, 29].

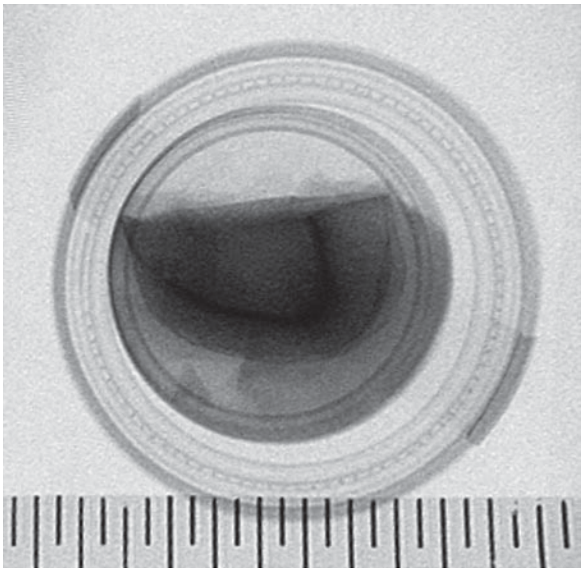

Fig. 10.2.5 Frontal view of a harvested meniscus

Types of Grafts

According to the preservation method, four types of allografts are distinguished: fresh menisci, frozen menisci with or without cryoprotectants and freeze-dried menisci. While fresh and cryopreserved grafts may still contain some viable cells at the time of transplantation, freeze-dried and deep-frozen ones are nonviable and are as such considered to be acellular material [11, 53].

Fresh meniscus is used for viable meniscus allografting. For maximal viability of the meniscus, procurement should be within 12 h after death.

After harvesting, the grafts are transported in a sterile saline solution and placed in a culture medium containing 20% of recipient serum. The graft material is stored at 37°C in a constant controlled environment [53, 55]. Post-implantation viability of fresh grafts has been documented [53, 54]. Because cultured meniscus does produce the components of the extracellular matrix in vitro, it can be expected to perform similarly in vivo. However, the duration of this cellular function in vivo remains unknown. In a goat model, DNA probing showed that cells from fresh and viable meniscus did not survive for more than 1 month [32]. However, Verdonk et al. were able to demonstrate some donor cell survival 64 months after transplantation [54].

Recipients of a fresh meniscal allograft do not require immunosuppression, but the importance of the recipient's immune response to the clinical outcome remains unknown [27]. So far, no clear benefit of a viable meniscal allograft compared to a frozen-preserved one has been shown.

Cryopreserved meniscal allografts are tissues that are immerged in a solution containing a cryoprotective agent such as dimethyl sulfoxide, a culture medium and an antiseptic agent. After impregnation, the graft is gradually frozen in a controlled fashion to minimize cellular lesions during freezing. Storage temperature is at −196°C. Even if this type of cryopreserved graft may still contain viable cells after thawing, their long-term survival remains questionable [23].

Freshly frozen allografts are soaked in a saline solution containing an antibiotic (rifampicin, 1.2 g/L) after harvesting. Subsequently, they are packaged in a sterile fashion and stored in a mechanical freezer at −80°C. These grafts can be preserved for as long as 5 years. At surgery, they are again soaked in an antibiotic solution, e.g. rifampicin, which will be gradually released from the implant for at least 3 weeks after the operation in a similar fashion as demonstrated for bone [16, 30].

Freezing a tissue without other physical treatment such as irradiation does not alter the original mechanical properties, whatever the freezing temperature [31, 42].

The maximal storage period of human deep-frozen tissue is limited to 5 years in Europe [19].

Freeze-dried allografts: lyophilization or freeze-drying, which consists of drying a tissue under vacuum and freezing conditions, is a suitable method to preserve cellular viability if cryoprotective solutions are used, as for vaccine production. Lyophilization without cryoprotection leaves nonviable dried tissue [15, 16]. Freeze-drying is just a preservation method, and as such, not a sterilant.

Freeze-drying is beneficial from a logistical standpoint, because the dried tissue can be stored at ambient room temperature. In addition, from an immunological standpoint, lyophilization has been demonstrated to be superior to freezing, because freeze-dried tissue does not elicit an immune response, at least not in experimental conditions [26].

Because sterile freeze-drying of tissues is difficult, further irradiation at 25 kGy is usually associated. In a clinical setting, the 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 a profound alteration of the mechanical properties and the extracellular matrix. From a clinical standpoint, freeze-dried and irradiated meniscal allografts are not suitable for transplantation [41, 56, 57].

Data from Our Bank

Our bank has always worked with freshly frozen tissues. Figure 10.2.6 summarizes the path followed by any tissue from donor to recipient. Over the past years, the demand for meniscal allografts has substantially

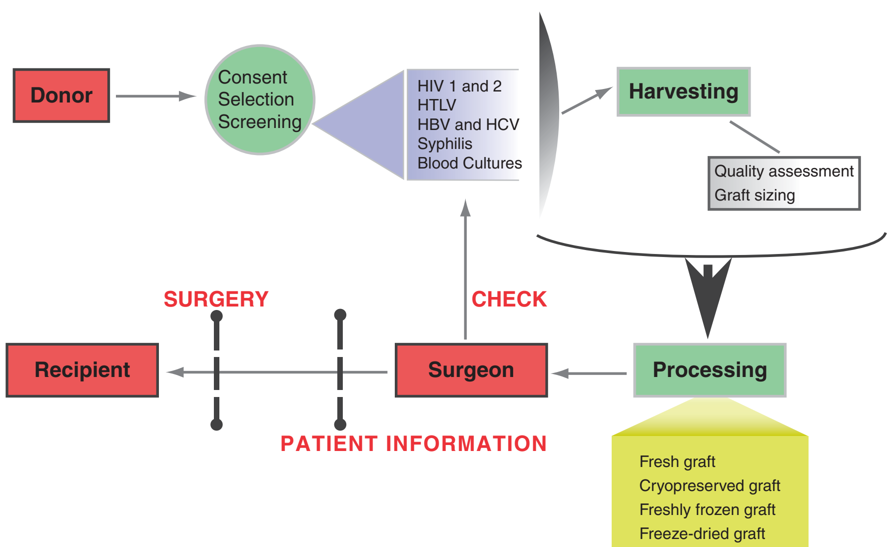

Fig. 10.2.6 Allograft use algorithm

increased, since the year 2000 even 20-fold, with an annual delivery rate of 45 menisci in 2006 and 2007.

We advocate the deep-freezing method for several reasons: (1) it does not affect the mechanical properties of the tissue; (2) even if the material is nonviable at surgery, experimental conditions have shown a rapid recolonization of the implant by host cells; (3) it allows storage for 5 years; (4) it requires minimal tissue handling compared to cultured tissue and (5) it allows the surgeon to schedule the time of surgery himself.

In 2007, we reviewed 69 fresh-frozen meniscal allografts procured by our tissue bank, with a follow-up of 2 years. Of these 69 grafts, 60% had been secured by peripheral suturing, 22% with one bone plug and 18% with two bone plugs. Using psychometric scores for knee evaluation, an increase of four points on the Tegner activity scale [5] was achieved, corresponding with a 65% improvement after allograft surgery. The mean Lysholm score [5] increased from 72 preoperatively to 90 at the last post-operative visit. As for patient satisfaction, we noted 90% of excellent results and 8% of intermediate results, while 2% of the patients were disappointed by the surgery. We encountered four complications: three tears and one infection.

Freshly frozen allografts can be safely and reliably used for meniscal transplantation.

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Meniscal Allograft: French Organization 10.3

O. Charrois and A. Podgorski

In France, the development of the surgical management of meniscal tears had been lagging behind the international trends for a long time. At some point, French orthopaedic surgeons, alerted by their poor long-term results [3, 13] and the short-term complications [2] that were likely to follow meniscectomies, developed the strategy of "meniscal sparing" performing a repair [1] whenever possible. Nevertheless, meniscectomies are still frequently performed: 125,000 in 2006 vs. only 2,800 repairs. Faced with young meniscectomized patients who sometimes already presented degenerative joint changes, it was not until 2002 that French orthopaedic surgeons (Beaufils and Charrois) with the assistance of René Verdonk performed the first meniscal transplantation. Meniscal transplantation in young individuals had been introduced in the eighties by Milachovski et al. and Kohn et al. [7, 16] and was performed first in Europe and then in the United States, using the technique developed by Verdonk [14].

In France, meniscal grafts did not exist from an administrative point of view. The costs of the procedure and hospitalization were not covered by the French National Health Service, nor was there a procedure which would allow to standardize graft removal and preservation.

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The French Meniscal Transplantation Group was established in 2005 under the aegis of the French Arthroscopy Society to promote the exchange of professional experience with this rather uncommon technique and find a solution for the administrative issues. It groups more than 30 public and private orthopaedic surgery departments specialized in knee surgery. Its initial goal was to launch a debate on the three main fields related to meniscal transplantation at the beginning of its availability in France. The members of the group intended to standardize this procedure, including removal of the graft, its preservation and distribution by the French tissue banks, to confirm its effectiveness and specify the indications in the first prospective and randomized study ever.

Standard Technique of Meniscal Grafting

The choice of technique includes the surgical approach (by an arthrotomy or arthroscopically) and the use of bone plugs, soft-tissue meniscal fixation or peripheral fixation. We decided to use an arthroscopic technique and bone plugs to ensure the stability of the fixation and to benefit from the presumed ease of cellular repopulation through the blood vessels of the meniscal horn (Fig. 10.3.1).

We conducted a feasibility study of this technique in a cadaveric model to determine whether it was applicable to both menisci, as the access to the posterior horn of the medial meniscus seemed to be more limited.

This work, realized at the Laboratory of Anatomy in Tours, is the subject of Chap. 10.6.

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.3, © Springer-Verlag Berlin Heidelberg 2010

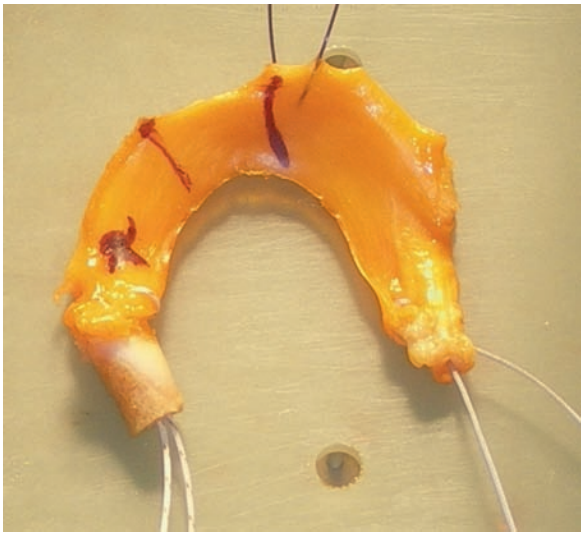

Fig. 10.3.1 Lateral meniscus allograft with bone plugs.

Graft Selection, Removal and Preservation Procedure. Graft Distribution by French Tissue Banks

Some of the techniques used in tissue banking, such as lyophilization and irradiation in order to ensure viral destruction, were not implemented due to the biomechanical deterioration of the meniscal matrix, which could cause rupture of the graft [16].

The main issue of the debate, which is still open, is the influence of the preservation procedure on graft cellularity and on the long-term outcome of the meniscus and the joint. Fresh allografts [15] raise important logistic problems regarding their removal, transport, storage and long-term preservation. The French Meniscal Transplantation Group recommended the use of a cell-protecting substance (dimethyl sulfoxide, DMSO) during graft preservation and submitted the standards of removal, preservation and distribution of meniscal grafts to the French Agency for Sanitary Security of Health Products early in 2008.

Donor Selection

Graft removal is carried out during a multi-organ donation, after it has been verified that there is no recorded objection from the donor and that his/her medical history does not preclude donation of the menisci (according to the definition of the French Meniscal Transplantation Group) or even of all organs.

Donor exclusion criteria are a history of knee surgery, known meniscal lesions, knee ligament sprain, osteoarthritis, local infections of the knee, inflammatory conditions, collagen diseases, Paget's disease, tuberculosis, bone infection, active hepatitis B, hepatitis C, HIV, syphilis and cancer.

Serological tests, imposed by French regulations, are carried out using the serum obtained before the donor's death.

Graft Removal

The meniscus, which must be macroscopically intact, is removed by an orthopaedic surgeon together with an at least 1-cm thick piece of the tibial plateau (Fig. 10.3.2). This bony fragment serves as a support for the meniscus, facilitates intra-operative adjustment of the height and allows the use of bone plugs. Meniscus measurements (length, width and height of the tibial plateau) are registered. The meniscus and the tibial plateau are placed in a special air-tight container in an 8% DMSO solution. A soft-tissue sample is taken for bacteriological analysis in a routine fashion.

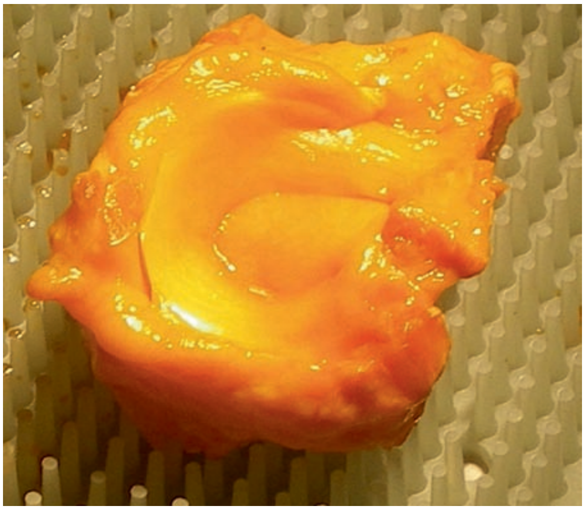

Fig. 10.3.2 Meniscus allograft harvesting with tibial plateau

Preservation

Radiographs of grafts are taken, which permits new radiological measurements. The graft is preserved at a temperature varying from +4 to +8°C. The interval between completion of the removal and the start of freezing must not exceed 6 h.

Frozen transplants are quarantaine-stored in a cryoprotector solution in a freezer, while waiting for the result of the bacteriological and serological tests. If necessary, additional tests can be performed using molecular biology techniques.

Once the absence of any viral or bacterial transmission risk has been verified, grafts are stored in a freezer at −80°C under constant control. The maximal time of preservation is 5 years.

Transplant Distribution and Preparation

Meniscal transplants are available from tissue banks registered for this type of transplants, which distribute it on registered demand. The selection of the most appropriate transplant is made by the surgeon, according to the measurements and the radiographs provided by the bank.

After the graft size has been matched, the graft is thawed and immediately transplanted. It cannot be frozen again.

All information on the donor, recipient, indications for the graft, graft characteristics and any complications are registered on a digital support

Effectiveness of Meniscal Grafting: Indications

According to Eriksson [4], the dispersal of cases and lack of treatment alternatives in young patients with pain from an earlier meniscectomy interferes with attempts to conduct a prospective and comparative study in spite of the extensive literature on this subject.

The Group started the randomized study of meniscal allografts, which obtained financial support from supervising authorities in 2007. It is a controlled, randomized and multi-centre study (17 hospital centres), which will run for 7 years and allow to compare the outcome of meniscal allografting to symptomatic medical care.

Material

For the test to achieve 90% statistical power, 190 patients have to be included.

The technique is always the same: grafts with bone plugs and an arthroscopic approach.

Method

The goal of this study is to evaluate the results of meniscal replacement with cryopreserved allografts at 2 and 5 years. These will be assessed by clinical criteria: pain, function (KOOS [8, 10–12] and IKDC 2000 questionnaires), quality of life (SF12 questionnaire [6]), return to work, early complications (infection, hemarthrosis, synovitis), late complications and the necessity of a new surgical procedure (osteotomy, knee arthroplasty). Radiological and histopathological criteria that will also be considered include graft healing evaluated by arthro MRI and arthro CT, positioning of the meniscus evaluated by MRI [9], meniscal status evaluated by MRI and biopsies to assess the cellularity and to search for any signs of rejection (lymphocytic infiltration, presence of giant cells on the periphery of the meniscus) [5] and cartilaginous status evaluated by the height of the joint space on standard radiographs and an arthro CT.

Hospital and extra-hospital costs will be estimated in order to devise a financial plan specific of this technique.

Eventually, an evaluation of encountered operative difficulties will permit to improve the technique.

Conclusion

Because of medical and administrative difficulties in France, where one is rather unreceptive to innovative methods, we organized and standardized meniscal allografting, taking advantage of the international experience in this field and grouping the orthopaedic departments interested in developing this technique. After standardization of the entire procedure and defining the criteria for this technique, meniscal transplantation using deep-frozen allografts fixed with bone plugs via an arthroscopic approach, performed in 17 orthopaedic departments, will be discussed in the first prospective and randomized study ever.

The administrative steps already accomplished (codification, preservation procedures) will allow the diversification and the diffusion of this technique in France, based on our results and experience.

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Open Technique

10.4

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Preoperative Considerations

In contrast to deep-frozen allografts, a strict time schedule from harvest to transplantation is mandatory for viable allografts. The transplantation of viable meniscal allografts implies the availability of *viable* donor tissues, cultured in vitro immediately following the harvest. Sizing of the graft is critical for correct implantation. For deep-frozen allografts, the mediolateral and anteroposterior length of the tibial plateau of the recipient is measured on a calibrated X-ray, and these measurements are transferred to the tissue bank. Since viable meniscal allografting is more limited in size options because there is only one donor and a limited number of recipients, the most appropriate recipient is chosen based on corresponding donor–recipient height and weight criteria. Once a patient is deemed to be a candidate for this type of procedure, 30–50 ml of autologous serum is prepared and frozen at −21°C. The waiting time for a viable meniscal allograft averages 2 months (range, 14 days to 6 months) at our institution. Once an appropriately sized meniscal allograft is harvested, the patient is notified and an operation is planned within the next 14 days.

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Surgical Technique

Introduction

The purpose of this technical chapter is to describe medial and lateral meniscal allograft transplantation performed as an open procedure [7–9]. This technique primarily uses soft-tissue fixation of the allograft to the native meniscal rim. Additional transosseous fixation of the anterior and posterior horn can be used, as well as a tag on the anterior horn for soft tissue-bone fixation.

Anaesthesia and Surgical Preparation

The choice of anaesthesia is made in consultation between the surgeon, the anaesthesiologist and the patient and depends on patient age, co-morbidity and history with regard to previous anaesthesia. General anaesthesia is preferred at our institution.

The patient is positioned supine on the operating table. A lateral leg holder is positioned at the height of the tourniquet, with the leg in 90° of flexion. A foot holder is used to hold the leg in 90 and 110° of flexion as needed. Previous skin incisions are marked. The limb is exsanguinated, and the tourniquet is inflated. The limb is then prepared with chlorhexidine gluconate-alcohol solution (Hibitane, Regent Medical Overseas Limited, Manchester) and draped at the mid-thigh level.

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.4, © Springer-Verlag Berlin Heidelberg 2010

Allograft Preparation for the Open Procedure

As described elsewhere, the allograft is positioned and fixed on a specially designed cork board with three 25-gauge needles (Fig. 10.4.1) [7]. With a scalpel, the residual synovial tissue is dissected from the allograft meniscus at the meniscosynovial junction level and discarded.

The upper side of the allograft is marked with a methylene blue skin marker.

Horizontal 2–0 polydioxanone surgical sutures (PDS II mounted on a double small needle, Ethicon, Somerville, NJ) or 2–0 non-absorbable polypropylene sutures (Prolene mounted on a double small needle, Ethicon) are placed every 3–5 mm through the posterior horn, the body and the anterior horn of the allograft and fixed onto a specially designed suture holder (holder A) (Fig. 10.4.1). The senior surgeon (RV) prefers to use 2–0 prolene sutures for the posterior horn since this suture material comes with slightly smaller needles, which facilitates surgical handling in the more narrow posterior joint space. The sutures are fixed onto the suture holder in sequence from posterior to anterior. Generally, six to eight sutures are needed to cover the complete allograft.

Open Meniscal Allograft Transplantation

A medial or lateral parapatellar incision of approximately 8 cm is made with the knee in 90° of flexion to gain access to the involved compartment of the knee joint (Fig. 10.4.1). The joint capsule is then opened and the anterior horn of the meniscus remnant is transected.

For the lateral procedure, the iliotibial band is released subperiosteally from its distal attachment. To further open the lateral compartment, the insertions of the lateral collateral ligament and popliteus tendon are detached with a curved osteotome on the femoral side. The centre of the osteotomy bone block is first predrilled with a 2.7-mm drill. This facilitates subsequent re-fixation with a screw and washer. The osteotomy is performed in a clockwise direction from the 8 o'clock position to the 4 o'clock position, and is approximately 1.5 cm deep and conically shaped. The bone block is gently folded out using a bone clamp and then the osteotomy is completed inferiorly from the 4 o'clock to the 8 o'clock position using the osteotome. The lateral joint space can now easily be opened 1–2 cm by placing the knee in the figure-of-four position in 70–90° of flexion, with the index foot positioned across the contralateral limb (Fig. 10.4.1).

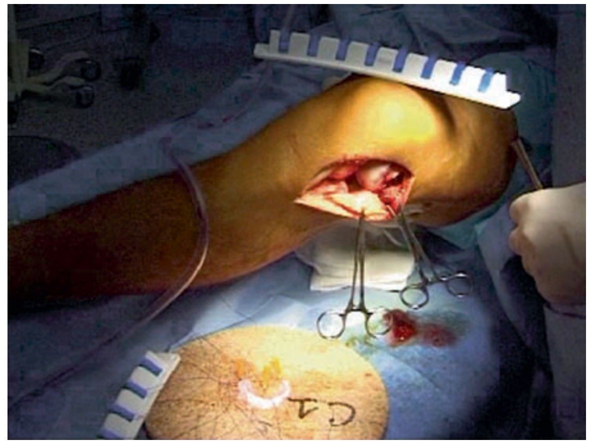

Fig. 10.4.1 The lateral joint space can easily be opened 1–2 cm by placing the knee in the figure-of-four position in 70–90° of flexion, with the index foot positioned across the contralateral limb

For the medial procedure, the medial collateral ligament is detached on the femoral side with an osteotome [3]. A flake osteotomy (0.5–1 cm in thickness) is performed with a straight osteotome at the level of the medial femoral epicondyle. The soft tissues posterior to the medial collateral ligament are left in continuity. By gently placing the knee in a valgus position, the medial compartment can now be opened in a controlled fashion.

The meniscus remnant is trimmed, preferably to a stable meniscal rim with a scalpel anteriorly and with arthroscopic instruments posteriorly. Most often, the insertion of the posterior horn is still intact and in continuity with the tibial plateau. The insertion of the posterior horn is also trimmed to fit the allograft. The meniscal rim deserves surgical attention, as it serves as a strong envelope encapsulating the medial or lateral compartment of the knee.

The meniscal remnant level is then marked with a small mosquito clamp anteriorly as a landmark for the correct level of subsequent fixation of the allograft. Next, the previously prepared viable meniscal allograft is introduced into the knee compartment. The sutures are taken from the holder in the correct sequence from posterior to anterior, driven through the meniscal rim

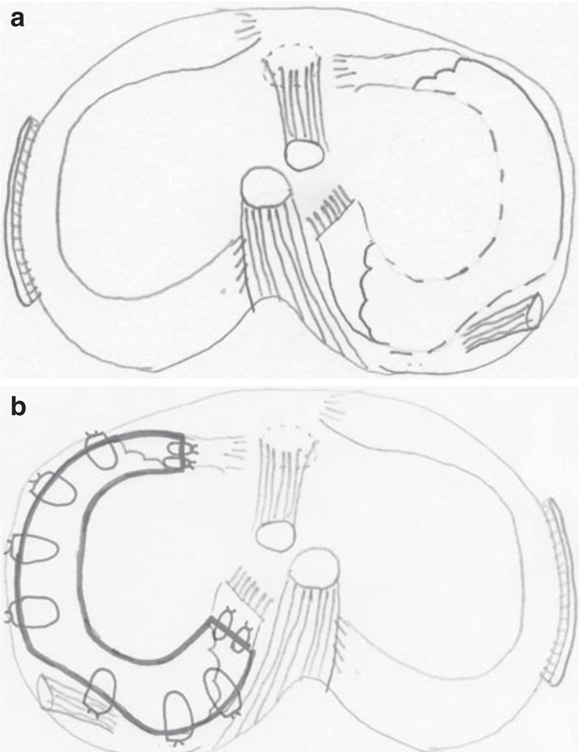

Fig. 10.4.2 The sutures are taken from the holder in the correct sequence from posterior to anterior, driven through the meniscal rim one by one in an all-inside fashion from inferior to superior, and transferred to a second suture holder (holder B), again in a sequence from posterior to anterior

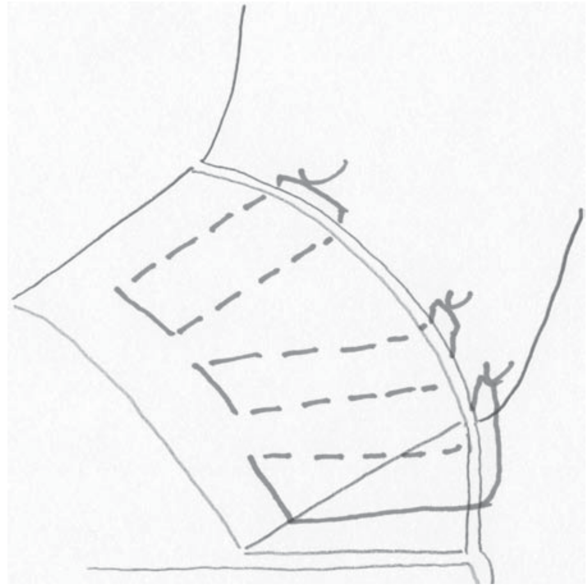

Fig. 10.4.3 Once the allograft has progressively been introduced into the compartment by pulling on each suture, the knots are tied securely in a sequence from posterior to anterior

one by one in an all-inside fashion from inferior to superior, and transferred to a second suture holder (holder B), again in a sequence from posterior to anterior (Fig. 10.4.2). The lateral allograft is also sutured to the popliteus tendon. On follow-up arthroscopy, we have found that the popliteal hiatus will recreate itself naturally. The insertion of the anterior horn of the meniscus is not yet sutured at this stage of the operation. Once the sequence of suture transfer from holder A through the meniscal rim (and popliteus tendon) to holder B is completed, the allograft is introduced into the compartment by gently pulling on each suture in a sequence from posterior to anterior. Generally, this procedure has to be performed progressively to establish a secure fit of the allograft to the meniscal rim (Fig. 10.4.3). The suture knots are then securely tied and cut. A fine-tipped suture driver and knot pusher are frequently required to securely tighten the posterior sutures. The knee is now positioned in a normal 90° flexed position. The bone block of the collateral ligament and popliteus tendon is re-positioned and fixed using a 35 or 40-mm 2.9 AO cancellous screw with a spiked washer. The anterior horn of the allograft is then fixed to the tibia using an anchor (GII, Depuy Mitek, Raynham, MA) (TLi: Tom Lootens improvement) (Fig. 10.4.4). The Hoffa fat pad and knee capsule are closed using interrupted Vicryl 1-0 (Ethicon) cross stitches after haemostasis.

Alternative Soft Tissue-Bone Fixation

Instead of tag fixation of the anterior horn, non-resorbable high-strength (Fibre wire, Arthrex, Naples) sutures can be placed in the anterior and posterior horn of the allograft. Generally, three whip stitches are placed on the inner and outer rim of the horn of the allograft (Fig. 10.4.3). An ACL aiming device is inserted through the arthrotomy and positioned at the anatomical posterior horn of the medial or lateral meniscus (Fig. 10.4.4). A guide pin is drilled first and subsequently overdrilled by a 4.5-mm cannulated drill. A double-loop metal

Fig. 10.4.4 The anterior horn of the allograft can be fixed to the tibia using an anchor (GII, Depuy Mitek, Raynham, MA) (TLi: Tom Lootens improvement)

wire is introduced through the tunnel from outside-in, picked up intra-articularly with an arthroscopic grasper and pulled out. Next, the posterior horn pull suture is pulled through using the double-looped metal wire, and soft-tissue suturing is performed from the posterior horn towards the anterior horn.

The anterior horn is introduced into the knee joint and the anatomical insertion site is identified and prepared in the same manner as for the posterior tunnel. If necessary, its position can be slightly adapted to that of the graft. Similar to the posterior horn, the anterior tunnel is prepared and the traction suture is pulled through.

Subsequently, the anterior and posterior horn traction sutures are knotted to each other over a bone bridge on the anteromedial or anterolateral side of the tibia for the lateral or medial meniscus allograft, respectively. This procedure reduces the possibly stretched capsule and native meniscal rim tied to the meniscal allograft, by pulling on the anterior and posterior horn by a transosseous suture fixation.

Special Note on Soft-Tissue vs. Bone-Block Fixation [1, 2, 4–6]

Biomechanical cadaver studies have shown the superiority of bony fixation to a soft-tissue fixation technique, although in a recent cadaver study comparable results have been found. Bony fixation, however, has also been shown to be associated with a higher risk of cartilage lesions if implanted incorrectly, and with an increased immunological potential due to the presence of allogeneic bone. It is the authors' experience that perfect allograft size matching is essential if bony fixation is to be used. A malpositioned bone block or plugs can inflict damage to the overlying cartilage. Too small a graft will result in the need to overtension the inside-out sutures and in possible failure of the soft-tissue fixation. Therefore, limited oversizing of the graft is commonly advocated when bone plugs or blocks are used. Separate bone plugs have the potential advantage that the implantation can be slightly more variable compared to a single bone block. In addition, on the lateral side, a straight bone block sometimes induces the need to sacrifice some posterolateral ACL fibres.

To date, no clinical and/or radiological differences have been found between soft-tissue and bone-block fixation.

Rehabilitation

Rehabilitation is initially focused on restoring mobility to the joint without endangering ingrowth and healing of the graft. Therefore, 3 weeks of non-weightbearing are prescribed, followed by 3 weeks of partial weightbearing (50% of body weight). Progression to full weightbearing is allowed from week 6 to 10 postoperatively. The use of a knee brace is not strictly necessary and depends on the morphology and profile of the patient. For the same reasons, the range of motion is limited from 0 to 30° during the first 2 weeks, and increased by 30° every 2 weeks.

Isometric muscle strengthening and co-contraction exercises are prescribed from postoperative day 1. Straight leg raise, however, is prohibited during the first 3 weeks. Proprioception training is started after week 3.

Swimming is allowed after week 6 and biking after week 12. Running is progressively introduced from week 20.

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Arthroscopic Technique Without Plugs

10.5

J. Bellemans

Introduction

The first meniscus transplantation at our institution was performed in 1994. Since then, we have applied this procedure in more than 100 cases. The surgical technique we initially used was a modification of the technique described by Shelton and Dukes and involved the use of an allograft meniscus with attached bone blocks on the anterior and posterior horn [1–4].

Initially, the purpose of these bone blocks was to provide reliable ingrowth of the allograft into the tibia by inserting them into an anterior and posterior tibial tunnel corresponding with the anatomical insertions of the anterior and posterior meniscal horns, respectively.

In those days, arthroscopic ACL reconstruction using bone-patellar tendon-bone autografts was commonly performed with good clinical success, and many people believed that fast and reliable ingrowth of the graft could be achieved by bone to bone healing into the corresponding tunnels.

A few years later, however, hamstring grafts became increasingly popular for ACL reconstruction, especially when it became clear that soft-tissue grafts incorporated relatively easily into host bone when they were inserted and fixed into an osseous tunnel.

It seemed attractive to us to apply the same principle in case of meniscal allograft transplantation, the more so since we had repeatedly encountered technical difficulties in passing the meniscal bone plugs through the joint into the respective bone tunnels. For example, in our first series of 22 cases, the average operating time amounted to 2 h and 25 min because of these difficulties. In three cases one of the bone plugs had disengaged out of the tunnel in the postoperative period, causing locking symptoms and necessitating a re-operation in two of them.

Based upon these experiences, we started to use meniscal allografts without bone plugs in 1998. Otherwise, our technique remained more or less the same, except that the soft-tissue attachments on the meniscal allograft were now used for insertion into a much smaller anterior and posterior tibial tunnel (5.5 mm instead of 10 mm when using bone plugs). On the posterior horn of the lateral meniscus, the meniscofemoral ligament was used for this purpose, whereas the transverse inter-meniscal ligament was used on the anterior horn for both the medial and lateral transplants.

Surgical Technique

We use a 30° arthroscope and standard knee arthroscopy instruments, with the patient positioned in a standard knee arthroscopy support applied 15 cm proximal to the patella, and with the leg hanging down. A tourniquet is applied.

A standard medial and lateral parapatellar portal 1 cm from the patellar tendon is created (Fig. 10.5.1).

Medial Meniscal Transplantation

As a stable and vascularized rim for peripheral attachment of the allograft has to be provided, any remaining scar tissue or meniscal remnant is removed first.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.5, © Springer-Verlag Berlin Heidelberg 2010

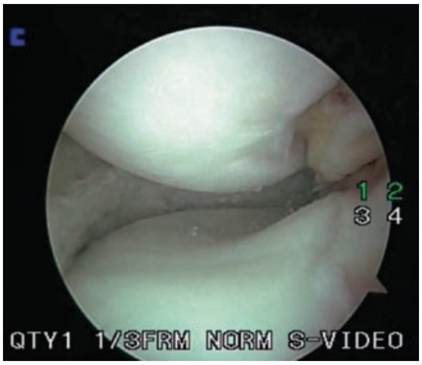

Fig. 10.5.1 Status post-meniscectomy, medial compartment right knee

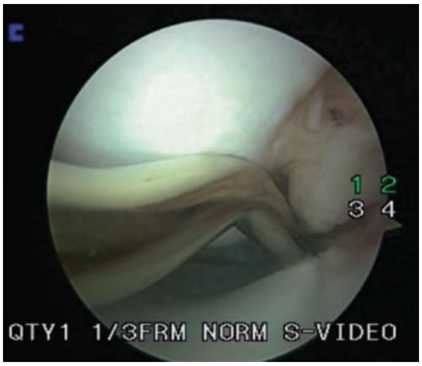

Fig. 10.5.2 Modified ACL guide in situ at the insertion of the posterior horn (arthroscope through antero-lateral portal, ACL guide through the antero-medial portal)

Fig. 10.5.3 Same guide in situ at the insertion of the anterior horn

Usually this is relatively easy to achieve with the use of a meniscal shaver, meniscal rasp or meniscal curette. A 2-mm Kirschner wire is used to make puncture holes into the rim in order to create vascular access channels that will facilitate peripheral ingrowth of the graft.

Next, the bone tunnels for attachment of the anterior and posterior horns are created, using a standard tibial ACL guide that has been modified for insertion into the narrow tibio-femoral compartment. For this purpose, its aiming tip is removed at the level just distal to the reference mark. The aiming guide is first positioned exactly onto the insertion area of the posterior horn (which is usually well recognizable), and the wire is drilled (Fig. 10.5.2). Once the correct position of the wire has been confirmed, it is over-drilled with a 5.5-mm cannulated drill through a 2-cm incision at the antero-medial tibial surface.

Next, exactly the same procedure is repeated at the anterior horn, in such a way that a bony bridge of 1–2 cm is created between the anterior and posterior tunnels at the level of the anterior tibial cortex. This is done through the same incision. Care is taken to reproduce the anatomic insertion sites of the anterior and posterior horns by using the footprints or meniscal remnants as a reference (Fig. 10.5.3).

Although this is not a necessity, all of the abovementioned steps are usually performed with the arthroscope in the lateral portal (healthy compartment) and the instruments inserted through the medial portal (working compartment).

After both tunnels have been created, a semi-rigid passing wire is inserted through the anterior and the posterior tunnel into the joint, and extracted through the medial portal. These wires will be used for inserting the meniscus into the joint and their respective anchoring tunnels (Fig. 10.5.4).

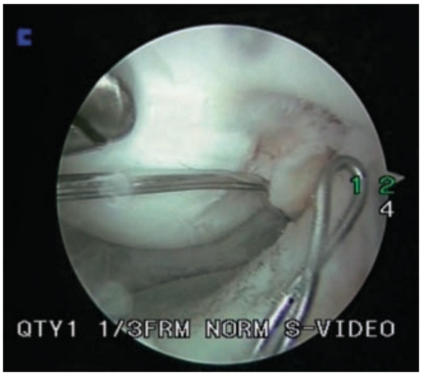

Fig. 10.5.4 Flexible passing wires through the anterior and posterior horn tunnel, exiting the antero-medial portal (arthroscope through antero-lateral portal)

In the meantime, the assisting surgeon prepares the allograft by passing a Ticron 2 suture criss-cross through the posterior and anterior horn extensions. This is usually easy at the anterior horn where the transverse inter-meniscal ligament can be used, but may be more difficult at the posterior horn.

Before inserting the graft, the antero-medial portal is enlarged until it allows the passage of a fingertip. One has to make sure that at this stage no soft-tissue bridge is present between the two semi-rigid wires, so that easy insertion of the graft can be achieved.

Next, the graft is inserted into the joint through the antero-medial portal, by pulling on the posterior guide wire. This process is facilitated by guidance of the graft with a non-aggressive grasper (Fig. 10.5.5).

When the posterior horn has been pulled a few millimetres into the posterior tunnel, the same process is repeated for the anterior horn, by pulling on the anterior guide wire. (Fig. 10.5.6). At this stage, the correct

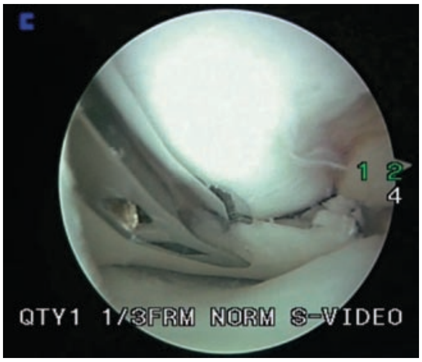

Fig. 10.5.5 Insertion of the meniscal allograft through the antero-medial portal, guided by an arthroscopic grasper (arthroscope through antero-lateral portal)

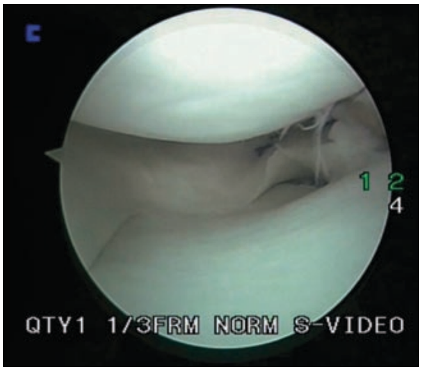

Fig. 10.5.6 Allograft in situ

Fig. 10.5.7 Suturing the allograft to the peripheral rim using meniscal arrows in the posterior part (arthroscope through antero-lateral portal, meniscal suturing device through antero-medial portal)

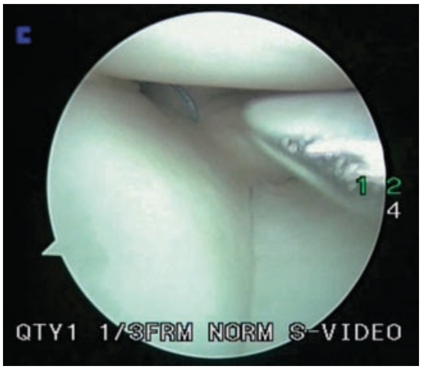

Fig. 10.5.8 Inside–out vertical loop sutures (Ticron 0) for the middle part (arthroscope through antero-medial portal, suturing cannula through antero-lateral portal)

position of the graft is confirmed and the anchoring sutures exiting the tibial tunnels are temporarily clamped, while the graft is sutured to the peripheral rim (Fig. 10.5.7).

A combination of suturing techniques can be used. We prefer to apply meniscal arrows or alternative all-inside suturing devices for the most posterior area, standard inside–out Ticron 0 sutures for the middle horn and inside–out or outside–in Ticron 0 sutures for the anterior horn (Fig. 10.5.8). We believe that peripheral vertical loop sutures, alternating on the upper and under-surface of the graft, provide the strongest fixation (Fig. 10.5.9). Usually six to eight sutures are necessary (Figs. 10.5.10–10.5.12) Suturing can be performed through the medial portal for the posterior meniscal aspect, whereas the middle and anterior horns are most easily sutured through the antero-lateral

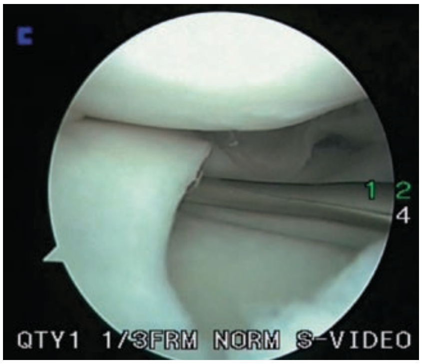

Fig. 10.5.9 Alternating sutures on the upper and lower meniscal surface

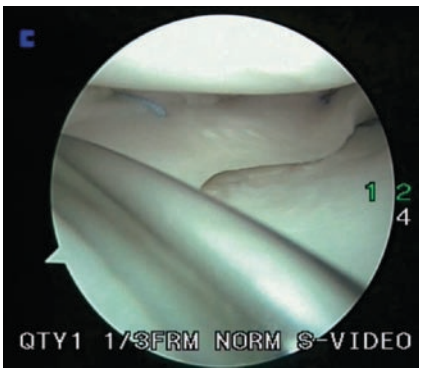

Fig. 10.5.10 Alternating sutures on the upper and lower meniscal surface

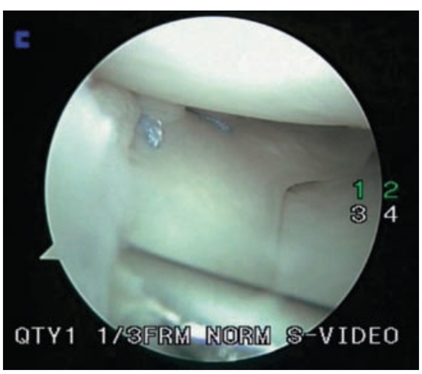

Fig. 10.5.11 Anterior horn sutures (arthroscope through antero-medial portal, suturing cannula through antero-lateral portal)

portal. For the anterior and middle horn, the arthroscope is inserted through the antero-medial portal cranial to the meniscal allograft.

After the sutures have been placed and tied, the arthroscope is extracted and the Ticron 2 sutures exiting the tibial tunnels are tied to each other over the

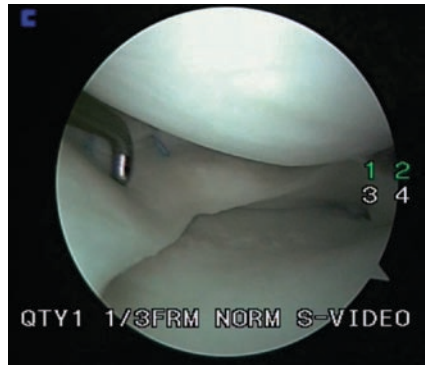

Fig. 10.5.12 Final arthroscopic view before closure, confirming direct approximation of the allograft to the capsule

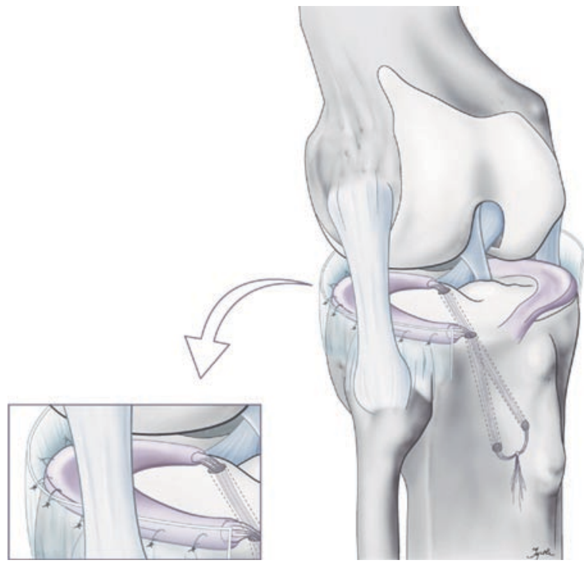

Fig. 10.5.13 General overview of the technique. The anchoring sutures are tied to each other over the bony bridge

bony bridge (Fig. 10.5.13) Subsequently, the portals are closed and a hinge brace is applied for 6 weeks, locked in 20° of flexion.

Postoperatively, the patient is instructed to perform progressive range of motion exercises under supervision of a physiotherapist (0–30° the first 3 weeks, with 30° increments every other 3 weeks), and partial weightbearing is prescribed for 6 weeks.

Lateral Meniscal Transplantation

As for the medial meniscus, any remaining scar tissue or meniscal remnant is removed until a stable and vascularized rim is obtained for peripheral attachment of the allograft. Again, this can be relatively easily achieved with the use of a meniscal shaver, meniscal rasp or meniscal curette. A 2-mm Kirschner wire is used to make puncture holes into the rim in order to create vascular access channels that will facilitate peripheral ingrowth of the graft. In contrast to the medial side, a vascularized rim cannot be achieved over the whole circumference of the meniscus because of the presence of the popliteal tendon. Since it is, however, not the purpose to obtain ingrowth of the transplant into the popliteal tendon area, this is not a problem and the tendon itself can be left untouched.

Once a vascularized and stable tissue rim has been obtained, the bone tunnels for attachment of the anterior and posterior horns are created, again using a standard tibial ACL guide that has been modified for insertion into the narrow tibio-femoral compartment. For this purpose, its aiming tip is removed at the level just distal to the reference mark. The aiming guide is first positioned exactly onto the insertion area of the posterior horn and the wire is drilled. Once the correct position of the wire has been confirmed, it is overdrilled with a 5.5-mm cannulated drill through a 2-cm incision at the antero-medial tibial surface. In theory, this can be performed at the antero-lateral surface also, but the orientation of the tibial antero-lateral cortex makes this much more difficult and impractical.

Next, the same procedure is repeated at the anterior horn, in such a way that a bony bridge of approximately 1–2 cm is created between the anterior and posterior tunnels at the level of the anterior tibial cortex. This is done through the same incision. Care is taken to reproduce the anatomic insertion sites of the anterior and posterior horns by using the footprints or meniscal remnants as a reference.

Although this is not a necessity, all of the above-mentioned steps are usually performed with the arthroscope in the medial portal (healthy compartment), and the instruments inserted through the lateral portal (working compartment).

After both tunnels have been created, a semi-rigid passing wire is inserted through the anterior and the posterior tunnel into the joint, and extracted through the lateral portal. These wires will be used for inserting the meniscus into the joint and their respective anchoring tunnels.

In the meantime, the assisting surgeon prepares the allograft by passing a Ticron 2 suture criss-cross through the posterior and anterior horn extensions. This is usually easy at the anterior horn where the transverse inter-meniscal ligament can be used, but may be more difficult at the posterior horn.

Before inserting the graft, the antero-lateral portal is enlarged until it allows the passage of a fingertip. One has to make sure that at this stage no soft-tissue bridge is present between the two semi-rigid wires, so that easy insertion of the graft can be achieved.

Next, the graft is inserted into the joint through the antero-lateral portal, by pulling on the posterior guide wire. This process is facilitated by guidance of the graft with a non-aggressive grasper.

When the posterior horn has been pulled a few millimetres into the posterior tunnel, the same process is repeated for the anterior horn, by pulling on the anterior guide wire.

At this stage, the correct position of the graft is confirmed and the anchoring sutures exiting the tibial tunnels are temporarily clamped, while the graft is sutured to the peripheral rim.

A combination of suturing techniques can be used. We prefer to apply meniscal arrows or alternative all-inside suturing devices for the most posterior area, standard inside–out Ticron 0 sutures for the middle horn and inside–out or outside–in Ticron 0 sutures for the anterior horn. We believe that peripheral vertical loop sutures, alternating on the upper and under-surface of the graft, provide the strongest fixation. Usually six to eight sutures are necessary. Suturing can be performed through the antero-lateral portal for the posterior meniscal aspect, whereas the middle and anterior horns are most easily sutured through the antero-medial portal. We usually do not suture the graft onto the popliteal tendon, and thus, leave the meniscopopliteal space open. The only exception to this is when posterior horn fixation is doubtful in quality. If so, a safety stitch or arrow is inserted through the allograft and the popliteal tendon, which usually provides solid peripheral anchorage of the graft. It is obvious that due to the lateral femorotibial kinematics, this suture may sooner or later fail during follow-up, with restoration of the normal meniscopopliteal recessus, but by that time hopefully the meniscus would grow into the capsule medial and lateral to the popliteal tendon (Figs. 10.5.14 and 10.5.15).

For the anterior and middle horn sutures, the arthroscope is inserted through the antero-lateral portal cranial to the meniscal allograft, and the suturing device is entered through the antero-medial portal.

After the sutures have been placed and tied, the arthroscope is extracted and the Ticron 2 sutures exiting

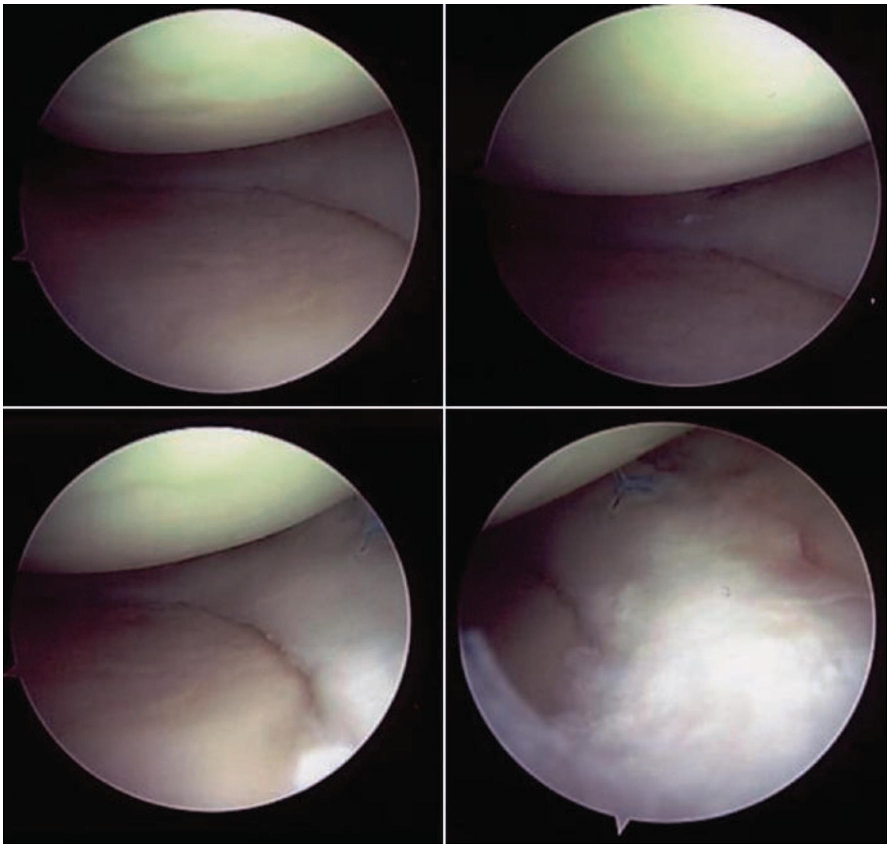

Fig. 10.5.14 Second look after 2 years on the occasion of plate and screw removal for an old fracture. Allograft in perfect macroscopic condition

the tibial tunnels are tied to each other over the bony bridge. Subsequently, the portals are closed and a hinge brace is applied for 6 weeks, locked in 20° of flexion.

The postoperative rehabilitation protocol is identical to that for medial meniscal transplantations. The patient is instructed to perform progressive range of motion exercises under supervision of a physiotherapist (0–30° the first 3 weeks, with 30° increments every other 3 weeks), and partial weightbearing is prescribed for 6 weeks.

Technical Pitfalls and Tips

Although meniscal transplantation can be performed using standard arthroscopic instruments and techniques, it is definitely one of the more challenging arthroscopic procedures in the knee. The major reasons for this are the narrow working space, the time constraints (tourniquet time) and the need for assisting staff that is familiar with the procedure and the working plan.

Therefore, it is wise to schedule enough OR time and to ensure that the assisting medical and nursing staff are competent and that all arthroscopic and suturing equipment is available and functioning. It is also wise to defrost and inspect the graft prior to incising, in order to confirm its correctness in side (medial–lateral and left–right).

Despite these measures, several pitfalls can still occur (and have happened to us), some of which are listed below.

Sub-Optimal Graft Size

Sub-optimal graft size is not unusual, despite the fact that we use calibrated CT-scans of the proximal tibial plateau as a reference for sizing. Too large a meniscal graft is not a problem and makes arthroscopic transplantation even easier. It suffices to pull the anterior and posterior horns slightly deeper into the corresponding tibial and femoral tunnels.

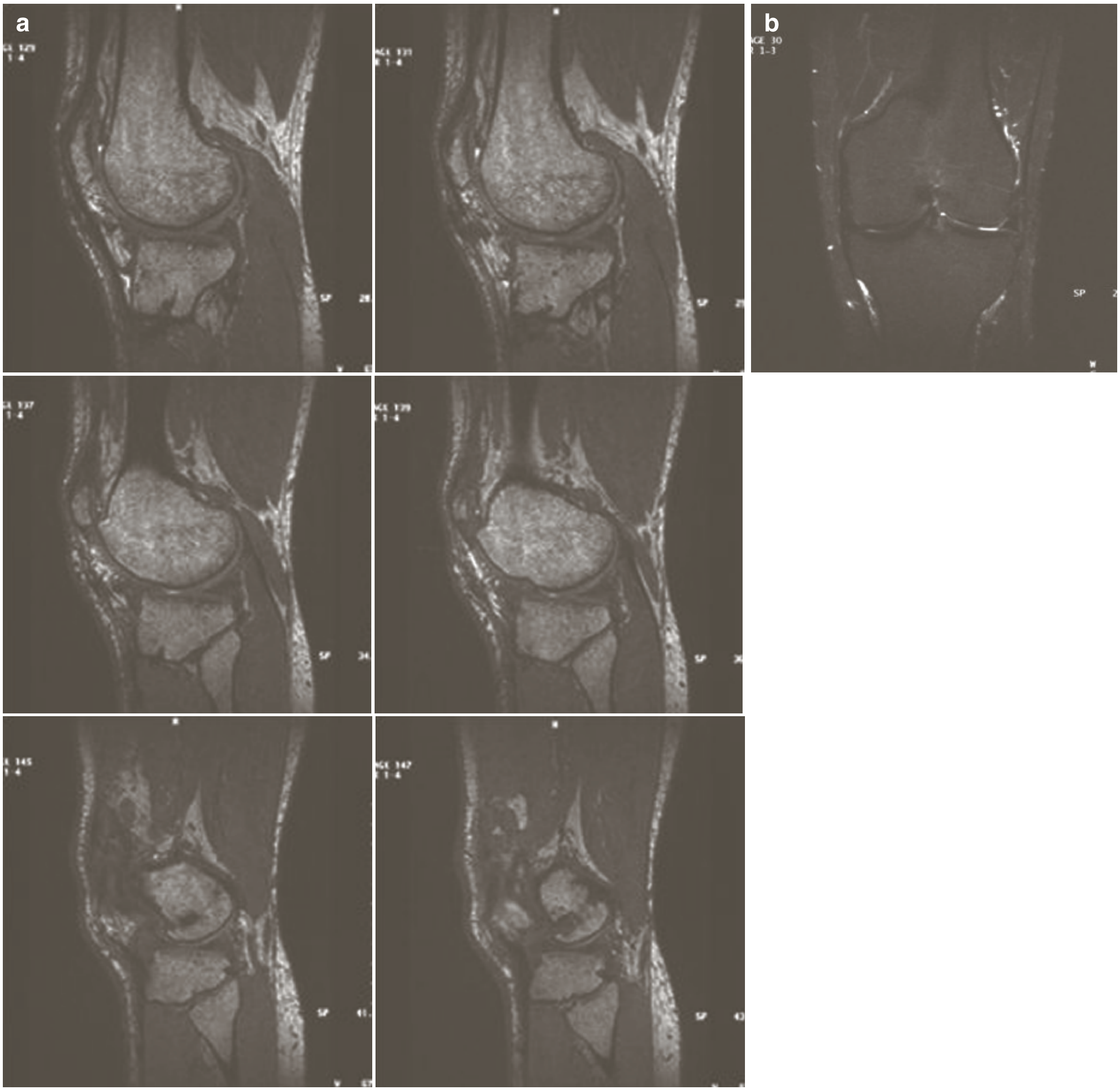

Fig. 10.5.15 (**a**, **b**) MRI scan of a patient 3 years after lateral meniscus transplantation. Perfect appearance of graft, with full peripheral ingrowth

An undersized graft, however, is much more of a problem. The graft may even not be long enough to span the distance between the two tunnels. If this is the case, we attach the posterior horn in the usual way (a few millimetres into the posterior tibial tunnel), but leave the anterior horn outside its tunnel.

Although we have been faced with this situation in three patients, none of them experienced a problem with it. To some extent, this issue can be prevented by leaving the anterior inter-meniscal ligament attached to the allograft during preparation, and using it to gain a few millimetres of total meniscal length (up to 5–10 mm is frequently possible).

Wrong-Sided Graft

Delivery of a wrong-sided graft is less uncommon than may be expected. The reason is that graft-retrieval teams are usually general orthopaedic surgeons (sometimes in training) who are not always intimately familiar with meniscal anatomy. Meniscal grafts are retrieved, kept on a sterile table, and labelled. The difference between a left or right (or upside down) medial or lateral meniscus is in these situations not always very clear. Therefore, the left and right medial and lateral meniscal allografts should immediately be labelled and stored separately after retrieval.

When faced with this problem during surgery, we have fortunately been able to use a (correct-sided) back-up allograft, but one could probably consider flipping the wrong-sided meniscus if this had not been the case.

Too Tight a Working Space

Insertion of the graft through the portal is one of the more difficult steps during the procedure, mainly because of the narrow tibio-femoral working space. It is, thus, imperative that sufficient varus or valgus stress be applied to the joint. We therefore believe that positioning of the knee in a solid arthroscopic knee holder is very important.

If tightness persists during the procedure (usually some stretching occurs after 15–20 min), a percutaneous release of the soft tissues using an aspiration needle or micro-knife can be performed, and may greatly facilitate the rest of the procedure. The standard rehabilitation protocol suffices to ensure healing of such a release.

Posterior Graft Retraction

Posterior retraction of the graft while the posterior horn is being sutured onto the posterior capsule can occur, especially when self-locking suturing devices are used. Tightening the knot of these devices can indeed induce posterior displacement of the graft onto the (relaxed) posterior capsule, since the knee is usually held in some flexion during this manoeuvre.

This may even lead to disengagement of the anterior horn insertion out of the anterior tunnel, which subsequently can no longer be pulled back into the tunnel. Also, approximating and suturing the middle and anterior horns onto the capsular rim may become difficult due to the posterior migration of the graft secondary to the over-tightened posterior sutures. The surgeon should therefore bear this potential complication in mind while suturing the posterior horn, and avoid over-tightening.

Results

We recently reviewed 51 cases in which we used meniscal allografts without bone blocks. Our operating time was on average 1 h and 25 min, which was significantly less than that with our initial technique using bone plugs (2 h and 55 min) ($p<0.001$). Additionally, we encountered not one single technical difficulty during insertion.

Important pain relief (VAS score less than 2) was achieved in 48 cases at an average follow-up of 3.5 years. The average Lysholm score improved from 55 pre-operatively to 85 postoperatively ($p<0.001$), and the average Tegner activity level improved from 3 to 5 ($p<0.001$). Full range of motion was obtained in all cases. Forty-eight cases would have the same procedure again, one was not sure, and two were dissatisfied. One of those was revised to a total knee arthroplasty. In two cases a second-look procedure was performed: in the first case during meniscal transplantation on the contra-lateral side 1 year after the initial transplantation, and in the second case 2 years postoperatively on the occasion of a plate and screw removal. In both cases, an intact and macroscopically normal meniscal transplant was noted.

When comparing these 51 cases with our first patient group, which had been treated using allografts with attached bone plugs, we found no difference in clinical outcome ($p>0.1$), but the operating time, number of technical difficulties and complication rate were significantly lower without bone plugs ($p<0.001$).

Conclusion

Based upon these data, we believe that arthroscopic meniscal allograft transplantation without bone plugs is an easier and much more straightforward procedure compared to the same procedure with bone plugs attached. The theoretical concern that hoop stress protection may not be adequately restored is not reflected in our outcome data. We therefore feel that soft-tissue fixation of the allograft into the corresponding tunnels is as effective as when bone plugs are used.

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Arthroscopic Technique with Bone Plugs

10.6

P. Boisrenoult and N. Pujol

Introduction

Meniscal allograft transplantation has become an accepted treatment option for symptomatic meniscus-deficient patients without advanced osteoarthritis. However, it is also a controversial procedure. While some experimental studies do not support the hypothesis that meniscal allograft transplantation provides chondroprotection [3], long-term clinical studies have shown a significant improvement in pain and function with 90% of good subjective results [11]. Whether bone-to-bone fixation or soft-tissue fixation should be used remains a more controversial technical issue. Biomechanical evidence seems to support the bone-to-bone technique, but some authors did not find any difference [4]. Technical procedures using bone-to-bone fixation can be classified into two groups. The first one is the technically demanding bone-block technique, which allows to preserve the meniscal shape. The second one is the bone-plug technique, which is easier to perform.

Allograft Sizing and Selection

Correct graft selection is the first crucial step in order to maximize the graft's chondroprotective capacity [12]. A mismatch of less than 10% of the size compared with the native meniscus is acceptable [2]. For Wilcox et al. [13], the graft should be within 5% of the original meniscus. A small size mismatch is easier to manage than a large size mismatch requiring meniscal reduction [5]. The gold standard of pre-operative graft sizing remains the method of Pollard et al. using plain radiographs [8, 10]. This technique requires an antero-posterior (AP) and a lateral X-ray with calibrated views (magnification: 100%). On the AP radiograph, the width of the meniscus is measured from the medial or lateral metaphyseal margin to the peak of the respective tibial eminence. On the lateral radiograph, the sagittal length of the tibial plateau is measured between the tibial anterior and posterior margins. The length of the lateral meniscus is calculated as 70% of the tibial length and the length of the medial meniscus as 80%.

Techniques

Native Meniscus Preparation

Whatever the surgical technique, during this first step, it is very important not to completely remove the remnant meniscal rim, but to simply sharpen it.

Arthroscopically Assisted or Open Technique?

These two techniques provide similar outcomes [9]. The main advantage of the open technique is that it allows more secure peripheral suturing but requires a collateral ligament release. The arthroscopically assisted technique reduces surgical morbidity, avoiding collateral ligament release and allowing earlier rehabilitation.

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.6,

Meniscal Allograft Using Bone Block

This technique is also known as the “bridge in slot” technique, described by Cole et al. [1] and Noyes et al. [7], or the “keyhole” technique described by Nissen [6]. The difference between these two techniques is a variation of the shape of the bone block and recipient slot.

Principles

The goal is to perform meniscal allografting with a graft that preserves the relationship between the anterior and posterior meniscal horns. It is especially indicated for lateral meniscus transplantation. The main advantage is that it allows anatomical placement of the meniscal allograft if there is no size mismatch. Disadvantages are the impossibility to adjust a size mismatch and the need for a specific device to create the bone slot and to calibrate the bone block.

Technique

An 8-mm wide bone bridge incorporating the bony insertion of the meniscal allograft horns is created using an oscillating saw. Transverse cuts are made parallel to a line 1 cm below the anterior and posterior horns. The graft is calibrated using a rectangular sizing block (Stryker Endoscopy, Kalamazoo, MI and Cryolife Kennesaw, GA). The bone block usually measures 35 mm in length, 8 mm in width and 10 mm in depth. A traction suture is then placed at the junction of the middle and posterior horns. After arthroscopic preparation of the meniscal rim, a postero-lateral open exposure is performed, just behind the lateral collateral ligament. After dividing the interval between the biceps tendon and the ilio-tibial band, a retractor is placed through this incision anterior to the gastrocnemius tendon to avoid injury to neurovascular structures from the popliteal fossa. The joint capsule is not opened. The location of the meniscal slot is identified using an 18-gauge needle. It should line up with the anterior and posterior horns of the meniscus. A vertical 3-cm antero-lateral arthrotomy is performed just adjacent to the patellar tendon for meniscal graft insertion.

The direction of the tibial slot between the anterior and posterior horns is marked using a burr to develop a superficial path, 2–3 mm deep. A drill guide arm is placed into this shallow tunnel and a guide pin is drilled, which should not exceed the posterior tibial cortex. The final slot, measuring 8 mm in width and 10 mm in depth, is created successively using an 8-mm cannulated drill and an 8-mm box-cutting guide, which is then advanced through the sub-chondral circular hole to transform this hole into an intra-articular slot. Final slot contouring is done using a rectangular hand rasp. The keyhole technique necessitates the use of a specific cutting block jig for tibial preparation and a specific key hole jig and circular saw to prepare the graft (Arthrex Inc., Naples, FL). A loop is now passed using a flexible needle toward the posterior corner of the knee and retrieved from within the para-patellar incision. The traction suture is placed in the loop-end and pulled out from the knee through the postero-lateral incision. The knee is flexed in a Cabot’s position to open the lateral joint space. The meniscus is then pulled into the joint and the bone block is carefully seated in the tibial slot (Fig. 10.6.1). The knee is flexed and extended to seat the meniscus anatomically relative to the tibia and femur. The block is fixed by 7 × 20 mm cortical interference screws. Peripheral meniscal suture

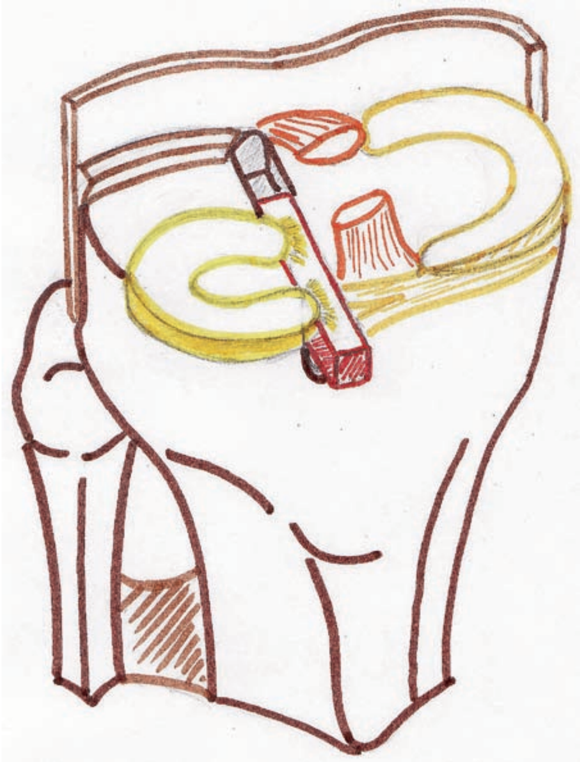

Fig. 10.6.1 Bone bridge technique: details of graft insertion and tibial bone slot (drawing)

is performed with eight to ten vertical 2–0 Ethibond mattress sutures (Ethicon Inc., Somervill, NJ). Stitches are first placed superiorly to reduce the meniscus and then inferiorly in the outer one-third of the allograft. The surgical exposures are closed.

Medial Meniscal Transplantation

This procedure is less frequently performed. The bone-block technique is not easy to use in the medial compartment. For further details, readers are referred to the paper of Noyes et al. [7].

Meniscal Allograft Using Bone Plugs

We present an all-arthroscopic technique described by the French Meniscal Allograft Group.

Principles

Each meniscal allograft horn with a bone plug is placed into a blind tibial bone tunnel in an anatomical position. The bone plugs are secured in the tunnels and the peripheral rim of the allograft is then sutured. Concomitant anterior cruciate ligament (ACL) reconstruction does not interfere with bone plugs. This technique can be used on both the lateral and medial side.

Lateral Meniscal Transplantation: Allograft Preparation

The meniscus is separated from the capsule at the peripheral rim. Anterior and posterior horn footprints are accurately marked. A centring wire is placed in each meniscal horn and in adjacent tibial plateau bone. A 9-mm cannulated coring reamer is placed around the centring wire and creates a bone plug capturing the meniscal horn. Bone plugs are 9 mm in diameter and 7–10 mm in length. A traction suture (FiberWire, Arthrex, Inc.) is successively passed through the centring hole, the meniscal horn and again the centring hole. This allows a solid and axial fixation of each meniscal horn (Fig. 10.6.2). A vertical traction suture (PDS no. 0) is passed just beneath the popliteal hiatus. Reference marks are made with

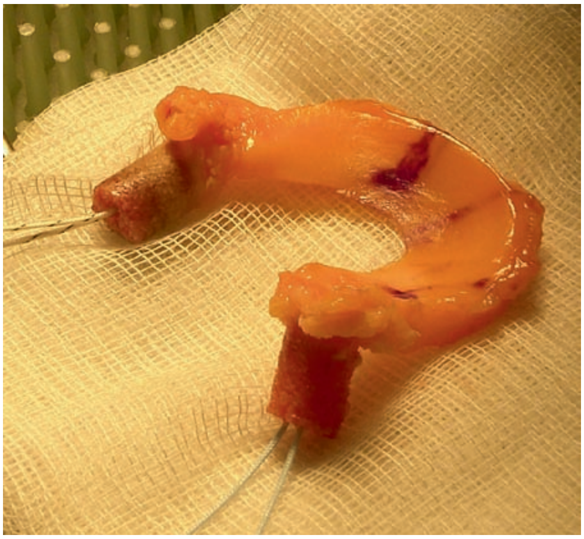

Fig. 10.6.2 All-arthroscopic technique: meniscal horn preparation

methylene blue to identify the posterior segment and popliteal hiatus.

Surgical Exposure and Portals

The patient is placed in a supine position with a tourniquet applied. Arthroscopy is performed using standard medial and lateral para-patellar portals. The meniscal rim is prepared, but not completely removed. The anterior and posterior horns of the native meniscus are accurately located.

Tibial Plateau Preparation (Fig. 10.6.3)

The knee is positioned in Cabot's position with varus stress to open the lateral compartment. A standard ACL tibial guide, introduced through the medial portal, determines the location of each tunnel. The posterior tunnel is created with the guide set at 45° with an anterior–posterior orientation. A guide pin is positioned into the middle of the posterior horn attachment. A 6-mm reamer is then drilled over the guide pin and replaced by a 10-mm TLS drill (Fournitures Hospitalières Inc., Heimbrum, France), which allows 15-mm long blind tunnel digging. The same steps are repeated to create the anterior tunnel, this time with the guide set at 60° with a medial to lateral orientation. The use of blind bone tunnels with a

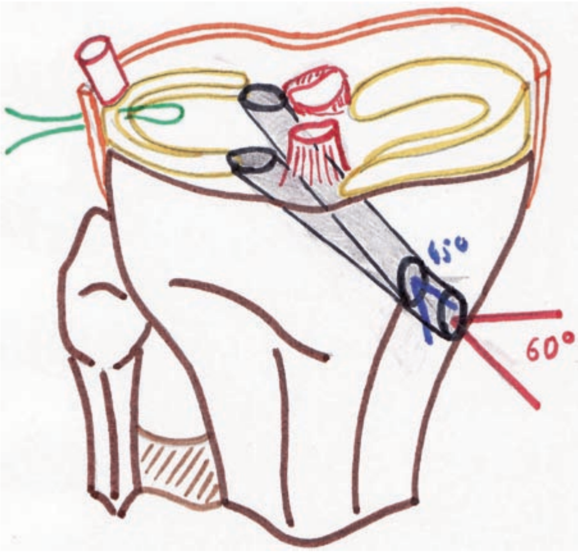

Fig. 10.6.3 All-arthroscopic technique: tibial plateau preparation for lateral transplantation

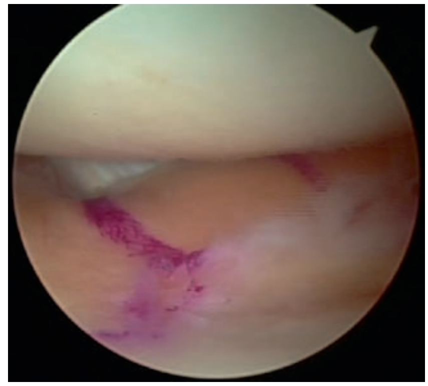

Fig. 10.6.4 All-arthroscopic technique: allograft in place (right knee)

perpendicular orientation prevents bone tunnel collapse during graft insertion.

Graft Introduction

A shaver is used to remove meniscal and cartilage debris from the entrance of the tunnels. A metallic loop is passed through each tunnel and a PDS no. 0 suture is passed just in front of the popliteal tendon. The antero-lateral arthroscopic portal is extended in a 1.5-cm arthrotomy. The posterior horn of the graft is first introduced into the knee. Under arthroscopic visualization, the posterior bone block is carefully introduced into the posterior tibial tunnel, with the aid of a probe. The second step is to introduce the middle segment of the meniscus using the traction suture passed into the popliteal loop; this allows to "automatically" place the mid-portion in a proper position. The anterior portion of the meniscus and the anterior bone plug are finally introduced into the knee joint.

Peripheral Suture (Fig. 10.6.4)

Peripheral suturing is done before bone plug fixation. The first stitch is placed just behind the popliteal tendon using a FasT-Fix device (Smith and Nephew Inc., Andover). The FasT-Fix deep penetration limiter is cut at 18 mm. The suture progresses from the popliteal tendon to the posterior meniscal horn. Usually, three stitches are positioned on this segment. Two other FasT-Fix stitches fix the mid-portion of the meniscus. The anterior segment is usually not sutured to avoid meniscus misplacement. After having completed peripheral meniscus suturing, traction sutures on each bone plug are tightened and secured with 8-mm bio-buttons (Arthrex, Inc.) on the tibial cortex. The skin is closed with absorbable sutures, without suction drain.

Association with ACL Reconstruction

The femoral and tibial cruciate tunnels are drilled first and the ACL graft is passed through these tunnels. Femoral ACL graft fixation is performed first, followed by meniscal transplantation and finally tibial fixation. This sequential procedure allows maximum tibio-femoral opening during meniscal transplantation and avoids ligament graft or ligament fixation failure

Medial Meniscal Transplantation

The meniscal allograft horns are prepared following the same procedure. However, one vertical traction suture (PDS no. 0) is passed at the junction between the anterior and middle segment and another one at the junction between the middle and posterior segment (Fig. 10.6.5). Three portals are required, including a medial and lateral para-patellar portal and a postero-medial portal. The posterior tunnel is placed under

Fig. 10.6.5 All-arthroscopic technique. (**a**) Lateral meniscal allograft preparation: right knee. (**b**) Medial meniscal allograft preparation: right knee

postero-medial arthroscopic visualization, using the ACL tibial guide set at 45° with an anterior–posterior orientation. The anterior tunnel is placed using the ACL tibial guide set at 60° with a medio-lateral orientation. Graft insertion and peripheral suturing are done in a similar fashion, except that two outside-in anterior stitches should be used to secure the anterior meniscal segment.

Rehabilitation

The effect of loading on the meniscal allograft remains unclear. There is no consensus on the rehabilitation programme. We prescribe non-weightbearing for 4 weeks, with the knee locked in extension in a knee brace. Mobilization of the knee through the first 60° of flexion is instituted for 4 weeks. After 4 weeks, full weight bearing is allowed with no limitation of flexion. Running is allowed after 3 months and non-competitive sports after 6 months.

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Results and Indications

10.7

P. Verdonk, M. Van Laer, M. ELAttar, K. F. Almqvist, and R. Verdonk

Indications and Contraindications

Indications

According to current recommendations, meniscal allograft transplantation is indicated in three specific clinical settings:

1. Young patients with a history of meniscectomy who have pain localized to the meniscus-deficient compartment, a stable knee joint, no malalignment and articular cartilage with only minor evidence of osteochondral degenerative changes (no more than grade 3 according to the International Cartilage Repair Society (ICRS) classification system (Table 10.7.1)) are considered ideal candidates for this procedure. Some studies [1–6] have shown that meniscal allografts can survive in an osteoarthritic joint (Outerbridge grade 3–4), with significant improvement in pain and function. Because of the more rapid deterioration in the lateral compartment [7], a relatively common indication for meniscal transplantation would be a symptomatic, meniscus-deficient, lateral compartment.
2. Anterior cruciate ligament (ACL)-deficient patients who have had previous medial meniscectomy with concomitant ACL reconstruction and who might benefit from the increased stability afforded by a functional medial meniscus. It is the authors' conviction that an ACL graft is significantly protected by the meniscus allograft as much as the meniscus is protected by an ACL graft.
3. In an effort to avert early joint degeneration, some also consider young, athletic patients who have had total meniscectomy as candidates for meniscal transplantation prior to symptom onset [8]. *However, the results obtained so far still preclude a return to high-impact sports*.

Contraindications

Advanced chondral degeneration is considered a contraindication to meniscal allograft transplantation, although some studies suggest that cartilage degeneration is not a significant risk factor for failure [9]. In general, greater than grade 3 articular cartilage lesions, according to the ICRS classification system, should be of limited surface area and localized. Localized chondral defects may be treated concomitantly, as meniscus transplantation and cartilage repair or restoration may benefit each other in terms of healing and outcome [10]. Chondrocyte transplantation or osteochondral

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_10.7, © Springer-Verlag Berlin Heidelberg 2010

Table 10.7.1 International Cartilage Repair Society cartilage lesion evaluation system

Grade 0	Normal
Grade 1	Superficial lesions, softening, fissures or cracks
Grade 2	Lesions, erosion or ulceration of less than 50%
Grade 3	Partial-thickness defect of more than 50%, but less than 100%
Grade 4	Ulceration and bone exposure

grafting procedures should be performed after completion of the meniscal transplantation in order to prevent accidental damage to the patch or graft during meniscal allograft insertion [11]. Radiographic evidence of significant osteophyte formation or femoral condyle flattening is associated with inferior postoperative results because these structural modifications alter the morphology of the femoral condyle [12]. Generally, patients over age 50 have excessive cartilage lesions and are suboptimal candidates.

Axial malalignment tends to exert abnormal pressure on the allograft leading to loosening, degeneration and failure of the graft [12]. A corrective osteotomy should be considered in patients with more than two degrees of deviation toward the involved compartment, as compared with the mechanical axis of the contralateral limb. Varus or valgus deformity may be managed with either staged or concomitant high tibial or distal femoral osteotomy [11]. However, as in any situation in which procedures are combined, it is unclear which aspect of the procedure is implicated in symptom resolution, such as relief of pain [12].

Other contraindications to meniscal transplantation are obesity, skeletal immaturity, instability of the knee joint (which may be addressed in conjunction with transplantation), synovial disease, inflammatory arthritis and previous joint infection and obvious squaring of the femoral condyle.

Results

It is difficult to perform a meta-analysis of all the published results, because of the small populations studied and the differences (Table 10.7.2) in indications, contraindications, preservation techniques, preoperative Outerbridge grade, fixation techniques, surgical techniques, concomitant procedures, evaluation tools, and rehabilitation protocols.

In this chapter, we will try to present outcome data based on a review of the literature. A total of 39 studies have been included, representing 1,226 meniscus allografts (626 medial vs. 446 lateral, 154 not specified) in 1,145 patients. The mean age at the time of surgery was 34.4 years. The mean follow-up was 5.5 years. Overall, 340 isolated allograft transplantations were analysed, 427 were associated with ACL reconstruction, 107 with a corrective osteotomy and 215 with other procedures. It was not specified whether the remaining 137 allografts were associated with other procedures. Concerning the surgical fixation technique, 631 allografts were fixed using bone blocks and 488 using a soft-tissue fixation technique. For 107 allografts, the fixation method was not specified. In the next paragraphs, the outcome is reported independently of the aforementioned parameters.

Methods to evaluate the success or failure of meniscal transplantation range from subjective pain scale measurements and patient perceptions of function to objective measurements such as physical and radiological examinations, magnetic resonance imaging (MRI) and second-look arthroscopy.

Subjective Assessment

All studies showed significant subjective improvement in pain scales and functional activity questionnaires. The data from most studies are summarized in Table 10.7.3. In general, isolated procedures and combined procedures tended to have similar outcomes. No differences were observed based on tissue preservation technique or fixation method. About 75–90% of patients experienced fair to excellent results.

Objective Clinical Scoring

Physical Examination

Almost all studies reported equal or improved physical examination findings at follow-up with regard to range of motion, pain, effusion, stability, function tests or IKDC score. The data from most studies are summarized in Table 10.7.4.

Radiological Examination (Table 10.7.5)

Joint space narrowing indicating cartilage degeneration was observed in a number of patients and tended to

Table 10.7.2 Publications on meniscus allografts

Author	Year s	No. of grafts	M	L	No. of patients	Age	Time M-TX	Preservation	Rad?	Fix	FUT	Preop cart	No. iso-lated	Concomitant procedures
Cameron and Saha [1]	1988–1994	67	37	30	63	41	16.7	DF	Yes	S	2.5	2–4	21	5ACL, 34OT, 7ACL+OT
Carter [20]	NA	46	39	7	46	NA	NA	Cryo.	NA	B	2.8	NA	NA	30ACL, 4OT, 1MCL
Garrett [15]	NA	43	34	8	43	NA	NA	16 DF, 27 Cryo.	NA	B	4.5	NA	7	24ACL, 13OT, 11OAL
Goble et al. [21]	NA	69	48	21	60	NA	NA	Cryo.	NA	B	2	NA	NA	28ACL
Groff et al. [22]	1993–1998	16	0	16	16	27	8	DF	No	B	3.8	1–2	16	None
Wirth et al. [23]	1984–1986	22	22	0	22	29.6	NA	6DF, 16Lyo.	6No, 16Yes	S	3/14	1.6	0	22ACL, 19MCL
Noyes et al. [2, 24]	NA	96	79	17	83	NA	NA	DF	Yes	B	<2	NA	19	77ACL
	1995–2000	40	20	20	38	30	NA	Cryo.	No	B	3.3	3.6	NA	7ACL, 1PCL, 1ACL+PCL, 1MCL, 16 OAU
Rath et al. [25]	1991–1997	22	15	7	18	30	7.7	Cryo.+DF	No	1S, 21B	4.5	NA	3	11ACL, 1TTT
Stollsteimer et al. [17]	1991–1995	23	11	12	22	31	3.8	Cryo.	No	B	3.3	COB: 5.6	23	None
Van Arkel et al. [26, 27]	1994–1995	19	6	13	16	40	16	Cryo.	No	NA	2.7	NA	NA	NA
	1989–1999	63	23	40	57	39	16	Cryo.	No	S	5	NA	61	2ACL
Verdonk et al. [3, 18, 28]	NA	27	0	27	27	33.9	NA	V	No	S	1	NA	NA	NA
	1989–2001	100	39	61	96	35	NA	V	No	S	7.2	2.5	69	3ACL, 17OT, 3Mi, 4OPT
	1989–1993	39	NA	NA	38	35.4	NA	V	No	S	12.1	2.7	NA	3ACL, 12OT
Shelton and Dukes [29]	NA	14	5	9	14	NA	NA	Cryo.	NA	B	NA	NA	NA	NA
Veltri et al. [30]	NA	16	8	8	14	35.3	11.3	DF+Cryo.	No	B	0.7	NA	4	10ACL, 1PCL, 1ACL+PCL
Cole et al. [31]	1997–2003	40	25	15	36	31	NA	32 DF+8 Cryo.	No	B	2.8	<4	21	ACL, 1OT, 3OAL, 3OAU, 1ACI, 2Mi, 2 ODfix
Rodeo et al. [32]	1989–1995	33	17	16	28	34	NA	DF	No	20B, 13S	1.3	NA	8	19ACL, 1OT
Del Pizzo [55] unpublished data	1991–1994	19	NA	NA	19	NA	NA	19 Cryo.	NA	NA	3.2	NA	6	11ACL, 2OT

(continued)

Table 10.7.2 (continued)

Author	Year s	No. of grafts	M	L	No. of patients	Age	Time M-TX	Preservation	Rad?	Fix	FUT	Preop cart	No. iso-lated	Concomitant procedures
Yoldas et al. [33]	1993–1996	34	NA	NA	31	28	8	DF	No	B	2.9	NA	11	20ACL
Ryu et al. [4]	1993–1999	26	10	16	25	34.5	NA	NA	NA	B	2.75	2.8	12	14ACL
Hommen et al. [34]	1991–1995	20	12	8	20	32	NA	20 Cryo.	No	13S, 7B	11.7	2.2	5	10ACL, 2OT, 3CHFC, 2CP, 3LR
Cryolife [35]	1989–1994	1,023	747	276	1,015	NA	NA	Cryo.	NA	930B, 92S	7	NA	NA	NA
Felix and Paulos [36]	1993–1999	36	20	16	33	28.5	6	Cryo.	No	B	5.2	NA	9	18ACL, 2OT, 4ACL+OT
Vacquero et al. (2003)	2001–2002	32	NA	NA	30	37	NA	DF	No	B	>1	2.3	NA	6ACL, 3Mi, 7RFA, 1TTT
Sekiya et al. [37, 38]	1994–1998	31	24	7	28	35	8.6	Cryo.	No	B	2.8	1–4	0	28ACL, 2ACL+OT
	1993–1998	25	0	25	25	30	5.7	Cryo.	No	8S, 17B	3.3	1–4	25	None
Potter et al.[13]	1989–1996	29	14	15	24	33.2	NA	DF	NA	B	NA	2–4	11	16ACL, 1OT, 1MCL
Stone et al. [5]	1997–1999	47	37	10	45	48	NA	18 DF, 29 Cryo.	No	S	5.8	3.8	7	6ACL, 17OT, 19Mi, 47CHFC, 24ACPG
Fukushima et al. [39]	1996–1997	43	30	13	40	37.3	11.4	Cryo.	No	S	1	NA	NA	8ACL, 1OT
Rankin et al. [40]	NA	8	5	3	7	31	NA	Cryo.	No	B	2	2.9	2	4ACL, 4OAU
Bhosale et al. [6]	NA	8	2	6	8	43	14	Cryo.	No	S	3.2	3.8	0	8ACI
Graf et al. [41]	1990–1992	8	8	0	8	32.6	10.5	Cryo.	1No, 7Yes	7S, 1B	9.7	NA	0	8ACL, 1OT, 8ACL+OT
Rueff et al. [42]	NA	8	8	0	8	52	NA	Cryo.	No	B	5.5	NA	0	8ACL
von Lewinski et al. [43]	1984–1986	6	6	0	6	25	NA	DF	No	S	20	2.6	0	6ACL
Milachowski et al. [44]	NA	22	22	0	22	NA	NA	NA	NA	NA	1.2	NA	0	22 ACL
Barrett [45]	NA	15	NA	NA	15	NA	NA	Cryo.	NA	NA	5	NA	NA	NA
Dienst and Kohn [46]										S	3–7			
Kim and Bin [47]	1996–2003	14	NA	NA	14	NA	NA				4.8			

Year S Years of surgery; *M* number of medial grafts; *L* number of lateral grafts; *Time M-TX* average time in years from meniscectomy to transplantation; *Age* average age of patients at time of transplantation in years; *Rad*? radiation of graft?; *Preop. cart.* preoperative cartilage Outerbridge grade; *Fix* fixation technique used to fix the allograft; *B* bony fixation; *S* only sutures; *FUT* average time of follow-up in years; *No. isolated* number of transplantations, without concomitant procedures; *OT* osteotomy; *OAL* osteochondral allograft; *OAU* osteochondral autograft; *ACL* anterior cruciate ligament reconstruction; *PCL* posterior cruciate ligament reconstruction; *MCL* medial collateral ligament reconstruction; *NA* not available; *DF* deep-frozen; *Cryo.* cryopreserved; *Lyo.* lyophilized; *V* viable; *TTT* tuberositas tibiae transfer; *COB* cumulative Outerbridge score: calculated by adding the scores for all areas of each knee; *Mi* microfracture; *OPT* osteochondral plug transfer; *ACI* autologous chondrocyte implantation; *ODfix* osteochondritis dissecans fixation; *CHFC* chondroplasty femoral condyle; *CP* capsular plication; *LR* lateral retinaculum release; *RFA* radiofrequent ablation; *ACPG* articular cartilage post-grafting

Table 10.7.3 Summary of subjective assessment

Authors	Subjective scoring
Cameron and Saha [1]	87% good to excellent rate (85% after 3 years) Fulkerson (=modified Lysholm) functional knee score, Tegner score, reduction in need of anti-inflammatory medication: SI
Carter [20]	IKDC: SI
Goble et al. [21]	Quality of life (regarding pain at rest, during recreational activity and functional stability): SI
Groff et al. [22]	Lysholm score: 91% fair to excellent ratio IKDC: 91% nearly normal to normal All (100%) were improved, 100% satisfaction with the condition of their knee as a result of the surgery SF-36: 6 of 8 categories higher scoring than age and sex-matched population KOS at FUT: ADLS: 79.3 SAS: 74.5 41% had pain with light sports activities
Wirth et al. [23]	Lysholm, Tegner (at 3 years/14 years FUT): SI (deep-frozen better than lyophilized, both deteriorated after 14 years) (influenced by preoperative cartilage condition and instability)
Noyes et al. [24]	Perception of knee condition: 73% good to normal. 89% improvement of knee function 76% participation in light low-impact sports Cincinnati score: SI
Heckmann et al. [48]	94% improvement of knee condition 77% participation in light low-impact sports
Rath et al. [25]	SF-36 for bodily pain, role physical, physical functioning and social functioning: SI Mean IKDC functional score: 54
Stollsteimer et al. [17]	Improvement of preoperative pain in 82%. Tegner score, IKDC score, Lysholm: SI Articular cartilage changes preoperatively and preoperatively higher IKDC score had significant effect on overall patient outcome score
Van Arkel et al. [26, 27]	KASS: 84% successful result Modified Lysholm: 84% fair to excellent Tegner: SI 77% success Lysholm: SI 91% improvement of pain
Verdonk et al. [3, 18]	Pain relief and improved function at 10 years in 70% 90% were satisfied with the operation and would do it again
Cole et al. [31]	75 % completely/mostly satisfied with procedure: 68% medial, 93% lateral, 81% isolated, 74% "combined with other procedure" subgroup Lysholm, Tegner, Noyes, IKDC, KOOS pain, symptom, ADL and sports, SF-12 PCS score, VAS pain and overall knee condition: SI 86% would have surgery again: 84% medial subgroup, 93% lateral subgroup, 86% isolated and 84% in combined subgroup
Rodeo et al. [32, 49]	88% of bone plugs + 47% soft-tissue fixated transplantations were rated as good or moderate Lysholm, IKDC, VAS: pain + function: SI 58% clinically successful
Del Pizzo [55] unpublished data	89% were satisfied with procedure 95% could perform occasional strenuous activities; none continuous They all returned to their previous activity level Pain was improved in all patients
Yoldas et al. [33]	97% somewhat to greatly improved IKDC: 97% nearly normal to normal Lysholm: 68% good to excellent ratio SF-36: in 7 of 8 categories better than age- and sex-matched population
Ryu et al. [4]	IKDC activity: 68% nearly normal to normal. VAS, Lysholm II, Tegner score: SI Outerbridge grade had significant impact on outcome. 83% overall satisfaction
Hommen et al. [34]	Lysholm, Pain, IKDC, Tegner, SF-12 score: SI. 80% had improvement

(continued)

Table 10.7.3 (continued)

Authors	Subjective scoring
L'Insalata et al. [50]	88% improvement
Miller and Harner [51]	100% improvement
Felix and Paulos [36]	VAS function: SI
Vaquero et al. [52]	VAS pain: SI IKDC: 77% nearly normal to normal
Sekiya et al. [37, 38]	96% had improvement of overall function and activity level SF-36: PCS and MCS: higher than age- and sex-matched scores from US population IKDC: 80% nearly normal to normal IKDC: 86% nearly normal to normal (patients with primary ACL reconstruction > revision ACL reconstruction) SF-36 PCS and MCS: higher than age- and sex-matched population KOS ADLS: 89.7 at FUT, SAS: 81 at FUT Lysholm: 88.4 at FUT 93% were somewhat to greatly improved
Stone et al. [5]	Pain score: SI of 21%. Self-reported activity scores: SI of 10%. Self-reported functioning scores: SI of 19% IKDC, WOMAC, Tegner: SI
Fukushima et al. [39]	95% satisfied 95% had disappearance of joint-line pain. 72% had disappearance of swelling
Rankin et al. [40]	Cincinnati Knee Rating System (pain, patient perception, squatting and run): SI
Bhosale et al. [6]	75% had improvement of function and pain relief at FUT Lysholm score: SI 75% was satisfied with operation
Graf et al. [41]	100% would recommend procedure to a friend 88% continue to actively participate in recreational sports IKDC: 50% nearly normal to normal
Rueff et al. [42]	Modified Lysholm, IKDC score, VAS pain: SI 94% considered their surgery to be a success and would undergo the procedure again given the same situation
von Lewinski et al. [43]	KOOS at FUT: mean value of 74 points Lysholm score: mean value of 74 points at FUT
Dienst and Kohn [46]	Joint function and pain reduction: SI

SI: significant improvement from preoperative to follow-up. FUT: follow-up time

increase with a longer duration of follow-up. However, a significant number of patients showed no signs of progression. Based on these limited data, meniscus allograft transplantation is believed to have a chondroprotective effect in 30–40% of patients. However, the majority of patients are on the "slippery slope of osteoarthritis" and will further deteriorate over time. It is unknown whether allograft transplantation delays the natural course of osteoarthritis after meniscectomy. Future research is mandatory to determine the chondroprotective power of meniscus allograft transplantation.

MRI Analysis (Table 10.7.6)

Routine preoperative MRI may be useful for documentation of articular cartilage defects, subchondral bone status and any remaining meniscus. Potter et al. [13] demonstrated that MRI provides accurate assessment of meniscal position, horn and capsular attachments, meniscal degeneration and adjacent articular cartilage. It correlates well with arthroscopic evaluation of the transplant and is non-invasive. The development of dynamic and weightbearing MRI shows promise for its use in meniscal transplant analysis.

In order to overcome the observed discrepancy between clinical outcome and meniscal allograft status and to assess any progression of degenerative articular changes after this type of surgery, objective outcome measures such as MRI have to be included in outcome studies. Only limited literature data are available reporting that meniscal allografting halts or slows down further degeneration [14–17]. In one recent long-term study, progression of cartilage degeneration according

Table 10.7.4 Objective clinical scoring summary

Authors	Clinical examination scoring
Groff et al. [22]	91% no effusion Mean passive flexion: 129°, NS loss of motion Side-to-side difference in laxity: NS 0% had joint-line tenderness Single-leg vertical jump 93% in comparison to non-involved limb Hop test: 95% in comparison to non-involved limb
Noyes and Barber-Westin [2]	3% had signs of a meniscal tear 97% had no tibiofemoral joint-line pain 89% had no effusion 95% normal anteroposterior stability
Heckmann et al. [48]	74% had disappearance of pain at tibiofemoral compartment
Stollsteimer et al. [53]	No patient had loss of motion
Van Arkel et al. [26, 27]	20% of patients had improvement in stability 20% of patients had improvement in stability: SI
Verdonk et al. [3, 18]	HSS pain and function: SI HSS pain score: SI (MMT + HTO group > MMT group) HSS walking score: SI HSS stair climbing ability score: SI
Cole et al. [31]	IKDC knee examination: 90% nearly normal to normal at FUT
Yoldas et al. [33]	81% no effusion 100% no joint-line tenderness Average flexion at FUT = 129° average extension at FUT: 2° 97% had negative to 1+ Lachman and pivot shift test at FUT Vertical jump + hop tests: 85% compared to contralateral knee KT 1000: average side-to-side difference of 2 mm translation
Hommen et al. [34]	IKDC: 40% nearly normal to normal
Sekiya et al. [37, 38]	IKDC ROM: 31% nearly normal to normal IKDC ligament examination: 94% nearly normal to normal Average loss of flexion compared with non-involved knee: 10°; extension: 4° Bony fixation has significantly better motion than suture group Single-leg hop and vertical jump: 91 and 85% of the non-involved leg IKDC laxity: 92% nearly normal to normal KT 1000: average increase in AP translation of 1.5 mm compared to contralateral knee IKDC ROM: 67% nearly normal to normal Single-leg hop and vertical jump: 83 and 82% of the non-involved leg
Fukushima et al. [39]	Average ROM + 7° at FUT
Graf et al. [41]	IKDC ROM: 100% nearly normal to normal IKDC ligament examination: 75% nearly normal to normal IKDC compartmental findings: 63% nearly normal to normal IKDC functional test: 75% nearly normal to normal Average loss of motion: 2.3°, average loss of flexion: 4.9°
von Lewinski et al. [43]	IKDC overall: 40% nearly normal to normal

FUT follow-up time; *NS* non-significant

to MRI and radiological criteria was halted in 35% of patients, indicating a potential chondroprotective effect [18]. A recent controlled large animal study also confirmed this chondroprotective effect [19]. These data could support the use of prophylactic meniscal transplantation in meniscectomized patients without clinical symptoms, thereby potentially limiting secondary cartilage degeneration. Further prospective comparative studies are mandatory to test this hypothesis.

Using MRI, meniscal allograft extrusion has been described independent of the surgical fixation technique. In our experience, using soft-tissue fixation,

Table 10.7.5 Radiological evaluation

Author	FUT (years)	Joint space narrowing (mean)	Fairbank (average)	IKDC radiological evaluation
Carter [20]	2.9	Progression in 4%	NA	NA
Garrett [15]	2–3.7	NS	NA	NA
Groff et al. [22]	3.8	NS	NA	NA
Wirth et al. [23]	3 and 14	Increased degenerative changes in all patients	Preoperatively: 0.7. At 3 years: 1.4. At 14 years: 2.5	NA
Noyes et al. [24]	3.3	Progression in 8%	NA	NA
Rath et al. [25]	4.5	NS	NA	NA
Stollsteimer et al. [53]	3.3	0.88 mm	NA	NA
Verdonk et al. [18]	12.1	Progression in 48%	Stable in 28%	NA
Yoldas et al. [33]	2.9	NS increase in joint-space width!	NA	NA
Ryu et al. [4]	2.8	No change in 63%, 1–3 mm in 25%, >3 mm in 12.5%	NA	NA
Hommen et al. [34]	11.7	Progression in 67%. Mean: 1.15 mm	Progression in 80%. Mean of 0.8 mm of progression from 0.5 to 1.3	NA
Vaquero et al. [54]	>1	NS	NA	NA
Sekiya et al. [37, 38]	2.8	NS	NA	48% nearly normal to normal
	3.3	NS	NA	50% nearly normal to normal
Graf et al. [41]	9.7	Progression in 75%. Mean of 0.38 mm	NA	12.5% nearly normal to normal (=same as preoperatively)
von Lewinski et al. [43]	20	Kellgren–Lawrence score: mean of 2.4	NA	40% nearly normal to normal
Barrett [45]	5	NS	NA	NA

Fairbank changes: average

Kellgren-Lawrence Radiographic Grading Scale of Osteoarthritis of the Tibiofemoral Joint. *0*: No radiographic findings of osteoarthritis, *1*: Minute osteophytes of doubtful clinical significance, *2*: Definite osteophytes with unimpaired joint space, *3*: Definite osteophytes with moderate joint space narrowing, *4*: Definite osteophytes with severe joint space narrowing and subchondral sclerosis

extrusion is observed in the corpus and anterior horn of the lateral graft, while the posterior horn is most frequently within normal values [18]. This extrusion could reduce the functional surface of the graft, and thus, potentially also its biomechanical function. Biological reasons for the observed extrusion post-transplantation could include progressive stretch and failure of the circumferential collagen bundle due to insufficient repair potential or increased catabolism. Future research should focus on the biology involved in ongoing metabolic and cellular processes after transplantation.

Lyophilized allografts showed more shrinkage and degeneration, indicated by altered signal intensity, than did other grafts. Therefore, this preservation technique is no longer used. In the long term, all allograft types show some shrinkage. The exact meaning of the observed shrinkage has yet to be determined. Possible hypotheses are tissue loss due to mechanical wear or a biological process of contraction often observed in scar tissue formation and healing.

In general, healing of the allograft to the rim is observed in the vast majority of patients. The meniscus allograft signal is most frequently abnormal with a more greyish appearance. The authors believe that this change in signal reflects biological remodelling of the extracellular matrix of the allograft, rather than true degenerative changes.

Table 10.7.6 MRI analysis

Author	FUT (years)	MRI
Wirth et al. [23]	14	Deep-frozen allografts Showed good preservation, no reduction in size, homogeneous signal Showed chondromalacia grade 2 Lyophilized allografts Were reduced in size, had altered signal intensity (=degeneration) Showed chondromalacia grade 2 in 16%, grade 3 in 67% and grade 4 in 16%
Noyes et al. [24]	3.3	In the coronal plane: Mean displacement: 2.2 mm 59% of the allografts had no displacement Intrameniscal signal intensity: 4% normal, 46% grade 1, 39% grade 2, 11% grade 3
Stollsteimer et al. [53]	2	42% had an abnormal MRI signal, but no tear Average size of meniscus was 62% of the normal meniscus (graft shrinkage) 9% had 1 mm extrusion
Van Arkel et al. [26]	2.7	63% completely healed to the capsule, 26% partially detached, 11% totally detached 21% showed severe shrinkage, 21% moderate shrinkage 0% had a normal position: 11% bucket-handle-like configuration, 32% extrusion, 58% sub-extrusion
Verdonk et al. [18, 28]	12	No progression of cartilage degeneration in 35% No changes in signal intensity of the allograft in 82% No change in graft position in 35% Tear observed in 12%
	1	The lateral transplanted meniscus is more extruded in comparison to the normal lateral meniscus. The anterior horn (mean 5.8 mm) seems to be more extruded than the posterior horn (mean 2.7 mm)
Hommen et al. [34]	11.7	71% had grade 3 signal intensities 57% had moderately truncated mid-zones; 29% had moderately diminutive anterior horns, 14% had a severely truncated mid-zone 100% moderate graft shrinkage Cartilage classification: 14% normal, 29% mild, 43% moderate and 14% severe
Vaquero et al. [54]	>1	5% changes in signal intensity
Potter et al. [13]	1	63% showed increased signal intensity in the posterior horn tibial attachment (=degenerative changes) Moderate (4) or severe (11) chondral degeneration in 63% 46% showed peripheral displacement Fragmentation (21%) and frank extrusion (12.5%) were associated with full-thickness chondral loss
Rankin et al. [40]	2	The mean height and width of the anterior and posterior horns were similar to native menisci MRI under weightbearing conditions The anterior horn of the native meniscus moved a mean of 5 mm compared to allograft Signal intensity: 25% grade 1, 50% grade 2, 25% grade 3
Bhosale et al. [6]	1	Good integration in all, no rejection Mild extrusion in 20% 63% wedge shaped, 25% flat, 12% expansion 50% had blurred surface 100% had increased signal intensity
von Lewinski et al. [43]	20	Transplants showed shrinkage, degenerative changes 17% subluxation Osteophytes

Stoller et al. classification: Grade 1 represents a non-articular focal or globular intrasubstance focus of increased signal; grade 2 represents a linear focus of intrasubstance increased signal that extends from the capsular periphery of the meniscus, but does not involve an articular meniscal surface; and grade 3 represents an area of increased signal intensity that communicates or extends to at least one articular surface

Extrusion of the allograft: the portion of the allograft that was displaced completely over the peripheral border of the tibial plateau.

Subextrusion: the portion of the allograft that was displaced partially over the peripheral border of the tibial plateau

Second-Look Arthroscopy (Table 10.7.7)

Some authors have demonstrated that clinical evaluation only based on symptoms and physical examination does not allow reliable assessment of the status of the meniscus. Arthroscopic evaluation, however, should not be used as a routine postoperative evaluation tool. Most frequently, it is performed upon clinical suspicion of an intra-articular problem. In some cases, arthroscopic evaluation can be performed in association with another procedure around the knee.

In general, and in accordance with the MRI evaluation, good healing of the allograft to the rim is observed in the vast majority of patients. Tearing and shrinkage can be present. The status of the allograft, however, correlates poorly with the clinical outcome.

Failures and Survival Analysis

In the literature, no consensus exists on the criteria for failure or success. A number of authors use the clinical outcome, while others propose more objective outcome parameters such as MRI or second-look arthroscopy. In general, using objective parameters, the clinical success rate is higher than estimated. In the majority of studies, a clinical success rate of 70% and higher has been reported at the final follow-up. Because the success rate has a tendency to decrease over time, it would be preferable to use survivorship analysis rather than failure rate to describe the success of such a procedure. A survivorship is much more powerful to describe the results irrespective of the duration of follow-up. We all are aware that nothing ruins good results more than a long-term follow-up.

Based on the available survivorship data, a clinical survivorship of 70% at 10 years can be anticipated for both medial and lateral allografts. Ligament instability, axial malalignment and cartilage degeneration are considered by most authors to be associated with a higher failure rate and inferior results, although some authors have reported satisfactory results in degenerative knees.

Conclusion

In conclusion, ample evidence has been presented to support meniscus allograft transplantation in meniscectomized painful knees, with observance of the proper indications. Significant relief of pain and improvement in function have been achieved in a high percentage of patients. These improvements appear to be long-lasting in 70% of patients. Based on plain radiology and MRI, a subset of patients does not show further cartilage degeneration, indicating a potential chondroprotective effect. The lack of a conservatively treated control group is considered a fundamental flaw in the reported studies, making it difficult to establish the true chondroprotective effect of this type of treatment.

Based on the presented results, meniscus allograft transplantation should no longer be considered experimental surgery for the meniscectomized painful knee.

Table 10.7.7 Evaluation by second-look arthroscopy

Author	FUT (years)	
Cameron and Saha [1]	2.5	77% complete healing, 23% failed healing, 0% shrinkage, 60% post-op. Posterior horn tear.
Carter [20]	2.8	18% failed healing, 14% shrinkage 9% arthritis progression
Garrett [15]	2	71% complete healing
Goble et al. [21]	2	72% intact
Wirth et al. [23]	3.8	Deep-frozen: 40% shrinkage, 100% complete healing Lyophilized: 14% incomplete healing/detachment and 93% shrinkage 91% complete healing
Noyes et al. [24] (1998)	1.3	8% complete healing, 31% partial healing, 57% failed healing 29% showed degeneration/tears
	3.3	56% failed healing/degeneration/tears Articular cartilage: 85% abnormal
Rath et al. [25]	2.6	100% complete healing 80% had degeneration/tears Arthroscopy was only performed in case of symptoms
Stollsteimer et al. [53]	3.3	4% loosening
Van Arkel et al. [26]	2.7	79% complete healing, 16% partial healing, 5% failed healing 58% subextrusion, 11% extrusion, 11% bucket-handle 21% shrinkage Articular cartilage: 50% grade 3, 38% grade 3–4, 12.5% grade 4 Outerbridge
Verdonk et al. [3]	7.2	Menisci with poor function or persistent pain had severe allograft degeneration or allograft detachment
Shelton and Dukes [29]	NA	100% complete healing
Veltri et al. [30]	0.5	71% complete healing, 29% partial healing 14% showed degeneration
Del Pizzo [55] unpublished data	3.2	100% showed complete healing 6% showed tear
Yoldas et al. [33]	0.5–1	100% complete healing 33% radial tear <1 cm
Ryu et al. [4]	2.75	50% complete healing 20% degeneration/tear
Cryolife [35]	7	91% fully intact in bone block cases
Vaquero et al. [54]	>1	20% shrinkage 20% loosening
Potter et al. [13]	1	58% subextrusion, 16% extrusion 26% degeneration (fragmentation) Only patients with frank displacement on MRI were confirmed at arthroscopic evaluation 52% focal synovitis at the peripheral capsular attachment All areas that were seen as moderate-to-full-thickness chondral degeneration were confirmed on arthroscopy as OB grade 3–4 change
Stone et al. [5]	5.8	21% torn menisci
Bhosale et al. [6]	1	100% complete healing 12.5% meniscus thinning 25% mild synovitis
Graf et al. [41]	4	100% complete healing 33% had a tear Loose body removal in one case 100% well-vascularized No progression of degenerative changes

Table 10.7.8 Rehabilitation

Author	Rehabilitation program
Cameron and Saha [1]	Week 1–3: immobilization Week 3–6: progressive ROM (first 6 weeks nwb) From week 6: quadriceps and hamstring exercises
Groff et al. [22]	First week: pwb (crutches) with immobilization in extension brace; cpm machine for 3 weeks; full extension at 1 week Second week: passive and active ROM of 0–90°; brace unlocked; weightbearing as tolerated Week 4–6: 90°, crutches discontinued From week 6: closed-chain exercises From week 8: low-impact sports Rehabilitation of 2–3 months Return to strenuous work at 3–4 months, to running at 4–5 months Return to strenuous sports not encouraged
Wirth et al. [23]	Immediately after surgery: CPM and physical therapy Week 1–12: rehabilitation program Week 13: fwb
Noyes et al. [24]	Immediately postoperatively: long leg brace for 8 weeks; ROM 0–90° exercises from the first day; flexibility and quadriceps exercises Flexion increased every week by 10° to allow 135° after week 4 Week 1–2: only toe-touch wb, increased to 50% wb after week 4 Week 6: fwb; balance, proprioception and closed-chain exercises Week 8: stationary cycling with low resistance Week 9–12: swimming and walking programs After 12 months: light recreational sports Advised to never return to high-impact strenuous athletics again If PCL reconstruction: restricted in flexion and wb for 8 weeks If ACL reconstruction: other protocol Bledsoe thruster brace when abnormal articular cartilage
Rath et al. [25]	From day 1: quadriceps and hamstring exercises, limited ROM 0–90° Week 1–4: nwb Week 4–6: pwb 6–9 months: full activity Never aggressive cutting sports or distance running again
Stollsteimer et al. [53]	Immediately postoperatively: full ROM exercises Week 1–6: no fwb Jogging at 3 months, sports at 6 months
Verdonk et al. [3, 18]	Week 1–3: nwb with ROM flexion to max 60° Week 3–6: ROM 0–90° + pwb From week 6: walking with one crutch Week 1–3: nwb with ROM flexion to max 60° Week 3–6: ROM 0–90° + pwb From week 6: walk with 1 crutch
Shelton and Dukes [29]	Immediately postoperatively: full ROM, nwb till week 6 From day 1: quadriceps and hamstring exercises Week 6: fwb 6 months: return to sports if knee is fully rehabilitated
Veltri et al. [30]	Week 1–6: pwb + ROM exercises in hinged brace After week 6: fwb as tolerated
Cole et al. [31]	Immediately postoperatively: wb as tolerated with crutches + hinged brace + immediate active and passive ROM without limitation Week 1–6: flexion wb <90° restricted After week 6: no brace + ROM as tolerated After 12 weeks: jogging allowed with progression to running and sport-specific-type drills
Yoldas et al. [33]	Immediately postoperatively: quadriceps sets and straight leg raises Day 1: start passive ROM with CPM, for 1 month

(*continued*)

Table 10.7.8 (continued)

Author	Rehabilitation program
	Week 1: full extension, pwb, brace locked in extension From week 2: wb as tolerated Week 4–6: 90° flexion, fwb, closed-chain exercises Rehabilitation of 2–3 months
Ryu et al. [4]	Immobilization in full extension with progressive wb over 4–5 weeks Week 1–4: ROM 0–90° From week 5: gradual increase in flexion of 10–15° each week If concomitant ACL reconstruction: ACL protocol was subordinated to meniscal allograft requirements
Hommen et al. [34]	Immediately postoperatively: quadriceps sets and straight leg raising 24h after surgery CPM till 1 month
Felix and Paulos [36]	Postoperatively braced in extension. Plantar touch wb Week 3: 60° flexion Week 4: progressive wb increased by 25% every week Week 6: full flexion Week 7–8: fwb 6–9 months: full activities and sports
Sekiya et al. [37, 38]	Immediately postoperatively: exercises, pwb with crutches, brace locked in full extension Day 1: cpm Week 1: full extension Week 2: wb as tolerated, sedentary work Week 4–6: 90° flexion, stop crutches From week 6: closed-chain exercises Strenuous work and running after 5–6 months – sports after 6–9 months Immediately postoperatively: exercises, pwb with crutches, brace locked in full extension Day 1: cpm Week 1: full extension Week 2: wb as tolerated, sedentary work Week 4–6: 90° flexion, stop crutches From week 6: closed-chain exercises Strenuous work and running after 5–6 months - sports after 6–9 months
Stone et al. [5]	Week 1–4: maximally protective phase = pwb (week 1 and 2: 10 and 20% toe touch), extension-locked hinged brace, passive and active ROM, daily icing and elevation, straight leg exercises, manually resisted hip, foot and ankle exercises, pool workouts, soft-tissue treatments, a trunk stabilization program, nwb aerobic exercises Week 4–12: moderately protective phase = stretching, manual treatments to restore ROM, introduction of functional exercises (i.e., partial squats, calf raises and proprioception exercises), road cycling as tolerated, slow walking on a low-impact treadmill and lateral training. Exercises increasingly focus on single-leg exercises, strength training and sport-specific training for a gradual return to activities No resisted leg extension machines, no high-impact, cutting or twisting activities for at least 4 months postoperatively
Fukushima et al. [39]	24–48 h postoperatively: start ROM exercises Week 1–4: nwb Week 5: pwb 50% Week 6: fwb + flexion >90° allowed Week 8–10: closed-chain exercises Never strenuous/contact/rotational sports in the future
Rankin et al. [40]	Postoperatively: long leg brace for 6 weeks, ROM 0–90°, toe-touch wb first 2 weeks, flexibility and quadriceps strengthening exercises Week 3–4: flexion to 120°, 50% wb Week 5–6: ROM 0–135° at 4 weeks Week 6: fwb + balance, proprioception, closed kinetic chain exercises Week 7–8: stationary cycling Week 9–12: start swimming and walking 12 months: light recreational sports Never high-impact activities/ strenuous athletics again

Table 10.7.8 (continued)

Author	Rehabilitation program
Bhosale et al. [6]	The Oscell rehabilitation for ACI procedure and limitation of knee flexion to 45° for 3 weeks Week 12: fwb
Graf et al. [41]	Week 1–2: nwb, light resistive isometric exercises, medial unloading brace 10–90° (if + ACL reconstruction: derotational brace), stationary biking when 90° was obtained Week 2–4: pwb Week 5: fwb Week 6: resistance exercises 3 months: advancement in rehabilitation exercises and strengthening programs 6 months: stop bracing, start straight line jogging (without cutting and pivoting) 8 months: start agility exercises 1 year: sporting activities (never high-impact, running, jumping, twisting or turning sports again)
Rueff et al. [42]	Week 1–6: ROM limited to 0–90° Early wb
von Lewinski et al. [43]	Postoperatively: strengthening exercises for quadriceps muscle, brace with limited ROM for 12 weeks Week 1–6: ROM 30–60° Week 6–12: ROM 20–90° Week 1–12: pwb 10 kg
Dienst and Kohn [46]	Postoperatively: ROM 0–90° active + passive exercises, pwb with brace locked in extension for 6 weeks 3 months: full squat allowed 1 year: sport activities allowed

ROM range of motion; *nwb* non-weightbearing; *cpm* continuous passive motion; *pwb* partial weightbearing; *fwb* full weightbearing; *wb* weightbearing

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Table 10.7.1 International Cartilage Repair Society cartilage lesion evaluation system

Grade 0	Normal
Grade 1	Superficial lesions, softening, fissures or cracks
Grade 2	Lesions, erosion or ulceration of less than 50%
Grade 3	Partial-thickness defect of more than 50%, but less than 100%
Grade 4	Ulceration and bone exposure

grafting procedures should be performed after completion of the meniscal transplantation in order to prevent accidental damage to the patch or graft during meniscal allograft insertion [11]. Radiographic evidence of significant osteophyte formation or femoral condyle flattening is associated with inferior postoperative results because these structural modifications alter the morphology of the femoral condyle [12]. Generally, patients over age 50 have excessive cartilage lesions and are suboptimal candidates.

Axial malalignment tends to exert abnormal pressure on the allograft leading to loosening, degeneration and failure of the graft [12]. A corrective osteotomy should be considered in patients with more than two degrees of deviation toward the involved compartment, as compared with the mechanical axis of the contralateral limb. Varus or valgus deformity may be managed with either staged or concomitant high tibial or distal femoral osteotomy [11]. However, as in any situation in which procedures are combined, it is unclear which aspect of the procedure is implicated in symptom resolution, such as relief of pain [12].

Other contraindications to meniscal transplantation are obesity, skeletal immaturity, instability of the knee joint (which may be addressed in conjunction with transplantation), synovial disease, inflammatory arthritis and previous joint infection and obvious squaring of the femoral condyle.

Results

It is difficult to perform a meta-analysis of all the published results, because of the small populations studied and the differences (Table 10.7.2) in indications, contraindications, preservation techniques, preoperative Outerbridge grade, fixation techniques, surgical techniques, concomitant procedures, evaluation tools, and rehabilitation protocols.

In this chapter, we will try to present outcome data based on a review of the literature. A total of 39 studies have been included, representing 1,226 meniscus allografts (626 medial vs. 446 lateral, 154 not specified) in 1,145 patients. The mean age at the time of surgery was 34.4 years. The mean follow-up was 5.5 years. Overall, 340 isolated allograft transplantations were analysed, 427 were associated with ACL reconstruction, 107 with a corrective osteotomy and 215 with other procedures. It was not specified whether the remaining 137 allografts were associated with other procedures. Concerning the surgical fixation technique, 631 allografts were fixed using bone blocks and 488 using a soft-tissue fixation technique. For 107 allografts, the fixation method was not specified. In the next paragraphs, the outcome is reported independently of the aforementioned parameters.

Methods to evaluate the success or failure of meniscal transplantation range from subjective pain scale measurements and patient perceptions of function to objective measurements such as physical and radiological examinations, magnetic resonance imaging (MRI) and second-look arthroscopy.

Subjective Assessment

All studies showed significant subjective improvement in pain scales and functional activity questionnaires. The data from most studies are summarized in Table 10.7.3. In general, isolated procedures and combined procedures tended to have similar outcomes. No differences were observed based on tissue preservation technique or fixation method. About 75–90% of patients experienced fair to excellent results.

Objective Clinical Scoring

Physical Examination

Almost all studies reported equal or improved physical examination findings at follow-up with regard to range of motion, pain, effusion, stability, function tests or IKDC score. The data from most studies are summarized in Table 10.7.4.

Radiological Examination (Table 10.7.5)

Joint space narrowing indicating cartilage degeneration was observed in a number of patients and tended to

Table 10.7.2 Publications on meniscus allografts

Author	Year s	No. of grafts	M	L	No. of patients	Age	Time M-TX	Preservation	Rad?	Fix	FUT	Preop cart	No. iso-lated	Concomitant procedures
Cameron and Saha [1]	1988–1994	67	37	30	63	41	16.7	DF	Yes	S	2.5	2–4	21	5ACL, 34OT, 7ACL + OT
Carter [20]	NA	46	39	7	46	NA	NA	Cryo.	NA	B	2.8	NA	NA	30ACL, 4OT, 1MCL
Garrett [15]	NA	43	34	8	43	NA	NA	16 DF, 27 Cryo.	NA	B	4.5	NA	7	24ACL, 13OT, 11OAL
Goble et al. [21]	NA	69	48	21	60	NA	NA	Cryo.	NA	B	2	NA	NA	28ACL
Groff et al. [22]	1993–1998	16	0	16	16	27	8	DF	No	B	3.8	1–2	16	None
Wirth et al. [23]	1984–1986	22	22	0	22	29.6	NA	6DF, 16Lyo.	6No, 16Yes	S	3/14	1.6	0	22ACL, 19MCL
Noyes et al. [2, 24]	NA	96	79	17	83	NA	NA	DF	Yes	B	<2	NA	19	77ACL
	1995–2000	40	20	20	38	30	NA	Cryo.	No	B	3.3	3.6	NA	7ACL, 1PCL, 1ACL + PCL, 1MCL, 16 OAU
Rath et al. [25]	1991–1997	22	15	7	18	30	7.7	Cryo. + DF	No	1S, 21B	4.5	NA	3	11ACL, 1TTT
Stollsteimer et al. [17]	1991–1995	23	11	12	22	31	3.8	Cryo.	No	B	3.3	COB: 5.6	23	None
Van Arkel et al. [26, 27]	1994–1995	19	6	13	16	40	16	Cryo.	No	NA	2.7	NA	NA	NA
	1989–1999	63	23	40	57	39	16	Cryo.	No	S	5	NA	61	2ACL
Verdonk et al. [3, 18, 28]	NA	27	0	27	27	33.9	NA	V	No	S	1	NA	NA	NA
	1989–2001	100	39	61	96	35	NA	V	No	S	7.2	2.5	69	3ACL, 17OT, 3Mi, 4OPT
	1989–1993	39	NA	NA	38	35.4	NA	V	No	S	12.1	2.7	NA	3ACL, 12OT
Shelton and Dukes [29]	NA	14	5	9	14	NA	NA	Cryo.	NA	B	NA	NA	NA	NA
Veltri et al. [30]	NA	16	8	8	14	35.3	11.3	DF + Cryo.	No	B	0.7	NA	4	10ACL, 1PCL, 1ACL + PCL
Cole et al. [31]	1997–2003	40	25	15	36	31	NA	32 DF + 8 Cryo.	No	B	2.8	<4	21	ACL, 1OT, 3OAL, 3OAU, 1ACI, 2Mi, 2 ODfix
Rodeo et al. [32]	1989–1995	33	17	16	28	34	NA	DF	No	20B, 13S	1.3	NA	8	19ACL, 1OT
Del Pizzo [55] unpublished data	1991–1994	19	NA	NA	19	NA	NA	19 Cryo.	NA	NA	3.2	NA	6	11ACL, 2OT

(continued)

Table 10.7.2 (continued)

Author	Year s	No. of grafts	M	L	No. of patients	Age	Time M-TX	Preservation	Rad?	Fix	FUT	Preop cart	No. iso-lated	Concomitant procedures
Yoldas et al. [33]	1993–1996	34	NA	NA	31	28	8	DF	No	B	2.9	NA	11	20ACL
Ryu et al. [4]	1993–1999	26	10	16	25	34.5	NA	NA	NA	B	2.75	2.8	12	14ACL
Hommen et al. [34]	1991–1995	20	12	8	20	32	NA	20 Cryo.	No	13S, 7B	11.7	2.2	5	10ACL, 2OT, 3CHFC, 2CP, 3LR
Cryolife [35]	1989–1994	1,023	747	276	1,015	NA	NA	Cryo.	NA	930B, 92S	7	NA	NA	NA
Felix and Paulos [36]	1993–1999	36	20	16	33	28.5	6	Cryo.	No	B	5.2	NA	9	18ACL, 2OT, 4ACL + OT
Vacquero et al. (2003)	2001–2002	32	NA	NA	30	37	NA	DF	No	B	>1	2.3	NA	6ACL, 3Mi, 7RFA, 1TTT
Sekiya et al. [37, 38]	1994–1998	31	24	7	28	35	8.6	Cryo.	No	B	2.8	1–4	0	28ACL, 2ACL + OT
	1993–1998	25	0	25	25	30	5.7	Cryo.	No	8S, 17B	3.3	1–4	25	None
Potter et al.[13]	1989–1996	29	14	15	24	33.2	NA	DF	NA	B	NA	2–4	11	16ACL, 1OT, 1MCL
Stone et al. [5]	1997–1999	47	37	10	45	48	NA	18 DF, 29 Cryo.	No	S	5.8	3.8	7	6ACL, 17OT, 19Mi, 47CHFC, 24ACPG
Fukushima et al. [39]	1996–1997	43	30	13	40	37.3	11.4	Cryo.	No	S	1	NA	NA	8ACL, 1OT
Rankin et al. [40]	NA	8	5	3	7	31	NA	Cryo.	No	B	2	2.9	2	4ACL, 4OAU
Bhosale et al. [6]	NA	8	2	6	8	43	14	Cryo.	No	S	3.2	3.8	0	8ACI
Graf et al. [41]	1990–1992	8	8	0	8	32.6	10.5	Cryo.	1No, 7Yes	7S, 1B	9.7	NA	0	8ACL, 1OT, 8ACL + OT
Rueff et al. [42]	NA	8	8	0	8	52	NA	Cryo.	No	B	5.5	NA	0	8ACL
von Lewinski et al. [43]	1984–1986	6	6	0	6	25	NA	DF	No	S	20	2.6	0	6ACL
Milachowski et al. [44]	NA	22	22	0	22	NA	NA	NA	NA	NA	1.2	NA	0	22 ACL
Barrett [45]	NA	15	NA	NA	15	NA	NA	Cryo.	NA	NA	5	NA	NA	NA
Dienst and Kohn [46]										S	3–7			
Kim and Bin [47]	1996–2003	14	NA	NA	14	NA	NA				4.8			

Year S Years of surgery; *M* number of medial grafts; *L* number of lateral grafts; *Time M-TX* average time in years from meniscectomy to transplantation; *Age* average age of patients at time of transplantation in years; *Rad*? radiation of graft?; *Preop. cart.* preoperative cartilage Outerbridge grade; *Fix* fixation technique used to fix the allograft; *B* bony fixation; *S* only sutures; *FUT* average time of follow-up in years; *No. isolated* number of transplantations, without concomitant procedures; *OT* osteotomy; *OAL* osteochondral allograft; *OAU* osteochondral autograft; *ACL* anterior cruciate ligament reconstruction; *PCL* posterior cruciate ligament reconstruction; *MCL* medial collateral ligament reconstruction; *NA* not available; *DF* deep-frozen; *Cryo.* cryopreserved; *Lyo.* lyophilized; *V* viable; *TTT* tuberositas tibiae transfer; *COB* cumulative Outerbridge score: calculated by adding the scores for all areas of each knee; *Mi* microfracture; *OPT* osteochondral plug transfer; *ACI* autologous chondrocyte implantation; *ODfix* osteochondritis dissecans fixation; *CHFC* chondroplasty femoral condyle; *CP* capsular plication; *LR* lateral retinaculum release; *RFA* radiofrequent ablation; *ACPG* articular cartilage post-grafting

Table 10.7.3 Summary of subjective assessment

Authors	Subjective scoring
Cameron and Saha [1]	87% good to excellent rate (85% after 3 years) Fulkerson (=modified Lysholm) functional knee score, Tegner score, reduction in need of anti-inflammatory medication: SI
Carter [20]	IKDC: SI
Goble et al. [21]	Quality of life (regarding pain at rest, during recreational activity and functional stability): SI
Groff et al. [22]	Lysholm score: 91% fair to excellent ratio IKDC: 91% nearly normal to normal All (100%) were improved, 100% satisfaction with the condition of their knee as a result of the surgery SF-36: 6 of 8 categories higher scoring than age and sex-matched population KOS at FUT: ADLS: 79.3 SAS: 74.5 41% had pain with light sports activities
Wirth et al. [23]	Lysholm, Tegner (at 3 years/14 years FUT): SI (deep-frozen better than lyophilized, both deteriorated after 14 years) (influenced by preoperative cartilage condition and instability)
Noyes et al. [24]	Perception of knee condition: 73% good to normal. 89% improvement of knee function 76% participation in light low-impact sports Cincinnati score: SI
Heckmann et al. [48]	94% improvement of knee condition 77% participation in light low-impact sports
Rath et al. [25]	SF-36 for bodily pain, role physical, physical functioning and social functioning: SI Mean IKDC functional score: 54
Stollsteimer et al. [17]	Improvement of preoperative pain in 82%. Tegner score, IKDC score, Lysholm: SI Articular cartilage changes preoperatively and preoperatively higher IKDC score had significant effect on overall patient outcome score
Van Arkel et al. [26, 27]	KASS: 84% successful result Modified Lysholm: 84% fair to excellent Tegner: SI 77% success Lysholm: SI 91% improvement of pain
Verdonk et al. [3, 18]	Pain relief and improved function at 10 years in 70% 90% were satisfied with the operation and would do it again
Cole et al. [31]	75 % completely/mostly satisfied with procedure: 68% medial, 93% lateral, 81% isolated, 74% “combined with other procedure” subgroup Lysholm, Tegner, Noyes, IKDC, KOOS pain, symptom, ADL and sports, SF-12 PCS score, VAS pain and overall knee condition: SI 86% would have surgery again: 84% medial subgroup, 93% lateral subgroup, 86% isolated and 84% in combined subgroup
Rodeo et al. [32, 49]	88% of bone plugs + 47% soft-tissue fixated transplantations were rated as good or moderate Lysholm, IKDC, VAS: pain + function: SI 58% clinically successful
Del Pizzo [55] unpublished data	89% were satisfied with procedure 95% could perform occasional strenuous activities; none continuous They all returned to their previous activity level Pain was improved in all patients
Yoldas et al. [33]	97% somewhat to greatly improved IKDC: 97% nearly normal to normal Lysholm: 68% good to excellent ratio SF-36: in 7 of 8 categories better than age- and sex-matched population
Ryu et al. [4]	IKDC activity: 68% nearly normal to normal. VAS, Lysholm II, Tegner score: SI Outerbridge grade had significant impact on outcome. 83% overall satisfaction
Hommen et al. [34]	Lysholm, Pain, IKDC, Tegner, SF-12 score: SI. 80% had improvement

(continued)

Table 10.7.3 (continued)

Authors	Subjective scoring
L'Insalata et al. [50]	88% improvement
Miller and Harner [51]	100% improvement
Felix and Paulos [36]	VAS function: SI
Vaquero et al. [52]	VAS pain: SI IKDC: 77% nearly normal to normal
Sekiya et al. [37, 38]	96% had improvement of overall function and activity level SF-36: PCS and MCS: higher than age- and sex-matched scores from US population IKDC: 80% nearly normal to normal IKDC: 86% nearly normal to normal (patients with primary ACL reconstruction > revision ACL reconstruction) SF-36 PCS and MCS: higher than age- and sex-matched population KOS ADLS: 89.7 at FUT, SAS: 81 at FUT Lysholm: 88.4 at FUT 93% were somewhat to greatly improved
Stone et al. [5]	Pain score: SI of 21%. Self-reported activity scores: SI of 10%. Self-reported functioning scores: SI of 19% IKDC, WOMAC, Tegner: SI
Fukushima et al. [39]	95% satisfied 95% had disappearance of joint-line pain. 72% had disappearance of swelling
Rankin et al. [40]	Cincinnati Knee Rating System (pain, patient perception, squatting and run): SI
Bhosale et al. [6]	75% had improvement of function and pain relief at FUT Lysholm score: SI 75% was satisfied with operation
Graf et al. [41]	100% would recommend procedure to a friend 88% continue to actively participate in recreational sports IKDC: 50% nearly normal to normal
Rueff et al. [42]	Modified Lysholm, IKDC score, VAS pain: SI 94% considered their surgery to be a success and would undergo the procedure again given the same situation
von Lewinski et al. [43]	KOOS at FUT: mean value of 74 points Lysholm score: mean value of 74 points at FUT
Dienst and Kohn [46]	Joint function and pain reduction: SI

SI: significant improvement from preoperative to follow-up. FUT: follow-up time

increase with a longer duration of follow-up. However, a significant number of patients showed no signs of progression. Based on these limited data, meniscus allograft transplantation is believed to have a chondroprotective effect in 30–40% of patients. However, the majority of patients are on the "slippery slope of osteoarthritis" and will further deteriorate over time. It is unknown whether allograft transplantation delays the natural course of osteoarthritis after meniscectomy. Future research is mandatory to determine the chondroprotective power of meniscus allograft transplantation.

MRI Analysis (Table 10.7.6)

Routine preoperative MRI may be useful for documentation of articular cartilage defects, subchondral bone status and any remaining meniscus. Potter et al. [13] demonstrated that MRI provides accurate assessment of meniscal position, horn and capsular attachments, meniscal degeneration and adjacent articular cartilage. It correlates well with arthroscopic evaluation of the transplant and is non-invasive. The development of dynamic and weightbearing MRI shows promise for its use in meniscal transplant analysis.

In order to overcome the observed discrepancy between clinical outcome and meniscal allograft status and to assess any progression of degenerative articular changes after this type of surgery, objective outcome measures such as MRI have to be included in outcome studies. Only limited literature data are available reporting that meniscal allografting halts or slows down further degeneration [14–17]. In one recent long-term study, progression of cartilage degeneration according

Table 10.7.4 Objective clinical scoring summary

Authors	Clinical examination scoring
Groff et al. [22]	91% no effusion Mean passive flexion: 129°, NS loss of motion Side-to-side difference in laxity: NS 0% had joint-line tenderness Single-leg vertical jump 93% in comparison to non-involved limb Hop test: 95% in comparison to non-involved limb
Noyes and Barber-Westin [2]	3% had signs of a meniscal tear 97% had no tibiofemoral joint-line pain 89% had no effusion 95% normal anteroposterior stability
Heckmann et al. [48]	74% had disappearance of pain at tibiofemoral compartment
Stollsteimer et al. [53]	No patient had loss of motion
Van Arkel et al. [26, 27]	20% of patients had improvement in stability 20% of patients had improvement in stability: SI
Verdonk et al. [3, 18]	HSS pain and function: SI HSS pain score: SI (MMT + HTO group > MMT group) HSS walking score: SI HSS stair climbing ability score: SI
Cole et al. [31]	IKDC knee examination: 90% nearly normal to normal at FUT
Yoldas et al. [33]	81% no effusion 100% no joint-line tenderness Average flexion at FUT = 129° average extension at FUT: 2° 97% had negative to 1+ Lachman and pivot shift test at FUT Vertical jump + hop tests: 85% compared to contralateral knee KT 1000: average side-to-side difference of 2 mm translation
Hommen et al. [34]	IKDC: 40% nearly normal to normal
Sekiya et al. [37, 38]	IKDC ROM: 31% nearly normal to normal IKDC ligament examination: 94% nearly normal to normal Average loss of flexion compared with non-involved knee: 10°; extension: 4° Bony fixation has significantly better motion than suture group Single-leg hop and vertical jump: 91 and 85% of the non-involved leg IKDC laxity: 92% nearly normal to normal KT 1000: average increase in AP translation of 1.5 mm compared to contralateral knee IKDC ROM: 67% nearly normal to normal Single-leg hop and vertical jump: 83 and 82% of the non-involved leg
Fukushima et al. [39]	Average ROM + 7° at FUT
Graf et al. [41]	IKDC ROM: 100% nearly normal to normal IKDC ligament examination: 75% nearly normal to normal IKDC compartmental findings: 63% nearly normal to normal IKDC functional test: 75% nearly normal to normal Average loss of motion: 2.3°, average loss of flexion: 4.9°
von Lewinski et al. [43]	IKDC overall: 40% nearly normal to normal

FUT follow-up time; *NS* non-significant

to MRI and radiological criteria was halted in 35% of patients, indicating a potential chondroprotective effect [18]. A recent controlled large animal study also confirmed this chondroprotective effect [19]. These data could support the use of prophylactic meniscal transplantation in meniscectomized patients without clinical symptoms, thereby potentially limiting secondary cartilage degeneration. Further prospective comparative studies are mandatory to test this hypothesis.

Using MRI, meniscal allograft extrusion has been described independent of the surgical fixation technique. In our experience, using soft-tissue fixation,

Table 10.7.5 Radiological evaluation

Author	FUT (years)	Joint space narrowing (mean)	Fairbank (average)	IKDC radiological evaluation
Carter [20]	2.9	Progression in 4%	NA	NA
Garrett [15]	2–3.7	NS	NA	NA
Groff et al. [22]	3.8	NS	NA	NA
Wirth et al. [23]	3 and 14	Increased degenerative changes in all patients	Preoperatively: 0.7. At 3 years: 1.4. At 14 years: 2.5	NA
Noyes et al. [24]	3.3	Progression in 8%	NA	NA
Rath et al. [25]	4.5	NS	NA	NA
Stollsteimer et al. [53]	3.3	0.88 mm	NA	NA
Verdonk et al. [18]	12.1	Progression in 48%	Stable in 28%	NA
Yoldas et al. [33]	2.9	NS increase in joint-space width!	NA	NA
Ryu et al. [4]	2.8	No change in 63%, 1–3 mm in 25%, >3 mm in 12.5%	NA	NA
Hommen et al. [34]	11.7	Progression in 67%. Mean: 1.15 mm	Progression in 80%. Mean of 0.8 mm of progression from 0.5 to 1.3	NA
Vaquero et al. [54]	>1	NS	NA	NA
Sekiya et al. [37, 38]	2.8	NS	NA	48% nearly normal to normal
	3.3	NS	NA	50% nearly normal to normal
Graf et al. [41]	9.7	Progression in 75%. Mean of 0.38 mm	NA	12.5% nearly normal to normal (=same as preoperatively)
von Lewinski et al. [43]	20	Kellgren–Lawrence score: mean of 2.4	NA	40% nearly normal to normal
Barrett [45]	5	NS	NA	NA

Fairbank changes: average

Kellgren-Lawrence Radiographic Grading Scale of Osteoarthritis of the Tibiofemoral Joint. *0*: No radiographic findings of osteoarthritis, *1*: Minute osteophytes of doubtful clinical significance, *2*: Definite osteophytes with unimpaired joint space, *3*: Definite osteophytes with moderate joint space narrowing, *4*: Definite osteophytes with severe joint space narrowing and subchondral sclerosis

extrusion is observed in the corpus and anterior horn of the lateral graft, while the posterior horn is most frequently within normal values [18]. This extrusion could reduce the functional surface of the graft, and thus, potentially also its biomechanical function. Biological reasons for the observed extrusion post-transplantation could include progressive stretch and failure of the circumferential collagen bundle due to insufficient repair potential or increased catabolism. Future research should focus on the biology involved in ongoing metabolic and cellular processes after transplantation.

Lyophilized allografts showed more shrinkage and degeneration, indicated by altered signal intensity, than did other grafts. Therefore, this preservation technique is no longer used. In the long term, all allograft types show some shrinkage. The exact meaning of the observed shrinkage has yet to be determined. Possible hypotheses are tissue loss due to mechanical wear or a biological process of contraction often observed in scar tissue formation and healing.

In general, healing of the allograft to the rim is observed in the vast majority of patients. The meniscus allograft signal is most frequently abnormal with a more greyish appearance. The authors believe that this change in signal reflects biological remodelling of the extracellular matrix of the allograft, rather than true degenerative changes.

Table 10.7.6 MRI analysis

Author	FUT (years)	MRI
Wirth et al. [23]	14	Deep-frozen allografts Showed good preservation, no reduction in size, homogeneous signal Showed chondromalacia grade 2 Lyophilized allografts Were reduced in size, had altered signal intensity (=degeneration) Showed chondromalacia grade 2 in 16%, grade 3 in 67% and grade 4 in 16%
Noyes et al. [24]	3.3	In the coronal plane: Mean displacement: 2.2 mm 59% of the allografts had no displacement Intrameniscal signal intensity: 4% normal, 46% grade 1, 39% grade 2, 11% grade 3
Stollsteimer et al. [53]	2	42% had an abnormal MRI signal, but no tear Average size of meniscus was 62% of the normal meniscus (graft shrinkage) 9% had 1 mm extrusion
Van Arkel et al. [26]	2.7	63% completely healed to the capsule, 26% partially detached, 11% totally detached 21% showed severe shrinkage, 21% moderate shrinkage 0% had a normal position: 11% bucket-handle-like configuration, 32% extrusion, 58% sub-extrusion
Verdonk et al. [18, 28]	12	No progression of cartilage degeneration in 35% No changes in signal intensity of the allograft in 82% No change in graft position in 35% Tear observed in 12%
	1	The lateral transplanted meniscus is more extruded in comparison to the normal lateral meniscus. The anterior horn (mean 5.8 mm) seems to be more extruded than the posterior horn (mean 2.7 mm)
Hommen et al. [34]	11.7	71% had grade 3 signal intensities 57% had moderately truncated mid-zones; 29% had moderately diminutive anterior horns, 14% had a severely truncated mid-zone 100% moderate graft shrinkage Cartilage classification: 14% normal, 29% mild, 43% moderate and 14% severe
Vaquero et al. [54]	>1	5% changes in signal intensity
Potter et al. [13]	1	63% showed increased signal intensity in the posterior horn tibial attachment (=degenerative changes) Moderate (4) or severe (11) chondral degeneration in 63% 46% showed peripheral displacement Fragmentation (21%) and frank extrusion (12.5%) were associated with full-thickness chondral loss
Rankin et al. [40]	2	The mean height and width of the anterior and posterior horns were similar to native menisci MRI under weightbearing conditions The anterior horn of the native meniscus moved a mean of 5 mm compared to allograft Signal intensity: 25% grade 1, 50% grade 2, 25% grade 3
Bhosale et al. [6]	1	Good integration in all, no rejection Mild extrusion in 20% 63% wedge shaped, 25% flat, 12% expansion 50% had blurred surface 100% had increased signal intensity
von Lewinski et al. [43]	20	Transplants showed shrinkage, degenerative changes 17% subluxation Osteophytes

Stoller et al. classification: Grade 1 represents a non-articular focal or globular intrasubstance focus of increased signal; grade 2 represents a linear focus of intrasubstance increased signal that extends from the capsular periphery of the meniscus, but does not involve an articular meniscal surface; and grade 3 represents an area of increased signal intensity that communicates or extends to at least one articular surface

Extrusion of the allograft: the portion of the allograft that was displaced completely over the peripheral border of the tibial plateau.

Subextrusion: the portion of the allograft that was displaced partially over the peripheral border of the tibial plateau

Second-Look Arthroscopy (Table 10.7.7)

Some authors have demonstrated that clinical evaluation only based on symptoms and physical examination does not allow reliable assessment of the status of the meniscus. Arthroscopic evaluation, however, should not be used as a routine postoperative evaluation tool. Most frequently, it is performed upon clinical suspicion of an intra-articular problem. In some cases, arthroscopic evaluation can be performed in association with another procedure around the knee.

In general, and in accordance with the MRI evaluation, good healing of the allograft to the rim is observed in the vast majority of patients. Tearing and shrinkage can be present. The status of the allograft, however, correlates poorly with the clinical outcome.

Failures and Survival Analysis

In the literature, no consensus exists on the criteria for failure or success. A number of authors use the clinical outcome, while others propose more objective outcome parameters such as MRI or second-look arthroscopy. In general, using objective parameters, the clinical success rate is higher than estimated. In the majority of studies, a clinical success rate of 70% and higher has been reported at the final follow-up. Because the success rate has a tendency to decrease over time, it would be preferable to use survivorship analysis rather than failure rate to describe the success of such a procedure. A survivorship is much more powerful to describe the results irrespective of the duration of follow-up. We all are aware that nothing ruins good results more than a long-term follow-up.

Based on the available survivorship data, a clinical survivorship of 70% at 10 years can be anticipated for both medial and lateral allografts. Ligament instability, axial malalignment and cartilage degeneration are considered by most authors to be associated with a higher failure rate and inferior results, although some authors have reported satisfactory results in degenerative knees.

Conclusion

In conclusion, ample evidence has been presented to support meniscus allograft transplantation in meniscectomized painful knees, with observance of the proper indications. Significant relief of pain and improvement in function have been achieved in a high percentage of patients. These improvements appear to be long-lasting in 70% of patients. Based on plain radiology and MRI, a subset of patients does not show further cartilage degeneration, indicating a potential chondroprotective effect. The lack of a conservatively treated control group is considered a fundamental flaw in the reported studies, making it difficult to establish the true chondroprotective effect of this type of treatment.

Based on the presented results, meniscus allograft transplantation should no longer be considered experimental surgery for the meniscectomized painful knee.

Table 10.7.7 Evaluation by second-look arthroscopy

Author	FUT (years)	
Cameron and Saha [1]	2.5	77% complete healing, 23% failed healing, 0% shrinkage, 60% post-op. Posterior horn tear.
Carter [20]	2.8	18% failed healing, 14% shrinkage 9% arthritis progression
Garrett [15]	2	71% complete healing
Goble et al. [21]	2	72% intact
Wirth et al. [23]	3.8	Deep-frozen: 40% shrinkage, 100% complete healing Lyophilized: 14% incomplete healing/detachment and 93% shrinkage 91% complete healing
Noyes et al. [24] (1998)	1.3	8% complete healing, 31% partial healing, 57% failed healing 29% showed degeneration/tears
	3.3	56% failed healing/degeneration/tears Articular cartilage: 85% abnormal
Rath et al. [25]	2.6	100% complete healing 80% had degeneration/tears Arthroscopy was only performed in case of symptoms
Stollsteimer et al. [53]	3.3	4% loosening
Van Arkel et al. [26]	2.7	79% complete healing, 16% partial healing, 5% failed healing 58% subextrusion, 11% extrusion, 11% bucket-handle 21% shrinkage Articular cartilage: 50% grade 3, 38% grade 3–4, 12.5% grade 4 Outerbridge
Verdonk et al. [3]	7.2	Menisci with poor function or persistent pain had severe allograft degeneration or allograft detachment
Shelton and Dukes [29]	NA	100% complete healing
Veltri et al. [30]	0.5	71% complete healing, 29% partial healing 14% showed degeneration
Del Pizzo [55] unpublished data	3.2	100% showed complete healing 6% showed tear
Yoldas et al. [33]	0.5–1	100% complete healing 33% radial tear <1 cm
Ryu et al. [4]	2.75	50% complete healing 20% degeneration/tear
Cryolife [35]	7	91% fully intact in bone block cases
Vaquero et al. [54]	>1	20% shrinkage 20% loosening
Potter et al. [13]	1	58% subextrusion, 16% extrusion 26% degeneration (fragmentation) Only patients with frank displacement on MRI were confirmed at arthroscopic evaluation 52% focal synovitis at the peripheral capsular attachment All areas that were seen as moderate-to-full-thickness chondral degeneration were confirmed on arthroscopy as OB grade 3–4 change
Stone et al. [5]	5.8	21% torn menisci
Bhosale et al. [6]	1	100% complete healing 12.5% meniscus thinning 25% mild synovitis
Graf et al. [41]	4	100% complete healing 33% had a tear Loose body removal in one case 100% well-vascularized No progression of degenerative changes

Table 10.7.8 Rehabilitation

Author	Rehabilitation program
Cameron and Saha [1]	Week 1–3: immobilization Week 3–6: progressive ROM (first 6 weeks nwb) From week 6: quadriceps and hamstring exercises
Groff et al. [22]	First week: pwb (crutches) with immobilization in extension brace; cpm machine for 3 weeks; full extension at 1 week Second week: passive and active ROM of 0–90°; brace unlocked; weightbearing as tolerated Week 4–6: 90°, crutches discontinued From week 6: closed-chain exercises From week 8: low-impact sports Rehabilitation of 2–3 months Return to strenuous work at 3–4 months, to running at 4–5 months Return to strenuous sports not encouraged
Wirth et al. [23]	Immediately after surgery: CPM and physical therapy Week 1–12: rehabilitation program Week 13: fwb
Noyes et al. [24]	Immediately postoperatively: long leg brace for 8 weeks; ROM 0–90° exercises from the first day; flexibility and quadriceps exercises Flexion increased every week by 10° to allow 135° after week 4 Week 1–2: only toe-touch wb, increased to 50% wb after week 4 Week 6: fwb; balance, proprioception and closed-chain exercises Week 8: stationary cycling with low resistance Week 9–12: swimming and walking programs After 12 months: light recreational sports Advised to never return to high-impact strenuous athletics again If PCL reconstruction: restricted in flexion and wb for 8 weeks If ACL reconstruction: other protocol Bledsoe thruster brace when abnormal articular cartilage
Rath et al. [25]	From day 1: quadriceps and hamstring exercises, limited ROM 0–90° Week 1–4: nwb Week 4–6: pwb 6–9 months: full activity Never aggressive cutting sports or distance running again
Stollsteimer et al. [53]	Immediately postoperatively: full ROM exercises Week 1–6: no fwb Jogging at 3 months, sports at 6 months
Verdonk et al. [3, 18]	Week 1–3: nwb with ROM flexion to max 60° Week 3–6: ROM 0–90° + pwb From week 6: walking with one crutch Week 1–3: nwb with ROM flexion to max 60° Week 3–6: ROM 0–90° + pwb From week 6: walk with 1 crutch
Shelton and Dukes [29]	Immediately postoperatively: full ROM, nwb till week 6 From day 1: quadriceps and hamstring exercises Week 6: fwb 6 months: return to sports if knee is fully rehabilitated
Veltri et al. [30]	Week 1–6: pwb + ROM exercises in hinged brace After week 6: fwb as tolerated
Cole et al. [31]	Immediately postoperatively: wb as tolerated with crutches + hinged brace + immediate active and passive ROM without limitation Week 1–6: flexion wb <90° restricted After week 6: no brace + ROM as tolerated After 12 weeks: jogging allowed with progression to running and sport-specific-type drills
Yoldas et al. [33]	Immediately postoperatively: quadriceps sets and straight leg raises Day 1: start passive ROM with CPM, for 1 month

(*continued*)

Table 10.7.8 (continued)

Author	Rehabilitation program
	Week 1: full extension, pwb, brace locked in extension From week 2: wb as tolerated Week 4–6: 90° flexion, fwb, closed-chain exercises Rehabilitation of 2–3 months
Ryu et al. [4]	Immobilization in full extension with progressive wb over 4–5 weeks Week 1–4: ROM 0–90° From week 5: gradual increase in flexion of 10–15° each week If concomitant ACL reconstruction: ACL protocol was subordinated to meniscal allograft requirements
Hommen et al. [34]	Immediately postoperatively: quadriceps sets and straight leg raising 24h after surgery CPM till 1 month
Felix and Paulos [36]	Postoperatively braced in extension. Plantar touch wb Week 3: 60° flexion Week 4: progressive wb increased by 25% every week Week 6: full flexion Week 7–8: fwb 6–9 months: full activities and sports
Sekiya et al. [37, 38]	Immediately postoperatively: exercises, pwb with crutches, brace locked in full extension Day 1: cpm Week 1: full extension Week 2: wb as tolerated, sedentary work Week 4–6: 90° flexion, stop crutches From week 6: closed-chain exercises Strenuous work and running after 5–6 months – sports after 6–9 months Immediately postoperatively: exercises, pwb with crutches, brace locked in full extension Day 1: cpm Week 1: full extension Week 2: wb as tolerated, sedentary work Week 4–6: 90° flexion, stop crutches From week 6: closed-chain exercises Strenuous work and running after 5–6 months - sports after 6–9 months
Stone et al. [5]	Week 1–4: maximally protective phase = pwb (week 1 and 2: 10 and 20% toe touch), extension-locked hinged brace, passive and active ROM, daily icing and elevation, straight leg exercises, manually resisted hip, foot and ankle exercises, pool workouts, soft-tissue treatments, a trunk stabilization program, nwb aerobic exercises Week 4–12: moderately protective phase = stretching, manual treatments to restore ROM, introduction of functional exercises (i.e., partial squats, calf raises and proprioception exercises), road cycling as tolerated, slow walking on a low-impact treadmill and lateral training. Exercises increasingly focus on single-leg exercises, strength training and sport-specific training for a gradual return to activities No resisted leg extension machines, no high-impact, cutting or twisting activities for at least 4 months postoperatively
Fukushima et al. [39]	24–48 h postoperatively: start ROM exercises Week 1–4: nwb Week 5: pwb 50% Week 6: fwb + flexion >90° allowed Week 8–10: closed-chain exercises Never strenuous/contact/rotational sports in the future
Rankin et al. [40]	Postoperatively: long leg brace for 6 weeks, ROM 0–90°, toe-touch wb first 2 weeks, flexibility and quadriceps strengthening exercises Week 3–4: flexion to 120°, 50% wb Week 5–6: ROM 0–135° at 4 weeks Week 6: fwb + balance, proprioception, closed kinetic chain exercises Week 7–8: stationary cycling Week 9–12: start swimming and walking 12 months: light recreational sports Never high-impact activities/ strenuous athletics again

Table 10.7.8 (continued)

Author	Rehabilitation program
Bhosale et al. [6]	The Oscell rehabilitation for ACI procedure and limitation of knee flexion to 45° for 3 weeks Week 12: fwb
Graf et al. [41]	Week 1–2: nwb, light resistive isometric exercises, medial unloading brace 10–90° (if + ACL reconstruction: derotational brace), stationary biking when 90° was obtained Week 2–4: pwb Week 5: fwb Week 6: resistance exercises 3 months: advancement in rehabilitation exercises and strengthening programs 6 months: stop bracing, start straight line jogging (without cutting and pivoting) 8 months: start agility exercises 1 year: sporting activities (never high-impact, running, jumping, twisting or turning sports again)
Rueff et al. [42]	Week 1–6: ROM limited to 0–90° Early wb
von Lewinski et al. [43]	Postoperatively: strengthening exercises for quadriceps muscle, brace with limited ROM for 12 weeks Week 1–6: ROM 30–60° Week 6–12: ROM 20–90° Week 1–12: pwb 10 kg
Dienst and Kohn [46]	Postoperatively: ROM 0–90° active + passive exercises, pwb with brace locked in extension for 6 weeks 3 months: full squat allowed 1 year: sport activities allowed

ROM range of motion; *nwb* non-weightbearing; *cpm* continuous passive motion; *pwb* partial weightbearing; *fwb* full weightbearing; *wb* weightbearing

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Part XI

Meniscal Reconstruction – Substitutes

Menaflex (TM) Collagen Meniscus Implant: Basic Science

11.1

W. G. Rodkey

Rationale and Development

We have used innovative tissue engineering techniques and collagen matrix technology to develop a resorbable collagen template (the Menaflex (TM) Collagen Meniscus Implant or CMI) that supports ingrowth of new tissue and eventual regeneration of the lost meniscus cartilage [1–9]. The hypothesis of this research was that the meniscus has the intrinsic ability to regenerate, provided that the biological environment is suitable for regeneration and that a tissue-engineered extracellular matrix scaffold can be used to support and guide meniscus regeneration [2, 5, 7, 8].

Collagen, a group of proteins of similar structural characteristics, is the most abundant protein in the body [1]. It is the major component of bone, skin, ligament, and tendon. Since collagen, particularly type I collagen, possesses the physicochemical, mechanical, and biological properties that are suitable for tissue and organ repair, this protein has been extensively researched in the past decades as a biomaterial for medical implant development [1].

For an engineered collagen matrix to function as a resorbable meniscus template, one must be certain that the design requirements for the device are met [1]. Of particular importance are the biomechanical properties of the matrix template since the template serves the biomechanical function of the meniscus. Thus, the initial biomechanical strength of the engineered template and the subsequent biomechanical properties of the regenerated and remodeled tissue must be adequate for the device to survive initially in the hostile environment of the knee, and then to function like meniscus tissue. Additionally, the extracellular matrix must be conductive for cells as well as permeable to nutrients. The biological signals (e.g., growth factors) and the cells may be incorporated into the template to accelerate the overall regeneration and remodeling process and may also provide an ideal biological environment for cellular infiltration and new matrix synthesis [1, 2, 5, 7].

The Menaflex CMI is a porous collagen-glycosaminoglycan (GAG) matrix of defined geometry, density, thermal stability, and mechanical strength [1, 2]. The CMI is composed of about 97% purified type I collagen, the most commonly found protein in the body. The remaining portion of the CMI consists of GAGs including chondroitin sulfate and hyaluronic acid [1, 7, 8]. The type I collagen is isolated and purified from bovine Achilles tendons from animals originating in the United States. The collagen-GAG complex is chemically cross-linked to enhance in vivo stability and for ease of handling and implantation [1]. The suture pull-out strength of the fully hydrated CMI at 3 mm from the edge is greater than 20 Newtons, thereby permitting the implant to be properly positioned in the joint and fixed with sutures to the host meniscus remnant [1].

In Vitro Laboratory and In Vivo Animal Studies

Numerous in vitro studies were completed before in vivo animal studies were begun [7]. We conducted several different organ culture studies to assess the different prototypes of the implant. These in vitro studies permitted us to evaluate this collagen scaffold in an organ culture system to assure that the pore size was adequate to permit the meniscus fibrochondrocytes to

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_11.1,

migrate into and through the matrix. We were also able to determine whether these cells then could divide and populate the scaffold while synthesizing new tissue matrix [7].

The positive results and findings of the in vitro studies encouraged us to move forward with laboratory animal studies. The collagen scaffold material that we selected for these initial preclinical in vivo studies was the one that supported the most cellular ingrowth in the in vitro studies.

We used immature pigs for the animal model for the initial pilot studies [7]. An 80% subtotal resection of the medial meniscus was done, and then an implant was trimmed to fit the ensuing defect. In this small pilot study, the implanted joints were evaluated at 1, 3, or 6 weeks following placement of the CMI. At each evaluation period, it appeared that the implant was in the process of being resorbed without evidence of joint destruction, cartilage wear or abrasion, or other degenerative joint disease. Grossly, there was early evidence of new tissue regeneration in all joints. Histologically, we consistently observed granulation tissue with vascular proliferation. The conclusion was that a CMI could be placed in the knee joint of animals without causing any negative effects [7]. However, this pilot study left unanswered questions regarding mechanism of resorption of the scaffold, any potential biomechanical function, and whether or not this material truly supported regeneration of meniscus tissue. Consequently, we felt that it was necessary to pursue additional longer-term studies in a more traditional animal model for the meniscus.

Most of our subsequent animal studies were performed in mature dogs because the biology of the canine meniscus has been reported extensively and is at least comparable to that of humans [5, 7, 8]. For example, canine menisci, like human menisci, may partially but incompletely and ineffectively regenerate after subtotal resection, and it is likely that any tissue that does regenerate probably does not protect the joint biomechanically from degenerative changes which lead to osteoarthritis. Furthermore, it has been well documented that after partial meniscectomy, dogs develop joint instability and arthritic changes in 6 to 8 weeks.

Observations from some early canine studies led us to conclude that this collagen scaffold would support tissue ingrowth and regeneration in an animal model that behaves biologically in a manner similar to the human [1, 7, 8]. We did not observe any adverse effects from placement of this material into the knee joints of dogs, and the newly regenerated tissue appeared to function biomechanically in a manner adequate to minimize degenerative joint disease and osteoarthritis [1, 7, 8]. These early studies left us with several more questions unanswered, and it stimulated us to continue with our laboratory research. Additionally, we made changes in the physical size and shape of the CMI that necessitated additional studies [1].

Consequently, several additional animal studies were done to answer specific questions. One such study involved a "die punch" model in which a 3-mm circular defect was produced in the red–white zone area of menisci of dogs [1]. These defects were then filled either with a similar sized piece of the collagen scaffold or with a fibrin clot produced from the dog's own blood. The knees were then evaluated at either 3 or 6 months. That study revealed that at 6 months, the scaffold regenerated tissue had excellent attachment to the host meniscus. A similar observation was made with the new tissue that had replaced the fibrin clot. Biochemically, both the scaffold regenerated tissue and the fibrin clot regenerated tissue contained more water than the normal canine meniscus. This finding would be expected since immature tissue tends to have higher water content. Biomechanically, the CMI-regenerated tissue was virtually identical to normal canine meniscus when evaluated for aggregate modulus and permeability. In contrast, the fibrin clot regenerated tissue at 6 months had a significantly higher aggregate modulus and a significantly lower permeability. This study further confirmed that the CMI-regenerated tissue matures over time, and by 6 months, has begun to take on characteristics similar to normal meniscus tissue [1].

Another study performed later in the development phases of the CMI was conducted after the size and shape of the implant were modified to its present physical structure. In this study, we examined the temporal changes of the implant and newly regenerated tissue complex using a subtotal meniscectomy model in 12 dogs [1]. Specimens were evaluated at 3, 6 weeks, 3 and 6 months. This study involved a correlation of gross findings, histology, and MRI examination of the joints. Both medial menisci of each dog underwent subtotal resection followed by placement of a CMI specifically designed for use in dogs. The timing of the surgery was staggered for the right leg vs. the left leg, so that each animal provided a specimen of two different time points. That is, 6 dogs provided a 3 week and a 3 month specimen, while the remaining 6 dogs provided 6 week and 6 month specimens [1].

We observed excellent healing of the implant regenerated tissue to the host meniscus rim (Fig. 11.1.1). Over the serial time points, it could be seen that there was more tissue integration at the outer periphery that appeared to progress toward the inner rim of the meniscus. Histologically, there were increasing amounts of tissue invasion and resorption of the CMI at each time point studied. By 6 months, virtually the entire implant had been resorbed and replaced with dense bundles of newly formed collagen (Fig. 11.1.2). The MRIs provided an excellent correlation with the gross and histological observations and supported the findings of continued tissue ingrowth and maturation over time [1].

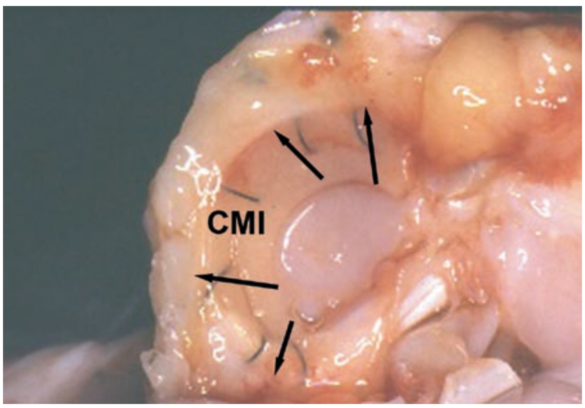

Fig. 11.1.1 As early as 6 weeks after implantation in a dog knee, the CMI demonstrates excellent healing to the host medial meniscus rim (*arrows*)

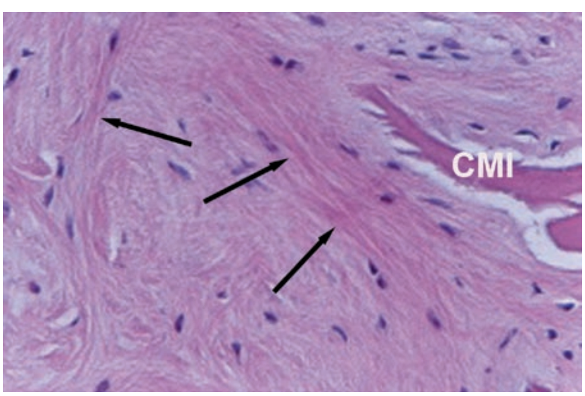

Fig. 11.1.2 In this histological section, virtually the entire CMI has been resorbed, leaving only a small remnant of the original implant (CMI). The *arrows* point to dense bundles of newly formed collagen that have replaced the resorbed CMI. H&E stain, original magnification = 100×

Based on these numerous animal studies [1, 5, 7, 8], we drew several conclusions. We found that the collagen scaffold can be implanted and conforms well to the shape of the joint into which it is placed. Most of the animals had good clinical results based upon treadmill exercise, gait analysis, and physical examination. We observed no apparent negative effects from placement of the CMI. Both grossly and histologically, the newly regenerated tissue had an appearance that was similar to native meniscus. It appears that this collagen scaffold material is biocompatible, and we confirmed that it supports tissue regeneration. We saw no degenerative changes, no joint motion interference, no abrasion or synovitis, and no allergic or immune reactions attributable to the collagen scaffold [1, 5, 7, 8]. Hence, we concluded that it was safe to move forward with human clinical trials.

Human Clinical Trials

These animal studies were the basis of United States Food and Drug Administration (FDA) approval for human clinical trials. An initial Phase I feasibility study was completed [9], and that experience led to improved shape of the CMI as well as improved surgical techniques (Figs. 11.1.3 and 11.1.4). A Phase II feasibility study was completed, and those results were reported at 2 years [4] and again at 6 years of follow-up [6]. The positive results after 2 years led to FDA approval of a large prospective randomized multicenter clinical trial in the US involving more than 300 patients at sixteen investigative sites [3]. The results of that study were positive, especially in those patients who had undergone previous partial meniscectomy [2, 3]. That study concluded that the Menaflex CMI supports growth of new tissue that is adequate to enhance meniscus function as evidenced by improved clinical outcomes [3]. The new CMI-regenerated tissue is stable, safe, and appears biomechanically competent [2, 3]. The Menaflex CMI has the utility to be used to reconstruct irreparable or lost meniscus tissue in patients with a meniscus injury and improve the functional outcomes of its recipients. The results of that study have been reported [3] (Figs. 11.1.5–11.1.7).

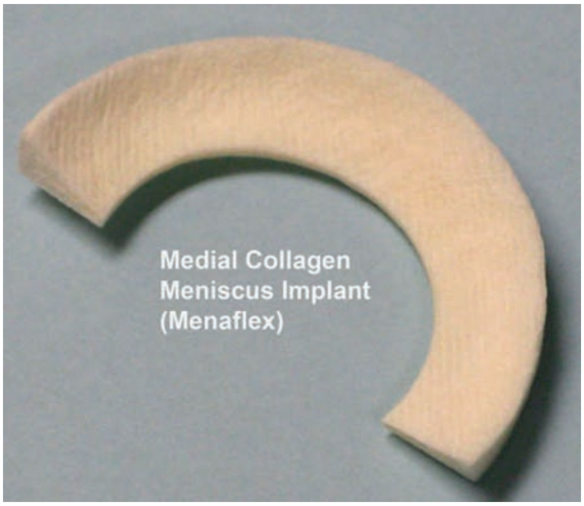

Fig. 11.1.3 Nude CMI. The CMI (Menaflex™) as it appears coming from the package

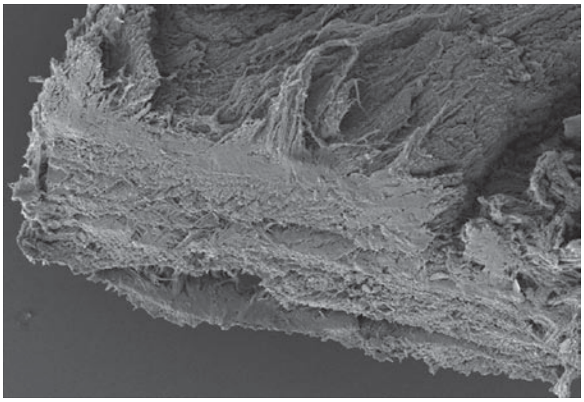

Fig. 11.1.5 Seven months. This scanning electron photomicrograph shows the appearance of the collagen meniscus implant 7 months after implantation in a human clinical patient. Note that the implant now appears as a solid structure due to the new tissue formation. (Courtesy of Paolo Bulgheroni and Mario Ronga, Varese, Italy)

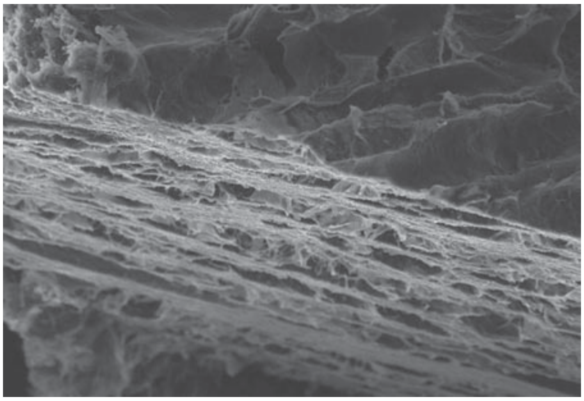

Fig. 11.1.4 Unimplanted CMI. This scanning electron photomicrograph shows the appearance of the collagen meniscus implant prior to implantation. (Courtesy of Paolo Bulgheroni and Mario Ronga, Varese, Italy)

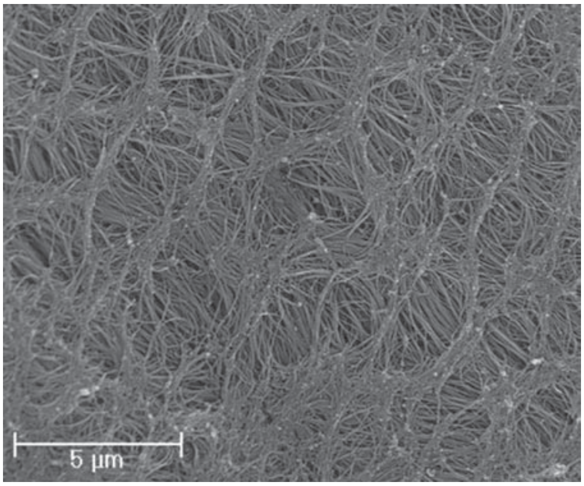

Fig. 11.1.6 Eighteen months. This surface scanning electron photomicrograph shows the appearance of the collagen meniscus implant 18 months after implantation in a human clinical patient. Note that the new collagen fibrils are smaller and more uniform than those in the original implant. (Courtesy of Paolo Bulgheroni, Varese, Italy)

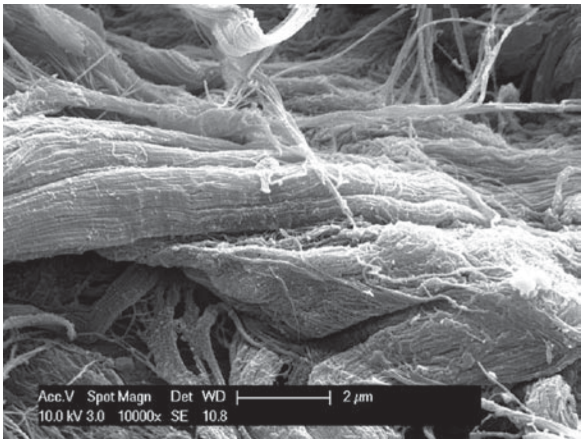

Fig. 11.1.7 Five Years. This scanning electron photomicrograph shows the appearance of the collagen meniscus implant in its center 5 years after implantation in a human clinical patient. Note that the new collagen fibers and fibrils are very compact and dense. (Courtesy of Paolo Bulgheroni, Varese, Italy)

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Collagen Meniscus Implant: Technique and Results

11.2

J. C. Monllau, X. Pelfort, and M. Tey

Introduction

The early degeneration of knee joint articular surfaces following meniscectomy was well described in the literature of the last century [4]. This detrimental effect, caused by the higher compressive loads in the involved compartment, has recently been introduced in the concept of meniscal replacement [5]. Although allografts used for meniscal substitution have shown good early results, information about the long-term effects of this procedure and particularly its protective effect on cartilage is scarce [12]. Furthermore, the limited availability of meniscal allografts along with potential infectious disease transmission has motivated some authors to explore the possibilities of scaffold-guided meniscal tissue regeneration.

The Menaflex™, former collagen meniscus implant (CMI), was developed from bovine collagen in the early nineties in order to promote meniscal regeneration in segmental defects of meniscal tissue [10, 11]. Experimental and clinical experiences with the medial CMI, to date, have shown promising results [8, 9, 13], and a lateral CMI has recently been developed.

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The purpose of this chapter is to describe the CMI surgical technique along with some tips and gems gleaned from experience that might provide the most successful outcome. The mid-term results of a medial CMI series are also presented.

Surgical Procedure

Implantation of the CMI is performed using an arthroscopic surgical procedure with specially designed instruments and requires skill in meniscal repair techniques. Basically, the damaged meniscus is debrided until healthy tissue is reached. After the size of the defect created in the meniscus has been measured, the implant is trimmed to fit the lesion. The prepared implant is then inserted into the knee joint, placed into the defect and fixed using either an inside–out or an all-inside suturing technique. The final goal is an implant that fits perfectly into the meniscus defect and is stable along the entire length. No drains should be used after surgery, especially if an isolated meniscus procedure has been performed. In case of poor bleeding, some microfracture holes should be made in the intercondylar notch to obtain an extra blood supply as well as some bone marrow stimulation.

Technical Points Specific to the Medial CMI

Patient Positioning

The patient is positioned supine on the surgical table. The affected limb is placed with the knee flexed to 90°

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_11.2, © Springer-Verlag Berlin Heidelberg 2010

and the thigh well beyond the table hinge. This provides access to the posteromedial corner of the knee, which can be useful in the subsequent suturing procedure. If a limb holder is used, it should be placed high enough on the thigh to allow access to the aforementioned area of the knee. The authors simply use a lateral post placed some 5 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.

Establishing Portals

The surgery starts with a standard anterolateral portal placed adjacent to the patella and a thumb's breadth above the joint line. Careful arthroscopic inspection is then performed. If the medial meniscus satisfies the criteria for CMI (irreparable meniscus tear or loss of meniscus tissue), an anteromedial portal is placed slightly more distally so that the surgeon can easily reach the posterior horn. The use of an 18-gauge spinal needle might help localize the most appropriate place. Accessory portals might be needed in order to obtain the desired view or access.

Preparing the Implant Bed

Proper preparation of the implant site requires the removal of any degenerative or unstable meniscal tissue in order to obtain a full-thickness defect and a stable meniscus rim over the entire length. 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 accept the CMI with maximum congruence. The prepared site should extend into the vascular zone of the meniscus to guarantee an adequate blood supply. This can be accomplished by making puncture holes in the meniscal rim with either an 18-gauge spinal needle (from the outside of the joint) or a microfracture awl (from the inside). Because the potential channels obtained with a needle tend to close after needle withdrawal [14], the authors currently use either formal trephination with a more aggressive trephine or radiofrequency trephination (Fig. 11.2.1). The latter creates an area of synovial necrosis adjacent to the implant that is promptly substituted by a newly formed and more vascular synovial layer, which invades the scaffold implant like a wave [3].

If the medial compartment space is too tight for proper visualization, an arthroscopic partial release of the medial collateral ligament permits good access and facilitates manoeuvrability. The medial release can easily be done with multiple outside–in needle punctures while applying a valgus stress to the leg until a crack is heard. As we have not noted any residual valgus instability following this procedure, there is no need for a knee brace or a knee immobilizer.

Once a stable and bleeding implant site has been prepared and there is sufficient manoeuvring space, the meniscus defect is measured using a specially designed measuring device (Fig. 11.2.2). The obtained measure should be oversized by 10% in order to obtain a good press-fit. The tailored implant can then be rehydrated and inserted into the delivery cannula (standard method) or just mounted on a curved atraumatic vascular clamp and directly inserted into the joint without previous rehydration (dry insertion) (Fig. 11.2.3). The latter is the authors' preferred method because of its simplicity and the swiftness of the procedure. Regardless of the method used, the anteromedial portal should be previously enlarged using a vertical cut to accommodate the surgeon's fifth finger in order to facilitate the manoeuvre. The implant tends to be stable within the compartment once it has been placed in the joint. However, a loop suture can optionally be used to temporally hold it in place until the first stitch is placed.

Suturing

Inside–Out Technique

According to Cannon [1], a 4-cm long posteromedial skin incision centred slightly below the joint line is made when an inside–out suture technique is used. The incision runs parallel to the posterior margin of the medial collateral ligament. The infrapatellar branch of the saphenous nerve should be identified after blunt dissection (Fig. 11.2.4). Subsequently, a spoon retractor is placed as deeply as possible between the posterior capsule and the medial head of the gastrocnemius

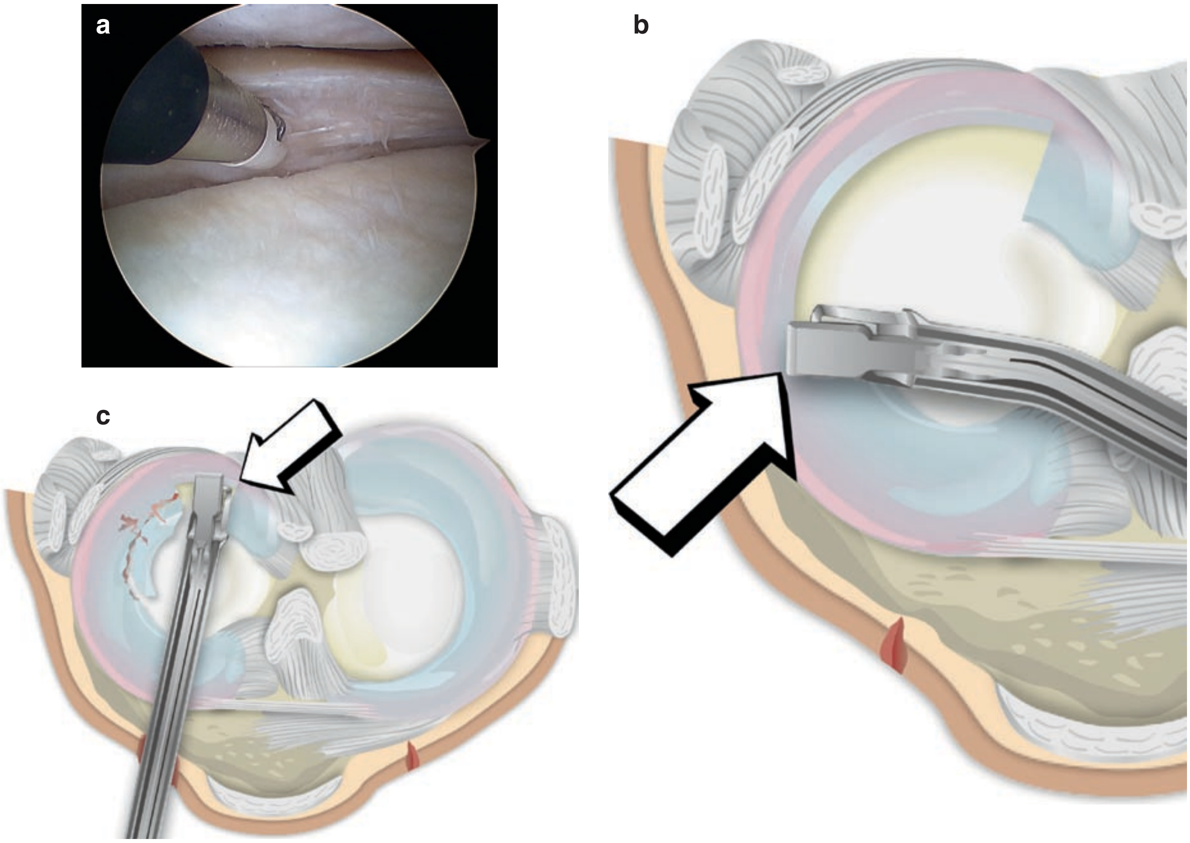

Fig. 11.2.1 (**a**) Arthroscopic view of a right knee medial meniscus after partial meniscectomy, showing the application of radiofrequency in the adjacent synovial tissue. (**b–c**) The prepared site should extend into the vascular zone of the meniscus. A combination of straight and angled basket punches is useful

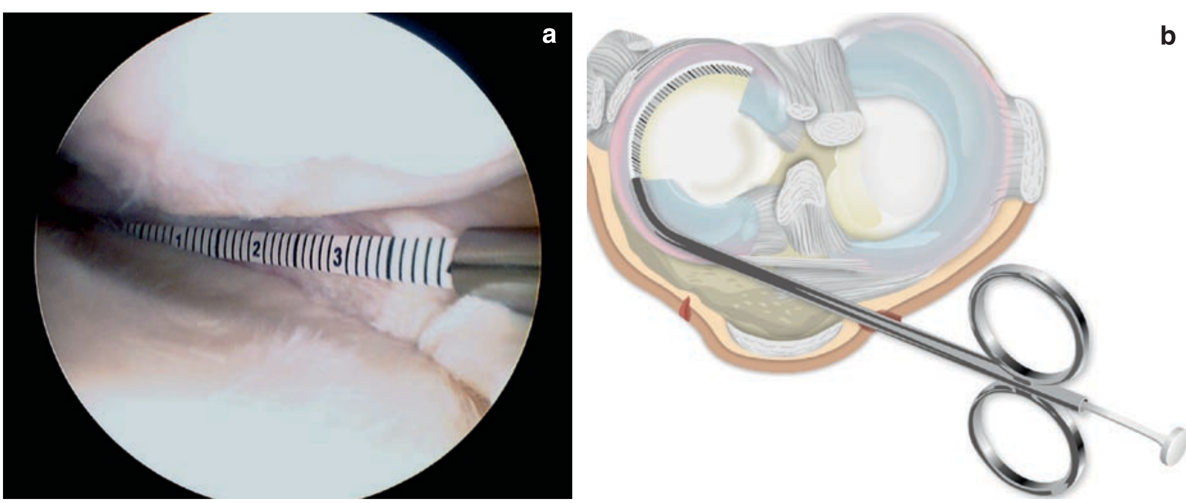

Fig. 11.2.2 (**a**, **b**) Arthroscopic view showing the measuring rod placed along the meniscus defect

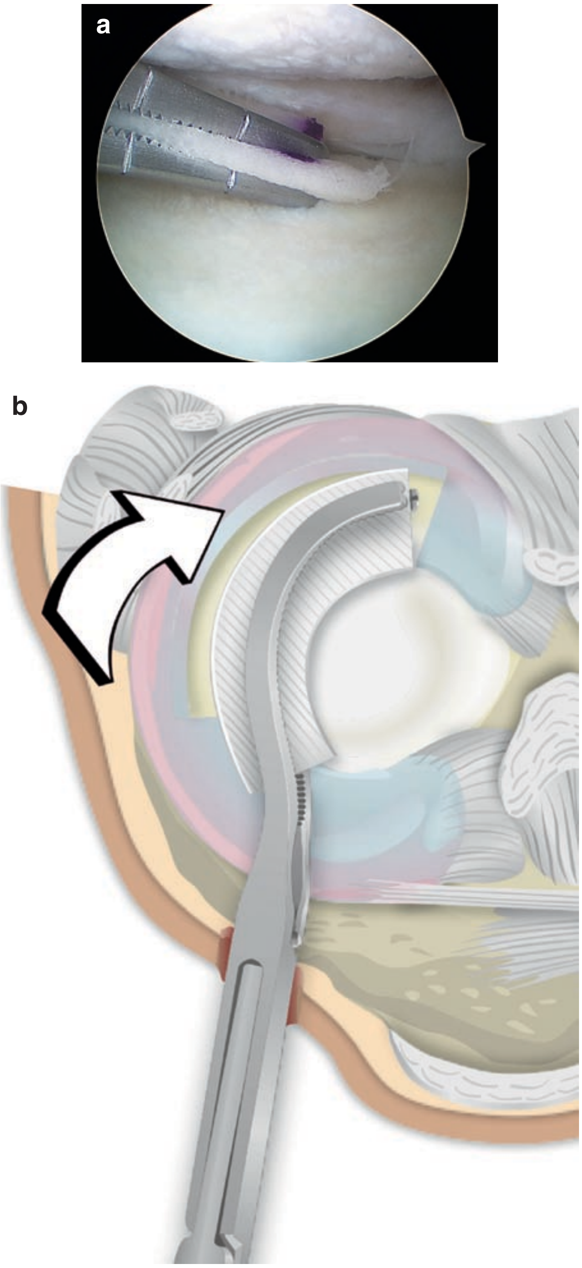

Fig. 11.2.3 (**a**, **b**) Dry insertion of a medial CMI. The vascular clamp leaving the scaffold in front of the already prepared defect site

to facilitate the capture of the needles during the suturing procedure. When a large defect (4–5 cm) is to be repaired, dissection superficial to the medial collateral ligament might be required. Alternatively, the needles can be retrieved directly by making small skin nicks (about 1 cm) and dissecting the soft tissues, because

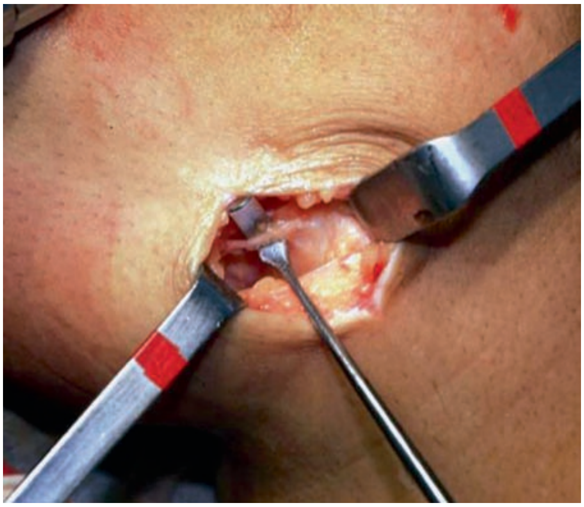

Fig. 11.2.4 Intraoperative photograph of the posteromedial approach to a left knee. The infrapatellar branch of the saphenous nerve (protected with a small retractor) should be identified to avoid iatrogenic injuries

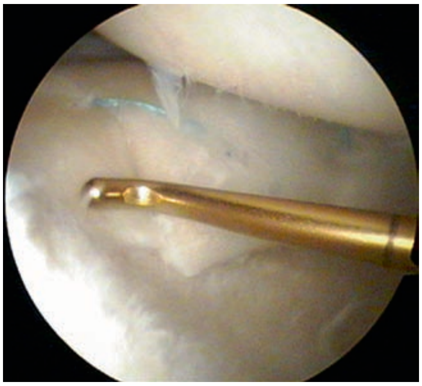

Fig. 11.2.5 Arthroscopic view of the most posterior part of a medial CMI. Note the horizontal suture placed to fix the implant to the posterior horn

the risk of neurovascular damage is low in this particular area.

Suturing can be done by using a conventional inside–out zone-specific instrumentation set (ConMed Linvatec, Largo, FL) or the more sophisticated SharpShooter® Tissue Repair System (ReGen Biologics, 545 Penobscot Drive, Redwood City, CA). The CMI is sutured to the remaining meniscus rim with vertical mattress sutures of 2–0 braided polyester placed approximately 5 mm apart. The anterior and posterior ends of the implant are secured with horizontal sutures (Fig. 11.2.5). Each part of the CMI is approached from the most appropriate portal using the most adequate cannula. In order to fix the stitches, knotting outside the joint capsule is necessary. The suturing process can be done either from the posterior to the anterior end of the implant or vice versa, depending on the surgeon's preferences.

All-Inside Technique

The use of the all-inside FasT-Fix™ Suture System (Smith & Nephew, Inc., Andover, MA) has recently been introduced as an alternative suturing technique. This new-generation meniscus repair device is designed to take advantage of the benefits of both the all-inside technique and the biomechanical properties of sutures. It is particularly useful for the posterior third of the meniscus, because it obviates the need for any additional approach to retrieve sutures. Although clinical experience with this procedure is limited, the authors have been using it over the last 2 years without complications. Again, vertical mattress sutures should be used to minimize the risk of damage to the implant (Fig. 11.2.6). It appears that fewer sutures, approximately one every 10–15 mm, are needed with this suturing technique.

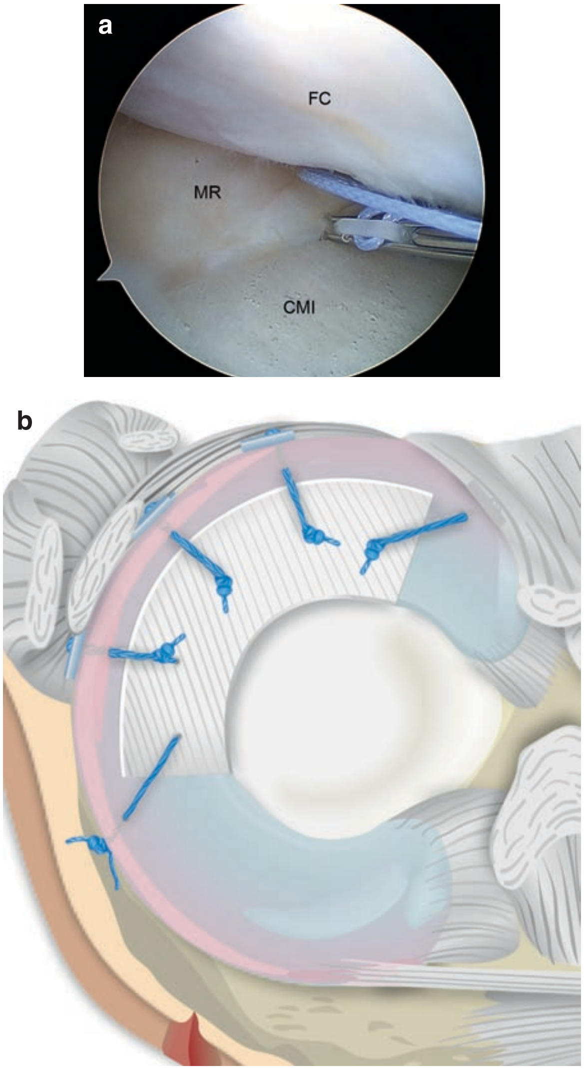

Fig. 11.2.6 (**a**, **b**) Operative view of a medial CMI fixed with an all-inside suturing device

Technical Points Specific to the Lateral CMI

The lateral CMI has been the subject of a post-marketing study in Europe since receiving the CE mark in 2006. Its specific surgical technique has recently been developed with the help of several experienced European surgeons (unpublished data). 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 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. Furthermore, it seems that a suture placed across the popliteal tendon does not cause any symptoms in a conventional meniscal repair procedure [1, 7]. However, the use of sutures across the popliteus tendon cannot be recommended in case of CMI substitution, because the physiological micromotion of this tendon might damage the still immature scaffold. An implant oversized by 20%, not fixed at the hiatus, seems to be the most prudent recommendation if the surgeon decides to use a CMI in this particular situation.

Patient Positioning

The patient is positioned supine on the operating table. The affected leg is positioned with the knee hanging free and flexed to 90° with the contralateral leg fully extended on the surgical table. This allows the leg to be flexed over the contralateral knee in a figure-four position. This position places a varus force across the knee, opens up the lateral compartment, and provides easier access to the posterolateral corner during an inside–out suturing procedure.

Arthroscopic Portals

The anterolateral portal is placed in the standard position 1 cm superior to the joint line, although slightly more lateral and approximately a thumb's breadth lateral to the patella. The anteromedial portal is placed in a position that allows good access to the lateral compartment, particularly to its most anterior aspect. This is usually a thumb's breadth medial to the patella and slightly higher over the joint line than that for the medial CMI.

Preparation and Delivery

The preparation of the implant site is largely the same as for the medial CMI. The O-shape of the lateral meniscus might make a square cut more difficult, particularly at the anterior horn. Therefore, special care should be taken to tailor the CMI in such a way that the implant matches the shape of the meniscus defect (Fig. 11.2.7). Dry insertion is the rule because of the almost circular shape of the lateral CMI. An enlarged lateral portal is mandatory. When enlarging this portal (Fig. 11.2.8), it is extremely useful to lower it to the level of the joint line with an 11-blade scalpel. This simple manoeuvre will facilitate the insertion of the loaded vascular clamp. The surgeon must be careful not to injure the cartilage with the clamp jaws after the CMI has been inserted into the lateral compartment, especially when opening the jaws. A probe or blunt trocar can be used to manoeuvre the implant into the correct position and an optional loop suture can again be used to hold it in place. If the lateral compartment is too tight, it may not be possible to place the CMI into the defect, which precludes CMI implantation.

Suturing

Inside–Out Technique

An additional posterior approach as described by Cannon [1] is required when an inside–out suture technique is used. With the knee flexed to 90°, a 4-cm longitudinal incision is made just posterior to the lateral collateral ligament. Surgical dissection proceeds between the posterior edge of the iliotibial band anteriorly and the anterior border of the biceps cruris posteriorly. The peroneal nerve is identified behind the biceps tendon. The interval between the posterior capsule and the lateral head of the gastrocnemius is defined and a spoon retractor is placed as deeply as possible.

When using zone-specific cannulas, the sutures are placed either from the anteromedial portal (anterior horn and middle third) or from the anterolateral portal (posterior horn) in order to approach the implant with maximum perpendicularity.

All-Inside Technique

Again, the main advantage of this technique is that the time-consuming posterior approach can be avoided. However, it is difficult to properly fix the most anterior part due to the curvature of the lateral CMI. Therefore,

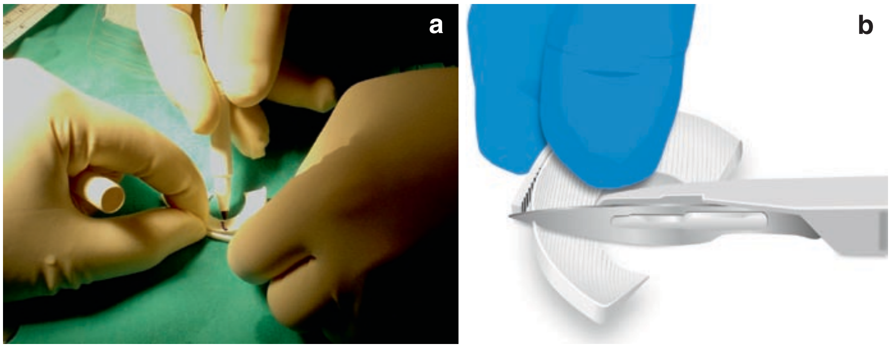

Fig. 11.2.7 (**a**, **b**) Tailoring a lateral CMI

the combined use of FasTFix™ (posterior and middle thirds) and SharpShooter® (anterior third) (Figs. 11.2.9 and 11.2.10) is not uncommon on this side. In some instances, the addition of an outside-in stitch to fix the anterior horn might even be useful. This can easily be done with the help of an 18-gauge spinal needle and a monofilament suture.

The early results obtained with the lateral CMI in a limited series of cases have been promising and the behaviour of the implant in terms of meniscal regrowth seems to be quite similar to that of the medial one (Fig. 11.2.11).

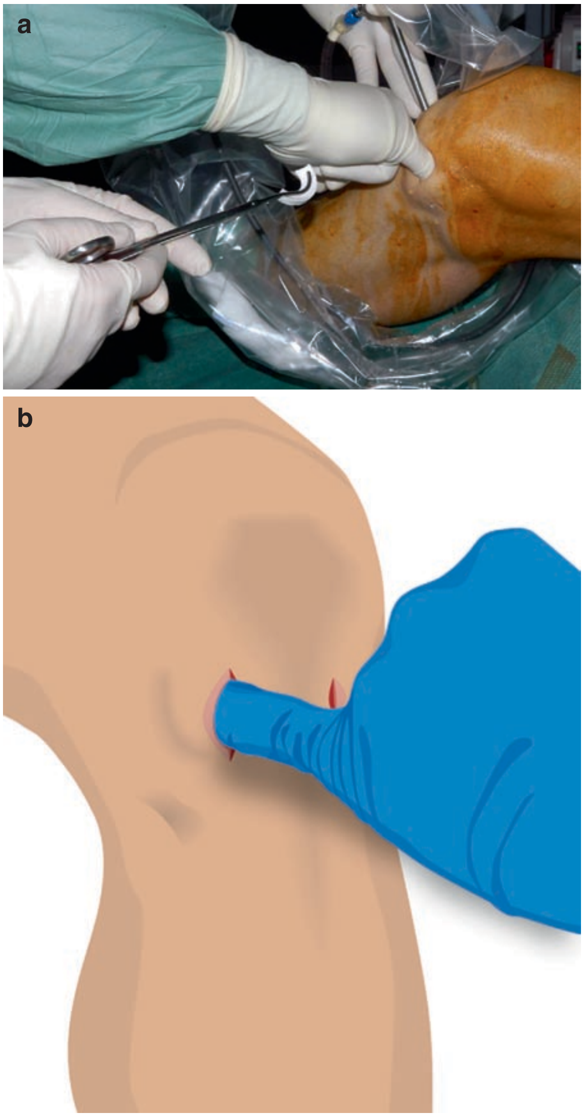

Fig. 11.2.8 (**a**, **b**) Enlarging the lateral portal with the surgeon's fifth finger previous to CMI insertion

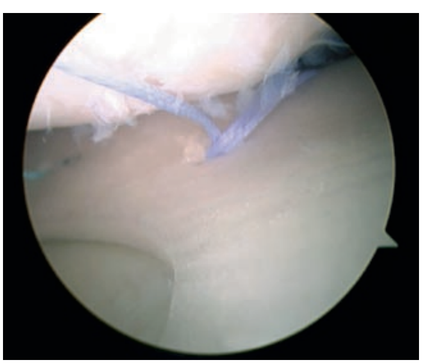

Fig. 11.2.9 Suturing a lateral CMI with zone-specific cannulae in the "safe zone". Arthroscopic view

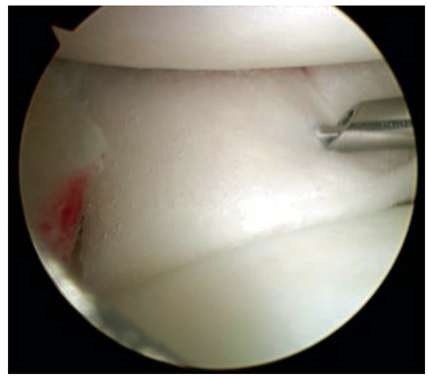

Fig. 11.2.10 The nitinol needles are retrieved through small skin nicks

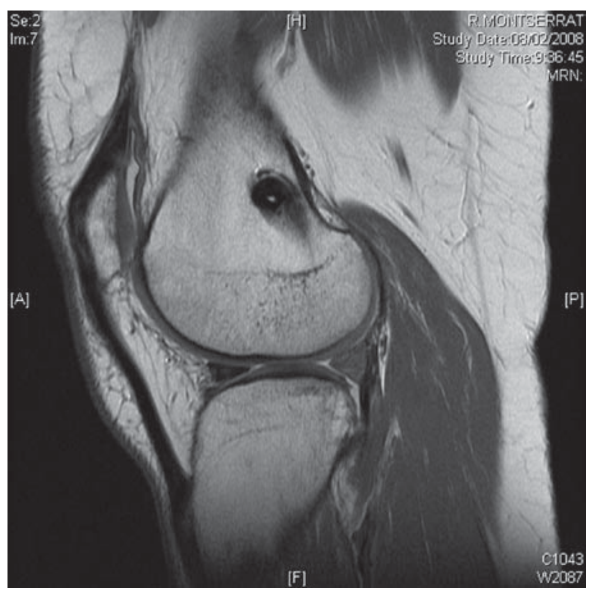

Fig. 11.2.11 One-year follow-up MRI result of the case shown in Figs. 11.2.9 and 11.2.10. Complete regrowth of a newly formed meniscus can be observed at the posterior horn

Combined Surgeries

ACL Deficiency

Combined ACL reconstruction and meniscus repair has been reported to create a more favourable environment for meniscus healing [7]. Since medial meniscectomy in an ACL-deficient knee may lead to a significant increase in laxity, combined reconstruction of both structures is especially recommended. If the procedures are to be staged, CMI implantation should be performed first and ACL reconstruction should be completed within 12 weeks, because knee instability might be detrimental to the implant. In case of concurrent procedures, the CMI must be implanted first because, with the reconstructed ACL resulting in a tighter knee, it may be more difficult or even impossible to work inside the compartments. When applying a valgus load to an ACL-deficient knee to open up the medial compartment, the tendency of the tibial plateau to slide forward has to be taken into account. In some instances, it makes it difficult to work on the posterior horn of the medial meniscus. No drain is used after surgery, since as mentioned before, postoperative hemarthrosis might create an appropriate biological environment to start the healing process of the CMI. However, if the surgeon prefers to use a drain, it should be without suction.

Axial Malalignment

Any angular deformity of the involved knee should be corrected before or concurrently with CMI implantation. The science and surgical procedure of osteotomies around the knee are beyond the scope of this chapter. However, according to the general guidelines, varus malalignment should be corrected by a high tibial osteotomy (HTO). Both an opening-wedge and a closing-wedge HTO can be used. When using the former technique, special care should be taken not to increase the tibial slope [6]. 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 to do the arthroscopy and implant the lateral CMI prior to performing the osteotomy. Although the rehabilitation programme does not differ greatly between the two procedures, the CMI-specific protocol is the most important and should be given full consideration.

Chondral Treatment

Historically, an Outerbridge grade IV chondral injury has been considered a formal contraindication to a CMI, because the gliding between the implant and an altered cartilage surface is thought to be detrimental to the new implant. This is also true when applying chondral treatments based on bone marrow stimulation, such as microfracture, when a rough surface is obtained at time zero. If this is the case, it is probably better not to stage the implant until 3 months later. However, it is the surgeon's choice whether to perform CMI implantation concurrently with chondral resurfacing procedures, such as osteochondral transplantation, using either a massive allograft or a mosaicplasty (Fig. 11.2.12), or autologous chondrocyte implantation, in which a smooth chondral surface can immediately be obtained.

Results

To date, more than 50 patients have been treated with a CMI at our institution. Twenty-five of them received a medial CMI from 1997 to 2000 as part of a EU multicentre clinical trial [2]. The series included 20 men and 5 women between the ages of 18 and 48. Five cases

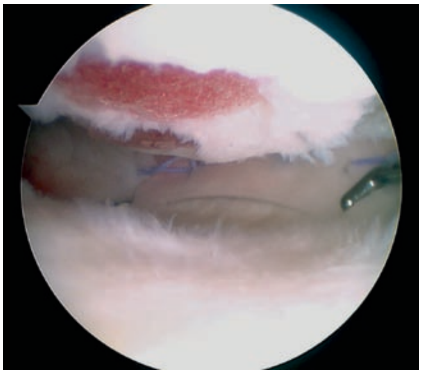

Fig. 11.2.12 Arthroscopic view of a medial CMI. Above the CMI, two chondral injuries treated with synthetic mosaicplasty plugs (TruFit® CB OsteoBiologics, Inc)

were operated on for a post-meniscectomy syndrome, 19 for degenerative meniscal ruptures and one for an acute rupture. The ACL was simultaneously reconstructed in 17 cases (68%). At the most recent follow-up, the Lysholm score was 89.6 ± 6.3 vs. 59.9 ± 15.8 preoperatively ($p < 0.003$). The visual analogue pain score decreased from a preoperative mean of 7.0 ± 1.8 to 2.0 ± 1.6 ($p < 0.001$). Conventional radiology showed no deterioration of the joint line. MRI showed some degree of meniscal regeneration in 68% of the cases. However, the implant tended to become smaller, and extrusion was commonly seen in some frontal sections.

Three patients had persistent pain on the medial side of the knee. We removed the CMI and performed an allograft meniscus transplantation (AMT) in one patient. The second patient was treated with an HTO and a staged AMT. The last patient was not treated at all.

We found no adverse effects on the knee after 4–7 years of follow-up. Clinically, the outcome was good in the majority of cases (22/25). Although the size of the newly formed meniscus was smaller than expected, regeneration appeared to occur in over two thirds of cases.

Further evidence supporting CMI-promoted regrowth of meniscal-like tissue has been provided in a very recently published paper [8]. This prospective randomized trial included more than 300 patients with an irreparable medial meniscus injury or previous partial medial meniscectomy. The patients were divided into two study arms: an acute group with no prior surgery to the medial meniscus and a chronic group with up to three previous surgeries to the involved meniscus. The patients were randomized either to undergo CMI treatment or partial medial meniscectomy (controls). Second-look arthroscopies and biopsies performed in the CMI patients 1 year postoperatively showed that the implant was able to produce new meniscus-like tissue. Furthermore, after an average follow-up of 5 years, the patients in the chronic group regained significantly more of their lost activity than did the control patients, and underwent significantly fewer operations.

Summary

The CMI is a collagen scaffold designed to develop a tissue-engineered meniscus. The device is placed in the space where a damaged meniscus has been removed, and is anchored to the surrounding tissue. Following implantation, the matrix is invaded by cells and undergoes a process of remodelling. The CMI has already been applied clinically for partial meniscus replacement. Subsequently, the formation of a newly formed meniscus was observed in over two thirds of cases. Selecting the suitable candidate is one of the key factors in achieving a successful outcome. The knee must be stable and well-aligned. Technically, a secure intra-articular attachment is probably the most critical factor in achieving implant stability and function. Therefore, the potential surgeon should be familiar with current meniscus repair and reconstruction techniques and be skilled in performing them.

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11.3 Actifit, Polyurethane Meniscus Implant: Basic Science

J. de Groot

Introduction

Increased awareness of potentially detrimental outcomes following partial meniscectomy led to the development of a novel meniscal scaffold, Actifit™, by Orteq Bioengineering. It received the CE Mark in July 2008 for the treatment of medial or lateral irreparable partial meniscal tears. Actifit™ consists of highly interconnected porous synthetic material (Fig. 11.3.1) enabling tissue ingrowth. Over time, transformation into meniscus-like tissue takes place as the implant slowly degrades. Furthermore, Actifit™ is made of an aliphatic polyurethane, which provides optimal mechanical strength, biocompatibility, porosity, safe degradation, and ease of use required for the indication. It is available in two shapes, medial and lateral (Fig. 11.3.2).

Background

Development of the meniscal scaffold started in the 1980s. Scaffold materials made of various synthetic polymers were tested in animal studies as meniscal repair or meniscal replacement material [1–6, 13–19, 21, 22, 25, 31–35, 38]. Based on these studies, a set of requirements for the optimal implant with respect to pore size, porosity, rate of degradation, degradation products, mechanical properties, and importantly, ease of use in an arthroscopic procedure were developed. With respect to the mechanical properties, a high suture pull-out strength and sufficient stiffness became essential. Synthetic polymers currently used as biodegradable polymers for implantable devices are mainly copolymers based on lactide, ε-caprolactone, glycolide and trimethylene carbonate, and cannot fulfill all these requirements.

Polyurethanes are a class of materials with properties ranging from very brittle and hard to very tough, soft and tacky, and viscous [20]. The molecular structure can be tuned and consequently also the mechanical

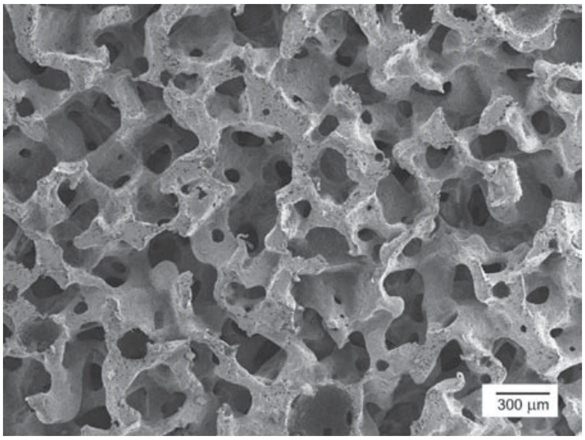

Fig. 11.3.1 Scanning electron micrograph of the porous structure of Actifit™

Fig. 11.3.2 Medial and lateral Actifit™

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_11.3, © Springer-Verlag Berlin Heidelberg 2010

properties and the rate of degradation. They are composed of alternating polydisperse blocks of soft and stiff segments (Fig. 11.3.3). These qualities combined with excellent biocompatibility make polyurethanes one of the most promising synthetic biomaterials [20]. Apart from the Orteq implant, marketed polyurethanes contain (aromatic) diisocyanate moieties, which may yield a small amount of toxic diamines upon degradation. Although it has never been proven that toxic diamines are released or that such a release would cause problems, and aromatic polyurethanes have successfully been implanted in dogs as meniscal reconstruction material in the past [1–4, 13–17, 31, 32, 34–36, 40], the possibility of toxic amine release has given polyurethanes a negative perception. Therefore, it was decided to focus on polyurethanes based on 1,4-butanediisocyanate [7–12, 25–30]. Upon degradation, this aliphatic polyurethane will release 1,4-butanediamine, also known as putrescine, already naturally present in the body.

A New Synthetic Polymer

The Actifit™ polymer consists of two components, polyester (soft segments) and polyurethane (stiff segments), specifically developed and tuned for meniscal application [11]. The soft segment, 80% of the polymer, is a biodegradable polyester, poly(ε-caprolactone). It provides flexibility and determines the degradation rate. The semidegradable, stiff segments (20% of the polymer) are of uniform size and provide mechanical strength.

Poly(ε-caprolactone) (lines in polymer chain in Fig. 11.3.3) is a degradable polyester found in several implantable biodegradable medical devices, mainly sutures (Monocryl by Ethicon; Caprosyn by Tyco Healthcare) and coatings of sutures (Vicryl and Panacryl by Ethicon; Dexon and Polysorb by Tyco Healthcare). The stiff segments (white boxes in polymer chain in Fig. 11.3.3) contain two 1,4-butanediisocyanate (BDI) and one 1,4-butanediol (BDO) moieties and are designed to be very small (2–3 nm), i.e., approximately 5,000 times smaller than a human cell.

In order to obtain a polyurethane with excellent mechanical properties comparable to the properties of aromatic polyurethanes, the conventional polyurethane synthesis process had to be changed [7, 12]. The polyurethane is made without a catalyst, which contributes to the polymer biocompatibility. The absence of a catalyst also contributes to the uniformity of the stiff segments, and therefore to the mechanical properties of the polyurethane [11].

Degradation

The Actifit™ polyurethane has a very low degradation rate. The degradation mechanism takes place in the presence of water through the hydrolysis of the ester bonds in the poly(ε-caprolactone) soft segments (Fig. 11.3.3). The stiff segments are more stable than the polycaprolactone segments and remain after the hydrolysis of polycaprolactone. It is expected that these segments do not degrade when integrated. In case the polyurethane segments are phagocytized by macrophages (or giant cells), the stiff segments degrade safely. This was determined in scientific studies of a polyurethane with similar

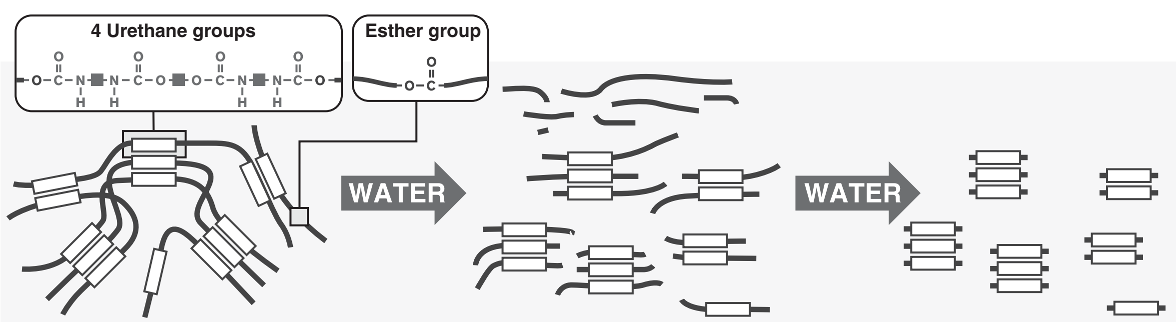

Fig. 11.3.3 Hydrolysis of the Actifit™ polyurethane

stiff segments [24, 40] and was confirmed in Orteq's biocompatibility testing program on stiff segments.

Degradation of the polycaprolactone segments is expected to take 4–6 years. In vitro degradation testing (at 37°C in phosphate buffer at pH 7.4) showed that after 1.5 years, the molecular weight of the polyurethane decreased to 50% of its original molecular weight while the implant weight was not reduced.

The biocompatibility of identified degradation products has either been tested by Orteq, or extensive documentation of their nontoxicity in the quantities released was already available. An overview of the tests performed is shown in the next section.

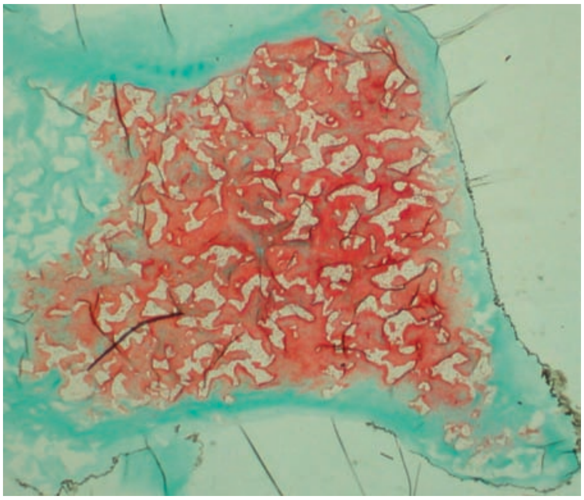

Fig. 11.3.4 Light micrograph of the posterior part of an Actifit™ implant, 24 months after implantation in a dog. *White areas*: polymer; *green areas*: fibrous tissue mainly containing type I collagen; *red areas*: fibrocartilage-like tissue containing proteoglycans and mainly type II collagen

Preclinical Biocompatibility and Animal Testing

Orteq has completed a number of biocompatibility tests on the Actifit™ implant and on hard segments (Table 11.3.1). Actifit™ has passed all the tests.

Two dog (beagles) studies were performed with the Actifit™ material [38, 41]. In the first study, Actifit™ was implanted following total meniscectomy [38]. The follow-up period was 6 months. The implant horns were fixed on the tibial plateau with sutures pulled through drill holes in the tibia. Total meniscectomy served as control. In the second study Actifit™ was implanted for 6 and 24 weeks, with total meniscectomy and native menisci as controls [41]. The Actifit™ implants were fully integrated into the tissue without capsule formation, and the immunological response was very mild, not exceeding grade I. Histological examination of the tissue ingrowth disclosed formation of meniscus-like tissue containing proteoglycans and type II collagen (Fig. 11.3.4). A chondroprotective effect was not expected nor observed, due to limitations of the animal model. Nevertheless, it was hypothesized that absence of chondroprotection could be implant material-related [38]. No definite conclusions could be drawn, since in this particular model, the tibial plateaus were severely damaged due to technical issues in the group receiving the implant. In a subsequent recent sheep study, Actifit™ was implanted after partial meniscectomy, with partial meniscectomy serving as control [23]. The material was not found to negatively affect the articular cartilage. In addition, the friction coefficient of the Actifit™ did not appear to be significantly different from that of native meniscus after 3 months.

Table 11.3.1 Tests Orteq has performed on Actifit™ and passed

Testing requirements	Relevant standards
Cytotoxicity	ISO10993-05
Sensitization	ISO10993-10
Intracutaneous irritation	ISO10993-10
Acute systemic toxicity	ISO10993-11
Combined subchronic toxicity & local tolerance (implant and stiff segments)	ISO 10993-06 & ISO10993-11
Combined chronic toxicity & local tolerance (implant and stiff segments)	ISO 10993-06 & ISO10993-11
Genotoxicity: bacterial reverse mutation	ISO10993-03
Genotoxicity: chromosomal aberration test in mammalian cell in vitro	ISO10993-03
Genotoxicity: mouse bone marrow micronucl.	ISO10993-03
Wear debris on small particles in rabbit knee	ISO10993-06 (adapted)
Carcinogenicity: transgenic ras H2 mouse (implant and stiff segments)	ISO10993-3

Clinical Results

Clinical results for Actifit™ showed significant improvement from baseline at three, six, and 12 months postimplantation, as evidenced by the Visual Analogue Scale (VAS), and the International Knee Documentation Committee (IKDC), Knee Injury and Osteoarthritis Outcome (KOOS), and Lysholm scores. DCMRI scans showed tissue ingrowth in 85.7% of subjects already at 3 months postimplantation, while biopsies at 12 months showed cells with meniscus-like differentiation potential [39]. In conclusion, Actifit™ is a novel, biocompatible, polymer device specifically designed for use as a matrix for tissue ingrowth to treat irreparable meniscal defects.

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Polyurethane Meniscus Implant: Technique

11.4

R. Verdonk, P. Verdonk, and E. L. Heinrichs

Introduction

The treatment of irreparable meniscal tears remains a major challenge for the orthopaedic community today. Removal of all or part of the meniscus eventually leads to degenerative changes of the articular cartilage and subsequent clinical symptoms [5]. The current treatment of choice for irreparable meniscus tears is partial meniscectomy, which aims to remove only the pathologic or torn tissue, thereby minimising risk to the articular cartilage. Total meniscectomy is now almost completely obsolete; however, it still remains necessary for large irreparable tears [5]. The use of meniscal allografts has proved promising in patients with meniscus tissue loss; however, it is generally used only in patients who have undergone total or subtotal meniscectomy [5].

Until recently, for young, active adults who desire a return to pre-lesion functionality and who have many productive years ahead of them, no satisfactory solution has been available to replace or regenerate meniscal tissue. For such patients, provided they have correct alignment and normal ligament status, partial meniscal tissue regeneration is an emerging possibility. The use of meniscal scaffolds to regenerate the lost tissue has become a valid treatment option.

Research has demonstrated that a biocompatible, degradable polyurethane scaffold (Actifit™ developed by Orteq Ltd.), with proven cellular ingrowth potential [3, 4, 6], is safe and effective for the treatment of irreparable meniscal tears or meniscal tissue loss. Tailored to the meniscal defect, the scaffold provides a three-dimensional matrix enabling vascular ingrowth, thereby facilitating tissue regeneration to replace the surgically removed tissue. The primary aim of this treatment is to provide pain relief and restore functionality.

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Indications for Use

The Actifit™ meniscal scaffold received European Union regulatory clearance for sale in July 2008. It consists of a highly porous, degradable, biocompatible, polyurethane material. It is intended for use in the treatment of irreparable, partial meniscal tissue defects in order to reduce pain and restore compromised functionality by reinstating the load-bearing and shock-absorbing capacity of the meniscus. Actifit™ is available in two configurations, medial and lateral, to fit the corresponding defect (Fig. 11.4.1).

Candidates suitable for implantation must have an intact meniscal rim and sufficient tissue present both in the anterior and the posterior horns to allow for secure fixation. In addition, the candidates should have a well-aligned stable knee, a body mass index (BMI) below 35 kg/m^2, and must be free from systemic disease or infection sequelae. Cartilage damage should not exceed the International Cartilage Repair Society (ICRS) classification of Grade 3. Long-term data showing chondroprotection post-implantation of Actifit™ are not yet available. Once such data become available, Actifit™ could also be indicated for acute partial meniscectomies not yet affected by chronic disability.

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_11.4, © Springer-Verlag Berlin Heidelberg 2010

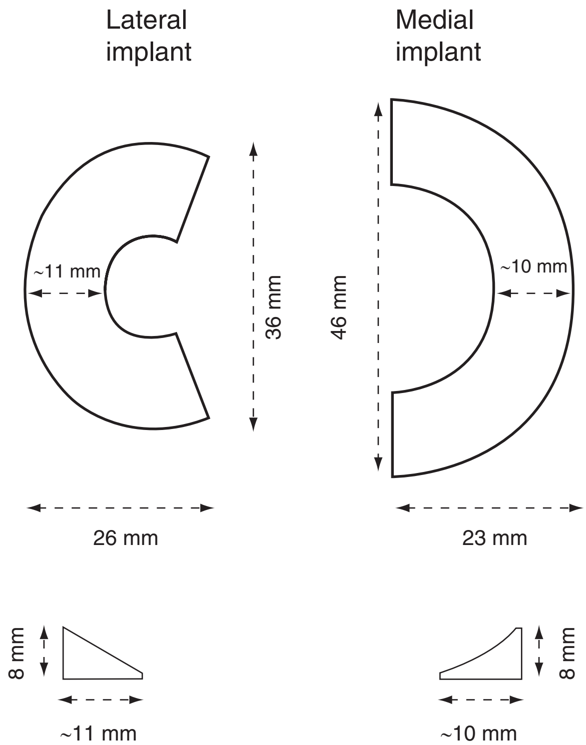

Fig. 11.4.1 The Actifit™ meniscal implant is available in a medial and lateral shape

Methods

Surgical Techniques

The Actifit™ meniscal scaffold is placed in the patient's knee at the time of partial meniscectomy using a standard arthroscopic surgery procedure and standard equipment. Detailed instructions for the surgical procedure are provided in the manufacturer's Instructions For Use (IFU), which also include warnings and precautions.

Implantation is usually performed using tourniquet conditions under spinal or general anaesthesia at the discretion of the orthopaedic surgeon. The surgeon may prefer thigh fixation to achieve appropriate valgus or varus stress positioning.

Medial Meniscal Implant

Verification of cartilage status and integrity of the meniscal wall remnant, both medially and laterally, should be performed. In the case of a tight medial compartment, the medial collateral ligament (MCL) can be distended using the outside-in puncture method. Under valgus stress, and directed by the inside arthroscopic light, the surgeon is able to bring a needle in the posteromedial side of the knee joint into the joint. The MCL is sensed and allows for progressive pie-crusting of the ligament until appropriate opening is obtained.

One can also use the inside-out pie-crusting release technique as described by Steadman. Under arthroscopic control, the posteromedial corner of the knee joint is visualised. Using the Steadman pick, the MCL can be reached and progressively disrupted in order to open the knee joint appropriately until visualisation is obtained.

If the meniscal lesion cannot be repaired, partial meniscectomy should be performed. To enhance healing, the meniscal rim may be punctured in order to create potential vascular access channels. Gentle rasping of the synovial lining may further stimulate meniscal healing (Fig. 11.4.2).

Following surgical debridement and preparation, the defect site should extend into the vascularised red-on-red or red-on-white zone of the damaged portion of the meniscus, i.e. 1–2 mm from the synovial border [1, 2]. Lesions situated further away from the synovial border are known to have only very limited healing potential and therefore should be excluded from this type of meniscoplasty.

The meniscal defect should be measured along the curvature of its inner edge using the accompanying specially designed meniscal ruler and meniscal ruler guide (Fig. 11.4.3). Actifit™ should then be measured, and using a scalpel, cut to fit in such a place and manner as to ensure that sterility is maintained at all times. To allow for shrinkage caused by suturing of the

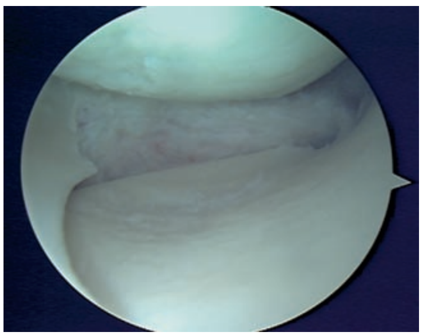

Fig. 11.4.2 The damaged meniscus is debrided to a stable and potentially bleeding rim

Fig. 11.4.3 The resulting meniscus defect is measured by the measuring tool and documented using the appropriate evaluation tools

sponge-like material and to ensure a snug optimal fit into the prepared defect, oversizing of the length by 3 mm for defects <3 cm and 5 mm for defects ≥3 cm is recommended. In order to achieve a perfect fit of the scaffold with the native meniscus at the anterior junction, the anterior side should be cut at an angle of attack of 30–45°.

The implantation requires 2–3 small incisions for anteromedial and anterolateral portals, with an optional arthroscopic central transpatellar tendon portal. To allow for easy insertion of the Actifit™ scaffold, an enlargement of the portal used for insertion of the device may be required (the size of the little finger is sufficient). In addition, a posteromedial or posterolateral incision may be required if an inside-out meniscal fixation technique is used.

Although the Actifit™ material is strong and flexible, it should be handled with care and manipulated using a blunt-nosed grasper (Fig, 11.4.4a, b), such as the Acuflex Grasper Tissue Tensioner™ (Smith & Nephew). Marking the cranial and caudal meniscal implant surface avoids positioning problems (Fig. 11.4.5). The Actifit™ device should be clamped at the posterior part of the scaffold and placed into the knee joint through the anteromedial or anterolateral portal. To ensure a good initial position of the meniscal scaffold implant and facilitate further fixation, a vertical holding suture may be placed in the native meniscus tissue to bring Actifit™ through the eye of this holding suture.

Fixation of Actifit™ is achieved by suturing the scaffold to the native meniscus tissue. Fixation of the device should begin with a horizontal all-inside suture from the posterior edge of the implant to the native meniscus. Suturing should be secure; however, attention must be paid not to over-tighten sutures as this may alter and indent the surface of the implant. In line with well-known meniscal suturing techniques, the distances between the sutures should be kept to approximately 0.5 cm. Each suture should be placed at one-third to one-half of the implant's height, as determined from the lower surface of the implant.

The suturing technique employed depends on the location of the defect and the surgeon's experience and preference. All-inside suturing has proven effective and this technique is commonly used for the posterior horn and posterior part of the rim. For the middle and anterior part of the rim, all-inside, inside-out and outside-in techniques may be used. Horizontal sutures with an outside-in technique are commonly used for the anterior horn.

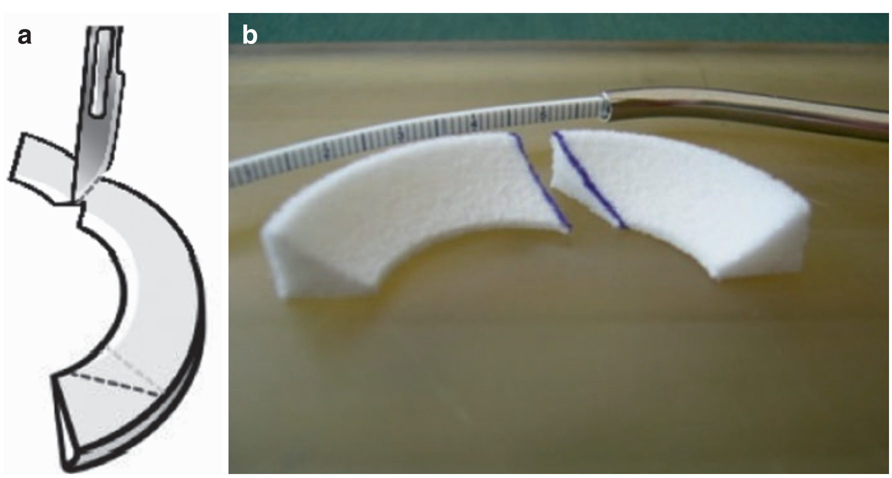

Fig. 11.4.4 (**a**) The Actifit™ meniscal implant is tailored on the back table using a scalpel for a perfect fit to the meniscus defect. (**b**) Care is taken not to undersize the device. The implant material is strong but needs to be handled with care

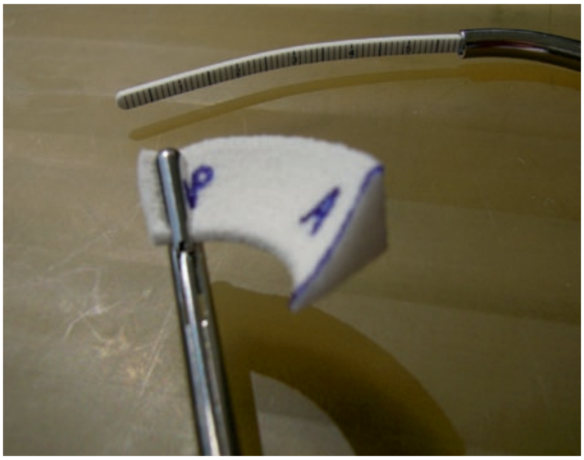

Fig. 11.4.5 The scaffold device should be manipulated using a pair of anatomical tweezers

The manufacturer recommends standard commercially available size 2.0 non-resorbable sutures, such as polyester or polypropylene and braided or monofil sutures.

Following suturing, if required the scaffold may be further trimmed and fine-tuned intra-articularly using a basket punch. Once the implant is securely fixed, stability of the fixation is tested using the probe and carefully moving the knee through a range of motion (0–90°) (Fig. 11.4.6a, b).

Lateral Meniscal Implant

As in the case with medial implants, verification of cartilage status and integrity of the meniscal wall remnant should be performed. In the case of the lateral meniscus, the integrity of the lateral meniscal wall across the hiatus popliteus is essential for secure fixation and optimal tissue regeneration results. All pathological cartilage and ligamentous findings should be carefully recorded. The progressive pie-crusting release techniques used in the medial compartment are not possible in the lateral compartment because of anatomical considerations; however, lateral compartment narrowing is rare. The surgeon needs to confirm that the meniscal lesion is irreparable and partial to ensure that reconstruction with the Actifit™ lateral meniscal implant is appropriate.

As described for the medial meniscus, the lateral meniscus also needs to be debrided and prepared to extend into the red-on-red or red-on-white zone of the damaged portion of the meniscus. Meniscal healing can be enhanced by puncturing the meniscal wall in order to create vascular access channels, and gentle rasping of the synovial lining may be performed to stimulate healing.

The lateral implant is tailored to fit the meniscal defect, as described above for the medial implant, and then manipulated into the correct position through an enlarged anterolateral portal. Suturing of the lateral Actifit™ device is similar to that of the medial implant.

Suture points are placed at a ±1 cm distance, allowing for good fixation of the device in situ. Suture points through the musculus popliteus are not detrimental to later function.

A posterolateral skin incision may be necessary to avoid lateral structure damaging as has been described for classic meniscal suturing techniques.

Once the implant is securely fixed, stability of the fixation is tested using the probe and carefully moving the knee through a range of motion (0–90°).

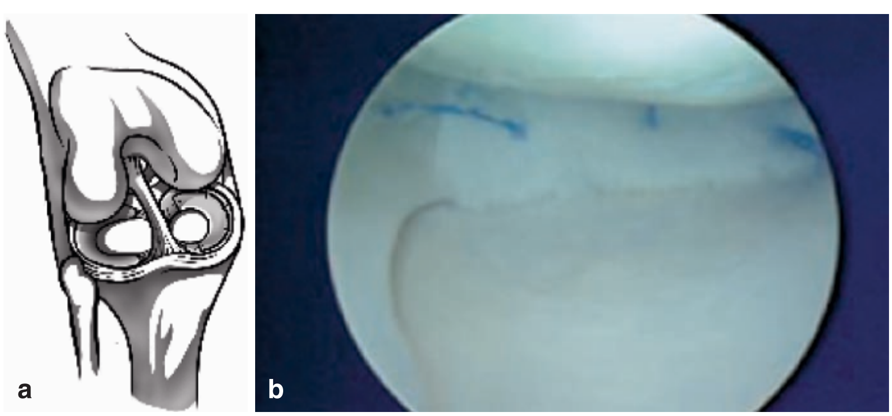

Fig. 11.4.6 (**a**) The distances between the sutures are kept to approximately 0.5 cm. (**b**) Each suture should be placed at 1/3 to 1/2 of the implant's height determined from the lower surface of the implant to allow proper fixation

Postoperative Procedures

Postoperative Care

Following implantation of the scaffold, pain and thromboprophylactic medications may be administered at the surgeon's discretion. Under normal circumstances, medications would be typical of those administered following classic meniscal suturing.

Dependent upon the meniscal scaffold stability as determined at the end of the surgical procedure, a rigid removable brace may be used over a compression bandage in the first week post-implantation.

Postoperative Rehabilitation

Following implantation of the Actifit™ scaffold, the specially designed rehabilitation protocol should be strictly followed. This is important in order to provide optimum conditions for healing and to protect the newly formed fragile tissue from potentially harmful stresses whilst the tissue remodelling and maturation process is ongoing during the first 3 months post-surgery. Rehabilitation is recommended for 16–24 weeks, with the patient non-weightbearing for the first 3 weeks. Partial weightbearing is permitted from week 4 onwards, with a gradual increase in loading up to 100% load at 9 weeks post-implantation. Progressive weightbearing is to be initiated in stages, increasing by 10 kg per week for patients weighing ≤60 kg and 15 kg per week for patients weighing ≤90 kg. Full weightbearing is indicated from week 9 onwards, and without the use of the unloader brace from week 14 onwards.

Under the rehabilitation protocol, motion is initiated immediately after implantation, with bending up to 30° with full extension permitted in weeks 1 and 2. Flexion is progressively increased to 60° in week 3, and to 90° in weeks 4 and 5. From week 6 onwards, flexion is further increased until a full range of motion is achieved; however, forceful movements should be avoided. Light exercise, including isometric quadriceps exercises, mobilisation of the patella, heel slides, quad sets, anti-equinus foot exercises and Achilles tendon stretching, is advised from week 1. Partial wall, under 90°, sits are permitted as of week 5 onwards, and as of 9 weeks, additional exercises, including increased closed hamstring exercises, lunges between 0 and 90°, proprioception exercises, dynamic quadriceps exercises and use of a home trainer, are indicated. Increased open and closed exercises, jogging on level ground, plyometrics and sports-related exercises without pivot are recommended from week 14 onwards. Hydrotherapy and swimming (crawl and breaststroke) can commence 24 weeks post-implantation. Gradual resumption of other sports is generally commenced as of 6 months at the discretion of the responsible orthopaedic surgeon; however, contact sports should be resumed only after 9 months.

Clinical Outcome Following Surgery

Safety, performance and efficacy results to support the use of Actifit™ in the treatment of irreparable meniscal tears or meniscus tissue loss were obtained from a prospective, non-randomised, single-arm, clinical investigation conducted at several orthopaedic centres of excellence located throughout Europe. Subjects recruited ($N=52$) had an irreparable medial or lateral meniscus tear or partial meniscus loss, intact rim, presence of both horns and a stable well-aligned knee.

Safety was assessed by the incidence of serious adverse device effects (SADEs), serious adverse events (SAEs) and adverse events (AEs), and by cartilage scores on anatomic MRI in the index compartment at 3 and 12 months post-implantation, as well as by gross examination of the knee joint and index compartment at re-look at 12 months ($N=45$).

Performance was assessed by tissue ingrowth. Tissue ingrowth was assessed at 3 months post-implantation by evidence of vascularization in the scaffold shown by DCE-MRI using intravenous gadolinium contrast material ($N=42$). All DCE-MRI scans were assessed for neovascularization in the peripheral half of the scaffold meniscus and integration of the implanted device. Tissue ingrowth into the scaffold was also assessed by histological examination of biopsies collected from the inner free edge of the implanted scaffold during the 12-month re-look arthroscopy ($N=45$).

Efficacy was assessed using validated clinical outcome scores. For knee pain, the Visual Analog Scale (VAS), at 3, 6 and 12 months post-implantation was used. For functionality, the International Knee Documentation Committee (IKDC), the Lysholm score, as well as the Knee and Osteoarthritis Outcome Score (KOOS) were used.

Preliminary Clinical Results

Between March 2007 and April 2008, 52 patients were enrolled into the above-described study. At the time of preparation of this chapter, preliminary 12-month efficacy data were available for 46 patients, with full safety data available for all 52 patients.

Of the enrolled subjects, 34 received a medial meniscal implant and 18 received a lateral implant. The demographics and baseline characteristics were representative of the population for which Actifit™ is intended. The mean age of the subjects was 30.8 ± 9.4 years and the majority were male (75%). The longitudinal length of the meniscus defects ranged from 30 to 70 mm (mean, 47.1 ± 10.0 mm). Baseline values were for VAS 45.7 (±26.2), IKDC 46.2 (±17.5) and Lysholm 58.9 (±20.6).

The AE profile reported in this clinical investigation was similar to that reported in the literature for meniscal surgery and meniscal implants. To date, no patients have experienced SADEs. Six patients have experienced SAEs, of which 4 experienced SAEs considered related to the procedure; however, these were not considered related to the scaffold itself. The majority of AEs were mild or moderate in intensity. Overall, 7 patients experienced AEs considered definitely, probably or possibly related to the scaffold and 22 patients experienced AEs considered definitely, probably or possibly related to the surgical procedure. No inflammatory reaction to the scaffold implant was observed during gross examination at 12 months. Anatomic MRI findings at 12 months post-implantation showed stable or improved cartilage scores in the index compartment compared to baseline.

At 3 months post-implantation, early evidence of tissue ingrowth in the peripheral half of the scaffold was observed on DCE-MRI in 37/43 (86%) patients. Vital tissue, with no evidence of necrosis or cell death was observed in all biopsies taken at the 12-month re-look arthroscopy, consistent with the biocompatibility of the scaffold. Further histological analyses revealed successful tissue ingrowth, with meniscus-like cells visible in distinct layers. Each layer was distinguished by its unique histological characteristics, the presence or absence of vessel structures, and the composition of extracellular matrix, indicative of an ongoing process of regeneration, remodelling and maturation of tissue.

Statistically significant improvements compared to baseline ($p < 0.05$) were reported for functionality on the IKDC and Lysholm scoring scales, as well as for knee pain on VAS, at 3, 6 and 12 months post-implantation. For the five subcomponents of the KOOS questionnaire, statistically significant improvements ($p < 0.05$) were reported in pain, daily living and quality of life at 3, 6 and 12 months post-implantation, and in sports / recreation and symptoms at 6 and 12 months post-implantation.

Conclusions

No safety concerns other than those generally acknowledged with surgery were identified in this prospective clinical investigation. Importantly, no safety issues related to the scaffold, including cartilage damage or inflammatory reactions to the scaffold or its degradation products, were observed. Performance data showed successful tissue ingrowth. Efficacy data demonstrated a statistically and clinically significant improvement compared to preoperative status for all subjective clinical outcome scores at 6 and 12 months post-implantation, with VAS, IKDC and Lysholm scores already significantly improved at 3 months post-implantation. In conclusion, the 12-month clinical results are comparable to those reported following partial meniscectomy; however, the Actifit™ scaffold has the added benefit of promoting meniscal tissue regeneration.

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Synthesis

11.5

R. Verdonk

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 indeed mandatory for true hoop stress protection.

In addition, animal experiments showed increased cartilage degradation when the normal anatomy had not been restored. Nowadays, no clear consensus is available on whether bone fixation of meniscal allografts is mandatory for normal homeostasis.

Choosing allograft tissue such as meniscal tissue, although of limited availability, is a logical option.

Deep-freezing appears to be the most accepted method of preservation, and standards of procurement have been well established.

If procured in a sterile fashion, the allografts can be used when the tissue bank has found the donor to be free of transmissible diseases. 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.

Meniscal 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. In the early beginning, meniscal transplantation was very often associated with other repair surgery (mostly ligamentous).

Open surgery is also required for bone plug fixation and to obtain elementary stability.

It is only because meniscal surgery and repair indications have increased that arthroscopic transplantation has been initiated.

Without bone plug fixation the technique becomes an arthroscopic soft-tissue procedure, also with the use of improved fixation and stabilization devices as applied constantly in routine meniscal repair procedures.

With growing surgical expertise and better visualization and anatomic positioning of the anterior and posterior meniscal horns, bone plug fixation has become technically less challenging.

The literature does not indicate whether one or the other technique is superior in terms of results, nor has any clinical difference in results been reported between deep-frozen, cryopreserved, or viable (fresh) transplants at a 10–15 years' follow-up.

Obviously, clinicians are more confronted with issues dealing with partial meniscectomy and functional derangement.

In animal experiments, collagen meniscus implantation (CMI) was found to yield good results and function. The regenerated tissue appeared to be similar to

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_11.5, © Springer-Verlag Berlin Heidelberg 2010

the native meniscus. The implants did not induce degenerative changes, abrasion, or synovitis, and were devoid of allergic or immune responses.

Human clinical trials, which were conducted at various centers over longer periods of time, showed a lesser need for revision surgery after CMI implantation in chronic meniscectomized knees, compared to controls.

Good alignment and stability are preoperative requirements.

Alternatives were searched as that would allow working with stronger as well as resorbable materials.

In animal studies, long-term assessment of a polyurethane scaffold showed that transformation into meniscus-like tissue took place as the implant slowly degraded.

Another requirement is the possibility to insert and manipulate the implant into position with the use of arthroscopic techniques. A first human safety and efficacy study of 52 patients demonstrated a statistically significant improvement in the quality of life and clinical scores at 1 year, suggesting that the implant was safe and effective.

Finally, meniscal allografts seem to sustain the hypothesis that meniscal replacement after total meniscectomy is a valid alternative, more specifically in the lateral compartment. For the medial compartment, other useful options are available.

The more common knee dysfunction after partial meniscectomy does not warrant total meniscal allograft replacement.

While we are still constantly searching for useful modes of treatment, partial meniscal replacement is already a first step in the right direction.

Part XII

The Future

The Future

12.1

P. Verdonk

In recent decades, the complexity of joint homeostasis and the importance of the meniscus have become clear. It is now well accepted that the human meniscus is a highly complex tissue with very specific biological and biomechanical properties, most of which are still not well understood. This said, multiple attempts have been made to substitute the lost tissue using different techniques and approaches. In general, these can be subdivided into three categories: (1) substitution with natural tissues such as meniscus allografts, quadriceps tendon, Hoffa fat pad, etc.; (2) substitution using tissue engineering based on scaffolds, cells and growth factors, or a combination of these; and (3) substitution by prosthetic devices. The concept of substitution by a meniscus allograft has been accepted by most physicians as a viable therapeutic option for the (sub)total meniscectomized knee. Substitution for partial defects is an ongoing field of research and has attracted greater interest in recent years.

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, 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 whether the fixation should be with bone blocks or only soft tissue. This illustrates the lack of supporting scientific evidence in favour 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 learnt 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. While segmental defects after partial meniscectomy are much more common in clinical practice, no data exist on partial substitution using natural tissues.

However, the clinical demand for partial substitution is growing based on the awareness that the risk of developing osteoarthritis is related to the amount of meniscus tissue lost. To address this issue, a number of acellular scaffolds have been introduced into clinical practice. The available data show that these scaffolds allow the human body to regrow tissue. Since knowledge of the repair potential and repair biology of the injured meniscus is very limited, these therapies also serve as an interesting "injury model" and have resulted in a better understanding of the healing processes. At short-term follow-up, the obtained tissue after implantation of an acellular scaffold appears to be immature at least compared to the native meniscus tissue. Accelerated healing is becoming a very interesting field of research and potential clinical implementation. To accelerate healing, cells and/or growth factors or a combination of these could be added to the acellular scaffold, or the biomimetic properties of the scaffold itself could be improved. Interestingly, at the time of publication of this book, the clinically available scaffolds still have inferior mechanical properties compared to the native meniscus. The influence of the mechanical stimulus on cell differentiation and maturation has been highlighted as important, and it appears logical that a more biomimetic scaffold could result in more meniscus-like tissue. The extensive current experience with autologous

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P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_12.1, © Springer-Verlag Berlin Heidelberg 2010

chondrocyte transplantation has taught us that the instability of the cellular phenotype upon culture is of paramount importance. It has also become clear that the cost of such an autologous cultured cell-based therapy is very high if not too high for most of our patients. Further efforts are necessary to elucidate the potential of a single-step isolation procedure using bone marrow or a combination of these cells with "on the spot isolated" primary cells, which would obviate the costly procedure of cell culture. Possible primary cell sources are bone marrow-derived mesenchymal stem cells (BMSC), local progenitor cells or differentiated meniscus and cartilage cells.

The application of autologous growth factors in the form of a platelet-rich plasma concentrate is gaining increased attention in many clinical applications for repair and healing. The use of isolated recombinant growth factors is still highly controversial and faced with regulatory constraints. Nevertheless, a number of growth factors of interest have recently been identified.

Transforming growth factor-β1 (TGF-β1) is involved in the development of bone and cartilage. In an in vitro cell culture of mesenchymal stem cells, TGF-β1 was found to induce the matrix production (e.g. type I, II collagen and aggrecan) and chondrogenesis [1].

Platelet-derived growth factor bb (PDGF bb) influences the chondrogenic potential of BMSC. This was investigated by placing these cells in a medium with TGF-β1 in combination with PDGF. These growth factors seemed to stimulate the proliferation rate of these BMSCs [2]. PDGF was also found to stimulate the proliferation rate of chondrocytes in a cell culture-based system of meniscal tissue [3, 4].

Insulin growth factor-I (IGF-I) is the main anabolic factor for the growth of hyaline cartilage. The effect of IGF-I on meniscus tissue has been investigated.

Fibroblast growth factor 2 (FGF2) seems to be a strong modulator for stem cell proliferation. FGF2 keeps the stromal bone marrow fraction immature. This means that osteochondrogenic progenitor cells retain their multipotent character in a cell culture-based system [5].

Bone morphogenetic protein-6 (BMP-6) seems to stimulate chondrogenesis in a subpopulation of stromal bone marrow cells [6].

A third, less well investigated approach to meniscus substitution is the application of a prosthetic meniscus device. A major advantage of this approach is that it bypasses the intrinsic variability and time consumption of the biological approach, i.e., the patient does not need to heal himself or herself, but receives a prosthetic implant with specific biomechanical properties. One of the major difficulties in designing and manufacturing such implants is the biomechanical behaviour of the meniscus and its fixation to the capsule and bone. It is this fixation mode that ensures the stability of the meniscus within the medial and, even more so, the lateral compartment. The biomechanical properties are hard to reproduce with commonly used orthopaedic materials. Novel biomaterials that allow us to reproduce anisotropy and can recreate those typical meniscus surface characteristics are currently being researched.

In conclusion, the future of meniscus substitution is strongly supported by a clinical need. Different approaches are currently under investigation. The potential patient-specific variability and time consumption are a major challenge for the biological tissue engineer, while for the prosthetic approach the perfect material still has to be developed. Maybe a combination of a prosthetic core with a bioactive surface would be the ideal implant?

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Part XIII

Conclusion

General Conclusion

13.1

R. Verdonk and P. Beaufils

Now that everything has been said about the meniscus, we have to come to a conclusion regarding the issues still facing us.

Meniscal diagnosis has come a long way. Clinical examination and patient history have been supplemented with other diagnostic tools such as digital-precision imaging. It still remains the orthopaedic surgeon's prerogative to take into account any of these and to tailor the treatment to the individual patient, while relating the clinical information to his or her experience.

On the other hand, imaging is black-and-white information – soon maybe more colourful – and needs to be put into perspective, taking into account the patient's complaints and physical limitations. Therefore, the combination of both worlds is essential, but may sometimes be difficult, even for the seasoned orthopaedic surgeon.

Once designated as the "gold standard" for the diagnosis of meniscus pathology, arthroscopy has currently become part of the therapeutic arsenal, because effective treatment can be associated to this type of surgery. It is now realized that even at that stage a common denomination of the same pathology remains difficult. Only recently have committees (ISAKOS – Allan Anderson) come to a conclusion on common denomination of the pathology at hand.

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In fact, the steps towards confronting the tentative preoperative diagnosis with the actual findings are being taken every day in orthopaedic diagnosis.

Arthroscopy has paved the way for straightforward arthroscopic surgery of the menisci. The concept of these being "vestigial" structures (Scott Dye) has long been refuted. The integrity of these semilunar cartilages is respected more and more as they are handled with care.

Because adequate resection has become the standard of care whenever appropriate, surgery and suture of the meniscus have gained importance in the armamentarium of surgical procedures.

With this has come an explosion of devices designed to obtain satisfactory stabilization of the torn part(s), which leads to good long-term clinical results. The relation of the torn meniscus to other traumatic lesions inside the knee – ACL, PCL, collateral ligaments – has sustained the importance of combined lesions and their treatment over time.

Long-term results have clearly shown the importance of both healed menisci and stable ligament structures to the cartilage surface of the knee, this being a prerequisite for the long-term integrity of this weight-bearing joint.

However, once a treatment has led to adequate and sometimes dramatic resection, the "slippery slope" (Peter Verdonk) concept comes into play. Most often, combined resection of the meniscus and loss of ligament balance will require proper treatment.

Tissue loss requires replacement, as does loss of stability. Ligament replacement has proven to be the standard of care. Meniscal replacement is still an ongoing field of research.

When confronted with total resection, total replacement with allografts has proven to be a valuable alternative with satisfactory long-term outcomes. Deep-frozen, cryopreserved and viable allografts tend to provide 70%

P. Beaufils and R. Verdonk (eds.), *The Meniscus*,
DOI: 10.1007/978-3-642-02450-4_13.1,

of near-satisfactory results whatever the preservation technique used. This is particularly true for the lateral compartment of the knee.

However, the number of these cases is limited, because most often only partial meniscectomy has been performed with preservation of the meniscal wall. This has led the way to partial replacement of the meniscus, exploring new concepts of implants capable of withstanding physiological stress, strain and loads in the knee joint.

In this emerging field of clinical science, research has led to the development of fascinating new products, such as the collagen meniscus implant (Steadman – Rodkey) and a polyurethane scaffold (Jacqueline De Groot) designed to recreate normal homeostasis, and thus, a pain-free and hopefully long-lasting, well-functioning knee.

Thus, researchers and clinicians are trying to beat the odds by searching for a replacement structure, resorbable yet strong enough to allow time for ingrowth of the "meniscal" cell so as to replace the implant scaffold with new-woven own collagen. This cell, the typing of which is still not fully understood, not only originates from the vascularized synovium, but also from the knee joint itself, as a provider of a stimulating medium.

Today's knowledge of knee meniscus physiology and pathology, as presented by the renowned authors in this work, might be a stimulus for a future breakthrough.

Index