Robert F. LaPrade
Elizabeth A. Arendt
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Editors

The Menisci

A Comprehensive Review of their Anatomy, Biomechanical Function and Surgical Treatment

INTERNATIONAL SOCIETY OF ARTHROSCOPY, KNEE SURGERY & ORTHOPAEDIC SPORTS MEDICINE • 1995 •

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ISBN 978-3-662-53791-6 ISBN 978-3-662-53792-3 (eBook)
DOI 10.1007/978-3-662-53792-3

Library of Congress Control Number: 2017932554

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The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

Preface

We extend our appreciation to ISAKOS for providing sponsorship and to Springer for the editorial leadership for this book on the menisci. This textbook was a collaborative project between the Sports Medicine and Knee Committee members and their research staff. The authors of this textbook certainly have a passion in trying to promote preservation of the menisci. As surgeons, it appears that the one factor that we can effect to prevent osteoarthritis more than any other is to perform a meniscus repair when it is possible. Thus, this textbook aims to review the different types of meniscus tears, those types of meniscus tears that are repairable, and the benefits that can be seen from repairing them.

We anticipate that this work will prove beneficial to surgeons worldwide. In the future, we believe that further biologic augmentation of meniscus repairs should stretch the indications for meniscal repairs even further compared to the types of tears that we repair commonly. We certainly hope that this textbook proves to be beneficial both for the arthroscopist in training and for those at advanced levels of sports medicine practice.

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Meniscus Anatomy

1

Urszula Zdanowicz and Robert Śmigielski

Contents

1.1 Introduction

Originally described by Bland Sutton in 1897 [14] as "functionless remnants of intraarticular leg muscles," menisci are currently recognized as one of the most important structures determining the future of the knee joint [1, 5]. Therefore, awareness of meniscal anatomy and attempts to save the menisci is a key in preventing early knee osteoarthritis.

1.2 Medial Meniscus

The medial meniscus has a semilunar shape of fibrocartilage localized between the medial femoral and medial tibial condyle [8]. The medial meniscus covers up to 60 % of the articular surface of medial tibial condyle [4] and helps with the loading distribution in medial compartment.

In 2015, Śmigielski et al. [17] proposed a new, anatomical division of medial meniscus into five, uneven anatomical zones (Fig. 1.1). Within each zone, there is similar anatomy and identical ligaments attaching the meniscus to surrounding structures. Therefore, not only anatomy but also technique of suturing may need to differ between zones.

1.2.1 Zone 1: Anterior Root

The anterior root of the medial meniscus inserts along the anterior intercondylar crest of the anterior

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_1

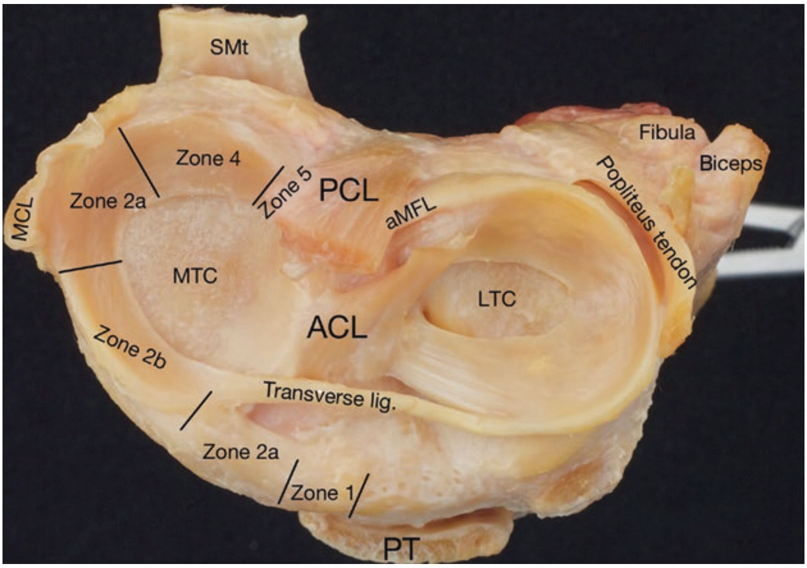


Fig. 1.1 Cadaveric specimen of left knee joint. Femur removed. Division into five anatomical zones of medial meniscus is shown. *PT* patellar tendon, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament, *MTC* medial tibial condyle, *LTC* lateral tibial condyle, *MCL* medial collateral ligament, *aMFL* anterior meniscofemoral ligament, *SMt* semimembranosus tendon

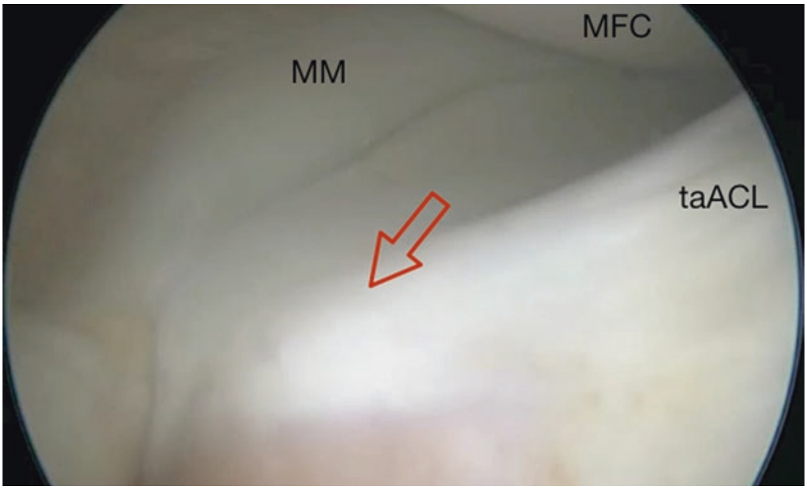


Fig. 1.2 Arthroscopic view of anteromedial compartment of the left knee joint. *MM* medial meniscus, *MFC* medial femoral condyle, *taACL* tibial attachment of anterior cruciate ligament. The absence of solid fixation of anterior root of medial meniscus is marked with *red arrow*

slope of the tibia [11]. In the anatomical study of 48 cadaveric knees, Berlet et al. [2] reported on four types of bony attachment of the anterior root of the medial meniscus:

Type I (59 % of all cases) is located in the flat intercondylar region of the tibial plateau.

Type II (24 %) occurs on the downward slope from the medial articular plateau to the intercondylar region.

Type III (15 %) occurs on the anterior slope of the tibial plateau.

Type IV (3 %) demonstrates no solid fixation.

In his anatomical study of 12 nonpaired human cadaveric knees, LaPrade et al. reported that the area of the anterior root attachment of medial meniscus was about 110.4mm^2 [12].

According to Rainio, in 1 % of cases, there might be an atypical insertion of the anterior root of the medial meniscus, which the most frequent is the absence or hypermobility of the anterior root attachment of the medial meniscus [16] (Fig. 1.2).

1.2.2 Zone 2: Anteromedial Zone

Zone 2 may be further divided by the meniscal attachment of the transverse ligament into two subzones: 2a and 2b. Zone 2a starts at anterior

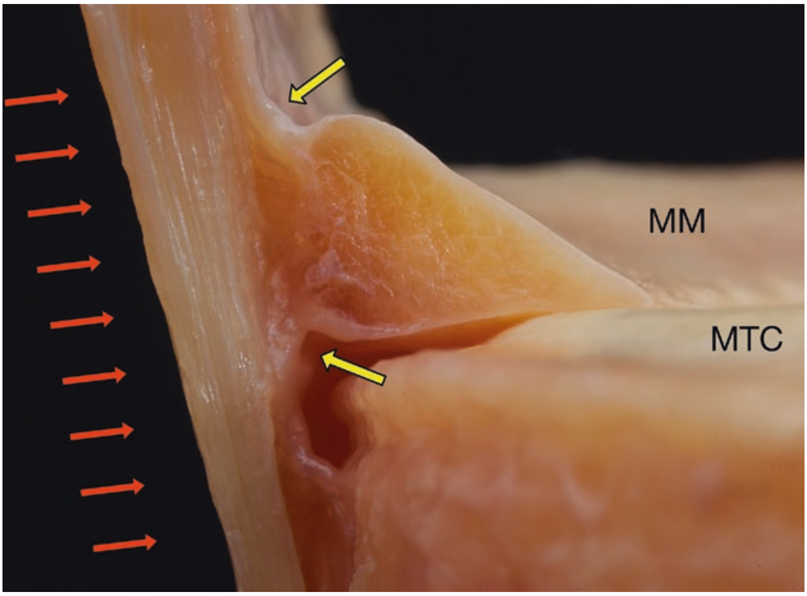


Fig. 1.3 Cadaveric specimen of the left knee joint. Cross section of medial meniscus at the level of zone 3. Meniscofemoral and meniscotibial (coronary ligament) is marked with *yellow arrows*. Medial collateral ligament is marked with *red arrows*. *MM* medial meniscus, *MTC* medial tibial condyle. Notice at this level, outer part of medial meniscus fully attaches to deep part of medial collateral ligament (also called thickening of joint capsule)

root of medial meniscus and ends by the attachment of the transverse ligament, where zone 2b begins to end at the anterior border of medial collateral ligament. The meniscus in this zone attaches to the tibia by the meniscotibial ligament, also called the coronary ligament. The superior edge of the medial meniscus within zone 2a shows no attachment to the surrounding tissues. In zone 2b, the most superior periphery of the medial meniscus is attached to the synovial tissue [17].

1.2.3 Zone 3: At the Level of the Medial Collateral Ligament

This is the only zone where the entire outer part of the medial meniscus fully attaches to the joint capsule. The deep part of the medial collateral ligament, also considered as a thickening of the medial joint capsule, has distinct meniscofemoral and meniscotibial components [13] (Fig. 1.3).

1.2.4 Zone 4: Posterior Horn

Zone 4 of the medial meniscus attachment extends from the superficial medial collateral ligament to the meniscal posterior root attachment. It is a very important zone, because it is the most frequently injured and sutured area. Within this zone, the medial meniscus has only its attachment to the tibia, via the meniscotibial (coronary) ligament, which attaches to the tibia about 7–10 mm below its articular surface. The meniscal superior edge and outer part do not attach to anything (Figs. 1.4 and 1.9a). Behind the outer part of the medial meniscus in this zone, there is a large posterior femoral recess [6]. Closing this recess by nonabsorbable sutures fixing the medial meniscus to joint capsule clearly might impair meniscal biomechanics and therefore might be responsible for failure of the meniscal repair.

1.2.5 Zone 5: Posterior Root

The posterior root attachment of the medial meniscus is localized posterior from the medial tibial eminence apex, lateral from the articular cartilage inflection point of the medial tibial plateau, and anteromedial from the tibial attachment of posterior cruciate ligament [10, 17] (Fig. 1.5).

1.3 Lateral Meniscus

1.3.1 Anterior Root

The anterior root of the lateral meniscus inserts to the tibia deeply beneath the tibial attachment of

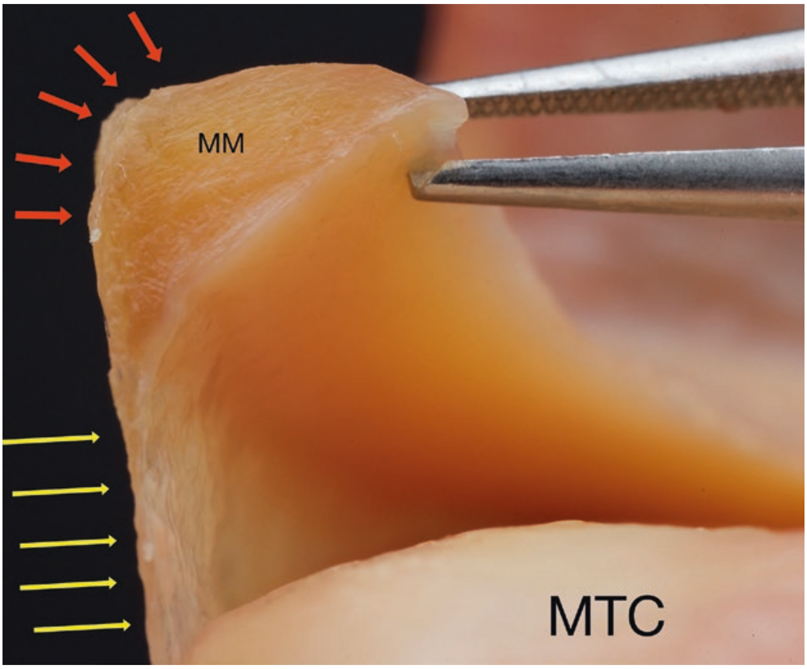


Fig. 1.4 Cadaveric specimen of the left knee joint. Medial meniscus (MM) in the zone 4. *MTC* medial tibial condyle. Meniscotibial (coronary) ligament is marked with *yellow arrows*. Notice superior edge and outer part have no attachments to surrounding tissues (marked with *red arrows*). This type of meniscal ligaments with this zone should be taken into the consideration while planning meniscus suturing and/or reconstruction

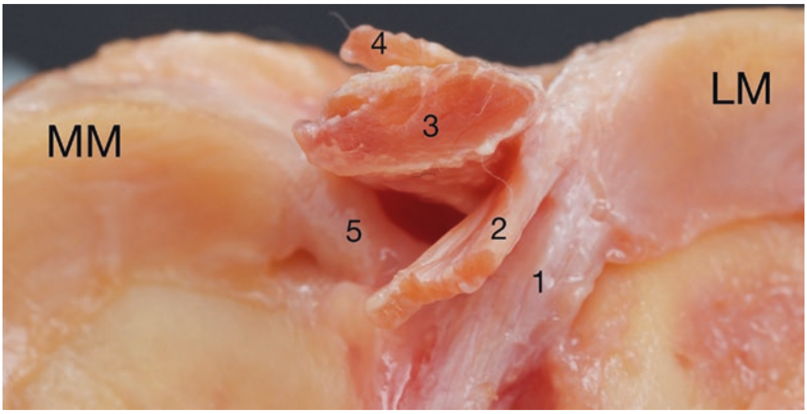


Fig. 1.5 Cadaveric specimen of the left knee joint. Area of meniscal posterior root is visualized. *MM* medial meniscus, *LM* lateral meniscus. *1* posterior root of lateral meniscus. *2* anterior meniscofemoral ligament (Humphrey ligament). *3* posterior cruciate ligament. *4* posterior meniscofemoral ligament (Wrisberg ligament). *5* posterior root of medial meniscus

the anterior cruciate ligament (ACL) [12] (Fig. 1.6a, b). The tibial attachment of ACL forms “C”-shaped insertion, in the middle of which there is a center of anterior root attachment of lateral meniscus. This insertion site is also called a “duck foot” or a tent over this meniscal insertion.

1.3.2 Anterior Horn

The anterior horn of the lateral meniscus is a very mobile part. It moves back and forth with knee flexion and extension (Fig. 1.7). One must carefully suture the meniscus in that area not to interrupt that movement.

1.3.3 Area at the Level of Hiatus Popliteus

At the level of the popliteal hiatus, the lateral meniscus forms an attachment to the fibula, via the capsular ligament: meniscofibular ligament. This ligament passes anteriorly to the popliteus tendon and, with rotatory movement

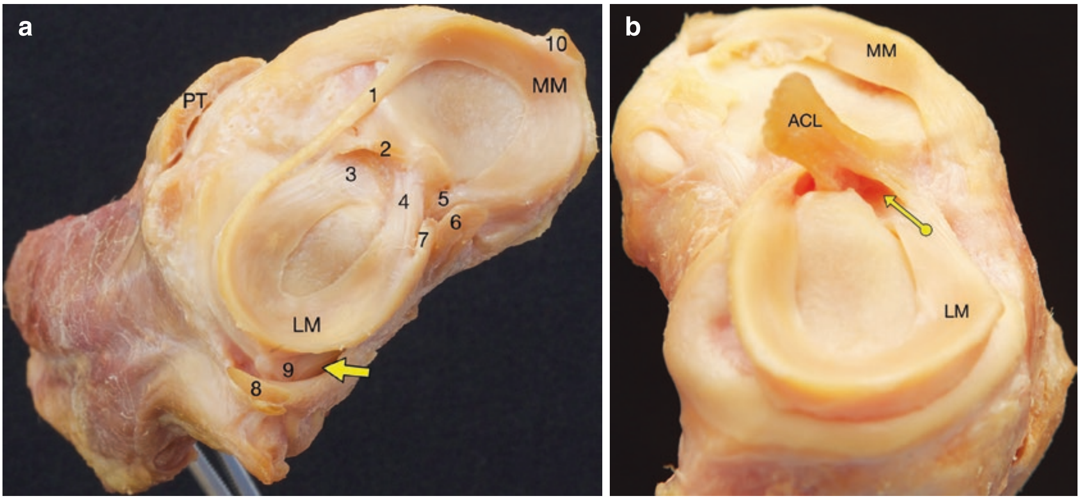
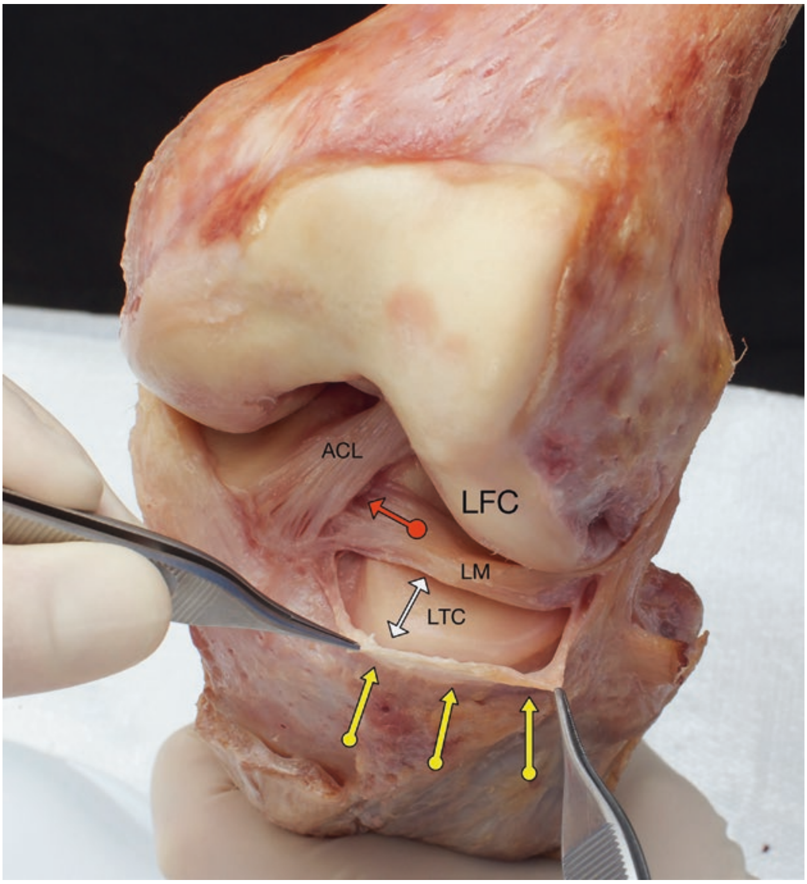


Fig. 1.6 (**a**) Cadaveric specimen of the left knee joint. *MM* medial meniscus, *LM* lateral meniscus, *PT* patellar tendon. *1* – Transverse ligament. *2* – Tibial attachment of anterior cruciate ligament. *3* – Anterior root of lateral meniscus. *4* – Posterior root of lateral meniscus. *5* – Posterior root of medial meniscus. *6* – Posterior cruciate ligament. *7* – Anterior meniscofemoral ligament. *8* – Popliteus tendon. *9* – Meniscofibular ligament. *10* – Msedial collateral ligament. Hiatus popliteus – marked with the *yellow arrow*. (**b**) Cadaveric specimen of the right knee joint. View from lateral side. *MM* medial meniscus, *LM* lateral meniscus, *ACL* anterior cruciate ligament. Notice the way ACL surrounds and cover like a tent (also called a “duck foot”) anterior root of lateral meniscus

Fig. 1.7 Cadaveric specimen of the left knee joint. *ACL* anterior cruciate ligament, *LM* lateral meniscus, *LFC* lateral femoral condyle, *LTC* lateral tibial condyle. Notice the way anterior root of lateral meniscus inserts beneath tibial ACL attachment (marked with *red arrow*). *Yellow arrows* mark loose meniscotibial ligament. *White arrow* marks the distance the anterior part of lateral meniscus moves with the knee in flexion



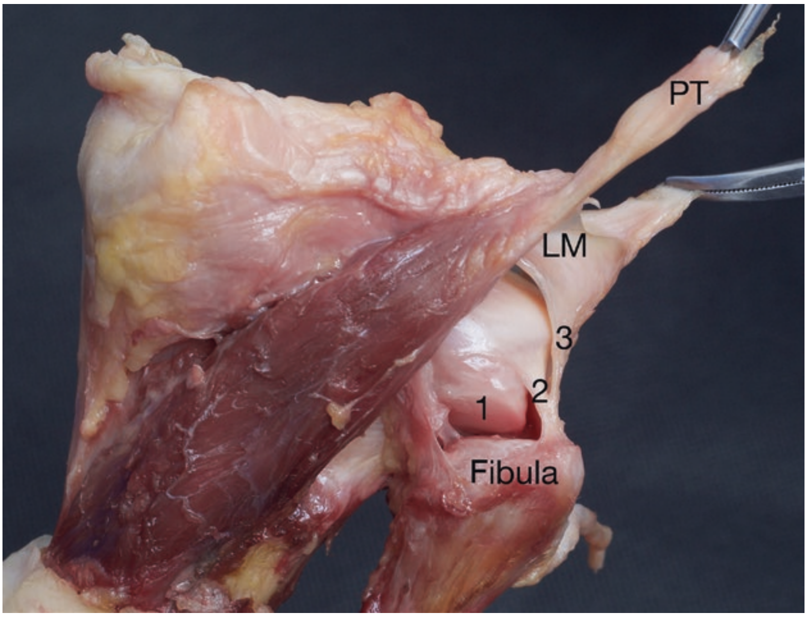


Fig. 1.8 Cadaveric specimen of the right knee joint, posterior view. *LM* lateral meniscus, *PT* popliteus tendon. *1* – Tibial articular surface of the proximal tibiofibular joint. *2* – Superior part of joint capsule of the proximal tibiofibular joint. *3* – Meniscofibular ligament

of the fibula, is believed to position the lateral meniscus [3] (Fig. 1.8). A failure to diagnose and reconstruct this underestimated ligament might play a role in poor long-term results in cases of meniscal suturing in this area. Additionally, the lateral meniscus is stabilized in this area by popliteomeniscal fascicles, connecting the lateral meniscus to the popliteal tendon sheet and joint capsule [18].

1.3.4 Meniscofemoral Ligaments

There are two ligaments connecting the posterior horn of the lateral meniscus to the femur: anterior meniscofemoral ligament (Humphrey ligament) and posterior meniscofemoral ligament (Wrisberg ligament) (Figs. 1.5 and 1.9a, b). Those ligaments contribute in reduction of contact pressure of lateral meniscus and also play an important role in the pathomechanics of the discoid lateral meniscus [9, 15, 19].

1.3.5 Posterior Root

The posterior root attachment of the lateral meniscus is a flat structure with a mean insertion site size between 28.5 and 115.0 mm^2. Its insertion was found to be posteromedial from the lateral tibial eminence apex, medial to the lateral articular cartilage edge, anterior from the posterior cruciate ligament tibial attachment, and anterolateral from the medial meniscus posterior root attachment [7, 10] (Fig. 1.5). You et al. [20] evaluated 105 knees in a 3.0 Tesla MRI and found three different types of posterior root attachment of lateral meniscus: in 76 % of cases, two insertion sites with the majority of fibers attaching to the intertubercular area with the anterior extension into the medial tubercle and the minor component attaching to the posterior slope of the lateral tibial tubercle. In the remaining 24 %, the posterior root of the lateral meniscus presents with isolated insertion site to either the intertubercular area or the posterior slope of the lateral tubercle, respectively.

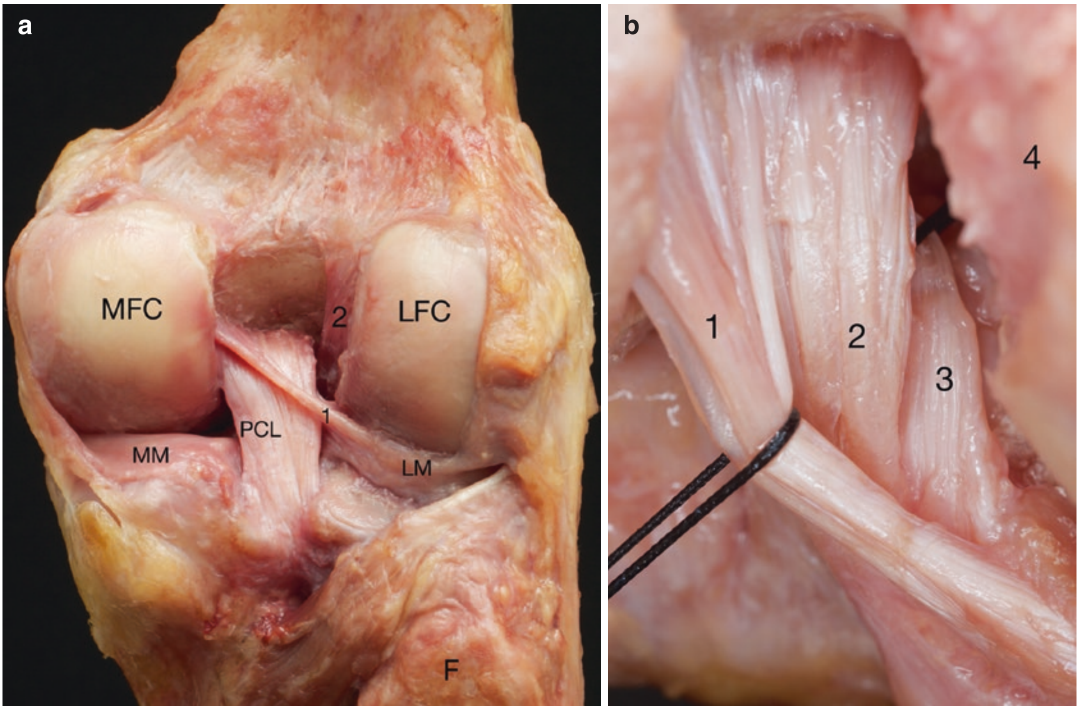


Fig. 1.9 (**a**) Cadaveric specimen of the right knee joint, posterior view. *MFC* medial femoral condyle, *LFC* lateral femoral condyle, *PCL* posterior cruciate ligament, *MM* medial meniscus (notice that medial meniscus in this area does not attach to anything). *LM* lateral meniscus, *F* fibula. *1* posterior meniscofemoral ligament (Wrisberg ligament). *2* femoral attachment of anterior cruciate ligament. (**b**) Close look into the posterior aspect of the right knee joint. *1* posterior meniscofemoral ligament (Wrisberg ligament). *2* posterior cruciate ligament. *3* anterior meniscofemoral ligament. *4* lateral femoral condyle

Acknowledgments The authors gratefully acknowledge Maciej Śmiarowski (maciej.smiarowski@gmail.com) for taking photographs and Center for Medical Education (www.cemed.pl) for its help.

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The Biomechanical Function of the Menisci

2

Scott Caterine, Maddison Hourigan,
and Alan Getgood

Contents

2.1 Introduction

The biomechanical nature of the menisci has been extensively studied and is well understood. Their unique anatomy and structural composition allow them to perform an array of tasks critical to normal knee function. This chapter will focus on the biomechanical properties of the menisci, and how it relates to their overall function. This will include a general understanding of their composition, compressive and tensile properties, followed by their general functions of load distribution, joint stability, lubrication and nutrition, and proprioception.

2.2 Microscopic Composition of Menisci and How It Relates to Function

The menisci are predominantly composed of water (about 65–75 %) and collagen (20–25 %), with the other 5 % made up of non-collagenous substances including proteoglycans, matrix glycoproteins, and elastin [1–5]. The collagenous network has a

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_2

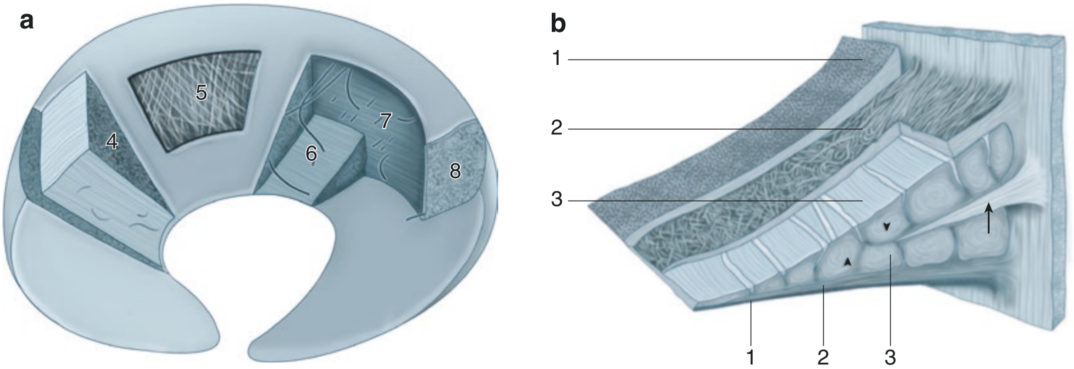

Fig. 2.1 Images taken from Bullough et al. (**a**) [12], Petersen and Tillman (**b**) [13]. (**a**) The different fibre directions of the menisci, showing randomly oriented fibres of the superficial layer, vertical fibres of the lamellar layer, and the radial and circumferential fibres of the deep layer. (**b**) The three distinct layers of the menisci. The superficial layer having disorganized fibres, the lamellar layer having peripherally oriented radial fibres with an internal interconnecting meshwork, and the deep layer having large circumferential oriented bundles intermingling with radial tie fibres

complex orientation, which greatly influences function due to the anisotropic property of the tissue. Fibres run in a variety of directions, which can be random, superficial to deep, extending radially, or circumferentially [5–11] (Fig. 2.1).

In contact with the femoral and tibial articular surfaces is the superficial layer of the menisci. This layer is composed of randomly oriented collagen mixed with a lubricating layer of proteoglycans, allowing for a low frictional surface [13, 14]. Beneath the superficial network is the lamellar layer. In this layer, the external area of the anterior and posterior menisci have collagen fibres extending radially, with the internal fibres intersecting at various angles, creating a mesh [13]. There are also vertical fibres in the lamellar layer projecting into the central 'main' layer of the meniscus which lies deep and is thought to secure the two together allowing for force transmission between the two layers [15]. In addition to these vertical fibres, there are radially oriented 'tie' fibres found in the central layer, which may also integrate with the lamellar layer through perpendicular branches. These tie fibres are found in the inner portion of the central layer and act to tie/hold circularly oriented circumferential collagen fibres, which are found peripherally in the central main layer [12, 16]. These tie fibres have been found to increase in population from anterior to posterior regions of the menisci, resulting in increased stiffness [16]. Circumferential fibres are larger bundles of mostly type I collagen, with the majority located in the internal and external circumference of the menisci because the middle portion experiences more uniform compressive stress and minimal radial stress [15, 17]. The radial tie fibres function to resist splitting of the circumferential fibres and may contribute to the compressive properties of the menisci [15, 17]. The circumferential fibres undergo great tensile or 'hoop' stresses when axially loaded [12, 15, 18–20].

2.3 Biomechanical Properties of Menisci

The function of menisci is largely attributed to their unique biomechanical properties.

2.3.1 Viscoelasticity

Human menisci are considered a viscoelastic material meaning that throughout an applied load, they exhibit both viscous and elastic properties. This transition occurs in a time-dependent nature, beginning in the elastic phase and shifting to the viscous phase during loading. The elastic quality, or the 'solid' phase of menisci, is due to its collagenous-proteoglycan structure, where the viscous or 'fluid' phase is due to its permeability and water content [7, 15, 21]. When a compressive load is applied to the menisci, the solid phase occurs initially exhibiting an elastic response. At the same time, fluid is extruded slowly, which accommodates the compressive load without excess deformation beginning the viscous phase [22, 23]. To help determine the contributions of these two phases during an applied load, biphasic theory was developed to describe the mechanical behaviour of viscoelastic tissues [24, 25]. An important characteristic of this theory is a tissue's permeability, which explains how fluid moves through both the interconnected pores in the solid matrix of menisci and the synovial space [6, 7, 21, 24]. Under compression, meniscal permeability determines the rate at which fluid is extruded. Meniscal permeability is much lower compared to articular cartilage, giving menisci the ability to maintain their shape during axial loads [7, 22, 25]. Menisci maintain their load-bearing capacity during gait by resisting fluid loss [5, 8, 26], which inhibits compression and maintains their shape. If the menisci did not maintain their shape, they would be essentially non-functional [22]. This is important to understand because these viscoelastic properties play a large role in the compressive resisting forces menisci possess.

2.3.2 Response to Compression

When a constant load is applied to the knee joint, there is an initial compression on the menisci which is resisted by the elastic characteristics of the collagen bundles and matrix [22]. Following this initial load, there is a diminished rate of compression as the fluid phase begins to take over. As fluid is extruded from the menisci, the compressive load is resisted which is referred to as 'creep' [15, 22]. When the menisci are compressed and held, the required load to maintain the compression is decreased. The menisci tissue relaxes, and the load needed to maintain the given held compression decreases. This is referred to as 'stress relaxation'. Creep and stress relaxation are two related characteristics of viscoelastic behaviour [22]. These two properties help to understand how menisci function during compressive loads. As stated previously, it is the permeability of menisci, along with these two properties, that allows them to maintain their shape during compression. This is supported as the compressive modulus for menisci is much greater at a physiological strain compared to equilibrium [10], showing that under axial loading, more force is needed to compress and ultimately affect the shape of the menisci.

When a compressive load is applied to the menisci, an axial load causes 'hoop stresses' to the circumferential fibres of the menisci extending to their attachments on the tibia and femur [12, 15, 19, 20]. As the femur compresses down, the menisci extrude peripherally due to their wedge shape causing a radially oriented tangential force [27]. This peripheral extrusion is prevented by the anterior and posterior meniscal attachments. As a compression force is applied, circumferential tension develops resulting in hoop stresses [19, 20, 28]. The menisci rely on conversion of the axial loads to tensile strains via these circumferential fibres, which travel along to both the anterior and posterior root insertions [29]. These hoop stresses allow distribution of stress over a large area of the articular cartilage, an important load-distribution function of menisci [30–32]. Hoop stresses can vary along the meniscus, and may also change in response to injury [33], such as a radial tear that disrupts the circumferential fibres resulting in a dysfunctional meniscus. It has been reported that the posterior region of the medial meniscus has a higher aggregate modulus than the rest of the menisci [26]. This may be because this region undergoes the highest compressive stress [34] and is the most commonly injured site [35, 36].

2.3.3 Response to Tension

Tension refers to the behaviour of a tissue as a stretching force is applied to it, resulting in elongation. When menisci undergo tensile forces, initially little is needed to elongate the menisci because collagen fibres are relaxed [37]. After the initial phase, there is a linear relationship between elongation and the load applied, followed by a dip in elongation as fibres begin to fail and tear [38]. The maximum load the menisci can maintain is referred to as the ultimate tensile load. The tensile properties can change depending on the location of the menisci.

In the superficial layer, there are no differences in tensile strengths. This is different than the central layer because the circumferential and tie fibres respond differently to tensile strains, with circumferential fibres having a greater tensile modulus than tie fibres [2, 7, 12, 21]. When comparing the different regions of the menisci, there is debate on whether significant tensile strength differences occur between the anterior, middle, and posterior portions. For the medial meniscus, it has been reported that the highest tensile modulus lies in the anterior region [21, 39], as well as the posterior region [7, 40]. For the lateral meniscus, there have been reports of the posterior portion having the highest tensile modulus [21] and others showing no significant difference at all [39]. A summary of the different tensile modulus of human menisci is shown in Table 2.1 [41].

In general, menisci have around a 150 MPa tensile modulus, where the ACL will be anywhere from 200 to 300 MPa and polyethylene will be around 1000 MPa [22].

2.3.4 Response to Shear

Shear stiffness is a measure of a material's resistance to changing shape. Menisci have a low shear stiffness relative to cartilage, with articular cartilage being over 100 times more shear resistant [18]. This low shear stiffness may allow the menisci to maintain optimal congruency between the tibia and femur through a full range of motion, ensuring even load distribution [15]. Additionally, tie fibres segregate circumferential fibres contributing to the low shear modulus of the menisci [7, 42, 43]. Shear modulus has also been found to be the lowest in the posterior portion of the medial meniscus [39].

2.4 Functional Properties of Menisci

2.4.1 Size, Shape, and Load Transmission

The size and shape of the menisci play a large role in their function. The medial meniscus covers anywhere from 50 to 54 % of the tibial articular cartilage surface and the lateral meniscus anywhere from 59 to 71 % [19, 44–47].

When unloaded, the contact areas across the knee are primarily on the menisci [47]. When the knee is loaded during gait, peak contact stresses on the medial plateau occur at the cartilage-cartilage interface, while stair climbing causes peak contact to move to the posterior portion of the plateau. During gait, peak contact stress on the lateral tibial plateau occurs under

Table 2.1 A summary of the different tensile moduli found in the human meniscus [41]

Type of specimen	Study	Width × thickness of specimens (mm)	Tensile modulus (MPa)			
			Anterior	Central	Posterior	Mean
Circumferential	Fithian [21]	0.4 × 1.0	159	161	159	160
	Tissakht [2]	1.75–3 × 1.5–2.0	91	77	81	83
	Lechner [40]	0.5 × 1.0	141	116	108	122
		1.5 × 1.0	105	94	61	86
		3.0 × 1.0	72	43	67	61
	Mean values		114	98	95	102
Radial	Tissakht [2]	1.75–3. × 0.8–2.0	8	11	13	11

the meniscus, whereas in the late phases of stair climbing peak, contact areas are on the cartilage-cartilage interface [48]. Additionally, there is a general transfer of contact from the anterior aspect of the meniscus to the posterior meniscus during flexion [34, 47]. The lateral meniscus is also displaced more than the medial during loading, with load transmission shifting away from the centre of the femoral condyles, resulting in a tensile stress towards the tibial plateau [49]. In the extended knee under load, the medial meniscus takes on anywhere from 40 to 60 % of the load, and the lateral meniscus takes on anywhere from 65 to 70 % [19, 46, 50]. Finite element models show that the menisci transfer 62 % of the total axial load under 134 N anterior tibial load and 1150 N compressive load (40 % being medial meniscus). In addition, during a 134 N posterior tibial load and a 1150 N compressive load, the menisci transfer 75 % of the total axial load (60 % by medial meniscus) [51].

By covering a large surface area, the menisci function in load transmission and distribution, by increasing the congruency of the tibiofemoral compartments. This is important because contact stresses begin to increase as surface contact areas decrease [47, 52, 53] and it is the function of the menisci to decrease these contact stresses by maximizing contact area. This is particularly important in the lateral compartment, where the convex surface of the femoral condyle articulates with the relatively flat or convex surface of the tibial plateau. The large surface area of the lateral meniscus creates a more congruent articulation, thereby distributing the load more evenly across the compartment. If the menisci are not functioning properly, contact areas will decrease and contact stresses will increase, which can lead to increased stresses on the articular cartilage. This concept is highlighted following meniscectomy, which reduces contact areas and increases contact stresses. Meniscectomy can cause an increase in contact area anywhere from 40 to 75 % and resulting contact stresses to rise anywhere from 200 to 300 % [20, 33, 47, 52, 54–57]. This is important because a linear relationship exists between the amount of meniscus removed and peak contact stresses [34], supporting the idea to conserve as much meniscus as possible and performing a meniscus repair over a meniscectomy.

2.4.2 Joint Stability

The size and shape of the menisci allow for congruency between the femur and the tibia [32, 58–63] with the intact menisci limiting excess motion in all directions [64] and helping to stabilize the knee joint. The medial meniscus is an important secondary restraint to anterior tibial translation [22, 65, 66], with the lateral meniscus having an important secondary role in restraining combined axial and rotary loads [67]. This is understandable because the medial meniscus is less mobile at moving anterior to posterior. This is because the middle portions are attached to capsule [68, 69], and the posterior portions are firmly attached to the tibial plateau [69]. The medial meniscus is also thought to have a 'wedge' effect created by compression on the posterior horn during loading, preventing anterior displacement, especially in ACL-deficient knees [32]. Due to the mobility of the lateral meniscus, it is thought that it plays a lesser role in anterior stability compared to the medial meniscus [32, 70, 71], but more recent studies have highlighted its importance in controlling anterolateral rotatory laxity [67].

The joint stabilizing capabilities of the menisci are mostly apparent in ACL-deficient knees. Following medial meniscectomy in the ACL-deficient knee, there is an increase in anterior tibial translation and a decrease in coupled internal tibial rotation when an anterior tibial load is applied [58]. Additionally, there is a significant increase in anterior displacement in an ACL-deficient knee plus medial meniscectomy versus ACL deficiency alone [32].

2.4.3 Lubrication and Nutrition

The menisci are reported to play a role in lubrication of the knee joint [72], and there is an increase in the coefficient of friction following meniscectomy [73]. In addition, as mentioned earlier, the superficial layer of the menisci have a large proteoglycan content allowing for a low-friction surface for articular cartilage to articulate against.

The menisci are also thought to play a nutritional role in the knee joint. They contain a porous network connecting the meniscal vasculature with the synovial space. It is believed during compression that fluid is able to pass from the menisci into the synovial space, both allowing the delivery of nutrients and reducing frictional forces on the articular cartilage [64, 74, 75].

2.4.4 Proprioception

The proprioceptive role of the menisci is well established, with multiple reports having found a variety of different mechanoreceptors within the tissue [30, 76–81]. Pacinian corpuscles have been located which mediate joint motion sensation (slow adapting), in addition to Ruffini endings and Golgi tendons which are believed to mediate sensation of joint position [82]. Mechanoreceptors are mostly found in the middle and outer third of the menisci and indicate the menisci may have an important sensory feedback role in the knee [42, 78, 83–85].

2.4.5 Shock Absorption

It is generally believed that the menisci act as prominent shock absorbers of the knee joint [28, 29, 56]. However, these reports have been recently criticized [86]. Some believe the shock-absorbing ability of the knee is actually attributed to the eccentric contractions of muscles which surround the knee joint [87] and not the menisci. More recently, it has been shown that the stiffness and energy dissipating ability of the menisci are much lower than that of articular cartilage and that if the menisci do play a role in shock absorption, it is a minor role [88].

2.4.6 Functional Movements of Menisci

Movement of the meniscus during flexion ensures maximum congruency over the articulating surfaces while avoiding injury [89]. It is this congruency that allows many of the actions of menisci to be so effective, such as load transmission, stability, and lubrication. This congruency is maintained because of the way the menisci move throughout a normal range of motion. The lateral meniscus can move up to two times as much as the medial meniscus [42], and the anterior horns move more than the posterior horns. This is critical because the femoral condyles' articulating shape with the menisci changes during flexion and extension, causing the anterior and posterior horns to move apart during full extension and together during flexion [7]. As the femoral condyles rotate over the tibia into extension, they push the meniscal roots anterior and posterior, respectively. The anterior horns allow movement to accommodate this, while the posterior horns are more secured, restricting excess movement [89]. This allows the menisci to maximize contact areas with the articular surfaces, reducing contact stresses [7]. Movements of the medial menisci during flexion and extension under load are anywhere from 2 to 5 mm anterior to posterior and the lateral meniscus anywhere from 9 to 11 mm [59, 71, 89–91]. Additionally, during internal rotation, the lateral meniscus moves posteriorly, and the medial meniscus moves anteriorly [92].

2.5 Pathology Resulting in a Dysfunctional Meniscus

Issues arise in the functionality of the menisci as a result of damage, specifically radial and longitudinal tears. As mentioned earlier, the menisci are composed mainly of radial tie fibres and circumferential collagen bundles. Meniscal tears can lead to instability, pain, and catching or locking of the knee [4]. Due to the direction of longitudinal tears, the biomechanics may not be disrupted as the circumferential fibres remain intact [93]. However, these types of lesions can alter the normal strains the menisci are exposed to during loading [33]. In extension, a longitudinal tear will increase anterior meniscus strain; however, during flexion, the lesion will cause an increased curvature of the meniscus posteriorly, likely altering strain as well. Horizontal tears, which divide the meniscus into superior and inferior segments tend to be more degenerate in nature and can result in pain and parameniscal cyst formation. A radial tear will result in disruption of the circumferential fibres which will alter strain throughout the tissue-reducing contact area and increasing stresses [94]. A 50 % tear will leave most circumferential fibres intact allowing the meniscus to maintain a significant contribution to normal knee mechanics, whereas a 100 % radial tear would usually cause the meniscus to extrude from the joint space [33] and be rendered functionless [79, 95]. This disrupts the hoop stresses associated with weight bearing, and as a result, when possible, repair should be attempted [96]. Additionally, pathology of the meniscal roots also have deleterious effects on the knee joint, because they are important in controlling rotation and maintaining hoop stresses [97–99]. Following a posterior root tear of the medial meniscus, there is an increase in peak contact pressures of the medial compartment compared to intact roots of up to 25 % [100, 101]. Disruption of the medial posterior root has also been shown to increase tibial external rotation and lateral translation [100] and is associated with osteonecrosis of the knee [102, 103]. Root avulsion and radial tears of the lateral meniscus posterior horn also result in decreases contact areas at all flexion angles, increasing cartilage contact stresses [104, 105].

These types of injuries are important, because as stated before, any loss or damage to the meniscus results in increase contact stresses, which will ultimately place larger stresses on the articular cartilage resulting in eventual osteoarthritis.

2.6 Meniscus-Associated Ligaments

In the previous chapter, the anatomy of the ligaments associated with menisci is described. Here we will briefly discuss known functions of these ligaments.

2.6.1 Anterior Intermeniscal Ligament (Transverse Geniculate Ligament)

The role of this ligament is still unclear, and it is postulated that it may contribute to helping transmit hoop stresses between the two menisci, therefore contributing to a decrease in contact pressure across the joint during compression [106]. However, it has been shown that sectioning of this ligament will increase peak pressures in the medial compartment at certain flexion angles [107], and it was also found to have no effect during full extension [106].

2.6.2 Coronary Ligaments

These ligaments connect the outer circumference of the menisci to the proximal tibia, anchoring the tissue to the tibial plateau thereby reducing translation and increasing stability.

2.6.3 Meniscotibial Ligaments

These are a continuation of the circumferential collagen fibres of menisci and attach to the subchondral bone deep to the tibial plateau to anchor the menisci to the tibial surface. The loss of function of these ligaments has been linked to significant medial meniscal extrusion [70], and the integrity of these ligaments is crucial to meniscal function [100]. Damage to the posterior root of either the medial or lateral meniscus has shown to significantly increase tibiofemoral contact pressures, decreasing contact areas and decreasing the functionality of menisci [100, 104, 105, 108]. Failure rates for these ligaments have tried to be determined, though large variations in ranges have been reported. The mean load to failure for the medial posterior root is 596 N, and the mean load to failure for the lateral posterior root is 579 N [109, 110].

2.6.4 Deep Medial Collateral Ligament (dMCL)

The deep medial collateral ligament has been shown to provide secondary varus-valgus restraint to the knee joint, while providing some restraint to tibial external rotation past 30 degrees flexion [111]. Additionally, when in tibial external rotation, the dMCL provides a restraint to anterior translation.

2.6.5 Anterior and Posterior Meniscofemoral Ligaments (aMFL/pMFL)

Also referred to as the ligaments of Humphrey (anterior) and Wrisberg (posterior), studies have shown that they act as stabilizers to the posterior horn of the lateral meniscus at different times throughout the range of motion [112]. They also reduce anterior-posterior laxity of the knee by moving the posterior horn of the lateral meniscus anteriorly and medially during flexion [113], though the magnitude of this effect is uncertain. The MFLs also play a substantial role in resisting posterior tibial drawer in both the intact and PCL-deficient knee [114] between 15 and 90 degrees flexion, although they have no defined role in preventing rotational laxity in the PCL-deficient knee [114].

2.6.6 Meniscofibular Ligaments

Attaching the meniscus to the head of the fibula, this ligament becomes tense while the knee is extended and externally rotated [115].

Conclusion

The menisci have a crucial role in the normal knee function. Their unique composition and tissue properties allow them to serve a variety of important tasks. Their mobility allows them to create a congruent surface between the different shapes of the femur and tibia, allowing for load distribution and joint stability. They also provide lubrication, nutrition, and proprioception. Overall, the menisci of the knee are versatile structures that play a crucial role in knee mechanics. Meniscal tears and resection can result in the loss of a functional meniscus with subsequent significant detrimental changes occurring within the knee, highlighting the importance of meniscal preservation, which will be discussed in later chapters.

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Classification of Meniscal Tears

3

Sergio Rocha Piedade

Contents

3.1 Introduction

The meniscus is described as a C-shaped fibrocartilage structure which is highly specialized to absorb energy when submitted to recurrent loading cycles and experiences both radial and circumferential stresses in different joint-loading planes [10]. Moreover, the menisci exhibit an independent healing ability, ordinarily restricted to their anatomical vascularity [2].

These anatomical and biomechanical particularities are linked to a vast spectrum of presentation and different patterns of meniscal injuries. Therefore, this should be considered for the treatment approach [4, 13, 15]. With this background, classifying meniscal injuries allows us to recognize, group, and delineate a proper treatment based upon outcomes reporting the characteristic for each of the meniscal tear injuries.

For example, the classification of meniscal injuries and the suggestion of maintaining the peripheral meniscus capsular rim, proposed by Trillat and Dejour [18] in 1968, were fundamental in establishing the concept of meniscal preservation surgery.

3.2 Classification of the Meniscal Tears

Several classifications of meniscal injuries have been proposed over time. Each system of classification approaches a particular aspect of the

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_3

meniscal structure according to its morphology, proximity to the blood supply, anatomical site, and injury pattern [9, 16, 19, 20].

Traumatic meniscal lesions are characterized arthroscopically as a tear produced by a specific, well-known trauma on normal meniscal tissue.

On the other hand, the degenerative meniscal lesions are, often, related to a decompensation after a minor trauma or even no traumatic event, and the meniscus substance exhibits macroscopic and microscopic alterations named myxoid degeneration [3, 6].

Different patterns of meniscal tears have been named in the literature, according to each specific pattern and configuration for the meniscal tear observed (Fig. 3.1). Therefore, meniscal tears can be classified as radial tears, flap or parrot-beak tears, bucket-handle tears, horizontal cleavage tears, longitudinal tears, and complex and degenerative tears (multiplanar) [6, 8].

3.2.1 Trillat's Classification

Trillat's classification [19] approaches the evolution of the different stages of the traumatic meniscal tear. In stage I, the injury may progress with a posterior flap. In stage II (longitudinal meniscal tear), three subtypes are described according to the location of the disruption of the meniscal longitudinal flap tear: anterior (IIa), middle (IIm), and posterior (IIp). Stage III represents the inner edge of the meniscus dislocated into the intercondylar notch (bucket-handle tear). Although this classification can be applicable in cases of lateral meniscal injury, this classification was described for medial meniscal tears (Fig. 3.2).

3.2.2 MRI Classification of Meniscal Tears

Currently, magnetic resonance imaging (MRI) is a valuable tool to evaluate for meniscal tears, particularly for traumatic tears. Meniscal tears are classified according to signal intensity T2W for three grades [17]. Grade I is defined as a small focus of increased signal; grade II demonstrates a linear area with no extension to the articular surface, while grade III represents articular surface involvement and a complete meniscal tear (Fig. 3.3).

3.2.3 ISAKOS Classification

The ISAKOS classification of meniscal tears [1] offers an interobserver reliability with satisfactory results for classifying depth, location, tear pattern, length, tissue quality, and the percentage of the meniscus excised.

3.2.3.1 Tear Depth

A complete tear extends completely through the inferior and superior surface of the meniscus, while a partial tear involves either the inferior or superior surface of the meniscus.

3.2.3.2 Tear Location: Rim Width

The meniscus tear location is graded according to how far the tear extends into the meniscus tissue. The rim width tear is classified into three zones, according to the extension of rim width tear: zone 1 (less than 3 mm), zone 2 (3–5 mm), and zone 3 (more than 5 mm) (Fig. 3.4). A radial meniscus tear should be graded based upon the rim width distance of the tear.

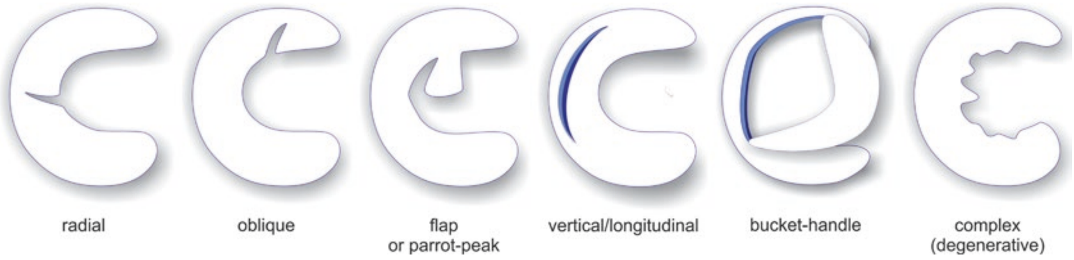


Fig. 3.1 Different patterns of the meniscal tears

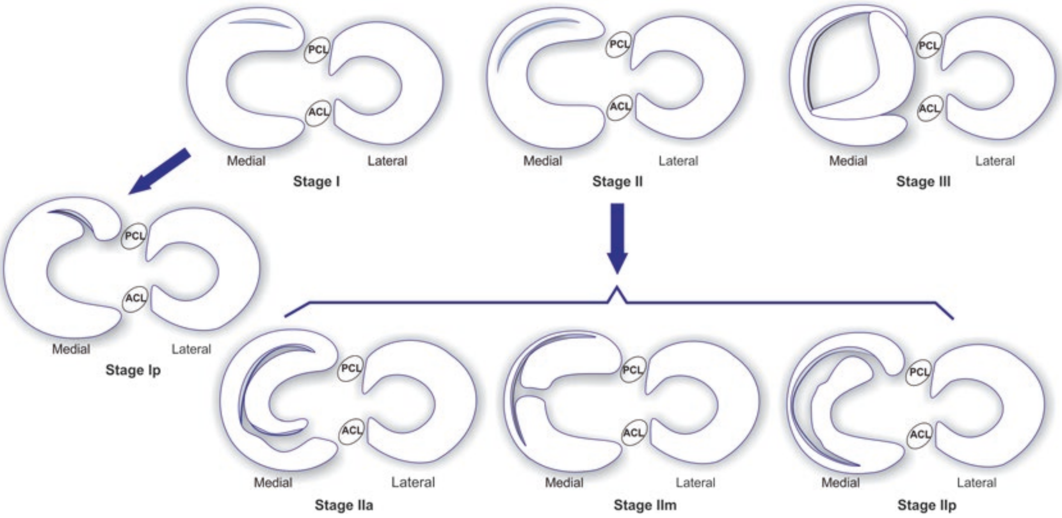


Fig. 3.2 Trillat's classification of traumatic meniscal injury

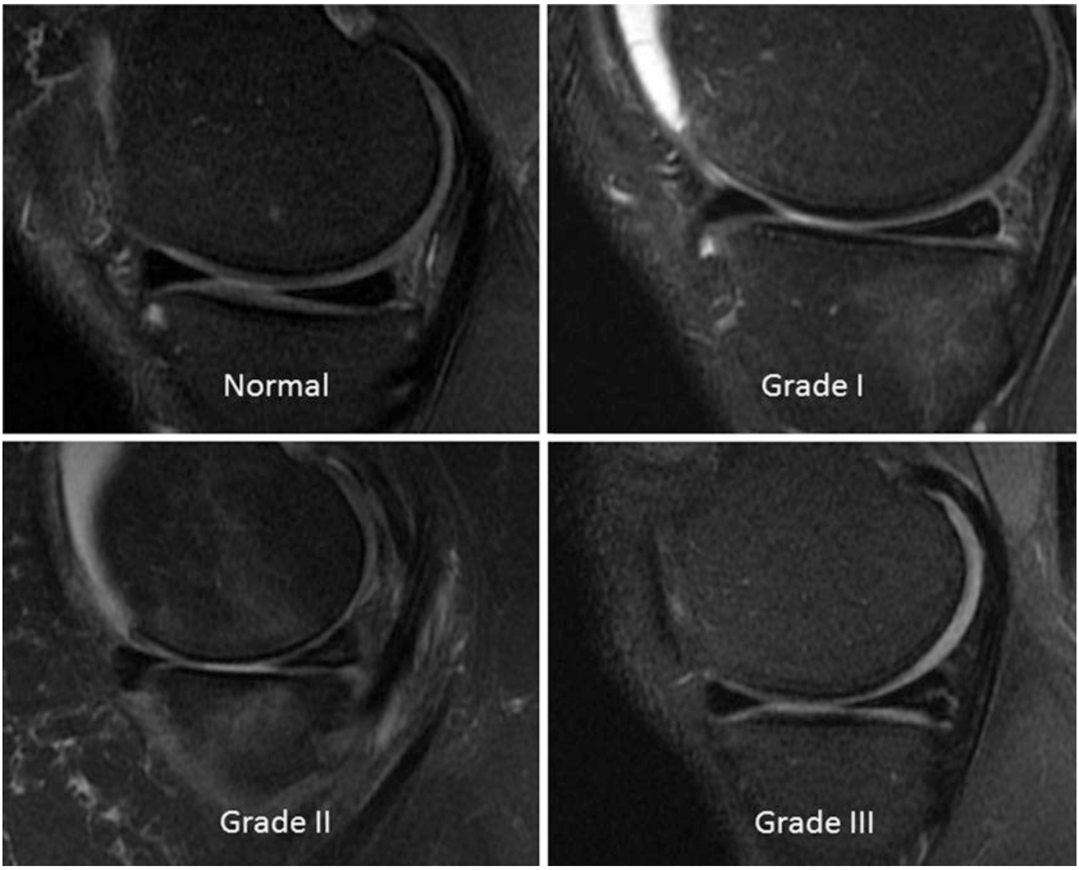


Fig. 3.3 MRI classification of meniscal tears

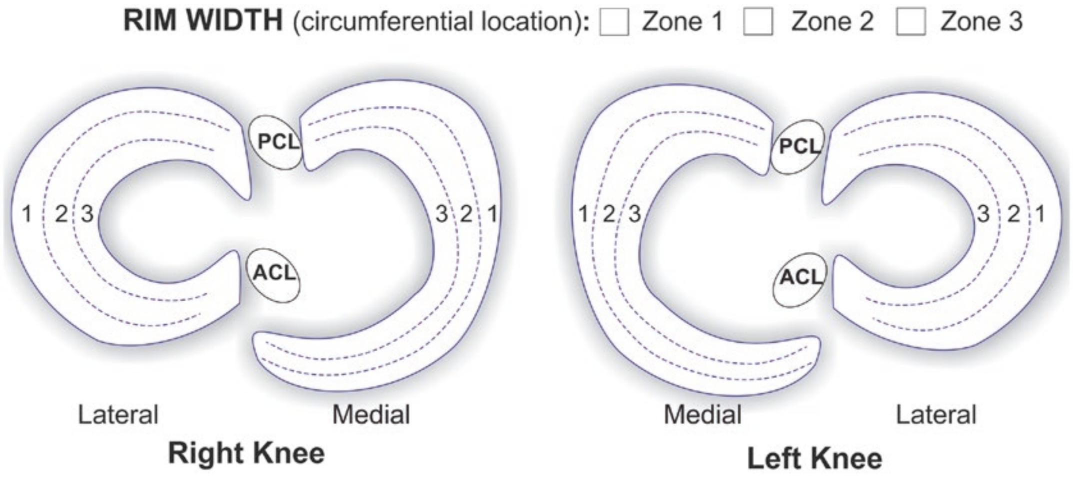


Fig. 3.4 Diagram of rim width location of the meniscal tear (ISAKOS classification)

3.2.3.3 Local Tear: Radial Location

For radial meniscal tears, two factors are considered. Firstly, the radial tear location is graded according to zones in which they are topographically located, posterior, midbody, or anterior (Fig. 3.5a), and then, they are graded as posterior-anterior classification as shown in the diagram below (Fig. 3.5b).

3.2.3.4 Patterns of Meniscal Tears

The diagram presented in Fig. 3.6 offers the references to register the different patterns of a meniscal tear. Each meniscal tear presents particularities inherent to the mechanism of trauma and the quality of the meniscus tissue (degenerative versus normal tissue).

Longitudinal Vertical Tear

This type of meniscal tear results from trauma and is particularly observed in young patients, most commonly with an anterior cruciate ligament tear. The tear pattern is vertically oriented to the edge of the meniscus and is usually a reparable lesion. When the inner fragment of the longitudinal tear is dislocated into the intercondylar notch, this lesion is named a bucket-handle tear.

Horizontal Meniscus Tear

In this type of meniscal tear, the superior and inferior meniscus surfaces are separated apart by the tear. The tear begins at the inner edge of the meniscus and continues toward the capsule. Typically, they are degenerative tears and mainly, but not always, affect older people.

Radial Meniscus Tear

This type of meniscal tear is often secondary to a traumatic event, often located at the junction of the middle and posterior thirds of the lateral meniscus. This lesion is vertically oriented toward the meniscus periphery, being either partial or complete (transecting the meniscus). Usually, this type of tear is unstable and historically was considered to be non-reparable lesion because they are located in the avascular zone of the inner edge of the meniscus. However, the chapter on radial meniscal repairs will provide new information on radial meniscal repairs.

Flap or Parrot-Beak Tears

These tears could be produced by a radial tear or a transection of the bucket-handle tear with a circumferential extension building a flap of meniscal tissue, being vertical or horizontal.

Complex Tears, Degenerative Flap

This type of meniscus tear is usually associated with two or more tear patterns occurring in different planes.

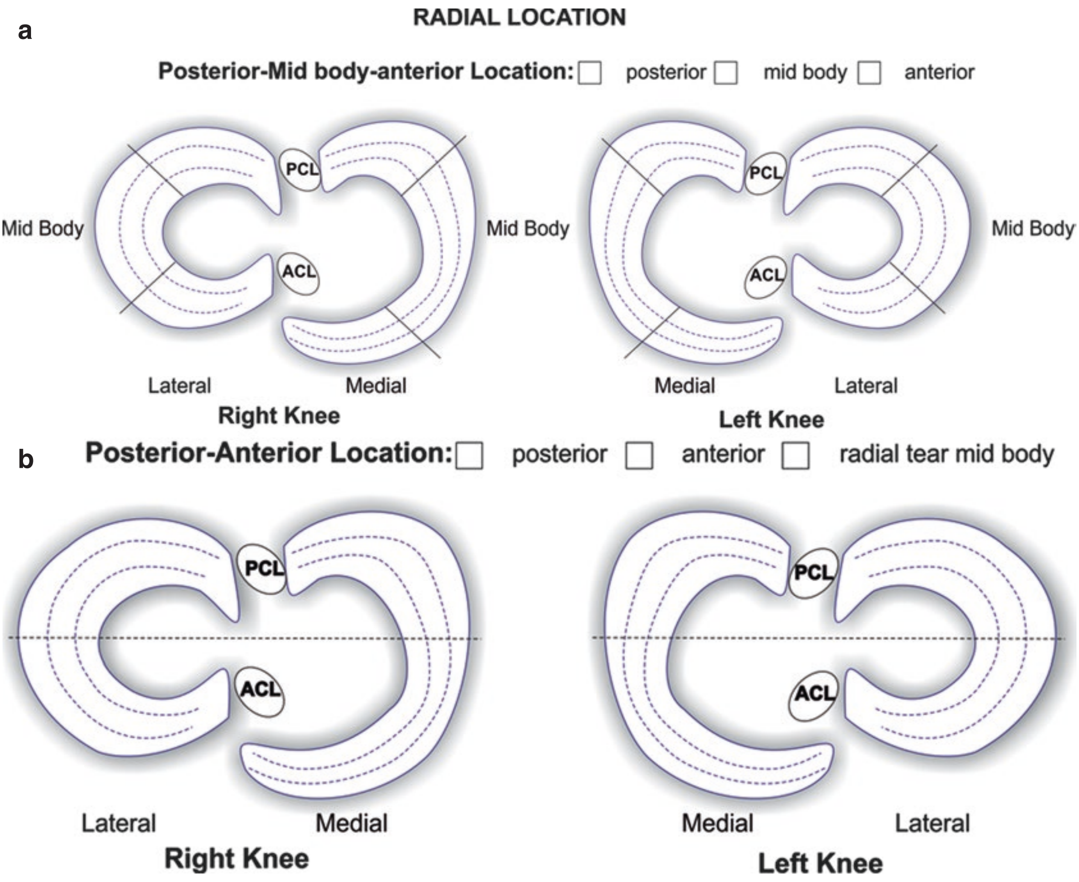


Fig. 3.5 Diagram of radial location of meniscal tear: posterior-midbody-anterior location (**a**) and posterior-anterior location (**b**) (ISAKOS classification)

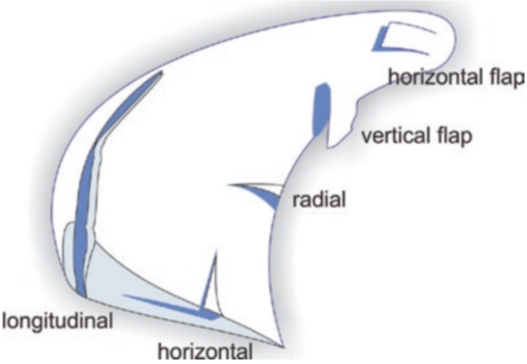


Fig. 3.6 Different patterns of meniscal tears (ISAKOS classification)

3.2.4 Classification of Discoid Meniscus

The meniscus discoid is a congenital anomaly that usually affects the lateral meniscus. It was classified by Watanabe [20] in three morphological forms according to the meniscus attachments and its dimensions related to the tibial plateau. Thus, in types I and II, the meniscus is larger than normal meniscus and has normal attachments, covering partially and completely the tibial plateau, respectively. In type III, the meniscus has no capsular attachment and is anchored posteriorly by the ligament of Wrisberg. Lately, a forth type of discoid meniscus called ring-shaped meniscus with normal attachments was described by Monllau et al. [12] (Fig. 3.7).

3.2.5 Classification of Degenerative Meniscal Tears

The clinical scenario of these injuries is often correlated to a decompensation after a minor traumatic or even no traumatic event. The meniscus substance exhibits macroscopic and microscopic alterations called myxoid degeneration. Dorfmann et al. (2010) [6] arthroscopically classified degenerative meniscal tears into five types (Fig. 3.8):

Type I – There is no interruption in the meniscal substance. Macroscopically, it appears flat and yellow and the inner edge is ragged.

Type II – It is characterized by the presence of calcium deposits, i.e., chondrocalcinosis.

Type III – It is a horizontal cleavage tear.

Type IV – In this type, the pattern of the meniscal tear is a radial tear (IVa) or flap (IVb).

Type V – It is defined as a complex injury, often associated with osteoarthritis.

3.2.6 Meniscal Root Tears

Recently, the interest of the meniscus root tear has been enhanced. Some authors have emphasized the importance of recognizing these meniscal tears that occur in the vascular zone of the meniscus tissue and their implications on their outcomes and particularly on accelerating the progression of osteoarthritis [7, 13].

Meniscal root tears have been historically underdiagnosed [11]. Usually, they are described as radial root meniscus tears, while a traumatic meniscus root tear is rare. Traumatic posterior lateral meniscal tear have often been found with ACL tears.

Christopher LaPrade et al. (2015) [9] presented a classification of meniscal root tears based on the tear morphology (Fig. 3.9). The authors classified meniscal root tears in five types, where:

Type 1 is defined as a stable and partial meniscal root tear.

Type 2 is a complete meniscal radial root tear within 9 mm of meniscal root attachment, which was further classified into three subtypes according to the meniscal tear root displacement in 2A (0 < 3 mm), 2B (3 to <6 mm), and 2C (6–9 mm).

Type 3 is an association of complete meniscal root tear and a bucket-handle tear.

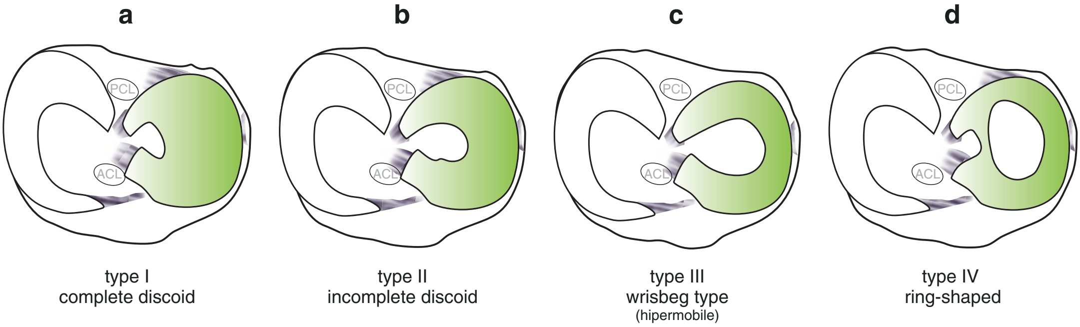


Fig. 3.7 Classification of discoid meniscus

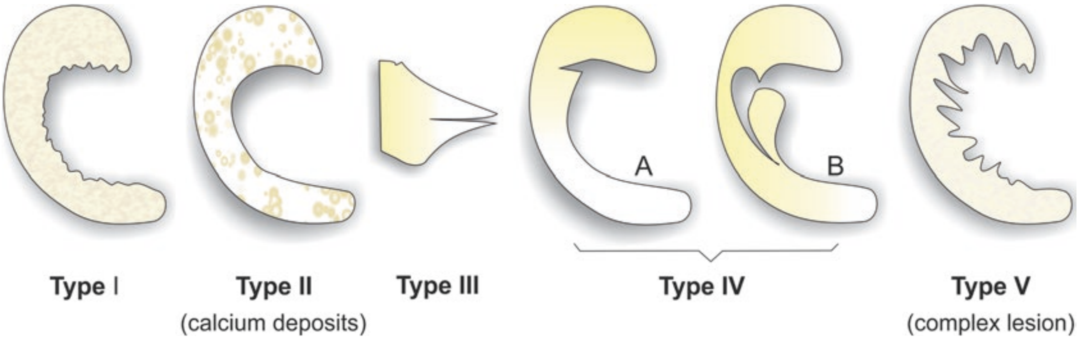


Fig. 3.8 Classification of degenerative meniscal tears (Dorfmann et al. 2010)

Type 4 is a complex and oblique meniscal within 9 mm of the center of the meniscal root attachment.

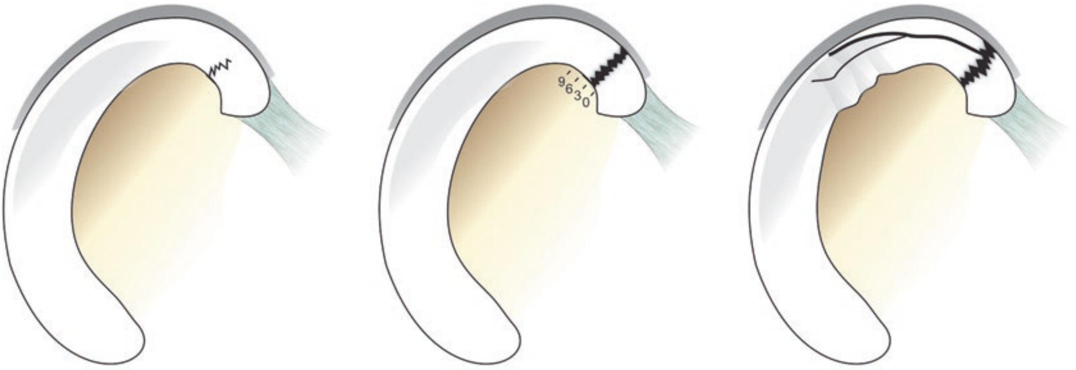
Type 5 is a bony avulsion of meniscal tear root attachment.

3.2.7 Classification of Medial Meniscal Capsular Tears

Meniscosynovial or meniscocapsular tears, also named ramp or hidden lesions, have received increased attention over the past few years. Although these lesions are usually associated with an anterior cruciate tear, it remains an underrecognized lesion to the great majority of orthopedic surgeons [5]. This happens because this meniscocapsular tear is, topographically, located in the "blind spot" of the knee, being difficult to visualize by standard arthroscopic approaches [14]. These observations reinforce the importance of performing a systematic arthroscopic evaluation to diagnose these hidden lesions.

Sonnery-Cottet et al. (2014) [16] proposed a classification of ramp lesions of the medial meniscus. The classification is based according to the tear pattern (partial or complete) and its association to a meniscotibial ligament tear (Fig. 3.10). The authors defined five different types of ramp lesion:

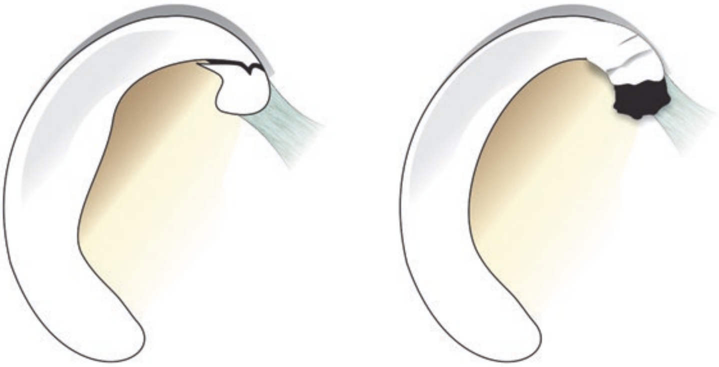
Type 1 – a very peripheral meniscocapsular tear



type 1
(partial)

type 2
(complete)

type 3
(complete root tear
+
bucket handle tear)



type 4
(oblique)

type 5
(root avulsion fracture)

Fig. 3.9 Classification of meniscal root tears

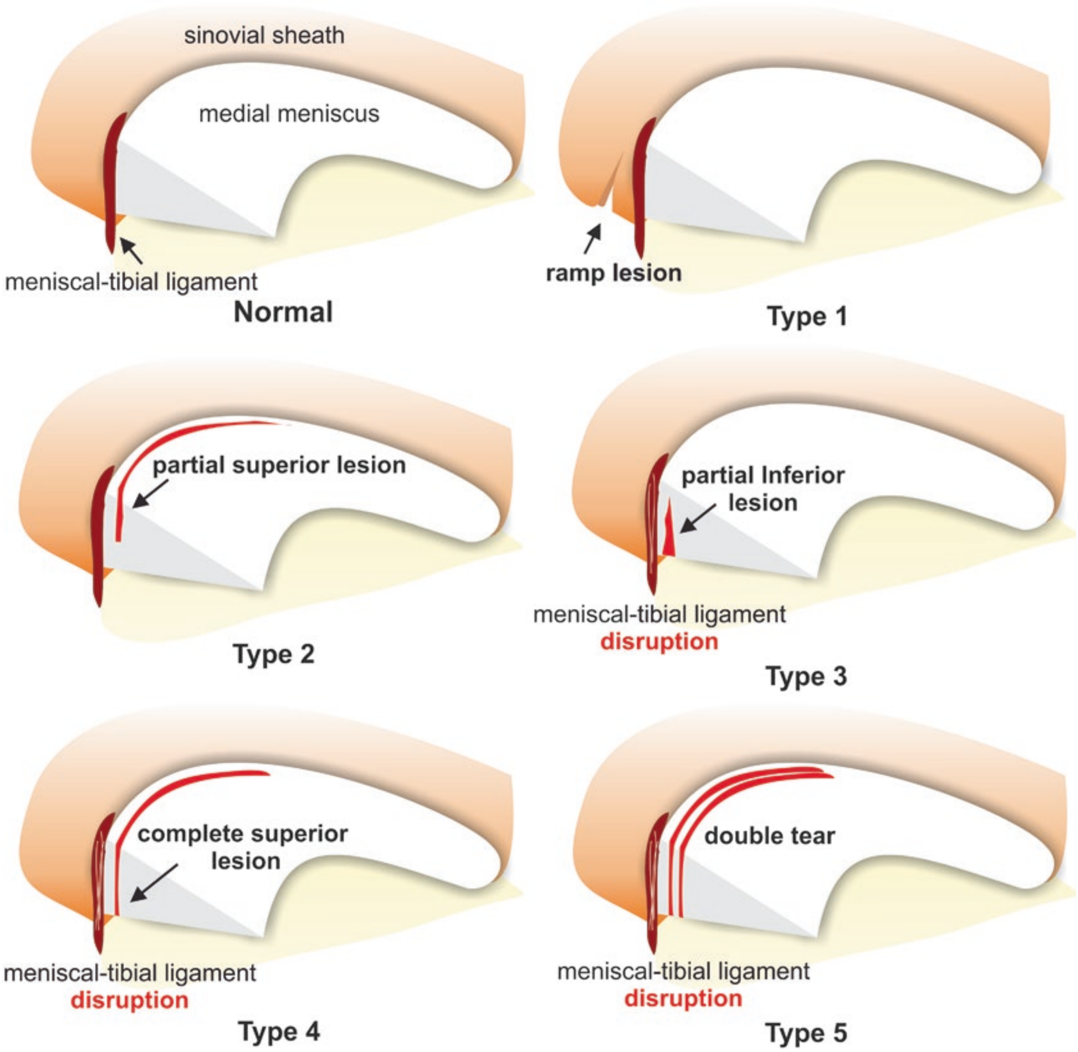


Fig. 3.10 Classification of meniscal meniscus capsular tears (ramp lesions)

Type 2 – defined as a stable tear characterized by a partial superior meniscal tear with no meniscotibial ligament disruption

Type 3 – partial inferior or hidden lesion, which is strongly suspected when an increased mobility of the posterior horn of the meniscus is present

Type 4 – a complete tear associated with high mobility of the meniscus (at probing)

Type 5 – a double longitudinal tear

So, according to this classification, when the meniscal tear demonstrates a higher mobility upon probing, in types 3, 4, and 5, it reinforces the presence of a meniscotibial ligament disruption.

In summary, there are many different classifications of meniscal tears. Breaking down the types of meniscal tears allows for their classification and allows for the comparison of nonoperative and operative outcomes. It is recommended that outcome studies on meniscal tears utilize one of these meniscal tear classification systems.

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4 Meniscectomy: Updates on Techniques and Outcomes

Gianluca Camillieri

Contents

4.1 Introduction

"Everything in excess is opposed to nature" (cfr. Hippocrates). If we turn back our mind to the history of meniscus surgery [12], we cannot argue with medicine's father, especially if we consider the enormous amount of open complete meniscectomies executed before arthroscopic surgery. In the early 1990s, I was helping a colleague of mine to write down his degree thesis titled "Long-Term Outcomes of Open Meniscectomies in Young Athletes" with a follow-up from 12 to 30 years. It was a retrospective study and we assessed kilograms of X-rays with Fairbank [17] classification. We found moderate to severe signs of osteoarthritis (OA) in 85 % of patients. In case of associated anterior cruciate ligament (ACL) reconstruction, the outcomes were even worse. Many of them progressed to osteotomy or total knee replacement. We knew the promising advantages of arthroscopy, but we couldn't imagine how much it was going to change the joint surgery.

Arthroscopic surgery was accepted with scepticism at the beginning, but its unstoppable evolution due to digital era and material sciences changed our mind about the treatment of meniscal lesions definitively. We moved from an open surgical technique with total/subtotal meniscal removal or rare cases of meniscal open suturing to partial and selective meniscectomies or more accurate suturing techniques. Advent of modern arthroscopic surgery marked a new era

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_4

with the aim to be less invasive and more conservative [35].

If we browse the literature about updates on techniques of meniscectomy, we will find a prevalence of surgical anatomy articles until the first years of the new millennium [23]. Few papers introduced new technical suggestions on meniscectomy through the last decade. The reason for this lack of new proposals should lie on the increasing global interest on meniscal suturing techniques, the tendency to avoid as much as possible extensive meniscectomies and the acquired knowledge through the long history of meniscectomy. Arthroscopy is a mandatory discipline for residents around the world; many international and national societies are devoted to its teaching and courses. Thus, most arthroscopists don't encounter difficulty to remove a meniscus partially or subtotally. Standard and accessory accesses, tourniquet, controlled inflow by automatic pump, high-definition visualisation, miniaturised instrumentation, advanced straight to curved to flexible motorised blades and radiofrequency cutters made medial and lateral meniscectomy quite easy, decreasing the learning curve for trainees. On the contrary, randomised controlled trials (RCTs) and systematic reviews on long-term outcomes of meniscectomies came out strongly during the last 10 years. In this manner new acquisitions around correlations between meniscectomy and osteoarthritis (OA), meniscectomy/meniscal suture and OA and conservative treatment versus meniscectomy drifted and shifted our behaviour to a more conservative approach to some meniscal tears. Still we need more RCT and systematic reviews to get a definitive answer about the role of meniscectomy, but the right road seems to be taken up.

4.2 Updates on Meniscectomy Techniques

Most arthroscopic meniscectomy techniques routinely used currently were developed during the last 20 years of the last century. Step by step with new technologies, arthroscopists minimised morbidity and reduced big operations into the space of two or three arthroscopic portals. It is not always that technology applied to meniscectomy represented an advantage: high costly holmium-Yag laser entered strongly into collective imagination without positive results so far [46, 58].

Different variables contributed to the advancement of meniscectomy techniques. Some of them walk arm in arm with technological development, so we can expect new releases into the near future.

Meniscectomy technique appears as something well established: if we look for papers on technical note or update about meniscectomy, we find few articles. On the contrary, we can browse many articles about meniscal suturing/repair and meniscal transplantation. The trend based on recent acquisitions drives researchers and companies to discover tools for meniscal repair and transplantation. Meniscectomy tools do not attract the "market" as in the past.

4.2.1 Tourniquet, Inflow Pump and Arthroscopic Portals

Clear visualisation of the anatomical structures during arthroscopy is mandatory. Beyond the definition in terms of pixels of the arthroscopic devices, water flow and pressure, haemostasis, correct positioning of the arthroscopic camera and instruments make a meniscectomy precise, effective and relatively fast procedures. Haemostasis by tourniquet associated with antithrombotic prophylaxis facilitates the meniscal procedure. However, in case of very short hospitalisation, some surgeon prefers to avoid pneumoischaemia. In this case, modern inflow pumps include a feedback servomechanism to maintain a constant flow and pressure. Most of these devices don't need a third inflow/outflow portal. Anyway, in literature there isn't evidence about avoiding the use of a tourniquet for arthroscopic procedures like meniscectomy [25, 53, 60].

Anterolateral (AL) and anteromedial (AM) accesses represent the gold standard of arthroscopic portals to perform a correct meniscectomy.

Recently, Cooper [11] suggested a single-portal approach by the use of an integrated system of instruments that was designed specifically for this purpose: it is a high-definition 2.9 mm arthroscope in a 4.6 mm-specific cannula (Fig. 4.1). A side Parallel Portal (Stryker Endoscopy) of varying lengths is assembled to the arthroscope cannula, around which it slides, rotates and locks in the desired position. A medial infrapatellar horizontal 8 mm portal is established at a level midway between the distal pole of the patella and the tibial plateau. Through the special cannula, working instruments are passed to complete the procedure. The author treated meniscus tears, loose bodies and synovial and chondral lesions by this technique on more than 600 patients with few complications.

Lateral meniscectomy is a slightly more complex procedure than medial meniscectomy, especially when surgeons have to deal with lesions involving the anterior horn of the lateral meniscus. Suk In Na et al. [55] introduced a new arthroscopic partial meniscectomy technique, using three portals (Fig. 4.2a), and a small skin hook retractor, to remove unstable inferior leaves within a horizontal meniscal tear that involved the anterior portion of the lateral meniscus. The extreme far anteromedial portal is created as another working portal 3 cm medial to the margin of the patella tendon. This portal is located 1 cm above the medial joint line and nearly anterior to the medial edge of the medial femoral condyle. This portal is used for removal of the unstable inferior leaf in the anterior horn of the lateral meniscus, while a small skin hook retractor is inserted through the standard anterolateral portal and pulls out the dominant superior leaf (Fig. 4.2b). Retrograde baskets (left and right) may be successfully used to remove the superior leaf of the anterior horn but not for biting the inferior leaf only. Ill Ho Park et al. [22] introduced the “joystick” technique to accomplish the same goal of Suk In Na. They used the same three portals: standard AL, standard AM and extreme far anteromedial portal. Under arthroscopic visualisation, an 18-gauge spinal needle was inserted into the superior leaf of the lateral meniscus anterior horn (Fig. 4.3 a, b). For a better visualisation of the lesion, the superior leaf of the anterior horn is mobilised upward by the joystick technique moving the spinal needle. To elevate the needle tip with the superior leaf, the needle should be carefully handled downward. In addition, the needle can be moved in the medial and lateral direction to provide more tension and clear visualisation of the medial and lateral sides of the lesion (Fig. 4.3c). Attention should be paid to avoid iatrogenic damage of the cartilage by the tip of the needle.

Lehman and Meyers [29] introduced the needle-assisted aid for arthroscopic meniscectomy with the aim to facilitate meniscal removal in case of central third bucket-handle and big flap lesions. At surgeon convenience, a number 2 monofilament can be introduced through a spinal needle or meniscus mender, to traction the meniscal fragment without any grasper or alligator clip. This technique allows less hardware inside the joint and more space to move and avoids an accessory portal.

Kim et al. [26] suggested the inframeniscal portal for horizontal tears of the meniscus. The authors reported successful procedures for both menisci. The inferior leaf of horizontal lesions is the target using this technique. Care should be

Fig. 4.1 Photograph of a side parallel single portal combined arthroscopic camera and shaver for an arthroscopic meniscectomy

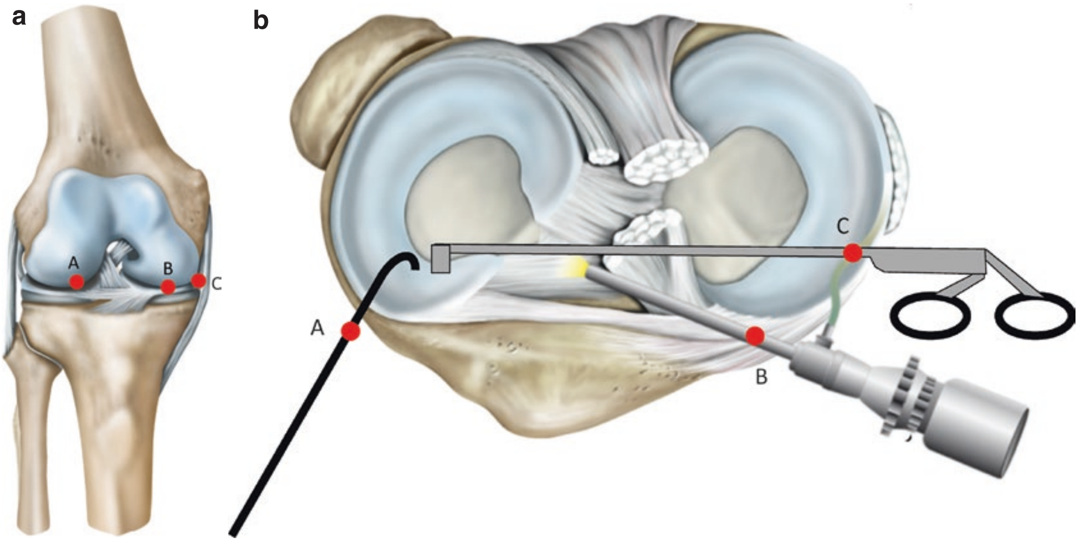

Fig. 4.2 Illustration of a 3 portal arthroscopic technique for partial meniscectomies (**a**). The small skin hook retractor is used to assist with the retrograde basket punches to perform the removal of the difficult to reach meniscal flap (**b**)

taken at this moment to avoid the collateral ligaments, especially the medial one, because the lateral collateral ligament is narrower and palpable and can be avoided easily, while the medial collateral ligament (MCL) is wider and not palpable. It is not uncommon to cause a partial MCL injury while creating an inframeniscal portal. Particular care is taken to avoid perimeniscal vascular and nervous structures. In my opinion, modern instrumentation including arthroscopic scissors, graspers and basket forceps with a huge variety of angulation (to the mouth and neck) and size, up to flexible shaver blades and radiofrequency electrodes, simplifies any meniscectomy without the necessity to resort to “not usual” portals and procedures. Nakase et al. [39] suggested to not remove the whole bucket-handle as usual but to reduce its size to the remnant of the posterior horn. In this fashion a clean debridement of the posterior horn is obtained without risk to the meniscal root.

4.2.2 Techniques to Improve Meniscectomy Execution

For assessing the intra-articular structures, visualisation is of paramount importance. Sometimes in spite of perfect muscle relaxation by anaesthesia, perfect portals and clear intra-articular views, opening and visualising the medial femorotibial compartment become difficult due to a tight knee. Javidan et al. [24] developed an arthroscopic technique to release the deep medial collateral ligament. From the AL portal, a 3.0 mm banana blade is inserted under camera view from the AM portal. Then the blade is directed under the body of medial meniscus to release the deep medial collateral ligament from posterior to anterior (Fig. 4.4). Once achieved the deep MCL release, a sudden opening of the medial compartment, under a gentle valgus force, improves visualisation of the posterior horn of the medial meniscus and simplifies the instrument access to those structures. They performed a deep MCL release in more than 35 patients (aged 13–60 years). Treatment did not require a postoperative period of bracing or immobilisation. No cases of chronic MCL valgus laxity were recorded. Only one patient was reoperated for complications not correlated to the described procedure.

Recently, Claret et al. [10] evaluated the effect of percutaneous release of the medial collateral ligament, in arthroscopic medial meniscectomy, on functional outcome. The authors used the pie-crusting technique for releasing the posterior part of the MCL. A mild valgus force

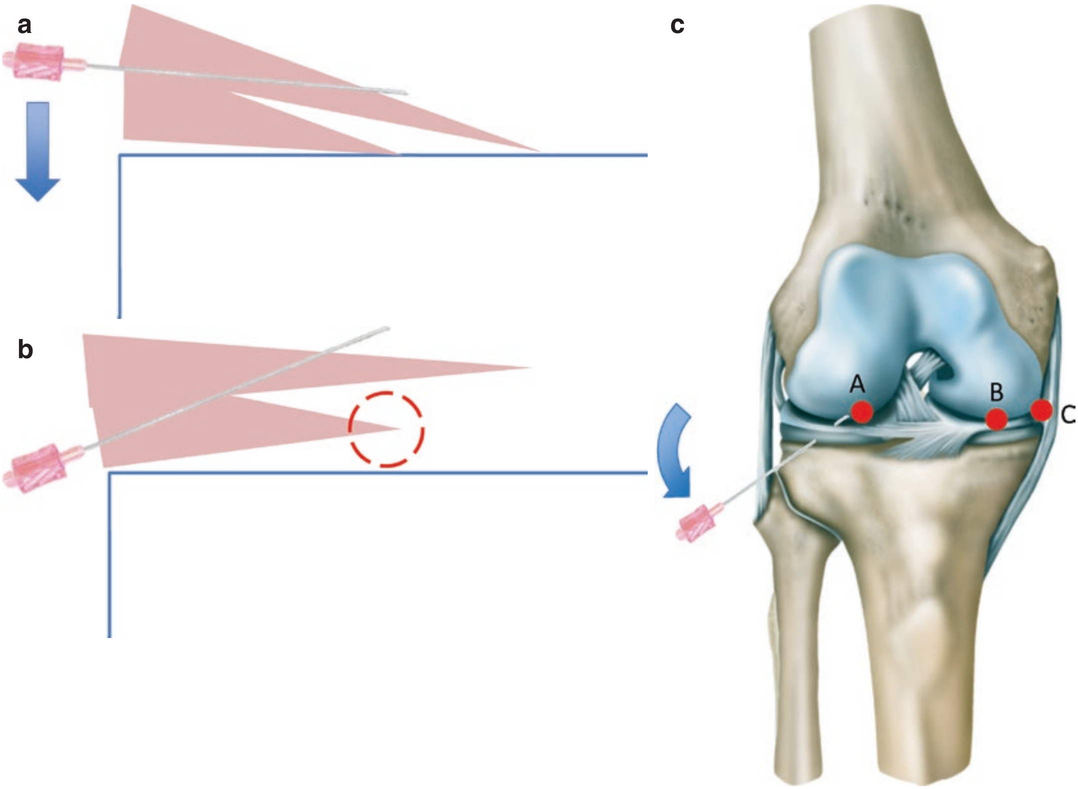

Fig. 4.3 Illustration of the joystick technique for partial meniscectomy. An 18 gauge spinal needle is used to lift up the superior leaf of a meniscal tear (**a** and **b**) to allow for exposure to access the inferior leaf of the meniscal tear for a partial meniscectomy

was applied while viewing by the arthroscope the controlled progressive gain in medial compartment space. A retrospective clinical study of 140 patients undergoing arthroscopic meniscectomy with or without MCL pie crusting was conducted. Tegner, Lysholm tests and VAS were used to assess pain and functional results. The group of patients treated by meniscectomy plus pie crusting showed better functional outcome and faster pain relief. Furthermore, no complications or residual MCL instability was recognised in this group.

4.2.3 Video Device

"Why look through a hole when you can open the door". This sentence has been widely used in the past by sceptics referring themselves to the first steps of a new surgical technique to indirectly observe, magnify and operate joints: arthroscopy. From the pioneers as Takagi, Bircher, Nordentoft and Watanabe to present days, arthroscopy has grown up and served a main role within orthopaedic surgery, improving our knowledge regarding the anatomy, functional anatomy and surgical techniques.

Optical and digital technology played a main role to support and improve the visualisation and magnification of the anatomical structures observed and eventually treated by arthroscopy. We started watching directly on the back of the optic, through analogue cameras and video to the modern high-definition systems. With a power of magnification up to 30 times, we are able to better discriminate anatomy and move with higher precision inside joints. The limits of arthroscopy include the closed field of action (inner joint), poor visualisation of ligaments and tendons lying on the outer aspect of the joint capsule and visualisation of flat images, decreasing the perception of the deepness of the different layers.

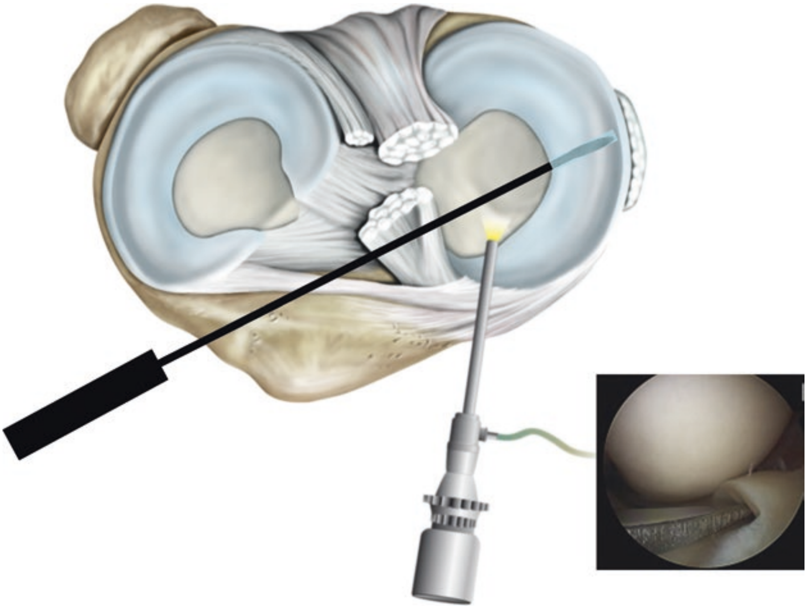

Fig. 4.4 Illustration of an arthroscopic technique to release the meniscotibial portion of the deep medial collateral ligament with a spinal needle to allow for improved access the posterior horn of the medial meniscus (*right knee*)

Technology is moving fast: we are already able to record and view anatomy and surgical procedures with 3D stereoscopic technology. This is based on the human system of vision: two eyes, two optic devices. If we use two cameras or a camera with two lenses, we can reproduce the stereoscopic view recording a left and right image and putting it on a dedicated monitor with a particular refresh rate (Fig. 4.5). These devices represent a substantial step forward into the field of teaching/learning anatomy, surgical approaches and procedures. The commercialisation of the 3D monitor for desktop and laptop computers will provide us the opportunity to build e-learning platforms based on this technology. Finally, the first 3DHD system for arthroscopy is now available on the market. In the span of a few years, we could appreciate the validity of stereoscopic view for arthroscopic surgery and meniscectomy.

4.3 Updates on Meniscectomy Outcomes

Meniscal tears are the most common pathology of the knee with a mean annual incidence of 66 per 100,000 [52]. Historically, it was believed that the menisci served no functional purpose, and they were often excised with [32, 33] an open total meniscectomy. McMurray [33] described that insufficient removal of the meniscus was the cause of failure of meniscectomy. In 1948 Fairbank reported the clinical outcomes of 107 patients after total meniscectomies and found that the majority had progressive flattening of the condyle, narrowing of the joint space and ridge formation. This study significantly changed our approach to dealing with meniscal tears.

Pengas et al. [43] evaluated 53 adolescents who had a total meniscectomy at a mean follow-up of 40 years (33–50). Patients showed a significant difference between the operated and nonoperated knee in terms of range of movement and osteoarthritis of the tibiofemoral joint, resulting in greater than fourfold relative risk of osteoarthritis at 40 years postoperatively. Seven patients (13.2 %) had already undergone total knee replacement at the time of follow-up.

Other recent studies have shown that function of the knee was directly related to the amount of residual meniscal tissue [20]. Increased knowledge of the long-term consequences and altered biomechanics in the knee post-meniscectomy has

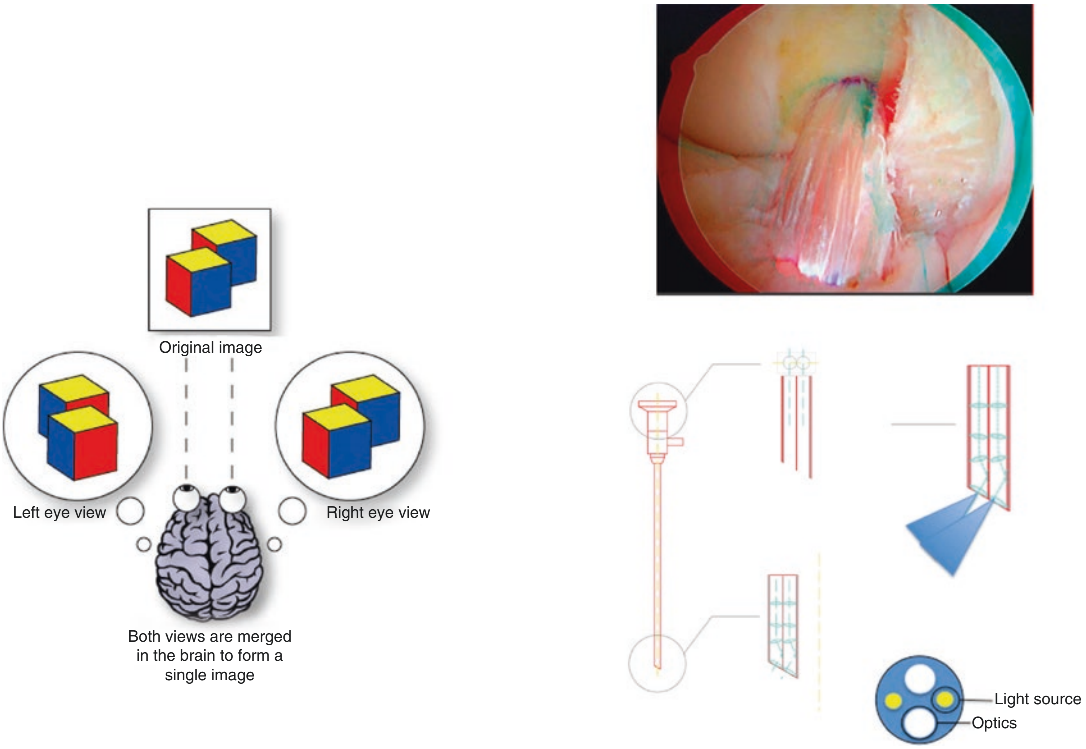

Fig. 4.5 Illustration of the principle of 3 dimensional stereoscopic technology during an arthroscopic surgery

placed greater emphasis on meniscal preserving techniques. Intervention for a meniscus tear is not required in all patients [63], as asymptomatic meniscal tears are common [6, 7]. Pujol and Beaufils [45] made an evidence-based review about healing results of meniscal tears left in situ during ACL reconstruction. Pain or mechanical symptoms related to the medial tibiofemoral joint were reported in 0–66 % of cases. Subsequent medial meniscectomy or repair was performed in 0–33 % of cases. Pain or mechanical symptoms related to the lateral tibiofemoral joint were reported in 0–18 % cases. Subsequent lateral meniscectomy or repair was performed in 0–22 % cases. A complete healing occurred in 50–61 % cases for the medial meniscus and in 55–74 % cases for the lateral meniscus. The conservative approach was more effective for lateral menisci. The rate of bad results for the medial meniscus remained high in case of conservative treatment.

Yim et al. [65] followed 102 patients up to a final follow-up at 2 years. Fifty patients underwent arthroscopic meniscectomy (degenerative horizontal tear of medial meniscus), while 52 patients underwent nonoperative treatment with strengthening exercises. Functional outcomes were compared using a visual analogue scale (VAS) for pain, Lysholm knee score, Tegner activity scale and patient subjective knee pain and satisfaction. Radiological evaluations were performed using the Kellgren-Lawrence classification. The authors did not find a significant difference between arthroscopic meniscectomy and nonoperative management with strengthening exercises in terms of relief in knee pain, improved knee function or increased satisfaction in patients after 2 years of follow-up. Worse clinical outcomes in the conservative group were recorded at the initial follow-up. Things change when we have to deal with unstable meniscal tears as reported by El Ghazaly et al. [14].

Sihvonen et al. [51] designed an RCT to evaluate partial meniscectomy versus sham surgery in 146 patients with a degenerative meniscal tear. The outcomes were examined by Lysholm and Western Ontario Meniscal Evaluation Tool

(WOMET) scores and in knee pain after exercise at 12 months after the procedure. In this trial involving patients without knee OA but with symptoms of a degenerative medial meniscus tear, the outcomes after arthroscopic partial meniscectomy were no better than those after a sham surgical procedure.

Surgical intervention is ideally reserved for those patients with persistent pain and mechanical symptoms who fail conservative management, for which no other source of pain can be identified [56]. Furthermore, functional requests by patients must be considered; most of middle-aged sportive/recreational patients badly accept long sessions of rehabilitation [14] and/or intra-articular injection therapy [21].

Once a decision to proceed with surgery is reached, the treatment options are currently partial meniscectomy or meniscal repair. The decision of which to perform is primarily based on the probability of meniscal healing, though other considerations may also be important. Weiss and Don Johnson in [64] published an update on meniscus debridement and resection. The authors focused their attention on the importance of right indications for meniscectomy and how this aspect changed over time in relationship to the release of RCTs and SRs on long-term results regarding treatment of meniscal lesions. Many factors influence the decision-making by surgeons. Factors related to meniscal tears are location, morphology, size and aetiology. Nevertheless, factors linked to patients, like age, BMI, functional level, associate lesions (ligaments, cartilage), comorbidities and rehabilitation, play a prominent role.

4.3.1 Inflammation Markers and Meniscectomy

Traumatic and degenerative meniscal tears have different anatomic features and different proposed etiologies, yet both are associated with the development or progression of osteoarthritis. In case of meniscal tears linked or not with established OA, synovitis is associated with pain and progression. Furthermore, as a result of meniscectomy, different markers of cellular damage and inflammation can be observed and assessed.

Scanzello et al. [49] evaluated the relationship between synovitis and symptoms in isolated meniscal disease. Thirty-three patients without evidence of OA who underwent arthroscopic meniscectomy for meniscal tears had pain and function assessed preoperatively. Inflammation in synovial biopsy specimens was scored, and associations between inflammation and clinical outcomes were determined. Microarray analysis of synovial tissue was performed, and gene expression patterns in patients with and those without inflammation were compared. Synovial inflammation was present in 43 % of the patients and was associated with worse preoperative pain and function scores. A specific chemokine signature was recorded in synovia with increased inflammation. Thus, the progression of meniscal tear-chemokines-synovitis happens in one of two patients with meniscal injury.

Recently, Ogura et al. [42] have deepened the study of Scanzello analysing four different sides of synovial biopsy in 19 patients undergoing arthroscopy for meniscal tear: injured meniscal site, noninjured meniscal site (NIM), synovium “nearest” the lesion (NS), synovium from the opposite knee compartment, “farthest” synovium (FS), tumour necrosis factor (TNF)-α and interleukin (IL)-6 levels were higher in the injured meniscal site compared to noninjured group, whereas IL-6 levels were also higher in the NS group compared to FS. The cytokine levels were sufficiently high to increase the risk of OA.

The associations between pro-inflammatory cytokines, in synovial fluid, and progression of OA in meniscectomised patients were explored by Larsson et al. [28]. The authors studied concentrations of interleukin (IL)-6 and IL-8 and tumour necrosis factor (TNF)-α by multiplex immunoassay. Lab results were compared with clinical assessment: radiographic features of tibiofemoral and patellofemoral OA according to the Osteoarthritis Research Society International (OARSI) atlas, Knee Injury and Osteoarthritis Outcome Score (KOOS) and logistic regression (adjusted for age, gender, body mass index and time between examinations) for assessment of associations. A sample of 132 patients was examined at 18 years of (average) follow-up and after an additional of 4–10 years. The authors concluded that after meniscectomy, higher or over time increasing synovial fluid levels of IL-6 and TNF-α were associated with an increased risk for progression of radiographic OA.

4.3.2 Age, Gender, BMI, Functional Request and Meniscectomy

Meniscectomy often means a critical point for the destiny of the knee and patients' quality of life. Arguably, before any knee operation, most of us don't consider gender, age, BMI and functional desires as risk factors for joint degeneration and OA [9]. Nevertheless, it is very difficult to stratify population for these risk factors.

Age is a critical point. Younger patient involved in partial or total meniscectomy is more prone to develop OA [18, 43, 1, 63]. Recent studies have questioned the efficacy of meniscectomy in older patients with and without evidence of osteoarthritis; however, there is limited information about age and other risk factors for adverse events and readmission after the procedure. Basques et al. [5] wondered if age and medical comorbidities were risk factors for postoperative adverse events and readmission after meniscectomy. Age $\geq$ 65 years and medical comorbidities were evaluated as risk factors for any adverse event (AAE), severe adverse events (SAEs) and readmission after meniscectomy using univariate and multivariate analyses. A number of 17,774 patients were identified and extrapolated from the American College of Surgeons National Surgical Quality Improvement Program database. The authors concluded that meniscectomy was a safe procedure in older patients. Age over 65 years did not increase the odds of any of the adverse events studied. However, regardless of age, patients with an increased comorbidity burden and those with a history of smoking are at increased risk of adverse events and/or readmission after the procedure.

Ericsson et al. [16] examined self-efficacy of knee function, physical activity and health-related quality of life (HRQoL) in two groups of patients (99 post-meniscectomy and 95 controls) and the impact of gender on outcomes. Females scored lower than males regarding knee function and SF-36 but no difference in terms of physical activity. Hence, they concluded that meniscectomy in middle-aged individuals may lead to a lower self-efficacy of knee function, sedentary lifestyle and poorer HRQoL.

Obesity is a widespread comorbidity affecting orthopaedic patients. In a retrospective cohort study on 1090 patients who underwent a partial meniscectomy [15], BMI over 26 worsens short-term outcome in terms of IKDC, Oxford scoring system and Lysholm score. On the contrary, Bailey et al. [3], after stratifying 270 patients according to BMI, observed that arthroscopic meniscectomy is beneficial regardless of patient BMI, duration of symptoms, history of injury or the presence of early osteoarthritis.

4.3.3 Knee Adaption and Meniscectomy

The knee joint is a homeostatic system with an intrinsic equilibrium. Removing meniscus partially or totally has implications on the kinematic, load distribution and biomechanical and anatomic axes. The joint and limb react to restore homeostasis, but changes happen in a transitory or definitive manner. If we remove 30 % of the meniscus, contact pressure (von Mises stress) increases to about 350 % [50].

Baratz et al. [4] reported that stress increased proportionally to the amount of removed meniscus. Recently, a 3D gait analysis study compared prospectively changes in knee joint load from before and 12 months after arthroscopic partial meniscectomy [59]. A relative increase of medial compartment loading was observed in the leg undergoing arthroscopic partial meniscectomy compared with the contralateral leg from before to 12 months after surgery.

In a similar manner, Ford et al. [18] studied gait analysis and load on force platforms in 18 young patients. Nine patients who underwent lateral partial meniscectomy for radial tear were evaluated 3 months after surgery; the other nine healthy subjects, as control group, matched the patient group in terms of sex, age, height, weight and sport. The patient group landed with a decreased internal knee extensor moment compared to the uninvolved side and controls. The involved limb quadriceps isokinetic torque was not decreased compared to the contralateral or control. Decreased knee extensor moments were significantly associated with reduced measures of function (IKDC scores, $r = 0.69$; $P < 0.05$). Athletes who return to sport at approximately 3 months following a partial lateral meniscectomy may employ compensation strategies during landing as evidenced by reduced quadriceps recruitment and functional outcome scores. Clinicians should adopt strategies to improve quadriceps function during landing on the involved leg and decrease residual limb asymmetries.

Adoption mechanisms cannot be separated from proprioception. Partial meniscectomy leads to a proprioceptive knee deficit that may be recovered with correct rehabilitation and functional training. Malliou et al. [30] tested 26 male patients, who had an arthroscopic partial meniscectomy (age 20–40), using a computerised balance board and functional test (triple jump), at 1 and 2 years of follow-up. Despite postoperative rehabilitation and return to preoperative level of activity, patients had reduced proprioception and knee muscular ability in the operated leg compared to the nonoperated leg at 1 and 2 years after surgery.

4.3.4 Return to Play and Meniscectomy

Meniscectomy has the benefit of a faster return to activities and sport. Rehabilitation following meniscectomy typically involves advancing activities as the patient tolerates them. Most are able to return to running, jumping and sport-specific training at approximately 6 weeks when knee pain and effusions have subsided and quadriceps/hamstring strength has returned to normal [8]. Kim et al. [26] reported a significant difference in time to return to play based on age (< 30, 54 days; > 30, 89 days) and level of competition (elite, 54 days; competition, 53 days; recreational, 88 days). A more recent article by Nawabi et al. [40], looking at soccer players undergoing lateral versus medial meniscectomy, identified a shorter time to return to play (5 weeks vs 7 weeks) and a 6.31 higher probability of returning to play in patients undergoing medial meniscectomy as compared with lateral at all-time points after surgery. Lateral meniscectomy had a higher incidence of adverse events in the early recovery period, including pain/swelling and the need for further arthroscopy. Finally, Aune et al. [2] evaluated 77 National Football League players, of whom 4 players had a midseason lateral meniscectomy and were able to return to play at either 19 or 29 days. It was also noted that speed position players, such as running backs, receivers, linebackers and defensive backs, were four times less likely to return to play.

4.3.5 Complications and Meniscectomy

Due to the nature of the procedure, meniscal debridement is subject to the known complications of knee arthroscopy. These typically occur in about 1 % of patients [31] but have been reported to be as high as 4.7 % [48]. The majority of arthroscopic complications are minor and transient, but neurovascular injury, infection and thrombophlebitis are possible [52]. These are also applicable to arthroscopic meniscectomy, because there are more specific risks of damage to intra-articular structures such as the healthy meniscus and cartilage, during debridement. Complications can be minimised with detailed knowledge of anatomy, proper portal placement, careful insertion and use of arthroscopic instruments.

Osteonecrosis after arthroscopic meniscectomy using radiofrequency is not difficult to imagine [13], especially if not used properly. However, a recent study by Turker et al. [61] stated that adding radiofrequency chondroplasty to meniscectomy did not increase the number of patients with osteonecrosis.

Sonnery-Cottet et al. [54] described ten cases of rapid chondrolysis after a partial lateral meniscectomy in elite athletes. Chondrolysis occurs primarily due to the excessive loading of the articular cartilage in the lateral compartment of the knee, and long-term outcome must be monitored due to the high rate of radiographic osteoarthritis of the lateral compartment.

4.3.6 Evidence-Based Medicine (EBM) and Meniscectomy

With an ever-increasing plethora of studies being published in the health sciences, it is challenging if not impossible for busy clinicians and researchers alike to keep up with the literature. Reviews summarising the outcomes of various intervention trials are therefore an extremely efficient method for obtaining the "bottom line" about what works and what doesn't. The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research. The scientific framework of evidence-based medicine is (1) systematic reviews based on clinical trials and (2) validated outcome measurements and (3) evidence is then used to guide clinical practice. Systematic reviews, as the name implies, typically involve a detailed and comprehensive plan and search strategy derived a priori, with the goal of reducing bias by identifying, appraising and synthesising all relevant studies on a particular topic. Often, systematic reviews include a meta-analysis component which involves using statistical techniques to synthesise the data from several studies into a single quantitative estimate or summary effect size.

Fortunately, EBM plays an eminent role in the field of orthopaedics and arthroscopic surgery. During the last 2 years, few systematic reviews were released about the keyword "meniscectomy". In my opinion this is the best method not to overlook outcomes about meniscal treatment. Nevertheless, inside the SRs you can better evaluate the value of RCTs and cohort studies.

One of the first evidence-based analysis dates back to 2005 by the Health Quality Ontario [19]. The scientists focused on arthroscopic lavage and debridement. In particular, the purpose was to determine the effectiveness and adverse effects of arthroscopic lavage and debridement, with or without lavage, in the treatment of symptoms of OA of the knee, and to conduct an economic analysis if evidence for effectiveness can be established. After accomplishing all the processes, the authors concluded that arthroscopic debridement of the knee, at the moment, has been found to be effective for medial compartmental OA only. All other indications should be reviewed with a target to reducing arthroscopic debridement as an effective therapy. Arthroscopic lavage of the knee is not indicated for any stage of OA. There is very poor quality evidence on the effectiveness of debridement with partial meniscectomy in the case of meniscal tears in OA of the knee.

In 2014, the same institute published an evidenced-based update on this topic. After 9 years, eight RCTs were identified. Again, the evidence did not show the superiority of arthroscopic debridement with or without meniscectomy in patients with osteoarthritis of the knee or with meniscal injury from degenerative causes.

In 2009 Howell and Handoll [21] evaluated the effects of common surgical interventions in the treatment of meniscal injuries of the knee. The four comparisons evaluated were (a) surgery versus conservative treatment, (b) partial versus total meniscectomy, (c) excision versus repair of meniscal tears and (d) surgical access, in particular arthroscopic versus open. After selection, only three trials, for a total of 260 patients, were included into the study. The lack of randomised trials meant that no conclusions could be extrapolated on the issue of surgical versus non-surgical treatment of meniscal injuries nor meniscal tear repair versus excision. In randomised trials so far reported (2009), there is no evidence of a difference in radiological or long-term clinical outcomes between arthroscopic and open meniscal surgery or between total and partial meniscectomy. Partial meniscectomy seems preferable to the total removal of the meniscus in terms of recovery and overall functional outcome in the short term.

Following the study of Howell and Handoll, Salata et al. [47] managed a systematic review of clinical outcomes after meniscectomy. From PubMed and Ovid only, the authors selected 4 RCTs, 2 prospective cohorts and 23 retrospective cohorts that fit the criteria for level I, II and III level of evidence. For the level III evidence studies, follow-up of 5 years or more was required. Preoperative and intraoperative predictors of poor clinical or radiographic outcomes included total meniscectomy or removal of the peripheral meniscal rim, lateral meniscectomy, degenerative meniscal tears, presence of chondral damage, presence of hand osteoarthritis suggestive of genetic predisposition and increased body mass index. Variables that were not predictive of outcome or were inconclusive or had mixed results included meniscal tear pattern, age, mechanical alignment, sex of patient, activity level and meniscal tears associated with ACL reconstruction. While an intact meniscus or meniscal repair was generally favourable in the ACL-reconstructed knees, meniscal repair of degenerative meniscal tissue was not favourable. The limit of this study was a low level of evidence for most of the study included versus two level I studies.

In 2011 Petty and colleagues tried to answer the assumption if partial meniscectomy resulted in osteoarthritis. Authors searched for terms such as “meniscus AND arthritis AND knee” and “meniscectomy AND arthritis AND knee” on PubMed with a minimum follow-up of 8 years. Five studies met the inclusion criteria. Radiographic signs of osteoarthritis were significant at 8 to 16 years of follow-up after knee arthroscopic partial meniscectomy, but clinical symptoms of knee arthritis were not significant. Few studies responding, absence of clinical control groups and heterogeneity of reported outcome measures were the limits of this SR.

Lamplot and Brophy [27] investigated the role of arthroscopic partial meniscectomy in knees with degenerative changes. The systematic review, based on six studies selected (five RCTs and one prospective cohort), reported that patients with symptomatic meniscal tears and degenerative changes in the knee can benefit from arthroscopic meniscectomy, particularly if the osteoarthritis is mild. A trial of conservative management may be effective and should be considered, especially in patients with moderate osteoarthritis.

Van de Graaf et al. [62] performed a level I systematic review and meta-analysis of RCTs about arthroscopic partial meniscectomy or conservative treatment for nonobstructive meniscal tears. The study included six RCTs with a total of 773 patients. The authors found small, although significant, favourable results of APM up to 6 months for physical function and pain. However, no differences at longer follow-up came out.

In 2016, the effectiveness of exercise therapy for meniscal lesions in adults was investigated in a systematic review and meta-analysis [57]. Nine databases were searched up to July 2015. Randomised and controlled clinical trials in adults with traumatic or degenerative meniscal lesions were considered for inclusion. Interventions had to consist of exercise therapy in non-surgical patients or after meniscectomy and had to be compared with meniscectomy and no exercise therapy or to a different type of exercise therapy. Exercise therapy and meniscectomy yielded comparable results on pain and function. Exercise therapy compared to no exercise therapy after meniscectomy showed conflicting evidence at short term but was more effective on function at long term. Unfortunately, the strength of the evidence was low to very low.

A systematic review comparing reoperation rates and clinical outcomes of meniscal repair versus partial meniscectomy was published in 2011 [44]. The level of evidence for these studies was low, with only 3 level I studies compared with 79 level IV studies. In the short-term follow-up period (0–4 years), isolated partial meniscectomies had a reoperation rate of 1.4 % (2 of 143), whereas meniscal repairs were reoperated on in 16.5 % of cases (47 of 284). Over the long-term follow-up period (10 years), partial meniscectomies required a reoperation in only 3.9 % of cases (52 of 1319), whereas meniscal repair had a reoperation rate of 20.7 % (30 of 145). Whereas meniscal repairs have a higher reoperation rate than partial meniscectomies, they likely result in better long-term outcomes.

Nepple et al. [41] studied meniscal repair outcomes at greater than 5 years of follow-up. They analysed different devices and techniques of meniscal repair. The study resulted in very similar rates of meniscal failure (22.3–24.3 %) for all techniques investigated.

In 2015, a meta-analysis was accomplished to review published articles that compared meniscal repair (open suture and arthroscopic inside-out procedures) with meniscectomy (arthroscopic partial or total meniscectomy) for short- or long-term outcomes and to determine which procedure leads to a better outcome. Seven studies were included. Meniscal repairs showed better long-term patient-reported outcomes and better activity levels than meniscectomy; besides, the former meniscal repairs had a lower failure rate. Recently, Moulton et al. [36] completed a study with a systematic review on surgical techniques and outcomes of repairing meniscal radial tears. The database included the Cochrane Database of Systematic Reviews, the Cochrane Central Register of Controlled Trials, PubMed (1980–2014), Medline (1980–2014) and Embase. A total of six studies (55 patients) were included in the study. Radial repair techniques differed among studies; however, postoperative subjective outcomes revealed patient improvement with repairing radial tears. With the increasing concern of long-term osteoarthritis after meniscectomy, meniscal preservation with repair of radial tears resulted in improved short-term clinical outcomes; however, long-term outcomes remain unknown.

Mutsaerts et al. [37] provided a closer look at the evidence of surgical interventions for meniscal tears. In a level I meta-analysis, they compared the outcomes of different surgical procedures for meniscal tears including total and partial meniscectomy, meniscectomy and meniscal repair, meniscectomy and meniscal transplantation, open and arthroscopic meniscectomy and various different repair techniques. Nine studies (RCTs) were included for a total of 904 subjects; 330 patients underwent a meniscal repair, 402 meniscectomy and 160 collagen meniscal implant. Due to the fact that the only surgical treatments that were compared in homogeneous fashion across more than one study were the arrow and inside-out technique, which showed no difference for retear or complication rate, the authors acknowledged the lack of level I evidence to guide the surgical management of meniscal tears. This is a clear invitation to perform more RCTs and cohort studies. If we want to produce valid and exhaustive systematic reviews and/or meta-analysis, a higher number of standardised level I–II evidence studies are needed. This necessity was advocated by Monk et al. [34] in their recent systematic review. The purpose was to compare the effectiveness of arthroscopic surgery for meniscal injuries in all populations. Research was conducted for randomised controlled trials (RCTs) and systematic reviews that compared treatment options for meniscal injury, on 11 databases. Nine RCTs and eight systematic reviews met the selection criteria in which no restrictions were placed on patient demographics. No difference was found between arthroscopic meniscal debridement compared with nonoperative management as a first-line treatment strategy for patients with knee pain and a degenerative meniscal tear. Some evidence was found to indicate that patients with resistant mechanical symptoms who initially fail nonoperative management may benefit from meniscal debridement. No studies compared meniscal repair with meniscectomy or nonoperative management. Initial evidence suggested that meniscal transplant might be favourable in certain patient groups. Based on these results, further evidence is required to determine which patient groups have good outcomes from each intervention. Given the current widespread use of arthroscopic meniscal surgeries, more research is urgently needed to support evidence-based practice in meniscal surgery in order to reduce the numbers of ineffective interventions and support potentially beneficial surgery.

Conclusion

Based on the review of the literature and the experience accumulated through the years, the assumption "meniscal tear – meniscectomy" needs to be scaled down. Selecting the correct treatment can be challenging and involves multiple factors. Knowledge and understanding of the anatomical structure, vascularity and biomechanics of the meniscus and the pattern of tear is important. Dedicated instrumentation and actions to obtain better visualisation of the intra-articular space are mandatory to avoid inadequate meniscal removal/reparation or iatrogenic damages. Evidence shows that nonoperative treatment can be sometimes successful, especially in the short term and in the presence of osteoarthritis. Partial meniscectomy can preserve some of the function of the meniscus and is beneficial for tears within the avascular white-white zone. In active patients with mechanical impingement, functional pain and a requirement for a faster recovery, a good accurate partial meniscectomy is still a good choice. Recently, some researchers have suggested to inject mesenchymal stem cells with some evidence of meniscus regeneration and improvement in postoperative knee pain [62]. Meniscal repair has grown in popularity and boasts excellent long-term results. This should be considered for all repairable tears provided the patient can comply with the postoperative rehabilitation. All principles exposed in this chapter to follow a correct approach in case of meniscal tear may be summarised in Mordecai's [35] flow chart (Fig. 4.6).

At this moment, EBM provides strong suggestions but no definitive conclusions. Researchers require more RCT studies and

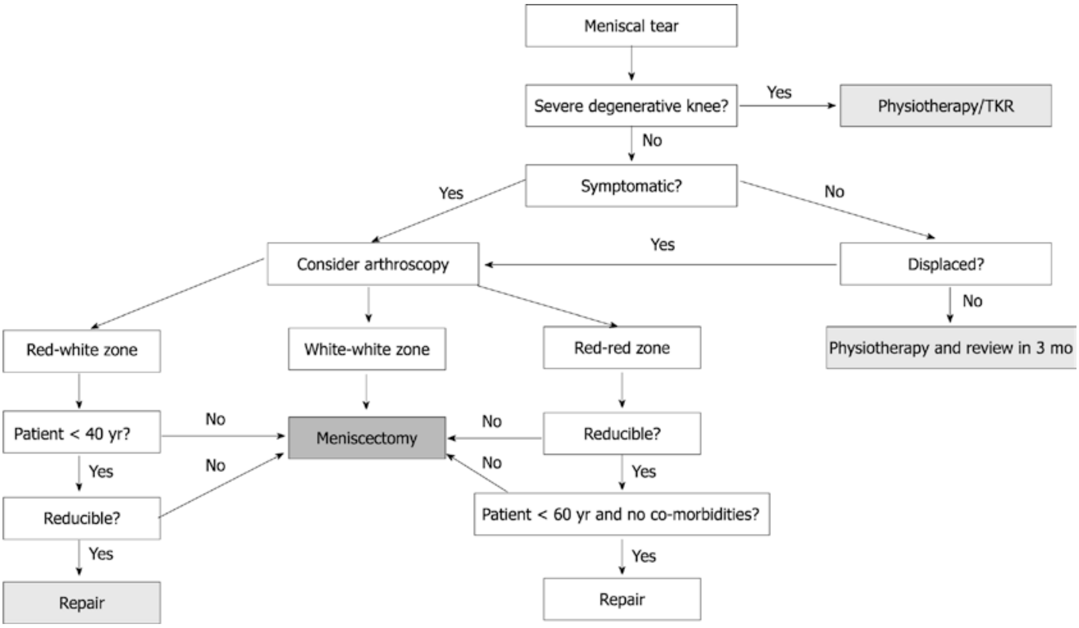

Fig. 4.6 Flow chart of Mordecai et al. [35] demonstrating the recommended treatment protocols for meniscal tears

established evaluation scores. For this reason, new methods such as a novel RCT within-a-cohort study design [51] and a new knee function assessment [38] have been recently developed for patients with meniscal injury.

Meniscectomy will diminish when regeneration/repair/transplantation reaches the highest level, but now is not the time.

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5

Meniscal Root Tears: A Missed Epidemic? How Should They Be Treated?

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Contents

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5.1 Introduction

Meniscal root tears constitute one of the most relevant pathologies of the knee because of its biomechanical immediate consequences and the long-term effects derived from its loss of functionality. These tears can be either an avulsion of the insertion of the meniscus attachment or radial tears which are within 1 cm of the meniscus insertion [2]. The uncompromised menisci absorb 40–70% of the contact force that is generated between the femur and the tibia, which allows for the menisci to convert the axial loads into circumferential hoop stresses [5]. When meniscal root tears occur, they result in the failure of the meniscus to distribute and absorb these forces, and this leads to degenerative changes in the knee [2]. These changes include accelerated cartilage degeneration, which are comparable to changes seen following a total meniscectomy [2]. Additionally, both partial and total meniscal root tears have been observed to cause extrusion of the meniscus. Extrusion of more than 3 mm has been reported to be associated with osteophyte formation and increased articular cartilage degeneration [43]. Up to a fifth of medial meniscus tears can occur in the posterior root attachments [25]. Anterior cruciate ligament (ACL) tears are oftentimes associated with posterior lateral meniscus root tears with one study reporting these root tears in 8 % of cases involving ACL tears [13]. Posterior medial meniscal root tears are oftentimes degenerative, but they can also

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_5

occur with multiple ligament knee injuries in acute settings [13, 16, 42]. Patients with medial meniscal tear were more likely to have concomitant chondral defects, while on the other hand, 81 % of lateral meniscal root tears occurred concomitantly with ACL tears [42]. In addition to tears that occur with ACL injuries, malposition of the ACL tibial tunnel and reaming for tibial shaft fractures during ACL reconstruction can damage the anterior root attachments of the menisci [14, 34, 36, 53]. It has been widely reported that failing to preserve the meniscal tissue accelerates degeneration of the knee cartilage surfaces [22]. The goal of meniscal root surgery is to restore the joint to its previous function without causing adverse side effects like cartilage degradation and an inability to convert force loads that are often seen when the injury is ignored or a meniscectomy is performed [43]. The most common surgical approaches to treat meniscal root tears are meniscectomy, partial meniscectomy, transosseous root repair, and suture anchor repair techniques [43]. This chapter will provide a comprehensive *review on meniscal root tears, diagnosis, indications*, and treatment options currently available.

5.2 Anatomy

The medial tibial eminence (MTE) apex is the most reproducible osseous landmark for the medial meniscal posterior root attachment. The distance between the MTE and the center of the root attachment is located approximately 10 mm posterior and 1 mm lateral. The most proximal posterior cruciate ligament (PCL) tibial attachment and the medial tibial plateau articular cartilage inflection point are two other consistent landmarks to identify the root attachment and are located 8 mm and 4 mm lateral from the posterior root attachment, respectively. Therefore, during arthroscopic root repair surgery, the primary objective would be to locate the apex of the medial tibial eminence and follow it posteriorly and laterally along the bony surface to find the anatomic root attachment site. The lateral meniscus posterior root attachment can also be identified using the apex of the lateral tibial eminence (LTE) which is the most consistent landmark. The center of the lateral meniscal posterior root is consistently found to be 4 mm medial and 1.5 mm posterior to the LTE. According to Johannsen et al. [26], the posterior root of the lateral meniscus attachment is located 4 mm medial to the lateral tibial plateau articular cartilage edge and 13 mm to the most proximal edge of the posterior cruciate ligament (PCL) tibial attachment. The footprint of the central main attachment fibers of the posterior roots of the menisci is 39 mm^2 for the lateral meniscus and 30 mm^2 for the medial meniscus [26].

5.3 Meniscal Root Biomechanics

The anteromedial (AM) root attachment is the strongest root attachment in the meniscus with an ultimate failure strength of 655 N, and the posterolateral (PL) root is the weakest with an ultimate failure strength of 509 N [15]. The increased mobility of the anterior roots compared to the posterior roots may account for the anterior root's higher failure strength [3].

Lateral complete root tears prevent the circumferential fibers from withstanding the hoop stresses which cause the contact area to decrease and the mean and peak contact pressures to increase, which emulates a complete meniscectomy [35]. The overall failure to reproduce the native attachments in a functional anatomic location will result in the continuation of the previously mentioned issues with contact area and contact pressure [32]. Repair of posterolateral meniscal root avulsions resulted in reduced contact areas that were significantly less than the contact areas of intact roots when combined across all angles [47] even though the repair of posteromedial meniscal root avulsions can restore the contact area to intact levels at all angles [2]. A recent biomechanical study concluded that lateral

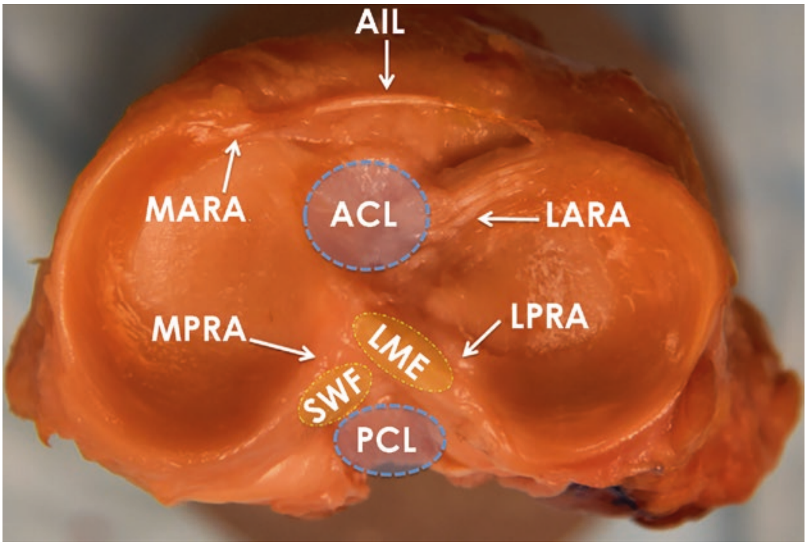


Fig. 5.1 Axial view of the tibial plateau showing the menisci and their attachments along with the *ACL* and *PCL* footprints. *LARA* lateral anterior root attachment, *LPRA* lateral posterior root attachment, *MARA* medial anterior root attachment, *MPRA* medial posterior root attachment, *LME* lateral medial eminence, *SWF* shiny white fibers, *AIL* anterior intermeniscal ligament, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament

meniscus posterior root avulsion produces significant alterations in the contact areas and pressures from full extension to 90° of flexion. Meniscectomy causes greater disorders than the avulsion left in situ. Transosseous repair with a single suture restores these alterations to conditions close to intact at 0° and 30° but not at 60° and 90° [49].

5.4 Natural History of Root Tears

There has been a recent push to understand the effects of meniscal root tears including both contact pressure distributions, similarities to meniscectomized states, and overall long-term outcomes. Harner et al. [23] reported that in tears of the posterior medial meniscus, peak contact pressures were on average 25 % higher than in the intact state. Additionally, when the peak contact pressures were compared to those following a medial meniscectomy, there was no significant difference between the two [23]. Another recent study by Chung et al. [9, 10] reported on the long-term results of patients who had a posterior meniscal root tear in their medial meniscus, and either underwent a refixation or a partial meniscectomy. The results of this study showed that those who underwent a refixation of the posterior root in the medial meniscus slowed the progression of arthritic changes compared to those who had a meniscectomy, although the refixation did not prevent the arthritic changes completely [9, 10]. Along with the overall difference in arthritic changes, 35 % of the patients who had undergone a meniscectomy underwent conversion to total knee arthroplasty (TKA) in contrast, whereas none of the patients who had undergone a repair underwent conversion to TKA [9, 10].

Choi et al. [7] reported that meniscal root tears were positively correlated with the grade of osteoarthritis (p=0.017), BMI (p=0.025), mechanical axis deviation (p=0.043), and varus deformity (p=0.027). Out of all the knees that underwent TKA, 78.17 % of patients under 60 years had meniscal root tear [7] (Fig. 5.2).

5.5 Diagnosis

5.5.1 Physical Examination

In order to effectively assess a potential meniscal root tear, both a physical exam and imaging methods should be performed since root tears are

Fig. 5.2 Image demonstrating a (**a**) coronal (T2) and sagittal view (T1) of the left knee showing the (**b**) progression of cartilage degradation over approximately six months in an undiagnosed posterior meniscal root after six months of follow-up

not always evident when a partial examination is done [13]. Additionally, when performing a physical exam, it is important to identify if the patient has varus alignment or a high BMI since these are some of the risk factors for medial meniscal root tears [25]. Meniscal root tears are often not associated with traumatic events, with one study reporting that 70 % of patients with meniscal root injuries could recall a minor traumatic event such as squatting, and the rest couldn't recall any specific event leading up to the injury [4]. The most common presenting symptoms in meniscal root tears are posterior knee pain and joint line tenderness which are nonspecific symptoms [20]. Another common but not always present symptom is a popping sound which is heard while doing light activities like going upstairs or squatting [37]. Seil et al. [51] described a test that has proven useful in diagnosing a medial meniscal root avulsion. It involves applying varus stress to the knee while it is relaxed and in full extension and palpating the anteromedial joint line [51]. When there is a medial meniscal root avulsion, the meniscal extrusion is reproduced and disappears when the knee is moved back to its normal alignment [51].

5.5.2 Imaging

Magnetic resonance imaging (MRI) is noninvasive and should be a part of the diagnostic workout of meniscal root tears due to the challenges associated with a clinical diagnosis [4, 18]. Prior studies suggested that MRI is 93 % sensitive, is 100 % specific, and has a positive predictive value of 100 % [8, 12, 24]; however, other authors reported that meniscal root tears could only be identified in approximately 73 % [46]. Of note, an accurate diagnosis of a meniscal root tear through an MRI is very reliant on the skill of the radiology and the quality of the images [4].

The posterior medial meniscus is most easily visualized as a band of fibrocartilage, which anchors the posterior horn to the tibial plateau in two consecutive coronal MRI images [4]. Lateral meniscal root tears are most easily visualized on coronal and sagittal sequences that show both the apex and posterior slope of the lateral tibial eminence [4, 12]. T2-weighted sequences are considered the best option for visualizing tears due to their maximum specificity and sensitivity values [39]; additionally, many believe that axial images produce the highest specificity and sensitivity [8]. When a posterior meniscal root tear is suspected, three locations should be assessed on MRI: (1) between the intercondylar tubercles, (2) at the level of the lateral tubercle, and (3) on the lateral edge of the tibial eminence adjacent to the lateral tubercle. Additionally, both coronal and sagittal planes should be evaluated to improve sensitivity [13].

Since visualizing a meniscal root tear is difficult due to the root's small size, the presence of meniscal extrusion has a high correlation with meniscal root tears [6, 41], although not all knees with meniscal extrusion have meniscal root tears [4]. Medial meniscal extrusions of more than 3 mm are strongly associated with severe meniscal degeneration and meniscal root tears [11, 40]. Another common and important sign associated with meniscal root tears is a ghost sign [4]. A ghost sign is defined to be the absence of an identifiable meniscus in the sagittal plane or an increased signal replacing the normally dark meniscal tissue signal [40, 48]. In addition to ghost signs, vertical linear defects on coronal imaging and radial linear defects at the bony insertion of the meniscal roots are also signs of meniscal root tears [29] (Fig. 5.3).

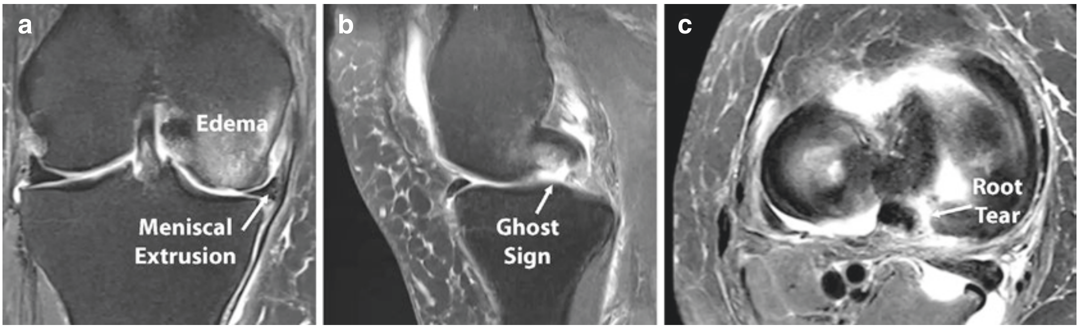


Fig. 5.3 Magnetic resonance imaging of the right knee demonstrating (**a**) meniscal extrusion (>3 mm) and an edema of the medial femoral condyle on a coronal cut. (**b**) Sagittal view showing the absence of the posterior horn of the meniscus ("ghost sign") and (**c**) sagittal view of a medial meniscus posterior root tear

5.6 Classification Systems

Our group developed an arthroscopically based classification system for both posterior root tears based on tear morphology. Root tears were divided in partial stable root tear (type 1), complete radial tear within 9 mm from the root attachment (type 2), bucket-handle tear with complete root detachment (type 3), complex oblique or longitudinal tear with complete root detachment (type 4), and bony avulsion of the root attachment (type 5) (Fig. 5.1) [33]. Of these types, type 2 was the more frequently encountered which can be subclassified in type 2A, defined as complete radial meniscal tears 0 to < 3 mm from the center of the root attachment; type 2B, defined as complete radial meniscal tears 3 to < 6 mm from the center of the root attachment; and type 2C, defined as complete radial meniscal tears 6–9 mm from the root attachment.

Forkel et al. [21] described a lateral posterior root tear classification (three subcategories). Type 1 is the avulsion of the root at the attachment on the tibial plateau with an intact meniscofemoral ligament. Type 2 is a radial tear of the posterior horn with an intact meniscofemoral ligament. Type 3 is a complete injury of the posterior horn of the lateral meniscus with rupture of the meniscofemoral ligament (Fig. 5.4).

5.7 Treatment

Although recently recognized as an important pathology, several treatment options have been described in the literature including nonoperative treatment, partial or subtotal meniscectomies, and root repair. Nonoperative treatment is advocated in the elderly population or those with advanced degenerative changes in the same compartment. Symptomatic treatment with rest, ice, nonsteroidal anti-inflammatory drug, and/or an unloader brace can help alleviate the symptoms in some cases. In this subset of patients (advanced

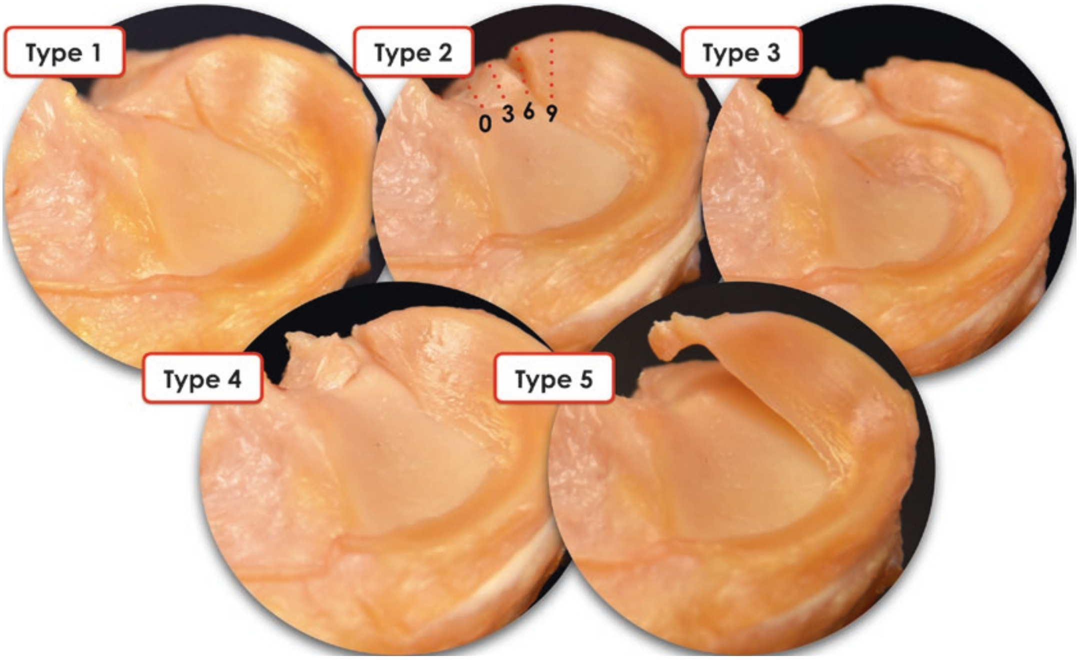


Fig. 5.4 Images of the five different types of meniscal root tears based on morphology: partial stable root tear (type 1), compete radial tear within 9mm of the bony root attachment (type 2), bucket-handle tear with complete root detachment (type 3), complex oblique or longitudinal tear with complete root detachment (type 4), and bony avulsion fracture of the root attachment (type 5). Types 2A, 2B, and 2C are marked on the image for type 2

degenerative changes), if mechanical symptoms are present such as locking, a partial or subtotal meniscectomy can improve the overall knee function.

Indications for meniscal repair are acute, traumatic root tears in patients with nearly normal or normal cartilage surface (Outerbridge less than grade 2) or chronic symptomatic root tears in young or middle-aged patients without significant preexisting osteoarthritis [4]. These injuries can develop subtly over time.

5.7.1 Transtibial Pullout Repair for Posterior Meniscus Root Tears

The transtibial pullout technique allows for anatomic reduction and fixation of the meniscal root. Padalecki et al. [47]) reported that a pullout repair of radial tears restored the joint contact pressure and area similar to the intact state. Drilling tibial tunnels may enhance healing due to the presence of growth factors and potentially bone marrow mesenchymal stem cells. The fixation construct has been reported to have significantly weaker fixation to the tibia compared to the native root [17, 31]. Feucht et al. [17] reported a 2.2 mm displacement of the meniscal root repair with transtibial pullout under cyclic loading in a pig model caused by the long length of the meniscus suture repair construct (bungee effect). Several authors have validated this technique the root transosseous repair [1, 30, 45, 50]. Starke et al. [52] reported that nonanatomic positioning of the posterior meniscal horn attachment had a significant effect on the resultant tension. Placing the horn attachment 3 mm medially decreased the tension at the horn attachment by 49–73 %, depending on knee flexion angle and femorotibial load. Conversely, fixation of the root in a lateral position resulted in a relative increase in the tension by 28–68 %. Lower levels of meniscal hoop tension caused increased cartilage stress.

The senior author's current preferred technique for fixation of a posterior horn meniscal root tear involves transosseous suture repair tied over a button on the anteromedial tibia. For this technique, standard anterolateral and anteromedial portals are created adjacent to the patellar tendon. It is important to be as close as possible to the patellar tendon to improve visualization for the posterior roots (Fig. 5.5).

A diagnostic arthroscopy is performed to assess for any associated lesions. The damaged meniscal root should be probed to assess for severity and tear pattern [33]. An accessory arthroscopic portal (anteromedial or anterolateral) can be made to help access the posterior root. The bony bed of the planned root repair anatomic location should then be carefully decorticated using a curved curette (Fig. 5.6).

A grasper can be used to position the torn meniscal root and determine the ideal location to perform the repair. If the root can be positioned at the desired location, peripheral release of the posterior horn should be carried out to allow the root for additional excursion (Fig. 5.7).

Once the desired position of the root has been confirmed, an incision is made for the transtibial tunnels just medial to the tibial

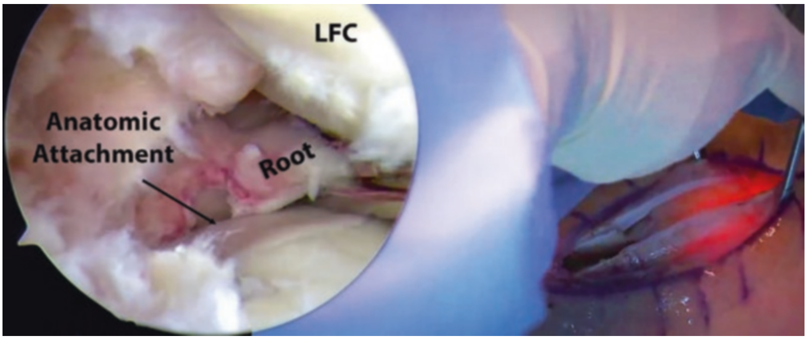


Fig. 5.5 Arthroscopic view of a meniscal root tear as viewed from the anteromedial portal, showing both the detached root and the anatomic root attachment. LFC *lateral femoral condyle*

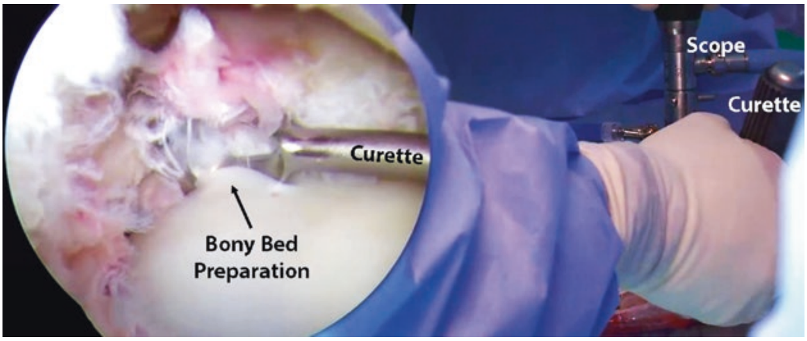


Fig. 5.6 Arthroscopic view of a lateral posterior root of the left side (viewed through the anteromedial portal). The bony bed is being prepared using a curette to decorticate the anatomic root attachment location. On the right side, intraoperative view of the portal management

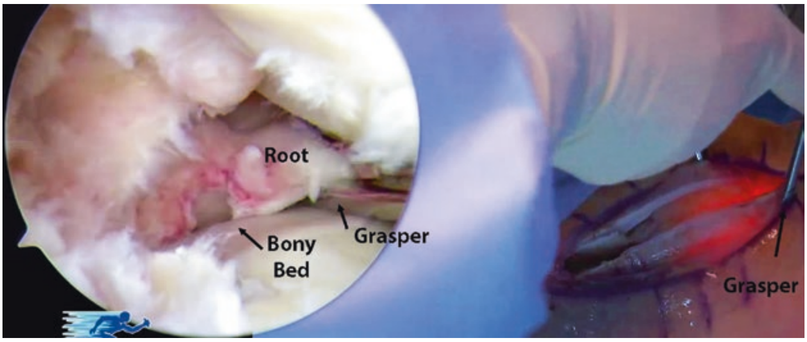


Fig. 5.7 Arthroscopic view through the anteromedial portal of the lateral posterior root. The torn meniscal root is being repositioned with a grasper so it can be secured in the anatomic position

tubercle (medial root). For a posterior lateral meniscal root repair, the incision will be made on the anterolateral tibia, just distal to the medial aspect of Gerdy's tubercle. In order to best restore the footprint of the repair, two transtibial tunnels are created at the location of the root attachment. A custom root aiming device with a cannulated sleeve is used to position a drill pin. A tibial tunnel guide is then used to ream the first tunnel (along the posterior aspect of the posterior root attachment site) (Fig. 5.8).

The second tunnel is placed approximately 5 mm anterior to the first tunnel using an offset guide. The tunnels are visualized arthroscopically to verify correct tunnel placement, and the drill pins are removed leaving the two cannulas in place for passing the sutures. An accessory anteromedial or anterolateral portal can be created if necessary depending on the root to be repaired (if not done previously) to allow an arthroscopic grasper to firmly hold the torn meniscal root and facilitate passing the sutures. A suture-passing device is utilized to pass a simple suture through the far posterior portion of the detached meniscal root, approximately 5 mm medial to its lateral edge for the medial meniscus, or 5 mm lateral to its medial edge for the lateral meniscus, passing from the tibial to the femoral side. Sutures are then pulled out through the anteromedial portal (through a cannula) as the device is removed. Prior to passing the second suture through the meniscus, the first suture is shuttled down through the more posteriorly placed tibial tunnel in order to avoid intra-articular suture tangling with the aid of a looped passing wire placed up the posteriorly placed tunnel cannula. The steps are repeated with the second suture positioned through the midportion of the meniscal root, anterior to the first suture placed into the meniscus. The second suture is then pulled down through the anterior positioned tibial cannula (Fig. 5.9).

The sutures are tied down over a cortical fixation device on the anteromedial tibia for the medial meniscal root repair, or the anterolateral tibia for the lateral meniscal root repair, while the posterior root of the respective meniscus is visualized and probed arthroscopically (Fig. 5.10).

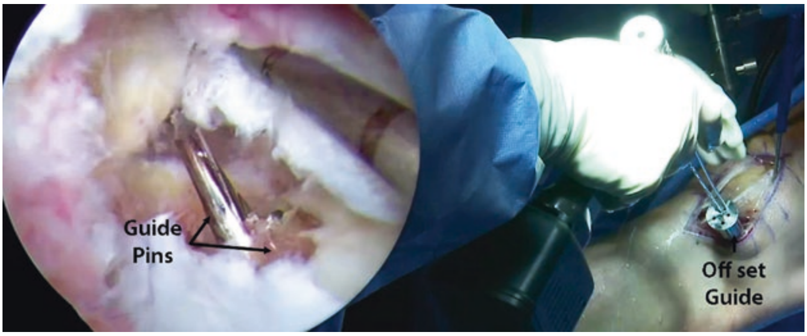


Fig. 5.8 Arthroscopic view through the anteromedial portal of the lateral posterior root (*on the left*). The guide pins are being positioned using an offset guide (as seen *on the right*) in order to ensure the positioning is as precise as possible

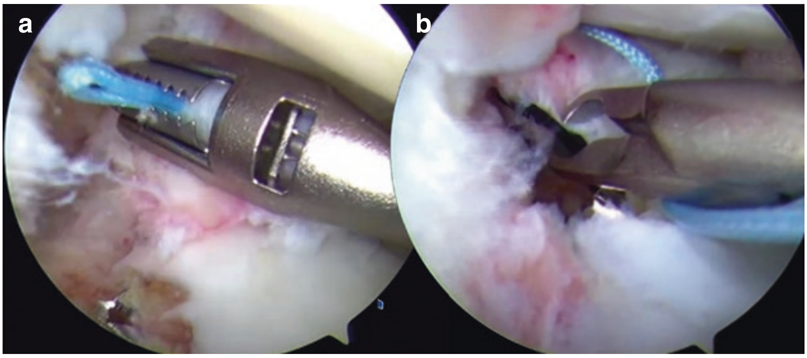


Fig. 5.9 Arthroscopic view through the anteromedial portal of the lateral posterior root. The meniscal root is being sutured into place in its anatomic location using a suture-passing device

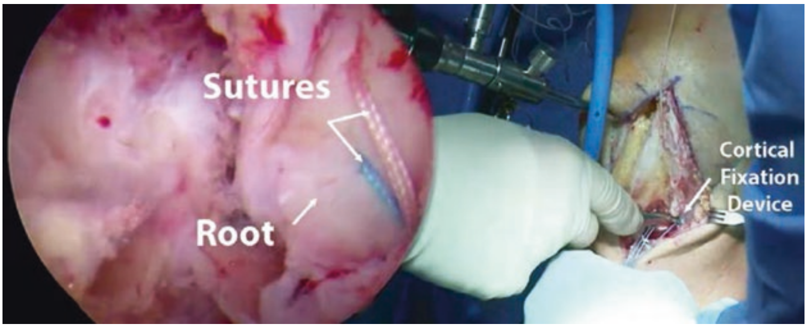


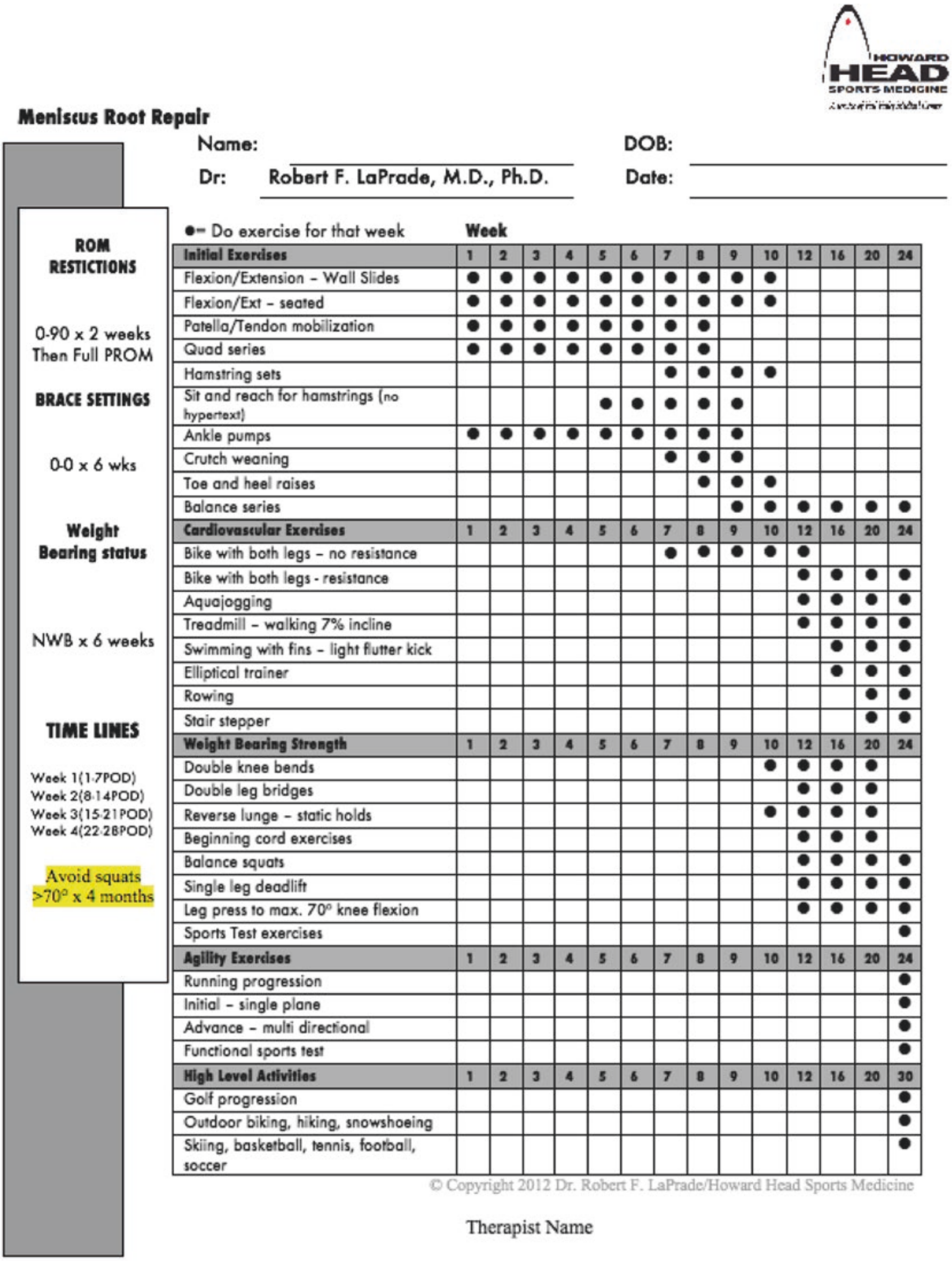
Fig. 5.10 Arthroscopic view through the anteromedial portal of the lateral posterior root (*on the left*). The repaired meniscal root can be seen in its anatomic location. *On the right* is the intraoperative view of the knee with both the anteromedial and anterolateral portals

5.8 Postoperative Rehabilitation

Patients should be non-weight-bearing for at least 6 weeks. Physical therapy should start as soon as possible after surgery, which should include early passive range of motion exercises in a safe zone of 0–90 degrees of flexion for the initial 2 weeks. After 2 weeks, patients can work on further increases in knee flexion as tolerated. Progressive advancement to full weight-bearing begins at 8 weeks. Deep leg presses and squats greater than 70 degrees of knee flexion should be avoided for at least four months after surgery (Fig. 5.11).

5.9 Outcomes

The optimal treatment of meniscal root tears is still debated due to the conflicting clinical and radiologic results that are being reported. Chung et al. [9, 10] reported in a recent meta-analysis on medial meniscal root tear repair that although there were significant improvements in postoperative clinical scores, the progression of arthrosis was not prevented and meniscal extrusion was not reduced. Feucht et al. [18] reported in a systematic review that there were improved outcomes when arthroscopic transtibial pullout repair was



HOWARD HEAD SPORTS MEDICINE

Meniscus Root Repair

Name:
DOB:
Dr: Robert F. LaPrade, M.D., Ph.D.
Date:

ROM RESTICTIONS

0-90 x 2 weeks
Then Full PROM

BRACE SETTINGS

0-0 x 6 wks

Weight Bearing status

NWB x 6 weeks

TIME LINES

Week 1(1-7POD)
Week 2(8-14POD)
Week 3(15-21POD)
Week 4(22-28POD)

Avoid squats >70° x 4 months

● – Do exercise for that week **Week**

Initial Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Flexion/Extension – Wall Slides	●	●	●	●	●	●	●	●	●	●				
Flexion/Ext – seated	●	●	●	●	●	●	●	●	●	●				
Patella/Tendon mobilization	●	●	●	●	●	●	●	●						
Quad series	●	●	●	●	●	●	●	●						
Hamstring sets							●	●	●	●				
Sit and reach for hamstrings (no hypertext)					●	●	●	●	●					
Ankle pumps	●	●	●	●	●	●	●	●	●					
Crutch weaning							●	●	●					
Toe and heel raises								●	●	●				
Balance series									●	●	●	●	●	●
Cardiovascular Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Bike with both legs – no resistance							●	●	●	●	●			
Bike with both legs - resistance											●	●	●	●
Aquajogging											●	●	●	●
Treadmill – walking 7% incline											●	●	●	●
Swimming with fins – light flutter kick												●	●	●
Elliptical trainer												●	●	●
Rowing													●	●
Stair stepper													●	●
Weight Bearing Strength	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Double knee bends										●	●	●	●	
Double leg bridges											●	●	●	
Reverse lunge – static holds										●	●	●	●	
Beginning cord exercises											●	●	●	
Balance squats											●	●	●	●
Single leg deadlift											●	●	●	●
Leg press to max. 70° knee flexion											●	●	●	●
Sports Test exercises														●
Agility Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Running progression														●
Initial – single plane														●
Advance – multi directional														●
Functional sports test														●
High Level Activities	1	2	3	4	5	6	7	8	9	10	12	16	20	30
Golf progression														●
Outdoor biking, hiking, snowshoeing														●
Skiing, basketball, tennis, football, soccer														●

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Therapist Name

Fig. 5.11 Spreadsheet example of a standard rehabilitation protocol after meniscal root repair used for posterior medial meniscal root tears. The systematic review reported that 84 % of the patients showed no progression of osteoarthritis on the Kellgren-Lawrence grading scale, and Lysholm scores improved from a mean of 52 preoperatively to a mean of 86 postoperatively [18]. Additionally, in 82 % of the patients, MRI did not show progression of cartilage degeneration, and in 56 % of patients, MRI showed a reduction of medial meniscus extrusion [18]. Overall the healing status was complete in 62 % of patients, partial in 34 %, and failed in only 3 % based on MRI and second-look arthroscopy [9, 10, 18]. A retrospective study by Ozkoc et al. [46] looked at patients with a medial meniscus posterior root tear (MMPRT) who were treated with a partial meniscectomy and had a mean follow-up of 4.7 years. This study found that the Lysholm scores of the patients had improved significantly although degenerative changes as defined by the Kellgren-Lawrence radiologic grade had increased postoperatively [46]. Another study done by Chung et al. [9, 10] compared the radiologic and clinical outcomes between a partial meniscectomy cohort and a medial meniscus root repair cohort at a 5-year minimum follow-up. The repair group reported significantly higher Lysholm and International Knee Documentation Committee (IKDC) scores although both groups showed a progression of Kellgren-Lawrence grade and medial joint space narrowing with the repair cohort showing less progression in comparison to the partial meniscectomy cohort [9, 10]. Finally, the repair cohort had a 0 % rate of conversion to total knee replacement, whereas the partial meniscectomy cohort had a 35 % rate [9, 10].

The median age of patients in meniscal root repair studies is around 50 years, meaning that the outcomes on meniscal root repairs are based on poorly designed studies with potentially skewed data [8, 27–29, 38, 44]. Although the majority of studies have reported subjective improvement of symptoms, the prevention of progression of arthrosis has not been adequately documented [9, 10, 16, 18, 19, 20, 46]. Additionally, the poor reduction of meniscal extrusion or the failure to do so and low reported healing rates coupled with the age of the patients may help explain the poor radiographic results [9, 10, 18, 19]. Meniscal root tears are technically challenging procedures, with an anatomic repair being crucial to the success and outcome of the surgery. This type of procedure may be better left to more experienced surgeons with enough volume. Overall there is still a great deal of need for better designed studies to explore some of the unanswered questions regarding meniscal root repairs.

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Meniscal Ramp Lesions: Diagnosis and Treatment Strategies

6

Rebecca Young, Brian M. Devitt,
and Timothy Whitehead

Contents

6.1 Introduction

Meniscal lesions occur in association with ACL tears over 60 % of the time [1–5]. In the setting of an acute ACL tear, lateral meniscal tears occur with slightly greater frequency than medial meniscus tears, with a mean distribution of 56–44 %, respectively. However, in the setting of chronic ACL deficiency, medial meniscus tears are much more common [6]. More than 75 % of tears of the medial meniscus in ACL-deficient knees occur in the periphery of the posterior horn [2, 6, 7].

> "It saw you but you didn't see it. Jack Hughston, Orthopaedic Surgeon"

One of the main issues with lesion at the posterior aspect of the meniscus is that they are difficult to visualise from standard anterior portals and are, therefore, frequently missed. The term *hidden lesion* has quite aptly been used to describe these meniscal tears. In addition, the term *ramp lesion* has emerged in the orthopaedic vernacular as another descriptive term [3]. The purpose of this chapter is to explain what exactly a ramp lesion is, how can it be diagnosed and how best to treat it.

6.2 What Is a Ramp Lesion?

The area on the posterior aspect of the meniscal rim adjoining the meniscocapsular junction is called the meniscal ramp (Fig. 6.1). A ramp

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_6

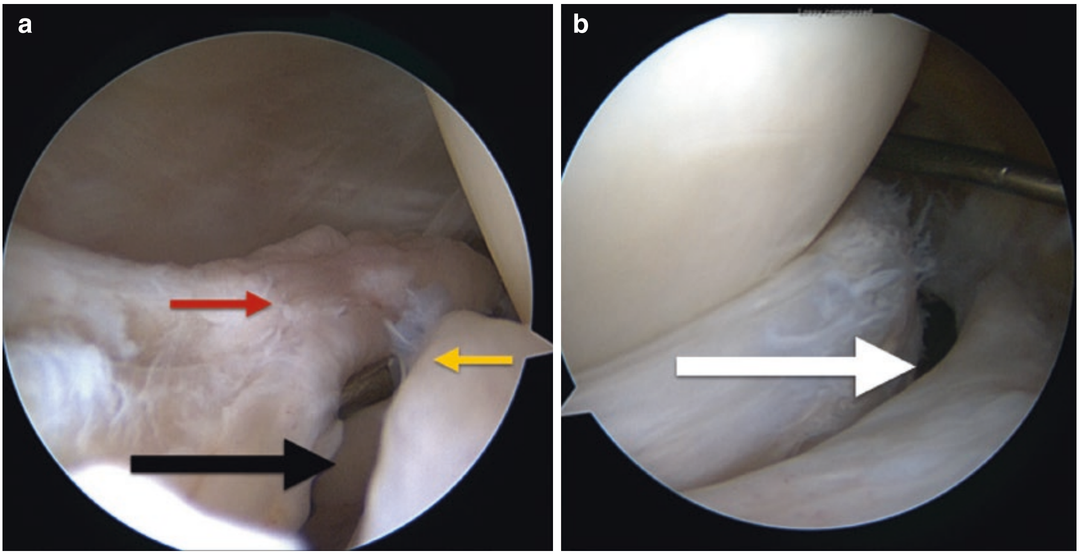

Fig. 6.1 (**a**) Arthroscopic view of the posteromedial aspect of a right knee through the intercondylar notch with a 70° arthroscope; the *black arrow* marks the ramp lesion, the *red arrow* the posterior capsule, and the *yellow* the posterior horn of the medial meniscus.(**b**) Arthroscopic view of the same patient with a 30° arthroscopic from the posteromedial portal, demonstrating the same ramp lesion with meniscocapsular separation (*white arrow*) (These photographs are courtesy of Professor Joon Wang, Samsung Medical Centre, Sungkyunkwan University Medical School, Seoul, Korea)

lesion, so described by Strobel in 1998 [8], is a longitudinal tear in the ramp area and is typically associated with ACL deficiency. Subsequent authors have extended the definition to a tear less than 2.5 cm in length involving the meniscosynovial or meniscocapsular attachments of the posterior horn of the medial meniscus (red-red zone) [9, 10]. Disruption of the meniscotibial ligaments of the posterior horn of the medial meniscus is most often recognised as a separate entity [2, 11].

6.3 How Do Ramp Lesions Occur?

The pathogenesis of ramp lesions can be explained by an understanding of the anatomy of the medial meniscus. The medial meniscus is a crescentic fibrocartilage covering approximately 50 % of the medial tibial plateau. It measures roughly 11 mm posteriorly and becomes narrower anteriorly towards the anterior meniscal root [10, 12]. Anatomically, it can be divided into three zones, the anterior horn, the body and the posterior horn (Fig. 6.2).

The medial meniscus is anchored to the medial tibial plateau by the anterior and posterior roots [13]. The body of the meniscus attaches to the adjacent joint capsule and to the tibia by the meniscotibial ligaments. The meniscus is thick peripherally where it attaches to the joint capsule and tapers to a thin, freely mobile edge centrally [14].This triangular or wedge cross section deepens the tibial articular fossa; enhances load bearing, force distribution and joint stability functions; and influences the stress and strain on the meniscus during activities [15].

The wedge shape of the anterior horn resists posterior translation of the tibia, and similarly, the posterior horn resists anterior tibial translation. As such, the posterior horn plays a fundamental role as a secondary stabiliser of the knee [9, 16, 17]. In the setting of an ACL-deficient knee, it must assume a more primary role in controlling anterior translation [18]. This results in increased loading of the posterior horn of the medial meniscus, increasing forces here by up to 100 %, which is reflected in the high numbers of peripheral medial meniscus posterior horns associated with chronic ACL tears [19].

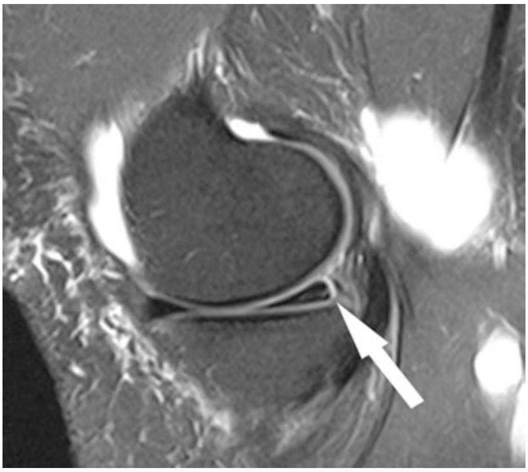

Fig. 6.2 Sagittal fat-saturated T2-weighted sequence showing medial meniscocapsular separation with thin fluid interposed between the posterior horn of the medial meniscus and capsule (*arrow*) [28]

Ramp lesions can occur acutely at the time of ACL ruptures or develop in the chronically ACL-deficient knee. Acute ramp lesion tears occur as a result of the high forces, which are transmitted through the posteromedial capsule during valgus strain and internal rotation of the tibial and axial loading of the knee [2].

Hughston's [20] proposed mechanism for medial meniscus tears in the ACL-deficient knee is that the loss of ACL function results in increased tibial translation, allowing the meniscus to become wedged between the femur and the tibia. At the same time, the semimembranosus muscle contracts along the posterior capsule, focusing a large amount of stress at the peripheral meniscus. If the contraction is intense enough, the medial meniscus will either tear peripherally or tear at the meniscocapsular junction: the ramp area. This may happen at the time of injury or during subsequent instability episodes [9, 21].

Song et al. have recently proposed that an increased medial meniscal slope is an independent risk factor of a concomitant ramp lesion in noncontact ACL injuries [19]. One of the issues with this theory is that the very presence of a tear may have an impact on the tibial slope. Also, the difference in mean medial meniscal slope between those patients with a ramp lesion and those without in noncontact ACL injuries was only 1.5°. Therefore, the clinical utility of this reading is of questionable value.

6.4 How Common Are Ramp Lesions?

Ramp lesions occur most commonly in association with ACL ruptures. Whether acute or chronic, the incidence ranges from 9 to17 % [9, 22]. Other reported risk factors include male sex, younger age and time from ACL injury to surgery [9]. Liu et al. [9] found the prevalence of ramp lesions in the presence of ACL injury in males to be 18.6 %, while the prevalence in female patients was 12.0 %. A significantly higher prevalence of ramp tears was detected in patients younger than 30 years of age, compared to those aged over 30. They also found a significantly higher prevalence of ramp tears in patients with chronic ACL tear (18.8 %) compared to patients with an acute (less than 6 weeks old) ACL tear (12.7 %). The time from injury to ACL reconstruction was reported to be associated with an increased incidence. This assertion was corroborated by Papastergiou et al., who reported that the earliest point of a significantly higher incidence of meniscal tears in an ACL-deficient knee occurred 3 months following injury [23]. Therefore, the authors recommended that ACL reconstruction should ideally be performed within 3 months of injury to mitigate against this risk. However, the prevalence of ramp lesions continues to increase significantly until 24 months post ACL tear where it plateaus [9]. Furthermore, it is likely that the incidence of ramp lesions will increase as a greater awareness of this pathology develops.

6.5 Why Are Ramp Lesions Important?

The posterior horn of the medial meniscus plays a fundamental role in knee stability, particularly in limiting anterior tibial translation. Although the biomechanical consequences of ramp lesions are unknown, longitudinal tears in the posterior horn of the medial meniscus increase anteroposterior tibial translation in the ACL-deficient knee [16]. The potential consequences of ramp lesions are threefold:

1. Failure of the ACL graft:

   Papageorgiou et al. [24] demonstrated the biomechanical interdependence between the medial meniscus and the ACL graft. When a medial meniscectomy is performed with an ACL reconstruction, the in situ forces in the ACL graft increase between 33 and 50 % [24] because of the loss of the secondary stabilising forces. Injury to the ACL increases forces in the meniscus by up to 100 % [11, 24]. Failure to recognise or treat a ramp lesion may lead to an increased risk of ACL graft failure.
2. Increased risk of requiring further surgery to address meniscal injury:

   If the diagnosis of ramp lesion is not made at the time of ACL reconstruction, secondary meniscal injury may occur in the form of extension of the tear. Extension of the lesion towards the middle third could easily destabilise the entire posterior meniscus or result in a bucket handle tear. This could potentiate in further surgery for meniscal repair, meniscal resection, or meniscectomy.
3. Increased risk of developing osteoarthritis:

   If neglected or misdiagnosed, ramp lesions can lead to instability or injury of the body of the medial meniscus which is a significant precursor to osteoarthritis and general debilitation of the knee. The literature reports that the risk of osteoarthritis in patients with an ACL and without a meniscal tear is between 0 and 13 %, but the risk increases to 21–48 % with meniscal tears. Thus, meniscal injuries that accompany ACL tears are important in the long-term prognosis, especially for OA after ACL reconstruction [4, 13, 25].

6.6 How Do You Diagnose a Ramp Lesion?

> "The eyes only see what the mind is prepared to comprehend. Henri Bergson, French Philosopher"

(a) History

Most commonly ramp lesions occur in the ACL-deficient knee. The clinician must therefore have a high index of suspicion for the pathology in the setting of ACL tear. Diagnosis is difficult acutely. The prevalence of ramp lesions increases in patients with a chronically deficient ACL, so one must be highly suspicious for their presence in this setting. In particular, one must enquire about the presence of medial joint line pain, which may point to a 'hidden lesion'.

(b) Clinical Evaluation

There are no specific clinical tests for ramp lesions. However, there are numerous clinical tests to examine for the presence of a meniscal lesion. A combination of various meniscal tests is recommended, because no single test is conclusive. Negative meniscal tests do not completely exclude a meniscal lesion. The accuracy rate of the tests ranges from 60 to 95 %, depending on the clinical experience of the examiner [12]. Physical examination in the setting of a tear of the posterior horn of the medial meniscus typically reveals posteromedial joint line tenderness and reproduction of posteromedial pain on maximal flexion of the knee [26].

Provocative manoeuvres may cause impingement of the meniscus between the femoral and tibial surfaces. The McMurray test is performed on the medial meniscus by flexing the knee, creating a varus stress by internally rotating the tibia and bringing the knee into full extension while palpating the joint line [26]. Other tests include the Steinmann I sign (tenderness shifting from anterior to posterior with increasing flexion) and the Fouche sign (reversed McMurray sign with internal rotation of the tibia) [12].

(c) Radiological evaluation

Ramp lesions are difficult to diagnose radiologically. MRI, widely used in the evaluation of meniscal injuries, has a low sensitivity for identifying ramp tears. Meniscal lesions are more difficult to detect on MRI in the presence of ACL rupture, and MRI is less specific for medial meniscal tears than for lateral tears [27]. MRI is unreliable in diagnosing ramp tears, presumably because the knee is in near full extension at the time of study, reducing the meniscocapsular separation [9, 22]. It can also be difficult to distinguish meniscocapsular separation from far peripheral vertical longitudinal tears of the posterior horn of the medial meniscus. Hash reported that the most specific sign of a ramp lesion on MRI was the visualisation of a thin fluid signal completely interposed between the posterior horn of the medial meniscus and the posteromedial capsule (Fig. 6.2 – appearance of a ramp lesion on MRI) [28].

It is generally considered that arthroscopic evaluation is necessary to completely rule out or accurately diagnose a ramp lesion [9, 10, 21, 22, 28].

(d) Arthroscopic Evaluation

Ramp lesions are frequently undiagnosed during ACL reconstructive surgery.

Given their high prevalence, they should be routinely looked for [2]. They may go unseen because of poor visualisation from standard anteromedial and anterolateral portals. Obstruction by the medial femoral condyle can make it difficult to visualise the posterior third of the medial meniscus [2]. Various methods have been described to improve visualisation of the posteromedial corner of the knee; however, there are many knees, the so-called tight knees, in which the posteromedial corner is impossible to evaluate via anterior portals only [2].

Sonnery-Cottet et al. [2] demonstrated that 40 % of ramp lesions are not identified without inspection of the posterior compartment via intercondylar view and posteromedial portal access. This is of particular importance, because many of these missed tears are repairable [2, 29].

Given the high prevalence of ramp lesions, some authors have suggested that a posteromedial portal should be used in all cases to enhance the visualisation of the posteromedial aspect of the medial meniscus [2]. Although this approach would certainly enhance diagnosis of the lesion, if it exists, there is still insufficient data to support an improved clinical outcome with repair of these lesions. Therefore, this suggestion remains somewhat controversial.

6.7 How Can I See a Ramp Lesion Arthroscopically?

A number of different arthroscopic techniques have been proposed to visualise ramp lesions properly. Key to any of these is accessing the posteromedial compartment for inspection.

Firstly, a thorough assessment of the knee should be made using standard anterolateral and anteromedial portals and a classic 30° arthroscope [9, 21, 30]. ACL rupture should be confirmed, followed by routine assessment of the posterior horn of the medial meniscus with the knee in extension and a valgus force applied. The meniscus should be inspected and probed to determine the presence of a tear and the stability of the meniscus [9, 29]. The ramp area should then be inspected and can be done so by two main approaches:

(a) Intercondylar approach

Strobel [12] proposed the ramp area of the medial meniscus be inspected by passing the arthroscope through the intercondylar notch and under the posterior cruciate ligament (PCL) into the posteromedial recess. The knee should be flexed to 90° and a valgus stress applied. A 2.7 mm diameter 70° arthroscope may be used to obtain a wider view of the posteromedial compartment [30]; however, this may not be required [2]. The use of a blunt trocar may facilitate passing the camera [2]. Once the cannula has been passed into the compartment, the blunt trocar is exchanged for the 30° or 70° scope. The optical lens is rotated to allow good visualisation of the posteromedial compartment and especially the meniscocapsular junction. Internal rotation applied to the tibia can help visualisation because this causes the posterior tibial plateau to sublux leading to posterior translation of the middle third of the medial meniscus [31] (Fig. 6.3).

Vision may be obscured by synovitis in the posteromedial recess or by osteophytes. If a ramp lesion is strongly suspected but cannot be

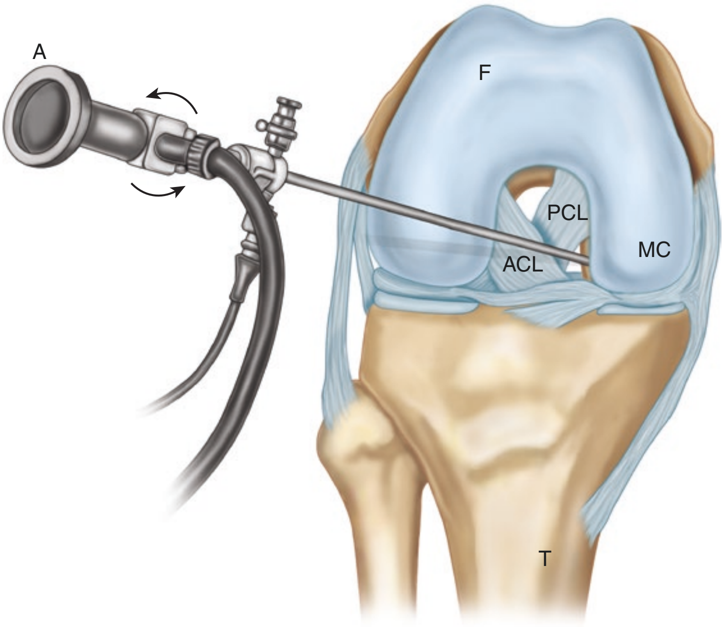

Fig. 6.3 Position of the arthroscope (*A*) for the intercondylar view. The arthroscope is advanced between the medial femoral condyle (*MC*) and posterior cruciate ligament (*PCL*). The arthroscope is then rotated to view the posteromedial recess (*arrows*) (*F*, femur; *T*, tibia) [29]

confirmed or excluded by viewing via an anterolateral portal, inspection can be aided by needling. A needle is inserted into the posteromedial recess percutaneously to help evaluate the ramp area [9, 12]. With the knee in 90° of flexion and the use of transillumination, a needle is inserted from the posteromedial aspect of the knee, proximal to the medial femoral condyle. The needle is passed into the posterior part of the meniscal attachment or the posterior part of the tear. Moving the needle posteriorly will open up the tear and more clearly define its location and extent [12]. Once the presence of a ramp lesion has been confirmed, it should be repaired [9, 10, 12].

(b) Posteromedial approach

Some authors advocate the use of a posteromedial portal [9, 12, 29]. Strobel advocates the use of a low posteromedial portal, placed at the level of the joint space, which provides relatively tangential access to the posterior horn and ramp area of the medial meniscus. This is the portal placement of choice for all-inside repairs [12]. A posteromedial portal is established under direct visualisation using a localising 18-gauge needle. Once the localising needle is in optimal position, a superficial incision is made through the skin only to decrease the risk of injury to the saphenous nerve and vein, and the portal is completed with the use of a straight artery forceps to penetrate the joint capsule and expand the portal. The established posteromedial portal can be used for both visualisation and as a working portal. The probe is first introduced through the posteromedial portal to manipulate the posterior horn of the meniscus. The arthroscope can then be inserted to view the posterior horn, with probing through the anterior portals [29]. It is also possible to create two posteromedial portals, one superiorly and one inferiorly, with an adequate skin bridge, to visualise and work exclusively posteromedially.

Sonnery-Cottet et al. [2] propose a four-step systematic arthroscopic exploration to ensure ramp lesions are not missed: (1) standard arthroscopic exploration via anterolateral portal and probing of the meniscal tissue, (2) exploration of the posteromedial compartment by introducing the arthroscope through the anterolateral portal and advancing it deeply into the notch and under the PCL, (3) creating a posteromedial portal and probing the posterior horn of the medial meniscus and (4) medial meniscal repair. In their study they found 42 % of ramp lesions at step 3. In true *hidden lesions*, the tears were not revealed until the area was evaluated with an arthroscopic probe, and superficial soft tissue was minimally debrided with a motorised shaver [2].

6.8 If I See a Ramp Lesion, How Should I Treat It?

No clear consensus exists on the appropriate management of ramp lesions [10]. Despite being in the red-red zone, an area with a rich vascular supply, questions have been raised on whether ramp lesions can heal without repair. Ahn et al. [32] showed that during knee flexion and extension, the hypermobility of the detached meniscocapsular structure disturbs the ramp area, preventing spontaneous healing. The rates of poor healing for medial meniscus remains high when nonoperative treatment is used, even though nonoperative treatment is reportedly more effective for lateral meniscus tears [33–35].

Studies have consistently demonstrated the improved healing capacity of the meniscus when associated with a concomitant ACL reconstruction, and conversely, multiple authors have demonstrated an increased failure rate of meniscal repairs in ACL-deficient knees [36].

When surgical repair is the treatment of choice, the anatomic location of a meniscal ramp lesion creates a surgical challenge. The posteromedial portal places the saphenous neurovascular bundle at risk [37]. Techniques that allow for direct visualisation of the posterior capsule to avoid iatrogenic injury to the saphenous nerve are recommended. While outside-in repairs can be useful for repairs of the anterior and middle thirds of the meniscus, this technique should be undertaken with caution in the setting of repair of the posterior horn of the medial meniscus [37, 38].

All-inside techniques and inside-out techniques have been shown to have success in treating ramp lesions [31]. The meniscus should be prepared for repair. The lesion is debrided with a meniscal rasp, and the edges of the tear trimmed with a shaver [31].

The major advantages of the inside-out meniscal repair technique are its versatility, ease of use, relatively short learning curve and reliability. Excellent healing rates have been widely reported in the literature [36, 39].

(a) Inside-out technique

For an inside-out repair, a posteromedial approach is required. With the knee in flexion, an oblique vertical incision is made at the posteromedial border of the tibia just below the joint line [2]. The sartorius fascia is incised as proximal as possible while preserving the pes anserine tendons. An anatomic *triangle* is formed by the posteromedial joint capsule anteriorly, the medial gastrocnemius posteriorly and the direct arm of the semimembranosus inferiorly [40]. A retractor is placed in this interval to protect the posterior neurovascular structures during the repair procedure [40]. Zone-specific cannulas are used to place sutures into the medial meniscus from the anterolateral portal. Single or double lumen cannulas can be used depending on the surgeon's preference [39]. Ten-inch flexible needles with preloaded non-absorbable or absorbable sutures are typically used. While applying a valgus force to the joint, the cannula is directed towards the tear. The tip of the needle is passed just beyond the end of the cannula to visualise its precise entry into the meniscus. The tear should be anatomically reduced, and the needle is passed through the meniscus. The second needle is then passed adjacent to the first in a horizontal, vertical or oblique mattress. The assistant retrieves the needles through the posteromedial incision, and the needles are cut from the sutures and clamped with a hemostat. The process is repeated every 3–5 mm. The sutures are tied with the knee at 90°, being careful not to overtighten the posteromedial structures [10, 39–41]. Inside-out repair offers a success rate of 60–80 % for isolated meniscal repairs and 85–90 % when performed at the time of ACL reconstruction [39].

(b) All-inside technique

All-inside meniscal repairs are performed entirely through arthroscopic portals. This technique avoids the need for accessory incisions and decreases the risk of neurovascular injury. Various meniscal repair devices are available.

They may be rigid or self-adjusting suture-based implants [38].

(i) Suture hook: Morgan [42] described an all-inside suturing technique, which although technically demanding allows for placement of vertically oriented sutures [43]. The tear is repaired using a curved suture hook angled approximately 90° at the tip (angled to the right for the left knee, to the left for the right knee). The arthroscope is placed from the anterolateral portal into the posteromedial compartment through the intercondylar notch. A posteromedial portal is made and the tear is debrided to enhance healing [44]. The suture hook is passed through the meniscal peripheral rim tissue (meniscocapsular tissue first) from superior to inferior and then through the mobile central meniscal fragment from inferior to superior. This allows the sagging posterior tissues to be lifted to the level of the meniscal posterior horn [12]. It is postulated that this lifting manoeuvre is essential and cannot be replicated with the standard anterior-to-posterior all-inside technique [12, 29, 32]. A probe can be used to keep the central meniscal fragment in place [45]. The suture hook is advanced and rotated until the tip of the hook appears on the upper meniscal surface. The suture is advanced and retrieved with an arthroscopic grasper [12]. The suture is tied with an arthroscopic knot pusher. Sutures are placed every 5 mm along the length of the tear [2].

(ii) Meniscal suture anchor: Proprietary meniscal suture devices can also be used for ramp lesion repair – the following description uses a FasT-Fix device (Smith & Nephew, Andover, MA, USA). With the arthroscope in the anterolateral portal, the device is advanced to the ramp lesion through the anteromedial portal. Using the intercondylar approach to gain direct vision of the posteromedial compartment, the first implant is inserted under the meniscus and obliquely into the joint capsule. The second implant is inserted into the peripheral edge of the meniscus. The pre-tied self-sliding knot is tensioned to achieve secure fixation. The curve of the FasT-Fix may be increased to allow for easier access below the meniscus and to avoid damage to the chondral surface of the femoral condyle. The knee may be flexed or extended while applying a valgus force to bring the capsular synovium as far as possible to the attachment. The anchors are inserted every 3–5 mm along the tear [30]. This technique does not use an accessory posteromedial portal, and one can postulate this may result in decreased accuracy of blind passage (Fig. 6.4).

Rates of structural healing and complications are comparable for inside-out and all-inside repair techniques. Complications are associated with both techniques. More nerve symptoms are associated with the inside-out repair, and more implant-related complications are associated with the all-inside technique [31, 32, 36].

All-inside repair using meniscal suture anchors has increased in popularity because of its easy application. Biomechanically, the horizontal sutures of these devices have inferior strength compared with vertical mattress sutures. Also, meniscal fixators cannot provide sufficient fixation strength at the repair site in the case of ramp lesions [44].

6.9 How Do I Rehabilitate Ramp Lesion Repairs?

Post-operative rehabilitation programmes following meniscus repairs are highly variable, and currently there is no general consensus [2, 9, 10, 30, 38]. There are a number of variables to consider including the range of motion and weight-bearing status. Most surgeons agree that early knee motion is beneficial. Prolonged immobilisation can lead to stiffness, atrophy and decreased collagen content and impaired healing of the meniscus repair site [38]. However, maximal knee flexion is associated with considerable anterior tibial translation and can increase the stresses within the posterior horn of the meniscus, especially with weight bearing. Weight bearing can help reduce and stabilise longitudinal meniscus tears. Therefore, weight bearing in full extension

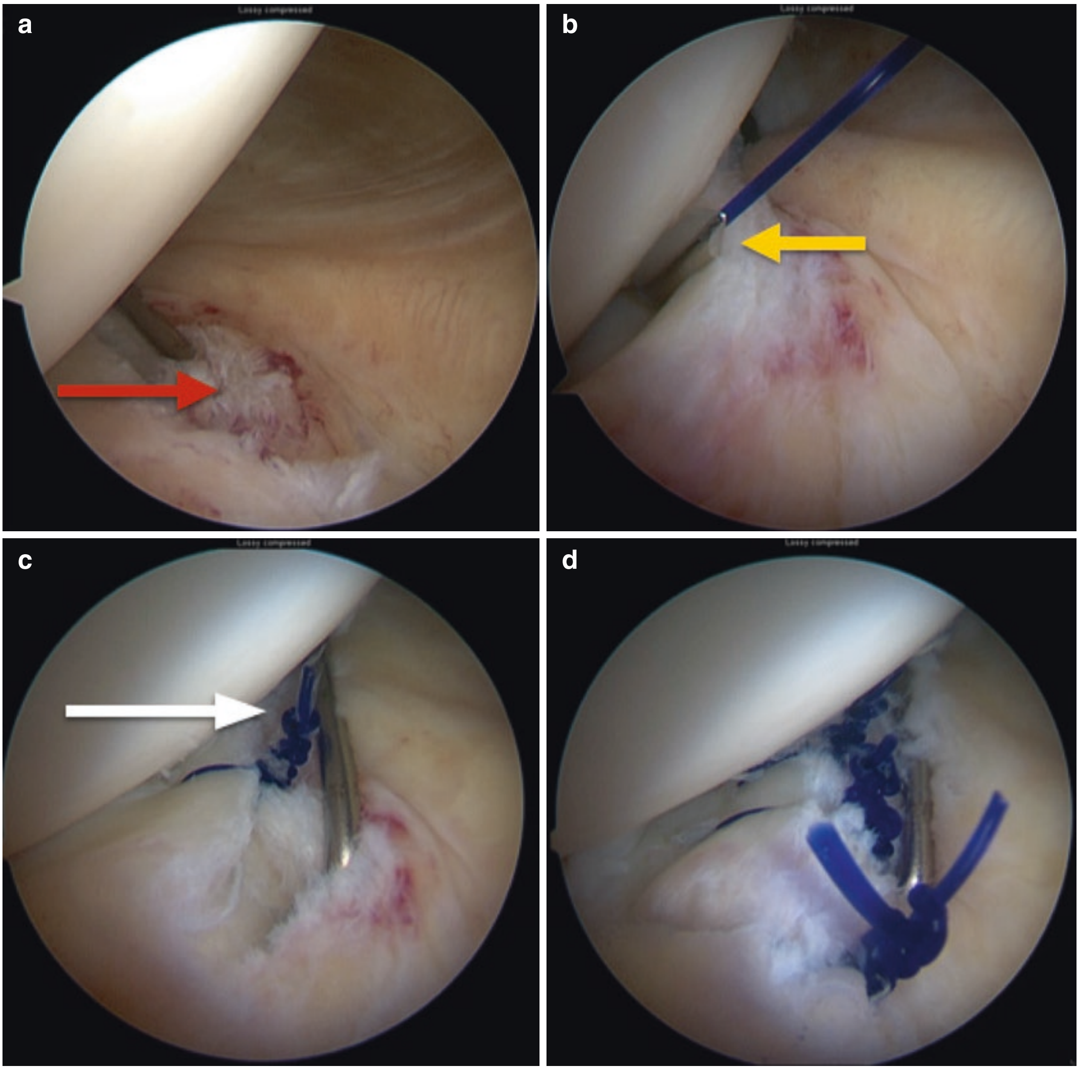

Fig. 6.4 (**a**–**d**) Arthroscopic view of posteromedial compartment of the left knee viewed through the intercondylar notch with a 70° arthroscope; (**a**) *red arrow* demonstrates the ramp lesion tear; (**b**) *yellow arrow* shows a curved suture hook used for an all-inside repair technique; (**c**) *white arrow* demonstrates a suture in situ with an arthroscopic knot; (**d**) the completed repair with approximation of the posteromedial capsule to the meniscus (These photographs are courtesy of Professor Joon Wang, Samsung Medical Centre, Sungkyunkwan University Medical School, Seoul, Korea)

theoretically poses less risk to ramp lesion repairs and may aid healing [38].

At present there is no clinical evidence that there is any need to slow or modify the ACL rehabilitation protocol when there is an associated meniscal repair.

Rehabilitation after a ramp lesion repair should follow usual protocols for ACL reconstruction when performed in combination or a meniscal repair when done in isolation [5].

6.10 What Do I Tell My Patients About the Outcome of Ramp Lesion Repairs?

It is still unknown at present what the natural history of a ramp lesion is and whether it will heal spontaneously once the knee has been stabilised by an ACL reconstruction or whether suture repair is mandatory to prevent it from extending to a larger tear [9]. There are no reported outcomes studies for nonsurgical management of ramp tears. There are only a small number of outcome studies for the diagnosis and management of ramp lesions in the literature [10]. Repair of the peripheral meniscus in conjunction with ACL reconstruction has been reported to produce favourable meniscal healing; therefore, the ramp area has high healing capacity. A systematic review by Grant et al. [36] in 2012 looked at inside-out versus all-inside meniscal repair in isolated, peripheral longitudinal unstable meniscal tears. They found no clear benefit of one technique over the other with regard to structural healing or perioperative complications.

The integrity of the ACL is a critical factor that affects the overall success of a meniscal repair. Studies have consistently demonstrated the improved healing capacity of the meniscus when associated with a concomitant ACL reconstruction [36, 38]. It is hypothesised this is related to the biological augmentation of the repair from factors in the bone marrow released within the joint [46]. Conversely, multiple authors have demonstrated an increased failure rate of meniscal repairs in ACL-deficient knees [47].

Take-Home Message

Ramp lesions are longitudinal tears at the meniscocapsular junction of the posterior horn of the medial meniscus. They are commonly associated with the ACL-deficient knee, both in the acute and chronic setting, with their incidence increasing in time from injury. Ramp lesions are difficult to diagnose preoperatively, and one must have a high index of suspicion in the setting of a chronic ACL tear. The key to diagnosing ramp lesions is to thoroughly evaluate the medial meniscus during arthroscopy, particularly the posteromedial aspect. This can be achieved through intercondylar access or via a posteromedial portal. Ramp lesions may be hidden under a superficial layer of tissue, and so probing with a needle or debridement with a shaver may reveal the tear. Once diagnosed, meniscal ramp lesions should be repaired to reinstate the biomechanical stabilising force of the medial meniscus. Options for repair include all-inside or inside-out techniques. Rehabilitation should follow standard protocols for isolated meniscal repair or ACL reconstruction.

Key Points

Incidence	The presence of a ramp lesion must be considered in the setting of acute ACL rupture, and the index of suspicion should be high in a chronically ACL-deficient knee (>3 months) The prevalence of ramp lesions is significantly increased with time from injury The interval between ACL injury and surgery is an important predictor of secondary meniscal injury
Significance	Ramp lesions appear to play a significant role in knee stability given the posterior horn of the medial meniscus is a secondary restraint to anterior tibial translation and external rotation Diagnosis is important because missed lesions contribute to meniscal instability and subsequent failure of the meniscus Failure to recognise or treat a ramp lesion may lead to an increased risk of ACL graft failure

Diagnosis	Ramp lesions are difficult to diagnose preoperatively as there may be no specific findings on examination, and the sensitivity of MRI is low The posterior compartment of the knee must be inspected arthroscopically to accurately diagnose ramp lesions The posterior compartment of the knee may be examined by intercondylar access or additional posteromedial portal
Management	Despite being in the vascular red-red zone, it is thought that ramp lesions may have low potential to heal spontaneously given the ramp area is likely to be disturbed during flexion and extension of the knee Therefore, repair of the meniscus should be performed Options for repair include inside-out and all-inside techniques Rates of structural healing and complications are comparable for inside-out and all-inside repair techniques. Complications are associated with both techniques. More nerve symptoms are associated with the inside-out repair, and more implant-related complications are associated with the all-inside technique
Rehabilitation	Rehabilitation should follow standard guidelines for isolated meniscal repair or ACL reconstruction when performed in combination

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Peripheral Meniscal Tears: How to Diagnose and Repair

7

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Contents

7.1 Introduction

Peripheral meniscal tears are located in the most vascular portion of the menisci and comprise 39–72 % [2, 3, 56, 69, 82] of all meniscal tears. The younger population, particularly males with knee instability, is most commonly affected by this type of tear [56]. The vascularity of the peripheral menisci is primarily derived from the superior and inferior medial and lateral geniculate arteries [7]. A synovial fringe that extends approximately 3 mm over the surface of each meniscus adds further to the peripheral vascularity. This intricate blood supply results in the outer rim of the meniscus being vascularized up to 30 % of its width on the medial side and 25 % on the lateral side [7]. There is discrepancy in the vascularity of the menisci, with the peripheral parts being more vascular than the central zones. The vascularity of the menisci has also been shown to decrease and become more peripheral with age [59]. Thus, the healing potential of the meniscus depends on the location of the lesion and the age of the patient [7, 41, 44]. Because of the high vascularity, peripheral meniscal tears (red-red and part of the red-white zone) have the greatest potential for healing [44] (Fig. 7.1).

Due to their anatomic position and attachments, the menisci are vulnerable to injury when particular forces are placed on the knee joint, with specific maneuvers placing certain meniscal areas at highest risk for injury. In this regard,

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_7

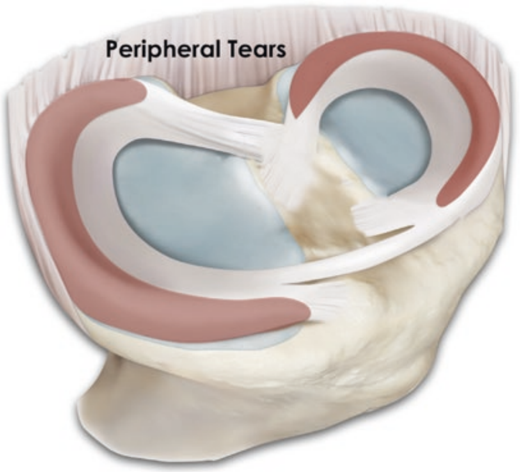


Fig. 7.1 Schematic diagram of a left knee (disarticulated from the femur) demonstrating the location of the peripheral zones of both menisci (demarcated in *red*)

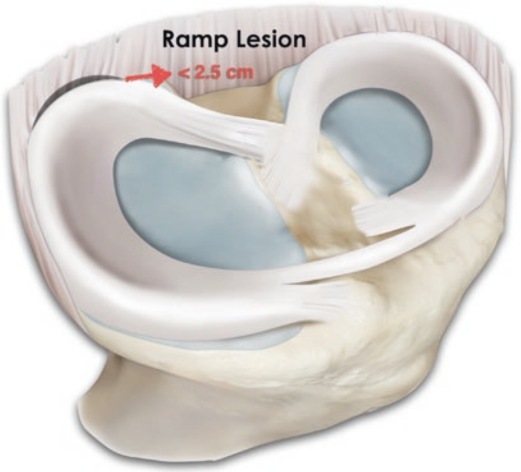


Fig. 7.2 Schematic diagram of a left knee (disarticulated from the femur) demonstrating the location of a ramp lesion in the posteromedial meniscocapsular junction of the medial meniscus. As per definition, ramp lesions are located in the meniscocapsular region and are less than 2.5 cm in length

when the knee is in flexion and the tibia in internal rotation, the posterior horn of the medial meniscus is stretched and pulled anteriorly [70]. This action may lead to a peripheral tear near its posterior attachment via the coronary ligaments [21], which is one of the most common locations for meniscal tears [47, 69, 79]. These tears, known as ramp lesions (Fig. 7.2), often occur in conjunction with ACL tears [13, 44, 79] and are commonly under-recognized when using standard anterolateral and anteromedial arthroscopic portals due to their location within the posteromedial “blind spot” [75]. Ramp lesions have been reported to be present in 9–17 % of all ACL tears [10, 53]. Conversely, the anterior horn of the medial meniscus is less commonly injured and, therefore, not well described in the literature. Chen et al. [15] demonstrated in porcine knees that the anterior horn of the medial meniscus restrains external rotational torque of the tibia. Thus, providing a possible mechanism of injury for humans in which the knee is in full extension and external rotational torque is placed on the tibia [15].

Peripheral tears, in general, are believed to partially preserve the load distribution function of the meniscus, whereas other tears, such as radial tears or more central, complex tears, do not preserve the load distribution function due to the disruption of the large circumferential fiber bundles [31, 55]. However, it has been reported that peripheral tears with meniscal rim involvement have a significant association with the development of radiographic osteoarthritis (OA) [63], likely resulting from altered biomechanics. The role of the meniscus as a secondary stabilizer of the knee joint should not be overlooked. The posterior horn has demonstrated importance in anterior tibial translation [9, 67]. In the setting of ACL deficiency, peripheral meniscal tears have been reported to drastically alter knee biomechanics, similar to that of a total meniscectomy [1]. Allen et al. [5] reported that a resultant force in the medial meniscus of an ACL-deficient knee increased by over 50 % in full extension and nearly 200 % at 60° of flexion. In contrast, in a knee with otherwise intact ligamentous structures, Goyal et al. [37] reported that there was no alteration in tibiofemoral kinematics or joint contact pressures when simulating a peripheral lateral meniscal tear. Additionally, a recent cadaveric study demonstrated that anterior tibial translation and external rotation laxities were significantly increased after inducing a ramp lesion in an ACL-deficient knee [74]. Therefore, the menisci play an important role of the biomechanics of the knee joint, particularly in the setting of ACL-deficient knees when additional force and stress is placed on the menisci. This increase in mechanical force likely leads to meniscal tears following ACL injury with delayed or inadequate repair. When taking into account the various biomechanical properties and roles of the menisci, it is clear that injury to the menisci can have detrimental effects on the knee joint. By reaching an appropriate, timely diagnosis with subsequent repair, surgeons can minimize future complications such as increased graft forces or OA [20, 56].

The diagnosis of peripheral meniscal tears often includes a detailed history, physical examination, and diagnostic imaging. Despite these diagnostic techniques, a peripheral meniscal injury can be misdiagnosed. Once identified, a surgeon must consider the characteristics of the tear, such as the location, size, appearance, chronicity, and presence of secondary tears, prior to intervention [44]. Furthermore, patient factors such as age, activity level, compliance, and concomitant ACL injury must be taken into account as well [44] due to their influence on patient outcomes.

Better comprehension of the function (shock absorption, stability, force transmission) and vascularity of the menisci, as well as the knowledge of degenerative articular changes after meniscectomy, has led to the development of numerous surgical meniscal repair procedures used to preserve the meniscus. Described surgical techniques include open, outside-in, inside-out, and all-inside, in addition to nonoperative treatment in certain circumstances [4, 11, 14, 28]. Outcomes with these techniques have been favorable overall [3, 4, 20, 24, 28, 38, 40, 43, 46, 58, 69], with arthroscopic techniques becoming the mainstay for surgical intervention. Improved outcomes are often associated with the type of tear, location, knee stability, surgery less than 8 weeks from injury, and age [2, 4, 24].

The following chapter includes diagnostic techniques and imaging studies used in the diagnosis of peripheral meniscal tears, followed by in-depth descriptions of surgical techniques, patient outcomes, and postoperative rehabilitation.

7.2 Diagnosis

Meniscal tears can be challenging to diagnose at times, even for an experienced surgeon, but an effective history and physical examination can direct the working diagnosis toward a meniscus problem. In this chapter, we will not cover history taking in the setting of suspected meniscal pathology but focus on physical examination maneuvers and diagnostic imaging involved in the diagnosis of peripheral meniscal tears. After a pertinent patient history is obtained, physical examination follows and is one of the major contributors to reach a diagnosis of a meniscal tear. When interpreting the findings from the various tests and examinations, it is important to understand the sensitivity, specificity, and limitations of each examination. As previously stated, a timely diagnosis of peripheral meniscal tears is important in limiting degenerative changes in the cartilage and the menisci that results from the changed joint loading and biomechanics.

7.2.1 Physical Examination

Many clinical tests have been described to assist in diagnosing meniscal tears, including joint line palpation, McMurray and Apley tests, as well as the figure-4 test [6, 25, 26, 33, 44, 48–50, 56, 60, 70, 85]. Tibiofemoral joint line palpation is among the most basic diagnostic physical exam test for meniscal pathology. During this exam, manipulation of the knee joint allows for the palpation of specific meniscal regions. For example, flexion of the knee allows for the palpation of the anterior half of each meniscus, valgus force on knee joint exposes the medial edge of the medial meniscus, and varus force on the knee enhances palpation of the lateral meniscus (Fig. 7.3) [54]. The literature reports the sensitivity and specificity of joint line tenderness to be 55–85 % and 29.4–67 %, respectively [6, 33, 49, 85].

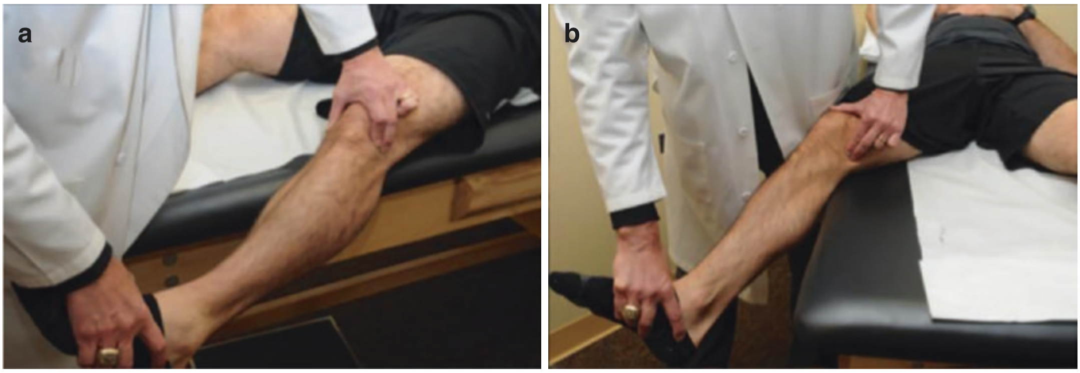


Fig. 7.3 Image demonstrating joint line tenderness test on a (**a**) lateral meniscus of a left knee while extruding the meniscus with a varus force and (**b**) medial meniscus of a right knee while extruding the meniscus with a valgus force

Additionally, joint line tenderness has potential discrepancies with laterality, showing increased sensitivity, specificity, and accuracy in lateral pathology compared to the medial side [25, 48, 60]. Positive predictive value (PPV) and negative predictive value (NPV) for the medial meniscus are reported to be 59 % and 90 %, respectively. Alternatively, the lateral side displayed a PPV of 92 % and NPV of 97 % [25]. Thus, the absence of joint line tenderness is suggestive of an intact, healthy meniscus, while joint line tenderness is by no means pathognomonic of meniscal injury.

Tests that assess meniscal integrity, such as the McMurray and Apley grind tests, may not be conclusive but can aid in diagnosis [44, 56, 70]. The McMurray test, first described in 1940 [26], is widely known as a primary clinical exam to evaluate for meniscal tears. A positive sign is indicated by a "popping" and sensation of pain symptoms along the joint line [70]. This test is examiner dependent, with the success and failure often being driven by the clinician. The sensitivity of the McMurray test ranges from 16 to 75.8 % [6, 26, 33, 49, 85] and a specificity of 77–98 % [26, 33, 49, 85]. In the clinical setting, a negative McMurray testing should be interpreted with caution given the wide range of reported sensitivity. In contrast, its utility in diagnosis of a meniscal tear is maximized with a positive test. The Apley grind test has reported sensitivity and specificity of 13–16 % and 80–90 % [33, 49], respectively, with an accuracy of 28 % [49]. The Apley test requires the patient to be in the prone position, which may be difficult in patients with limited mobility. A positive test produces increased pain on compression. With reported PPV of 95 % and NPV of 35 % [85], a positive result indicates a likely meniscal tear whereas the absence of pain during the maneuver does not necessarily eliminate meniscal pathology.

The figure-4 test, first described in 2005, places the affected knee in flexion, varus, and external rotation [50]. This maneuver produces tension on the posterolateral structures of the knee, as the popliteus complex and popliteomeniscal fascicles prevent medial displacement of the lateral meniscus [45, 68, 72, 77]. When this test is performed on a patient with an injury to the popliteomeniscal fascicles, the lateral meniscus can displace medially into the joint causing increased pain along the joint line [72, 77]. The figure-4 test was first used by LaPrade and Kowalchuk in a case series with six patients who had isolated unstable tears of the popliteomeniscal fascicles of the lateral meniscus. All patients were noted to have lateral joint line pain that was exacerbated by the figure-4 test, despite the absence of locking, catching, or difficulty squatting [50]. Therefore, this test of the knee is likely to be clinically useful in the setting of unstable popliteomeniscal fascicle tears, with the need for additional evidence in a larger cohort.

In addition to physical exam maneuvers aimed at diagnosing meniscal tears, the collateral and cruciate ligaments should also be assessed to determine the presence of an additional injury.

This is particularly important in the setting of ACL injury or deficiency, because a peripheral meniscal tear increases knee joint instability in a similar fashion to a total meniscectomy [1], and failure rates of meniscal repair dramatically increase with residual knee laxity [4, 23, 65]. Thus, knee laxity and meniscal tears should be addressed concurrently. These maneuvers will not be covered in this chapter but should be included for a thorough exam of the knee.

As noted before, when all physical exam maneuvers and observations are used in combination, the resulting diagnosis is more accurate than any test alone. Tenderness to palpation along the joint line is among the most common signs of meniscal tear, but joint effusion, crepitus, quadriceps atrophy, or lack of full knee range of motion (i.e., loss of extension more than 5°) may also be noted on examination [44, 56]. In studies using multiple clinical exam tests (joint line tenderness, McMurray, Steinmann, and modified Apley) for the diagnosis of meniscal tears, clinical diagnosis from an experienced surgeon was similar to that of a diagnosis obtained via MRI [48, 60]. Within these studies, lateral meniscal tear diagnostic specificity and sensitivity of clinical examination ranged from 90 to 95% and 67 to 75%, respectively. Alternatively, medial meniscal tear specificity was 60–68 % and sensitivity was 87–92 % [48, 60]. Moreover, when using five separate criteria on physical examination—crepitus, effusion, joint line tenderness, McMurray examination, and loss of motion—91 % of medial or lateral and 96 % of combined medial and lateral tears were associated with one or more of the five criteria [56]. When comparing these results from previously stated individual sensitivities and specificities for each examination, it is clear that multiple physical examination tests have increased diagnostic value than any individual test. Thus, physical examination maneuvers cannot and should not be used individually to accurately diagnose meniscal pathology, but in combination with one another [48, 60, 70]. This notion must be understood and applied within clinical practice in order to appropriately diagnose and subsequently manage peripheral meniscal tears.

7.3 Imaging

Imaging is an important part of the diagnostic work-up. Preoperative imaging is necessary to help the treating surgeon verify/confirm the diagnosis, evaluate the type of meniscal injury, and diagnose concomitant injuries in order to inform the patient and develop a treatment plan. Several imaging modalities exist, but MRI is the most sensitive and regarded as the gold standard for imaging the knee soft tissues including the meniscus. Even though diagnostic arthroscopy can provide both the diagnosis and opportunity to treat meniscal lesions, it is not considered the first option because of its invasiveness, costs, and risk associated with surgery. The different imaging modalities will be discussed below.

7.3.1 Standard Radiographs

Menisci and noncalcified soft tissue are not normally visualized on standard radiographs, limiting the value of this imaging modality in the setting of meniscal damage. Plain standard radiographs are most valuable when assessing for differential diagnoses such as in cases of recent trauma and for the evaluation of elderly patients (>50 years) where the risk of concomitant osteoarthritis is high. This is particularly important when evaluating menisci pathology, because degenerative menisci are associated with osteoarthritis and, therefore, the indication for repairs of meniscal tears in older patients depends on the amount of underlying arthritis and their physiologic age. When osteoarthritis is suspected, standing AP, lateral, and flexion view radiographs should be taken to evaluate the joint space. Loose bodies and signs of osteochondral lesions can be visualized on standard radiographs, which can be signs of chronic meniscal lesions which led to the development of osteoarthritis. Furthermore, a relative widening of the lateral joint space can be a sign of discoid meniscus. Finally, chondrocalcinosis can be usually detected in patients with calcium pyrophosphate dihydrate (CPPD) crystal deposition disease [73]. Fisseler-Eckhoff and Muller [30] reported on 3228 patients undergoing knee arthroscopy, where a radiographic diagnosis of chondrocalcinosis was confirmed in 39.2 % of patients with pathologically proved CPPD crystal deposition. The authors concluded that chondrocalcinosis is an important factor in posttraumatic or degenerative meniscal pathology.

7.3.2 Ultrasound

Ultrasound is not routinely used for the diagnosis of meniscal lesions because it lacks adequate visualization of deeper structures and requires an experienced, well-trained operator. Although the reliability of ultrasound in the diagnosis of meniscal pathology varies in the literature [12, 18, 35], ultrasound can be a valuable tool for visualizing meniscal cysts and joint effusion, as well as tendon and collateral ligament injuries. Dynamic ultrasound has a reported sensitivity of 82 % for the detection of meniscal degeneration based on certain criteria such as cystic lesions, calcifications, and meniscal irregularities [17]. Using ultrasound for detecting meniscal cysts has a reported sensitivity of 97 %, a specificity of 86 %, and an accuracy of 94 % [62].

7.3.3 Magnetic Resonance Imaging

Magnetic resonance imaging is the "gold standard" for evaluating meniscal lesions. It is less invasive when compared to arthroscopy and, thus, can be used on the majority of patients. The quality of the MRI has improved significantly and has eliminated the use of diagnostic arthroscopies in meniscal lesion diagnoses. The advantages of utilizing MRI are the ability to see in different planes, high resolution, and ability to evaluate using different sequences (T1, T2, diffusion, STIR) depending on the structure of interest. Both the location and extent of the meniscal injury, as well as associated chondral and ligament lesions, can be evaluated on MRI. Meniscal root lesions, which can otherwise be difficult to diagnose, can be effectively diagnosed on MRI [52]. MRI has a sensitivity of 86–96 % and a specificity of 84–94 % for medial meniscal lesions. The sensitivity for lateral meniscal lesions is lower compared to that for medial meniscal lesions. The sensitivity is 68–86 % and the specificity is 92–98 % [19, 57, 64]. The variability of reported specificity and sensitivity can largely be explained by interobserver variations, low study populations, and the quality of the images.

There remain few limitations to the use of MRI, such as obese patients and patients with orthopedic metal implants. The use of non-ferromagnetic metals, such as titanium, minimizes artifacts on MRI [76] (Fig. 7.4).

7.3.4 CT Arthrography

CT arthrography can be valuable in patients who are unable to obtain an MRI because of weight, battery-powered cardiac or other implants, or claustrophobia. High-quality multi-planar reconstructions can be acquired for better visualization. Contrast enhancement can aid in detecting some of the lesions that may not be visible on MRI, such as lesions between the meniscus and the capsule. A sensitivity of 84–100 % is reported for CT arthrography in detecting meniscal and

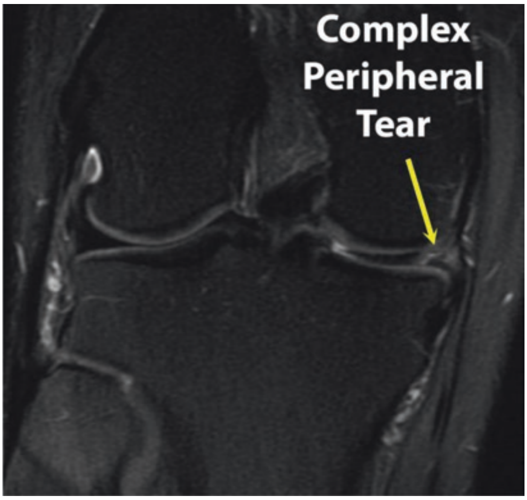


Fig. 7.4 Magnetic resonance image (T2 sequence) demonstrating a complex peripheral tear of a medial meniscus in a right knee

cartilage lesion [16]. It is a relatively safe procedure. However, ionizing radiation exposure and the risk of adverse reaction from the contrast are a concern.

Based on what is known about these imaging modalities, it can be concluded that MRI is the imaging modality of choice for evaluating meniscal lesions. Tear morphology, extent of tear, and concomitant pathologies can be evaluated on MRI. For patients who cannot take MRI because of claustrophobia or weight problems, CT arthrography is a good alternative with good sensitivities reported for meniscal and cartilage lesions while taking into account radiation and contrast exposure.

7.4 Surgical Techniques

Meniscal repair techniques can be divided into inside-out, outside-in, and all-inside technique [36]. Among these, the inside-out technique allows for versatility of placing sutures, lower implant cost, and the use of low-profile needles that allow for multiple sutures without compromising the structural integrity of the meniscus [38]. Disadvantages of this technique include additional incisions (posteromedial and posterolateral), the risk for neurovascular injury, the need for an assistant, and theoretical increased procedure time [14]. The outside-in repair technique was described in an attempt to eliminate the need for a posterior incision and dissection. An outside-in repair technique allows for adequate access to the anterior horn of the meniscus, provides a stable fixation construct, and avoids leaving prominent intra-articular material. However, it has a limited access to tears in the posterior third of both menisci and has lower precision when compared to the inside-out technique. Lastly, the all-inside technique can be performed without additional approaches, allows access to the middle and posterior thirds, and does not require an assistant. Nonetheless, the larger sizes of the all-inside implants when compared to inside-out sutures can compromise the meniscal tissue when trying to place multiple sutures due to the larger holes these devices make in the meniscal tissue. All-inside devices are not exempt from intra-articular deployment of the device and neurovascular damage. A recent systematic review [38] analyzing 19 studies comparing inside-out and all-inside meniscal repair techniques showed no differences in clinical failure rate (17 % vs. 19 %) or subjective outcome. Complications are associated with both techniques. Nerve symptoms are more commonly associated with the inside-out repair, while implant-related complications (soft tissue irritation, swelling, implant migration, or breakage) are more common with the all-inside technique. Stärke et al. [71] reported that regardless of the repair technique employed, there is a general trend of increasing failure rates with time (75–94 % of success in the first year of surgery to 59–76 % beyond the fourth year). Of note, criteria for success and failure were heterogeneous among studies.

7.4.1 Inside-Out Repair

The posteromedial and posterolateral approaches will be described in detail in Chap. 10 (step-by-step surgical approaches for meniscal repairs). Before performing a peripheral meniscal repair, a complete evaluation of the lesion should be performed including size, stability, state of the meniscus, type, and zone of the lesion. Typically, lesions between 1 and 4 cm, located peripherally, have been reported to yield good results; however, every meniscal repair should be attempted. The tear should be anatomically reduced by placing sutures perpendicularly to the lesion to restore its position (Fig. 7.5).

For an inside-out repair, a self-delivery gun fitted with a cannula (SharpShooter) is used to pass double-loaded nonabsorbable sutures (No. 2 FiberWire) into the meniscus. Prior to placing the sutures, the knee is positioned in 20°–30° of flexion, and the meniscal needle is advanced through the superior or inferior aspect of the meniscus. Then the corresponding portion of the capsule (superior or inferior) is penetrated with the second needle of the suture (Fig. 7.6).

In order to help the assistant, retrieve the needle through the previously made posterolateral or posteromedial approach the knee can be flexed to 70°–90,° while the needle is advanced through the meniscus or capsule. The needles are cut from the sutures, and the suture ends are clamped while maintaining slight tension. The same process is repeated adjacent to the previous suture, with sutures in the superior and inferior borders of the meniscus placed between 3 and 5 mm apart. An average of eight sutures are used in order to create a strong construct. When possible, a vertical suture pattern is preferred because it allows for greater capture of the strong circumferential fibers of the meniscus; however, oblique and horizontal patterns can also be used if necessary to reduce the meniscal tear. Lastly, with the knee at 90° of flexion, all sutures are tied, being careful not to overtighten the tissue (Fig. 7.7).

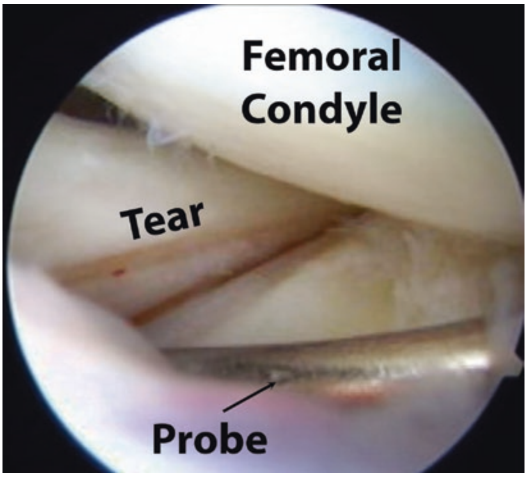


Fig. 7.5 Arthroscopic image of a peripheral tear in a right knee of a medial meniscus assessed with the probe viewed through the anteromedial portal

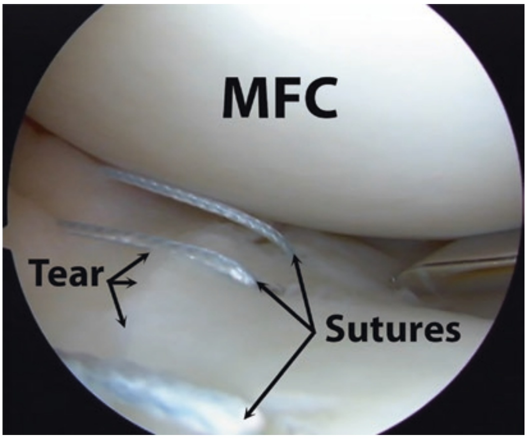


Fig. 7.7 Arthroscopic image showing medial meniscal repair after passing the sutures with an inside-out repair technique. A peripheral tear and the superior sutures (*black arrows*) are shown through the anteromedial portal. The sutures are then tied to stabilize the repair construct

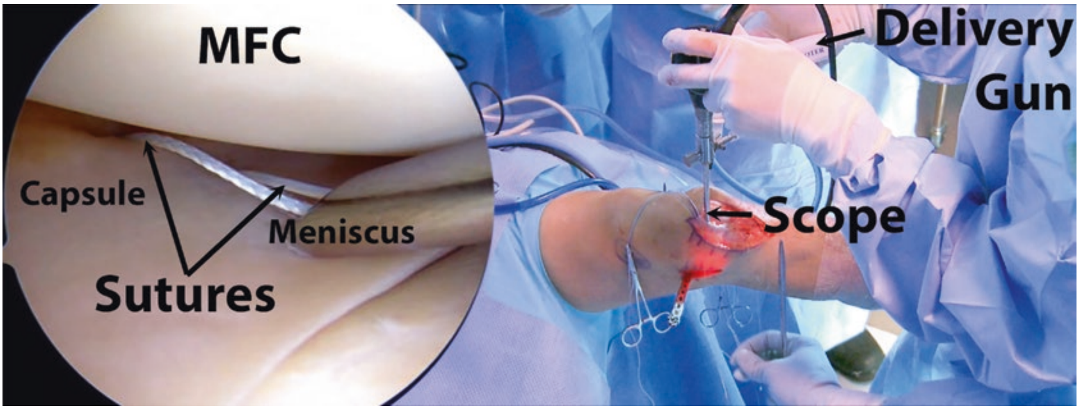


Fig. 7.6 Arthroscopic image (*left*) of a medial meniscal tear being repaired with an inside-out technique (viewed through the anteromedial portal). Of note, one suture is penetrating the superior border of the capsule and the other the corresponding side of the meniscus. On the *right*, an intraoperative image demonstrating the setup for this technique

7.4.2 Outside-In Repair

Following a standard diagnostic arthroscopy, the scope is placed through the contralateral portal in the compartment of the involved meniscus to visualize the extent of the tear. Initially, no skin approach is needed for this procedure. The surgeon uses a spinal needle from an outside-in repair kit to pierce the overlying capsule. Transillumination of the skin can sometimes be useful to locate the tear and joint line when introducing the needle. The spinal needle is then advanced through the superior or inferior side of the meniscus traversing the area of the tear. The inner cannula of the needle is removed, and a #1 PDS suture is placed through the needle into the joint. An arthroscopic grasper is used to secure the free end of the suture, while the needle is subsequently removed, leaving the suture in the joint. A second pass is made with the spinal needle through the corresponding side of the capsule in a similar manner as before. The inner cannula is again removed, and a looped suture retriever is passed through the second needle into the joint. The free end of the previously passed PDS suture is then placed through the looped retriever using a grasper, and the suture is pulled back out of the knee creating a mattress suture construct to secure the meniscal tear. Depending on the nature of the tear and surgeon preference, either a horizontal or vertical mattress suture configuration can be utilized. Once the outside-in repair is complete, a minimal incision can be made with the knee flexed to 90° where the exit of the suture is to be able to tie them in the surface of the capsule (Fig. 7.8).

7.4.3 All-Inside Technique

Once the meniscal tear has been carefully assessed, the penetrating points of the meniscus are decided strategically. The meniscal depth probe is utilized at this point to determine the

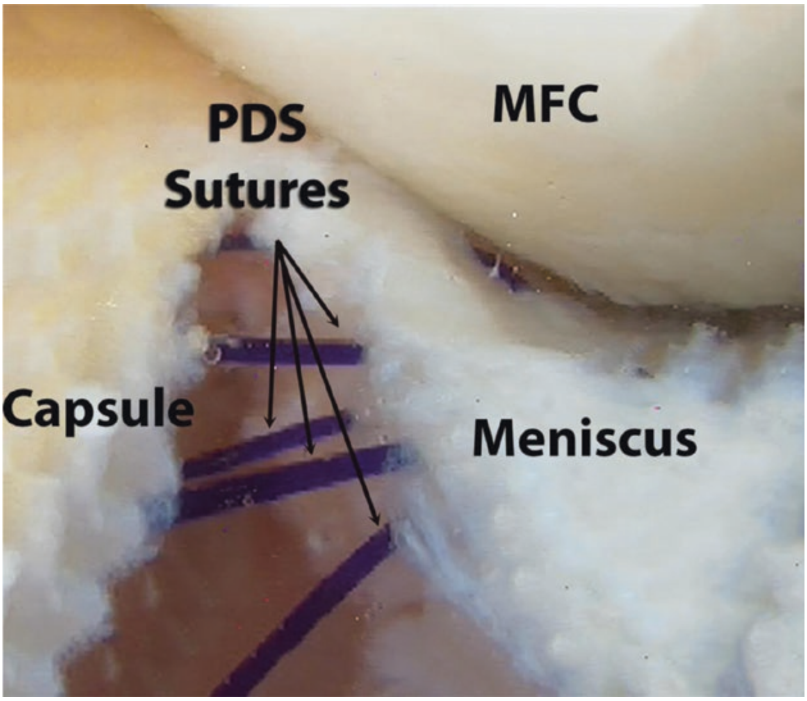


Fig. 7.8 Arthroscopic view of an anterior horn of a medial meniscus demonstrating PDS sutures penetrating the capsule and the meniscus in a horizontal mattress configuration to repair the tear

desired depth limit of the meniscus. The tip of the probe should be placed at the meniscosynovial junction and used to measure the width of the meniscus at the desired entry point for the delivery needle. Usually a depth of 14 mm is adequate. Next, the depth penetration limiter is adjusted to the desired length. After preparation and debridement of the stumps, the all-inside device is inserted into the joint through the corresponding portal. It is important to dilate the portal to allow for easier passage of the delivery needle into the joint. Lateral meniscal tears can be approached using the anterolateral portal as a viewing portal and the anteromedial portal for the delivery needle and vice versa for medial meniscal tears. An arthroscopic rasp should be used in the meniscal tear area to stimulate healing before the sutures are placed. When attempting a vertical mattress suture repair, place the first implant on the superior side of the meniscal tear. Once the needle has been inserted, the tip should be rotated away from the neurovascular structures. The device can now be deployed using the deployment slider on the handle. Complete release of the deployment slider and slowly withdrawing the needle out of the meniscus can prevent intra-articular migration of the device. Next, the entry point for the second implant is defined at least 5 mm away from the tear site. The delivery needle is again advanced until the depth penetration limiter contacts the surface of the meniscus and the second device is deployed in a similar manner. Finally, the delivery needle is removed from the knee, pulling the free end of the suture out of the joint. The free end of the suture is pulled to advance the sliding knot and reduce the meniscal tear. Slight tension should be applied to the suture until the knot is secured.

7.5 Outcomes

Meniscectomy and partial meniscectomy are associated with increased risk of osteoarthritis, likely due to joint loading changes associated with these procedures [27, 51, 80, 84]. It is inherent that preserving the meniscus restores the joint congruity and loading, thus, preventing the development of osteoarthritis. Different techniques for repair have been described (all-inside, inside-out, outside-in, and trephination) for peripheral tears that allow for preservation of the meniscus. Repair of the meniscus improves clinical outcomes of pain, catching, and knee function using Tegner and Lysholm scores. Mean Lysholm scores and Tegner scores for all-inside techniques are reported to be 90 and 6 respectively, while for the inside-out technique, they are 88 and 5 respectively. When comparing the all-inside technique with the inside-out technique, no significant differences in clinical or anatomic failure rates (clinical failure, 11 % vs. 10 %, respectively; anatomic failure, 13 % vs. 16 %, respectively) were found [29]. Complication rates are 4.6 % for all-inside vs. 5.1 % for inside-out [29]. The clinical healing rates for red-white zone repairs are reported to be 83 %. Patient age, gender, chronicity, compartment involved (medial vs. lateral), and concurrent ACL reconstruction do not influence healing rates [8].

Peripheral meniscal lesions in the red-red zone have inherently good healing rates because of the blood supply. Lateral meniscus lesions of <10 mm in length and not extending > 1 cm anterior to the popliteus can be left in situ during ACL reconstructions [22, 32, 66].

Unfortunately, most studies on healing rates, and those comparing the different techniques, are of low level of evidence. The chondroprotective effect of meniscal repairs and the role of biologics as adjuncts to meniscal repairs need to be evaluated further.

It is well established that meniscal repair in the setting of anterior cruciate ligament reconstruction results in better healing than meniscal repair alone [61, 81, 83]. Several studies have looked at the effects of augmenting meniscal healing after meniscal repair. Although some laboratory studies have been promising, clinical outcomes are still lacking. Biologic factors such as fibrin clot, platelet-rich plasma (PRP), and growth factors have been studied, and their application to meniscal repair has been evaluated. PRP has been reported to enhance meniscal tissue regeneration in vitro and in vivo, as noted in mRNA expression of extracellular matrix proteins compared with meniscal cells without PRP [42]. However, Griffin et al. [39] reported no difference in reoperation rates between patients with meniscal repair with or without PRP augmentation.

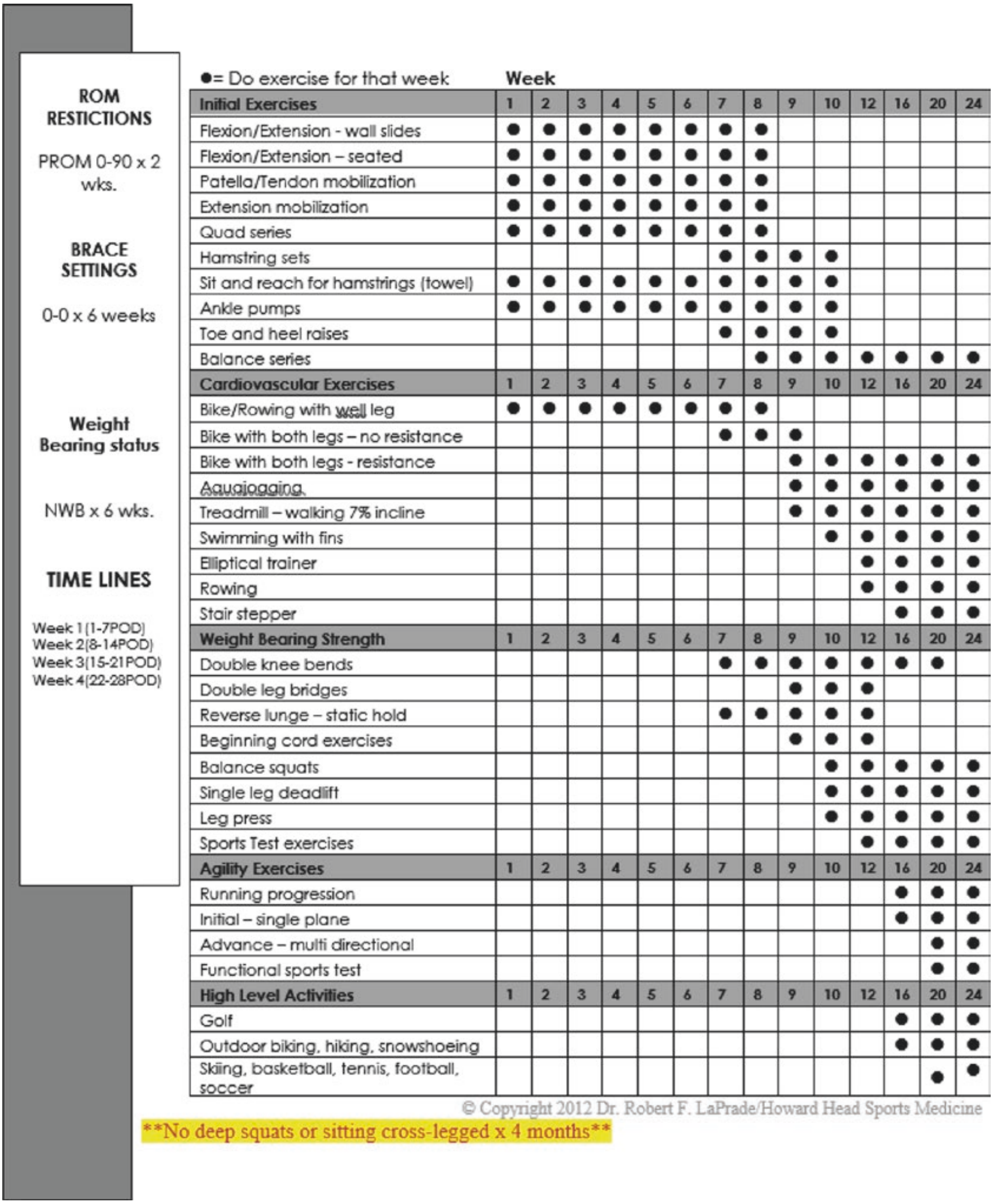
Trephination is reported to improve healing in goat models and in clinical practice [34]. There are no controlled clinical studies evaluating the use of biologics in augmenting peripheral meniscal healing. Some promising results are reported for the use of fibrin clot on radial tear.

7.6 Rehabilitation

Patients with an isolated meniscal tear remain non-weightbearing for 6 weeks. A recent systematic review of different rehabilitation protocols concluded that outcomes after restricted weightbearing protocols and accelerated rehabilitation (immediate weightbearing) yielded similar good to excellent results; however, there was lack of similar objective criteria, and consistency among surgical techniques and existing studies makes direct comparison difficult [78]. Meniscal repairs benefit from early range of motion (ROM) that is limited to the initial 2 weeks postoperatively. This early mobility facilitates postsurgical joint effusion resolution, normal range of motion restoration, and reduction of the scar formation. Passive ROM is completed with the patient in the supine or seated position. Passive ROM is limited to 0–90° during the first 2 weeks and then progresses to full range of motion as tolerated by the patient. Isolated hamstring contraction is performed in the first 6 weeks post-surgery to reduce meniscal stress through posterior tibial translation. Hyperextension of the tibiofemoral joint should be avoided at least for the first 4 weeks in order to prevent stress on the meniscal repair. After this initial period of restriction, restoration of symmetrical extension is encouraged for optimal tibiofemoral biomechanics. After 6 weeks, if joint conditions and clinical examination deem appropriate, a progressive, weightbearing program is initiated. Also at this time, patients may begin the use of a stationary bike with low-resistance settings, and ¼ body weight leg presses to a maximum of 70° of knee flexion. Starting 12 weeks postoperatively, additional increases in low-impact knee exercises may be permitted as tolerated. Patients are recommended to avoid deep squatting, sitting cross-legged, or performing any heavy lifting or squatting activities for a minimum of 4 months following surgery (Fig. 7.9).

Conclusion

Meniscal tears constitute one of the most frequent pathologies in sports medicine. Due to the increasing understanding of its function and knee physiology, preservation of this tissue should be attempted in every case. A high index of suspicion is necessary at times to accurately diagnose some of these lesions, while meniscal tears are often evident in the physical exam and on imaging. Several techniques have been described with good to excellent reported outcomes. Determination of which technique to use depends on the anatomic meniscal region, the surgeon’s preference, and experience on each device. A robust rehabilitation protocol is mandatory to achieve the best results.



ROM RESTICTIONS

PROM 0-90 x 2 wks.

BRACE SETTINGS

0-0 x 6 weeks

Weight Bearing status

NWB x 6 wks.

TIME LINES

Week 1 (1-7POD)
Week 2(8-14POD)
Week 3(15-21POD)
Week 4(22-28POD)

●= Do exercise for that week **Week**

Initial Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Flexion/Extension - wall slides	●	●	●	●	●	●	●	●						
Flexion/Extension – seated	●	●	●	●	●	●	●	●						
Patella/Tendon mobilization	●	●	●	●	●	●	●	●						
Extension mobilization	●	●	●	●	●	●	●	●						
Quad series	●	●	●	●	●	●	●	●						
Hamstring sets							●	●	●	●				
Sit and reach for hamstrings (towel)	●	●	●	●	●	●	●	●	●	●				
Ankle pumps	●	●	●	●	●	●	●	●	●	●				
Toe and heel raises							●	●	●	●				
Balance series								●	●	●	●	●	●	●
Cardiovascular Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Bike/Rowing with well leg	●	●	●	●	●	●	●	●						
Bike with both legs – no resistance							●	●	●					
Bike with both legs - resistance									●	●	●	●	●	●
Aquajogging									●	●	●	●	●	●
Treadmill – walking 7% incline									●	●	●	●	●	●
Swimming with fins										●	●	●	●	●
Elliptical trainer											●	●	●	●
Rowing											●	●	●	●
Stair stepper												●	●	●
Weight Bearing Strength	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Double knee bends							●	●	●	●	●	●	●	
Double leg bridges									●	●	●			
Reverse lunge – static hold							●	●	●	●	●			
Beginning cord exercises									●	●	●			
Balance squats										●	●	●	●	●
Single leg deadlift										●	●	●	●	●
Leg press										●	●	●	●	●
Sports Test exercises											●	●	●	●
Agility Exercises	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Running progression												●	●	●
Initial – single plane												●	●	●
Advance – multi directional													●	●
Functional sports test													●	●
High Level Activities	1	2	3	4	5	6	7	8	9	10	12	16	20	24
Golf												●	●	●
Outdoor biking, hiking, snowshoeing												●	●	●
Skiing, basketball, tennis, football, soccer													●	●

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No deep squats or sitting cross-legged x 4 months

Fig. 7.9 Standard rehabilitation protocol sheet demonstrating suggested activities and progression during the rehabilitation phase

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8

Radial Meniscal Tears: Updates on Repair Techniques and Outcomes

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and Jeffrey A. Macalena

Contents

8.1 Introduction

Radial tears of the meniscus are oriented perpendicular to the circumferential fibers and appear in a vertical orientation, which extend from the inner edge of the meniscus toward the periphery. This chapter will discuss the diagnosis, biomechanics, treatment, and clinical outcomes of radial meniscal tears.

Radial tears are classified as partial or complete (Fig. 8.1) based on the depth of the tear. Complete tears disrupt the circumferential fibers located at the periphery of the meniscus, impairing the meniscal ability to transmit circumferential hoop stresses during load bearing and shock absorption. Variability exists in the depth of radial tears, where depth refers to the perpendicular meniscal length extending from the central white-white zone through to the periphery. A small radial tear involving less than 60 % of the depth of the meniscus does not significantly influence tibiofemoral biomechanics, whereas a large radial tear that extends greater than 90 % of the depth of the meniscus to the periphery results in a significant alteration in peak compartment pressures [1]. Additionally, larger partial radial tears increase the risk of progression to complete tears [2]. Radial tears that have greater involvement of the periphery can result in increased joint contact stress, meniscal extrusion, meniscal root pathology, osteoarthritis, and long-term cartilage damage [3–5]. Consequently, radial tears left

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_8

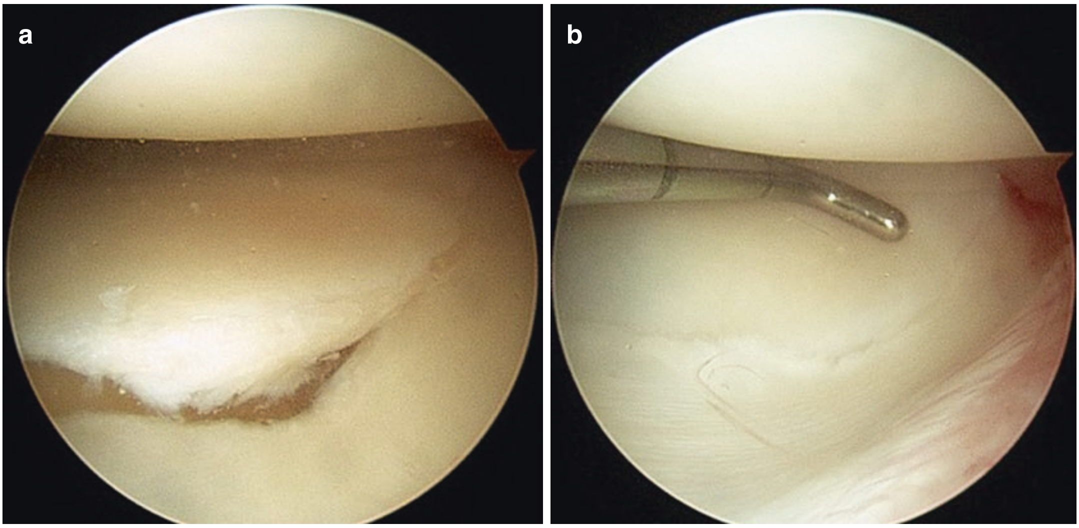

Fig. 8.1 Arthroscopic images of the left knee lateral meniscus demonstrating (**a**) partial and (**b**) complete radial tears at the junction of the anterior horn and body

untreated can have a profound biomechanical detrimental effect on knee health, greater than longitudinal (vertical) tears.

The incidence of radial tears has been reported to be 14–15 % of all meniscus tears, with the majority involving the junction of the middle and posterior third of the medial and lateral menisci [6, 7]. Radial meniscus tears are also commonly identified in the lateral meniscus after an acute rupture of the anterior cruciate ligament (ACL).

8.2 Diagnosis

Radial tears of the meniscus do not have specific history or physical examination findings; therefore, MRI has become useful for qualifying the type of meniscus tear. Radial tears present unique challenges and entail special consideration; correct preoperative characterization of radial tears can allow better operative planning and preoperative patient counseling. MRI has demonstrated high sensitivity in the detection of meniscus tears; however, identification of the tear as "radial" in orientation has been less reliable [6]. Classically, four signs have been described to detect and characterize radial tears [6].

1. *Truncated triangle sign* describes the amputated edge on sagittal and coronal images if the tear parallels the image orientation (Fig. 8.2).
2. *Cleft sign* simply describes a gap of the meniscus on sagittal and coronal images (Fig. 8.3).
3. *Marching cleft sign* is observed with obliquely oriented tears, typically occurring at the junction of the anterior horn and body. It is demonstrated with a migrating cleft on consecutive images.
4. *Ghost meniscus sign* refers to the complete absence of meniscal tissue that results with diastasis of the radial tear (Fig. 8.4).

Typically, a truncated triangle sign represents a shearing of the free edge, with preservation of its peripheral portion, often as a result of a partial radial tear. In contrast, a ghost meniscus has no in-plane residual normal meniscus signal, often as a result of a full-thickness tear. The two most reliable signs have been the cleft and truncated

Fig. 8.2 Truncated triangle sign revealing a radial tear of the left knee lateral meniscus

Fig. 8.3 Cleft sign of the left knee lateral meniscus indicating a radial tear

triangle signs, with the use of these two signs increasing MR detection identification rates of radial tears to 76 % [6]. The use of all four signs increases the rate of detection for radial tears to 89 % [6].

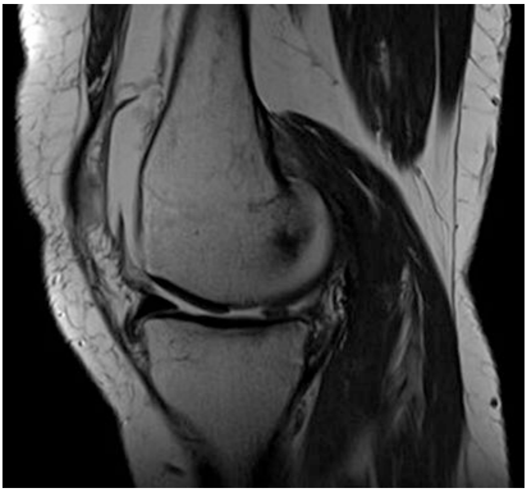

Fig. 8.4 Sagittal MRI with the absence of the posterior horn of the medial meniscus, demonstrating a ghost sign indicative of a radial tear

8.3 Treatment

8.3.1 Nonoperative Treatment of Radial Tears

Nonoperative treatment may be considered for asymptomatic partial radial tears, often found incidentally when other structures of the knee have been injured.

Radial tears, including those extending into the vascular zone (outer one third of the meniscus), have shown low rates of spontaneous healing and often progress to complete tears [8, 9]. This is in contrast to vertical longitudinal tears, which have an increased potential for spontaneous healing, thought to be due to the creation of a vascular channel to the inner avascular portion of the meniscus. Nonoperative management can be considered for symptom management of radial tears, which can include rest, activity modification, and use of anti-inflammatory modalities or corticosteroid injections. This may have a positive effect on symptom reduction, with no evidence of healing of the meniscus tear.

8.3.2 Partial Meniscectomy of Radial Tears

Previously, radial tears were regarded as unrepairable and were managed with partial meniscectomy, with the goal of reducing mechanical symptoms in a straightforward manner [10]. In most circumstances, partial radial tears located in the central, avascular zone can be debrided to a stable edge, working to preserve as much native tissue as possible and attempting to decrease the chance of tear extension into a deeper zone (Fig. 8.5). The extent of meniscal debridement, however, should never extend beyond the original depth of the tear.

Meniscectomy to reach a stable edge has been shown to reduce joint surface contact area by 75 % and increase compartment peak load contact stresses by more than 350 %. As little as 20 % of meniscal debridement has been shown to increase tibiofemoral contact forces [11]. Despite the benefits of short-term pain relief, partial meniscectomy has been associated with a

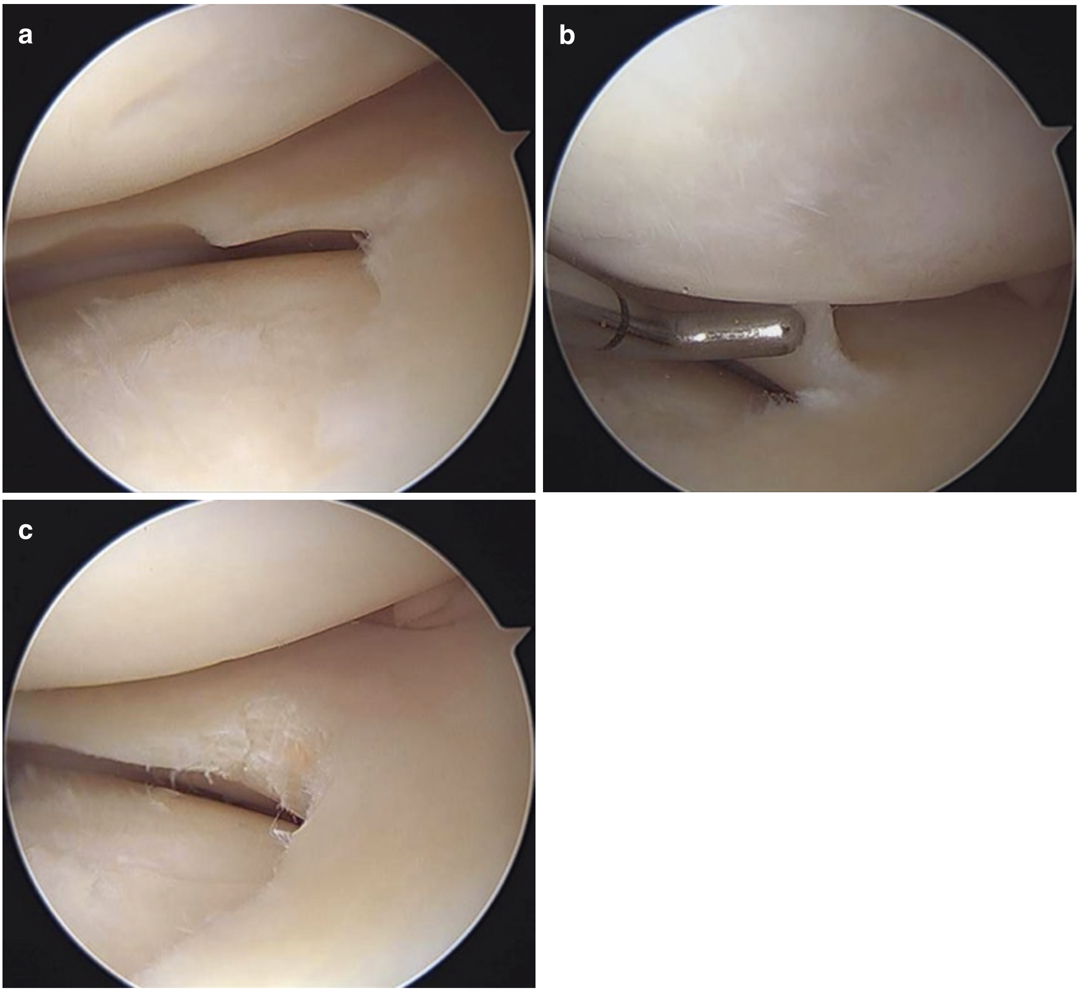

Fig. 8.5 Arthroscopic images of the left knee lateral meniscus demonstrating (**a**, **b**) partial radial tear (**c**) following debridement to a stable edge

substantially increased incidence of progressive degenerative changes [12].

Currently, there is limited evidence to detail the length of a partial tear that may progress to a deeper tear. Moreover, evidence-based criteria in guiding surgical treatment based on the depth of the tear are lacking. With the increasing concern of long-term osteoarthritis after meniscectomy and the risk of progression to complete tears, meniscal preservation with repair of radial tears should be considered.

8.3.3 Repair of Meniscal Radial Tears

The goal of repairing radial tears, regardless of technique, is restoring the circumferential meniscal fibers that work to resist hoop stresses, vital to its role in load transmission and energy absorption. Recently, a variety of radial tear repair techniques have emerged as viable alternatives to meniscectomy [13–17]. These modern repair techniques aim to improve patient outcomes and diminish long-term degenerative damage from loss of this chondroprotective structure.

Generally, two techniques have been described for arthroscopic repair: all-inside horizontal mattress repair or inside-out repair with single, double, or crossed horizontal mattress sutures. Both inside-out horizontal mattress repairs and in situ pull-out suture repairs have been reported to decrease tibiofemoral contact pressures and increase contact area [1, 18].

8.3.3.1 Inside-Out Meniscal Radial Repair Technique

The inside-out technique remains the standard for repair of radial meniscus tears. The current technique involves a double horizontal suture technique with parallel sutures 5 mm and 10 mm from the meniscal rim [15, 19–21]. The sutures are shuttled across the radial tear via a cannula, using a suture-passing device and tying horizontal mattress sutures above and below the radial tear (Fig. 8.6). This technique requires an additional incision for retrieval of the sutures. The inside-out technique allows the surgeon more control in tensioning the sutures; however, it is technically more challenging and may require additional personnel to retrieve sutures while protecting the surrounding neurovascular structures [15, 19, 20].

Furthermore, Bedi et al. [22] reported that inside-out double horizontal suture repair of a radial tear involving 90 % of the depth does not restore the location of the pressure peak to that of the intact knee. It was hypothesized that this was due to the horizontal sutures being orientated parallel with the circumferential meniscal fibers which are important for transmitting hoop stresses. In response, Matsubara et al. developed a cross-suture technique in which two stitches cross over each other at the site of the meniscal tear [21]. Theoretically, this allows for capturing a greater portion of the circumferential fibers because the direction of the sutures is oblique to, rather than parallel to, the fibers. The authors found this provided superior stiffness and a greater ultimate load to failure when biomechanically tested [21]. Although some authors have reported favorable healing rates of the peripheral meniscus with these techniques [15], other authors have reported an unacceptably low rate of meniscal healing, particularly when the tear location is in the central, white-white zone of the meniscus [23].

To decrease the need for further surgery, Haklar et al. [20] recommended performing a partial meniscectomy of the white-white portion of the meniscus while simultaneously performing a double inside-out horizontal mattress repair of radial midbody meniscal tears. Although they reported a high healing rate, which is favorable, the potential for a partial meniscectomy to lead to a detrimental effect over time on the articular cartilage persists.

Recent focus has moved toward improved stability of meniscal repairs and anatomically restoring the meniscus to its proper position. New techniques have been developed to augment horizontal suture repair constructs with transosseous tunnels [13, 24]. Biomechanical analysis by Bhatia et al. [24] demonstrated significantly less meniscal gapping and stronger ultimate failure loads, when compared to the classic double

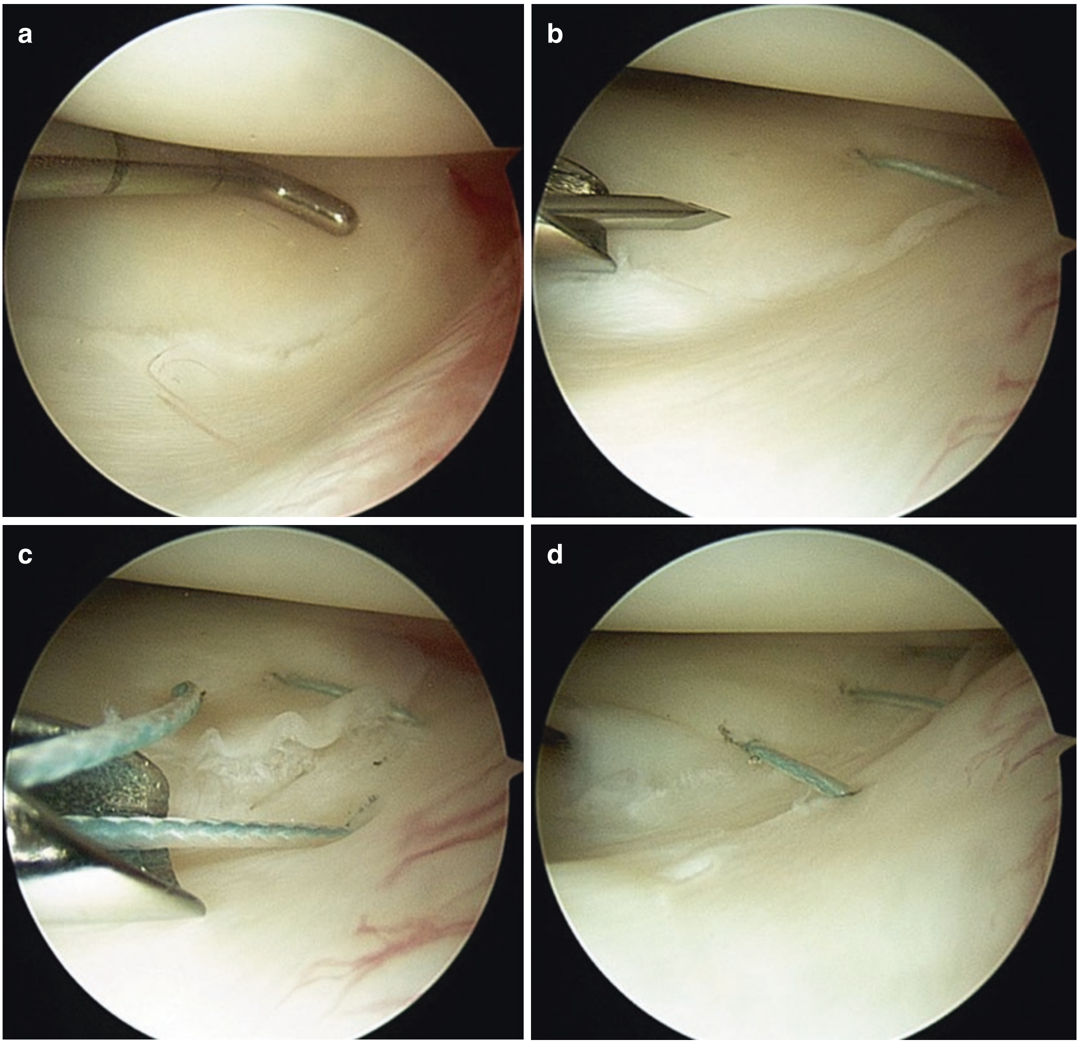

Fig. 8.6 Arthroscopic images of the left knee demonstrating an inside-out lateral meniscus repair. (**a**) Complete radial tear at the junction of the anterior horn and body. (**b**) Sutures are shuttled across the radial tear via a cannula, (**c**) using a suture-passing device and (**d**) tying horizontal mattress sutures above and below the radial tear

horizontal mattress technique. After each radial tear edge is released, one or two tunnels are placed at the meniscocapsular region of the tibia. Each torn edge of the meniscus is sutured superoinferiorly at the posterior corner of the tear edge, and sutures are shuttled through transtibial tunnels. The sutures can then be tied together over a button while directly visualizing the radial tear to ensure an accurate reduction. Once the transosseous portion of the repair is complete, two inside-out horizontal mattress sutures are additionally placed on both the superior and inferior portion of the meniscus as described above. Importantly, this technique allows for anchoring the meniscal tissue to the proximal tibia (Fig. 8.7). Both one- and two-tunnel techniques have been described, but to date no significant difference has been observed with respect to displacement or ultimate failure load [25]. The results of current clinical outcome studies are outlined in Table 8.1.

8.3.3.2 All-Inside Radial Repairs

In an effort to eliminate the need for a separate incision, as well as decreasing personnel demands, all-inside devices have been developed. The all-inside technique uses standard

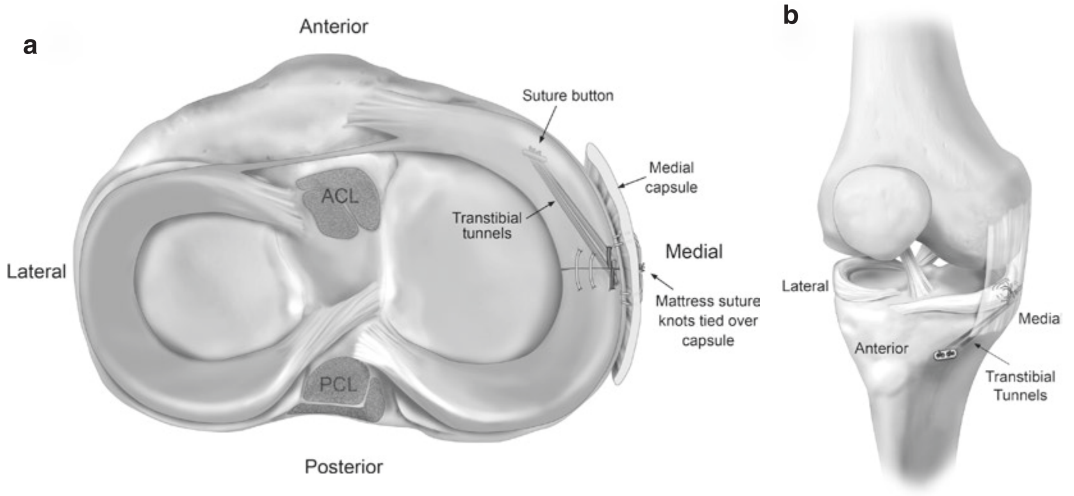

Fig. 8.7 (**a**) Superior and (**b**) anteromedial view of transtibial two-tunnel repair of a meniscal radial tear illustrating the crisscross transtibial tunnel technique in a left knee. Sutures were passed through an anterior and posterior tibial tunnel to the anteromedial cortex and tied together over a button. ACL, anterior cruciate ligament; PCL, posterior cruciate ligament [24]

Table 8.1 Studies with a minimum 2-year follow-up reporting radial tear inside-out meniscal repair techniques and outcomes

Study	Level of evidence	Number of patients	Mean follow-up, mo	Mean age, yr	Operative technique	Concurrent procedures	Outcomes reported
Anderson et al. [19]	IV	8	70.5	29	Inside-out sutures	ACL reconstruction (8/8)	Lysholm, IKDC, Tegner
Haklar et al. [20]	IV	5	31	28.6	Inside-out double horizontal sutures	None	Lysholm, MRI
Ra et al. [15]	IV	12	12	–	Inside-out with fibrin clots	ACL reconstruction (2/12)	Lysholm, Tegner, second-look arthroscopy

mo months, *yr* year

anteromedial and anterolateral portals for suture placement [15, 16, 23, 26]. This technique has been reported to be less technically challenging; however, proper tensioning and securing the sutures arthroscopically can be more challenging when compared with using an open posterior incision.

There are several all-inside meniscus repair devices. Most commonly, these devices deliver an anchor containing self-adjusting sutures across the tear. Two passes of an insertion needle on either side of the tear place an anchor in the extra-articular recess behind the meniscus on the capsular surface. Sutures spanning the tear are tensioned, and a self-locking knot is tightened to close the gap in the meniscus. Likewise, fixation is possible without the use of anchor devices. Systems have been designed to deliver a needle through the meniscus tear to capture a suture loop from the instrument's tip, which can then be tensioned and tied to compress the meniscus repair site.

Although less invasive than inside-out techniques, the all-inside repair techniques are not without potential complications. In addition to neurovascular injury, irritation from the anchors and implant failure have been reported [27]. Furthermore, follow-up studies with MRI and second-look arthroscopy have demonstrated high rates of no healing or partial healing following all-inside radial tear repair [23, 28].

Currently, most all-inside devices work to place the suture horizontally in a fashion similar to that of an inside-out repair. All-inside horizontal sutures, however, fail to fully encircle the tear at the periphery. Additionally, horizontal sutures are oriented parallel to the longitudinal fibers of the meniscus, leading to suture cleavage through the meniscal tissue. As such, new techniques and all-inside devices have been developed to incorporate both vertical and horizontally oriented sutures, effectively encircling the meniscal fibers. A recent biomechanical study demonstrated the combined vertical and horizontal suture configuration resulted in lower displacement, higher load to failure, and greater stiffness compared with the classic horizontal inside-out technique [29]. The vertical loop tended to fail by suture breakage, while the horizontal loop failed when it tore through the tissues [29]. Vertical suture techniques have been described, but further literature support is needed.

A summary of clinical outcomes of all-inside techniques is summarized in Table 8.2.

8.4 Postoperative Rehabilitation Protocol

Previously, strict non-weight-bearing rehabilitation was instituted after repair of complete radial tears to reduce the potential for tear diastasis. Weight bearing increases hoop stresses, thus placing distraction forces on the repair, separating the tear margins, and preventing healing. Recently, some authors have chosen to allow partial weight bearing postoperatively and have reportedly demonstrated equivalent healing rates [30]. Further investigation of postoperative rehabilitation protocols is warranted.

8.5 Outcomes of Radial Tear Repairs

Overall, the current level of evidence on clinical outcomes after meniscal radial tear repairs is scarce [31]. Outcomes are typically reported as failure due to subsequent reoperation and meniscectomy. Patient-reported outcome tools are varied and include Lysholm, IKDC, and Tegner scores. A recent systematic review of six level IV studies demonstrated that surgical repair of meniscal radial tears led to improved patient outcomes in most patients at an average follow-up of 38.4 months [31]. They reported two general categories of radial repair techniques: an inside-out suture technique and an all-inside suture technique. Similar to repair of other meniscus tear patterns, outcomes after inside-out suture

Table 8.2 Studies with a minimum 2-year follow-up reporting radial tear all-inside meniscal repair techniques and outcomes

Study	Level of evidence	Number of patients	Mean follow up, mo	Mean age, yr	Operative technique	Concurrent procedures	Outcomes reported
Choi et al. [23]	IV	14	36.3	29.9	All-inside with absorbable sutures	None	Lysholm, Tegner, MRI, second-look arthroscopy
Song et al. [16]	IV	15	24	34	All-inside FAST-FIX repair system	ACL reconstruction (15/15)	Lysholm, Tegner, MRI, second look arthroscopy

repair (Lysholm, 86.9–94.2; IKDC, 81.6–92) were comparable to all-inside repair (Lysholm, 94–95.6; IKDC, 90). Literature comparing the effectiveness and complications of the inside-out repair technique and the all-inside technique in isolated meniscal tears has consistently demonstrated no differences in clinical failure rate or subjective outcomes [27]. Clinical failure rate in isolated meniscal tears of all types has been cited between 17 and 19 % [27]. More nerve symptoms have been associated with the inside-out technique while more implant-related complications are associated with the all-inside technique. Unfortunately, much of the literature does not isolate radial tear repairs from other tear patterns. Additionally, most studies are confounded by concomitant ACL injury and/or reconstruction. Hence, the outcomes of radial tear treatment have a paucity of published results.

8.6 Conclusions/Future Directions

Meniscal preservation with repair of radial tears results in improved short-term clinical outcomes; however, long-term outcomes remain unknown. Significant differences between repair and partial meniscectomy may only occur in long-term (10+ years) follow-up, as prior studies have reported worse long-term outcomes for partial meniscectomy compared with short-term results [32, 33]. At this time, no supported conclusions can be made about the long-term effects of meniscal repair and preservation of its chondroprotective function; however, we do know that resected or ignored meniscal tears do poorly [3, 5, 8].

While the biomechanics, natural history, and treatment techniques of radial tears have been increasingly investigated, a paucity of long-term clinical outcomes remains. Future studies will require particular attention to defining and isolating radial tears from other tear patterns, with stratification of concomitant injuries and consistency in outcome reporting.

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All-Inside Meniscal Repair: Updates on Technique

9

Sergio Rocha Piedade, Rodrigo Pereira da Silva Nunes, Camila Cohen Kaleka, and Tulio Pereira Cardoso

Contents

9.1 Introduction

In the past, meniscectomy was described as a straightforward and efficient procedure to treat meniscal tears, presenting satisfactory results in the short term [10]. For decades, McMurray [15] and Smillie [20] agreed with the opinion that "incomplete resection of the meniscus was a very common mistake" on treating meniscal injuries. However, this concept has changed over time.

Analyzing the effects of a meniscectomy, Fairbank [8] observed that a partial meniscectomy had less progression of degenerative changes of the knee joint compared with a complete meniscal resection. Likewise, Englund and Lohmander [7] stated that the damage to the knee joint was directly related to the amount of meniscus removed.

In this background, partial meniscectomy was one of the first treatments proposed, in the literature, to minimize the effect of meniscal tissue loss and its effect on degenerative changes in the knee joint (Fig. 9.1).

The first meniscal suture was performed in 1883 by Tomas Annandale [2], while Hiroshi Ikeuchi [11] performed the first arthroscopic meniscal suture in 1969. However, the benefits of an open meniscal repair were demonstrated only at the end of the 1970s and the early 1980s [6].

However, meniscal resection is more commonly performed than meniscal repair; the literature has identified that the vast majority of knee

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The original version of this chapter was revised. An erratum to this chapter can be found at DOI 10.1007/978-3-662-53792-3_18

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_9

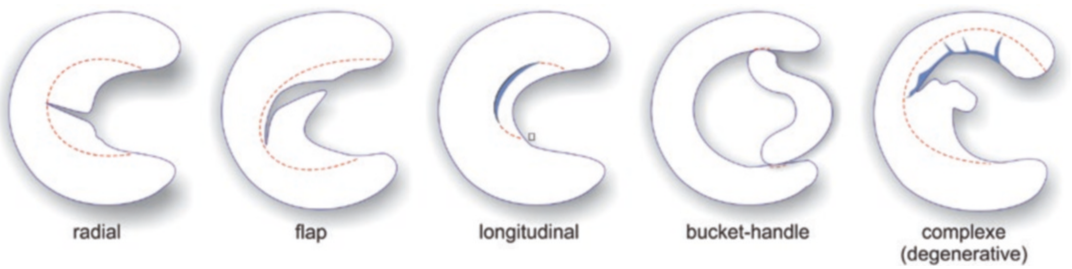

Fig. 9.1 Examples of partial meniscectomy proposed for specific meniscal tears

surgeons are adopting the concept of preserving the meniscus. Some authors have reported that the numbers of meniscal suture repairs are increasing, while the number of meniscectomies is stable. [24].

9.2 Indications for Meniscal Repair

The blood supply of the meniscus tissues is not uniform, and therefore, this influences the process of meniscal healing. Therefore, tears closer to the meniscosynovial junction of the meniscus have a higher potential to heal, while central tears in the white-white zone have a lower capacity to heal.

Several factors have a direct influence on the decision to repair a meniscal tear, such as tear location, tear type, the size of a meniscal tear, the quality of meniscal tissue, and its configuration and stability. Moreover, in clinical practice, the patient's expectations, their physical demands, or even their professional issues should be taken into account to decide the therapeutic approach.

9.3 Placement of Meniscal Sutures

The orientation of meniscal sutures has important implications for the quality of the meniscal repair [23]. Biomechanical analysis of various meniscal repair techniques has consistently demonstrated that vertical mattress sutures resist the highest tensile loads to failure, suggesting that the circumferential orientation of the collagen fibers is better captured by the repair and is the gold standard technique for meniscal repairs [4, 13].

9.4 Meniscal Repair Technique

Different meniscal suture repair techniques have been described, such as outside-in, inside-out, and all-inside. In clinical practice, the outside-in technique is not the first choice, but it is still remembered as part of the technical possibilities, particularly for cases of anterior horn and body meniscal tears.

Although the inside-out technique remains the gold standard, it is not free of complications, with potential complications, such as stiffness, pain, and neurovascular complications. Moreover, a possibly increased operative time and an additional incision present a minor limiting factor, particularly when an associated ligament tear is concomitantly reconstructed.

In this context, the all-inside technique can be more attractive to some knee surgeons, especially those with a less knowledgeable surgical team [12, 17].

9.5 All-Inside Meniscal Repair Technique

In 1991, Morgan [16] published on the all-inside meniscus repair. The all-inside technique allowed for an easy insertion and decreased the surgical time. Aros et al. [3] reported that the newest generation of meniscal repairs associated the best features of this technique with improved biomechanical properties. The all-inside arthroscopic technique involves a gamut of devices such as arrows, darts, and other devices designed to hold the meniscal fragments together while potential healing occurs (Figs. 9.2 and 9.3). They provide the possibility of applying sutures in different meniscal tears according to the pattern of meniscal tear such as horizontal, vertical, oblique, or longitudinal tears.

Most of this increasing popularity is related to the possibility to perform a meniscal repair with no additional skin incision [19]. The fourth generation of meniscal tears suture devices is self-adjusting suture devices. In this context, the RapidLoc (DePuy Mitek, Raynham, MA) and the FasT-Fix (Smith & Nephew, Andover, MA) represent this category of meniscal repair devices. With technological advances in repair devices, some studies in recent years have reported equivalent biomechanical properties and success rates to those of the traditional gold standard inside-out suture technique [17]. However, as well as any other surgical procedures, there exist some points that the knee surgeon should keep in mind when repairing meniscal tears with all-inside repair devices.

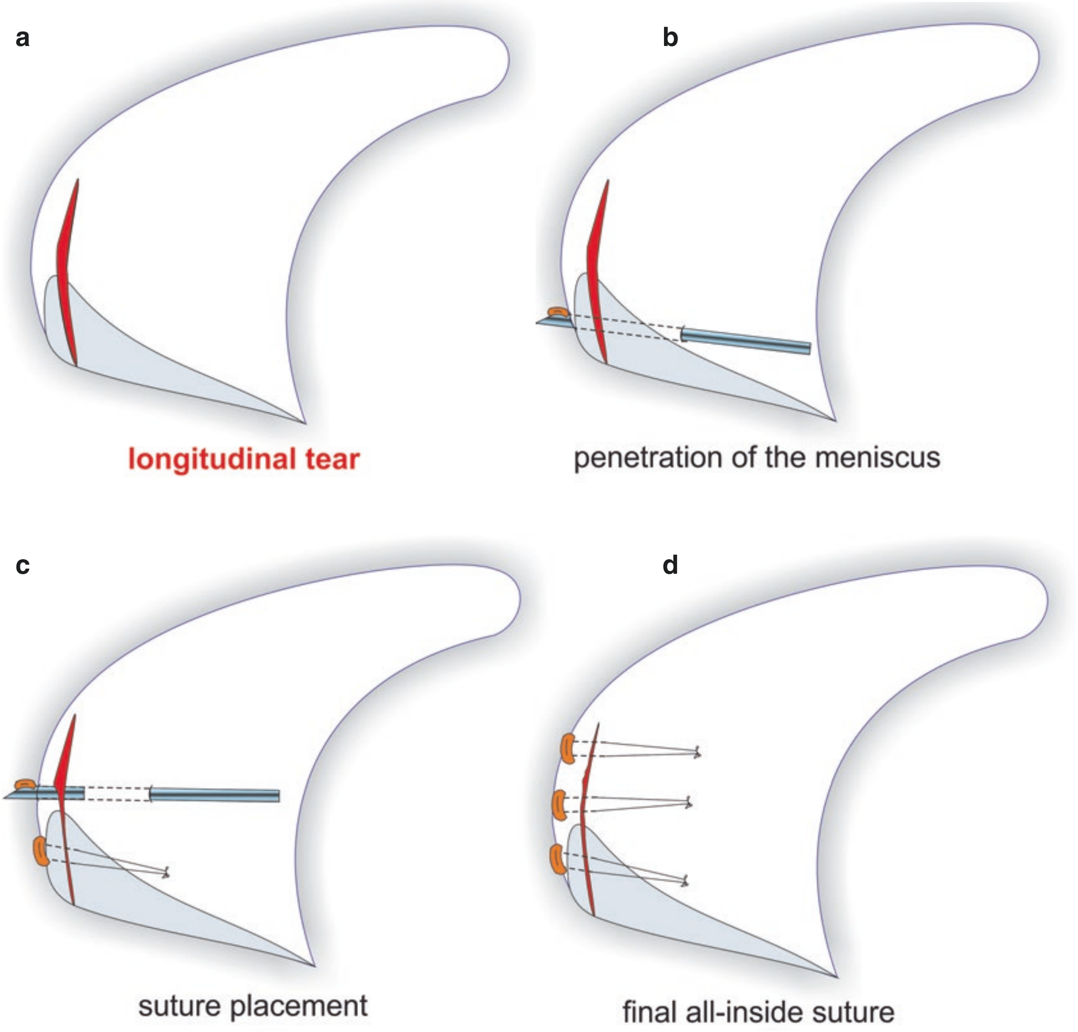

Fig. 9.2 Diagram of a longitudinal meniscal tear (**a**) repaired by using the self-adjusting suture device: meniscus penetration (**b**), suture placement (**c**), and the final suture: 3 points (**d**)

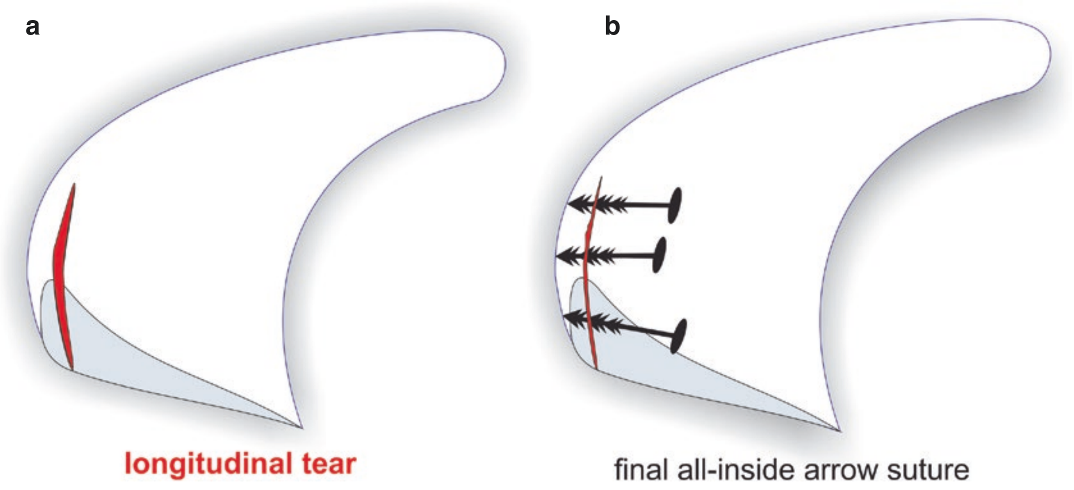

Fig. 9.3 Diagram of a longitudinal meniscal tear (**a**) repaired by using three-point arrow device (**b**)

9.5.1 Anatomical Considerations on All-Inside Meniscal Repair

The lateral meniscus has some particularities that should be carefully evaluated when approaching this anatomical site, even with recent technological advances that have made all-inside repair devices safer with the stopping mechanism to prevent neurovascular injury.

Regarding the anatomical proximity of the lateral meniscus to the neurovascular structures, Abouheif et al. [1] analyzed, in a cadaveric model, the depth of the FasT-Fix meniscal suture regarding the posterior aspect of the lateral meniscus. The authors supported that it should avoid the use of straight needles, particularly when the lateral meniscus tears are treated more centrally by a direct lateral approach.

Another anatomical consideration is about the absence of lateral meniscus insertion on the popliteus hiatus, mainly, when a full radial meniscal tear is from the front of popliteus recess to the posterior tibial insertion site. Soejima et al. [21] support the importance on reestablishing the meniscus hoop function and advocated that the repair of this meniscal injury performed by an all-inside technique was a safe and feasible procedure.

9.5.2 Biomechanical Considerations for All-Inside Meniscal Repairs

In the literature, biomechanical studies have an important role in the development of new generations of meniscal suture devices and on analyzing different techniques of meniscal tear repairs.

Massoudi et al. [14] compared an all-inside suture-based device (NovoStich; Ceterix, Menlo Park, CA) with an all-inside anchor-based repair (FastT-Fix 360°; Smith & Nephew, Andover MA) and with the inside-out meniscal repair. The authors repaired longitudinal meniscal tears in 36 fresh-frozen porcine menisci. A biomechanical analysis reported that the all-inside suture-based repair and the inside-out repair showed a higher load to failure, while the two all-inside techniques employed showed no difference between displacement values.

9.5.3 Outcomes of All-Inside Meniscal Repairs

Moulton et al. [17] performed a systematic review evaluating the results of radial meniscal repair procedures and complications. Although the study displayed an improvement of postoperative evaluation, the authors reinforced that the long-term outcomes remain unknown. At 2-year follow-up is the period commonly adopted to evaluate the failure rate of these meniscal repairs, and it is not long enough to determine the long-term consequences of repairs versus meniscectomies. Concerning with this possibility, Nepple et al. [18] performed a systematic review approaching the results of meniscal repair at greater than five years postoperatively. The authors analyzed the data of repair type, tear location, and the status of the anterior cruciate ligament and concluded that the failure rate was comparable for all of the techniques analyzed and ligament status had no influence in the review.

Solheim et al. [22] evaluated the outcomes of meniscus repair using a suture anchor system, named RapidLoc (DePuy-Mitek, Rayham, MA, USA). A vertical longitudinal meniscal tear of 10 mm of length or greater, located in the red-red zone, was eligible to repair. At a 7-year minimum follow-up, the authors detected a rate of failure of about 50 % and stated that all-inside meniscal repair techniques similar to this one could not solve the problem in the long term.

In a prospective randomized multicenter clinical trial study, Kise et al. [12] compared the outcomes of vertical longitudinal meniscal repair using a Biofix® (arrow device) and a FasT-Fix® suture device, considering that the main endpoint of the survey was reoperation within two years. The data obtained in this study reported a 3.6 times higher risk of reoperation within 2-year follow-up for the Biofix, strongly reinforcing the use of a self-adjusting suture device (FastT-Fix®) over an arrow.

Meniscal Repairs with Concomitant Ligament Reconstruction Choi et al. [5] studied and compared the functional outcomes of the meniscal suture repair against all-inside meniscal repair devices (FasT-Fix® (Smith & Nephew Endoscopy, Andover, MA, USA)) with a concomitant hamstring anterior cruciate ligament reconstruction. The results showed satisfactory results and no difference on the meniscal signal on MRI for both techniques of meniscal repair.

Pujol et al. [19], in a retrospective study, reevaluated 41 patients who had an all-inside meniscal repair and a concomitant anterior cruciate ligament reconstruction with bone-patellar-bone graft. The authors concluded that there was a long-term protective effect of the meniscal repair against degenerative joint disease, and they emphasized that a meniscus repair should be performed whenever possible, even if there was a potential risk of partial healing failure.

Finally, in a systematic review, Fillingham et al. [9] analyzed the inside-out versus all-inside meniscal repair techniques on an isolated meniscal tear. The authors strongly emphasized that the quality of evidence was low because the vast majority of the studies were level 4 evidence. However, there was no difference in the functional outcomes, failure rates, and complications in this review.

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10

Step-By-Step Surgical Approaches for Inside-Out Meniscus Repair

Ryan D. Scully and Scott C. Faucett

Contents

10.1 Indications

The inside-out technique is the gold standard for meniscal repair. This repair technique is highly versatile and can be applied to most meniscus tear types along the middle-third and posterior horn, including those tears at the peripheral rim and capsular attachment. Inside-out repair is also favorable for large, complex, multi-planar tears because it allows for the precise placement of multiple sutures. Other applications for inside-out repair include bucket handle tears, ramp lesions, and meniscus transplants. While peripheral zone tears have an increased probability of healing potential, successful repair of tears extending into the central avascular zone using an inside-out technique has been reported. In a series of nearly 200 such central zone repairs, some of which underwent subsequent second-look arthroscopy, and 80 % were asymptomatic at a mean of 42 months postoperatively. Despite this success, second-look arthroscopy revealed

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© ISAKOS 2017
R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_10

complete healing in only 25 % of tears [1]. This paradox suggests that stabilizing the tear, regardless of ultimate healing, may be beneficial. Particularly in young, competitive athletes, we recommend repair of tears extending into the central avascular region.

10.2 Benefits

The inside-out technique offers several advantages. Sutures can be placed with great precision and versatility in either a horizontal or vertical mattress configuration. Additionally, sutures can be deployed to both the femoral and tibial surfaces of the meniscus with minimal trauma to the adjacent stable meniscus, which ultimately produces a stronger repair construct. Some surgeons routinely place up to 10–12 sutures [2]. Since the suture is secured with knots tied on the capsule, there are no prominent intra-articular knots or fixation devices; this minimizes the potential for intra-articular irritation, chondral injury, or impingement with motion and weight-bearing. Lastly, aside from suture, no implants are required which lowers the cost of this repair method.

10.3 Preoperative Planning

As with any meniscus repair, a careful review of the MRI is necessary to ensure an understanding of the tear morphology and to identify any concomitant pathology. We routinely obtain radiographs of the knee, including full-length weight-bearing views, to rule out conditions which may preclude meniscus healing and overall repair success, such as osteoarthritis or limb malalignment respectively.

10.3.1 Special Equipment

- Suture
  - Double-loaded, braided, nonabsorbable 2–0 suture.
  - Needles should be swaged (eyeless), flexible, and approximately 30 cm in length:
    - The swage lowers the profile of the suture as it passes through the tissue and limits drag, which can damage adjacent tissue.
- Cannulas
  - The cannula is used as a targeting device for suture deployment. Therefore, it is helpful to have an assortment of cannulas with varying degrees of curvature available to address tears aptly based on the tear morphology and anatomic location.
  - The cannulas can be single or double barreled to help with spacing.
  - Sharply curved cannulas can facilitate safe suture passing for posteriorly based tears as the needle is directed immediately lateral or medial after piercing the capsule, avoiding the neurovascular bundle.
  - Malleable single-use cannulas and cannula bending tools are commercially available for custom cannula creation.
- Retractors
  - Several different retractors can be used and are listed below. The retractors have a dual functionality of retracting the gastrocnemius head and receiving the needle as it passed through the capsule. A common feature of the different retractors is a concavity to catch and deflect the needle toward the assistant as it is passed through the capsule.
    - Bottom half of a vaginal speculum
    - Wedding spoon [3]
    - Henning and other commercially available popliteal retractors
- Suture passing
  - The needle can be passed through the cannula by the surgeon manually using a standard needle driver.
  - Alternatively, automated gun-type devices are available and can be used based on surgeon preference.
  - Regardless of how the suture is passed, a needle driver is required for needle retrieval posteriorly by the assistant.
- Suture management
  - If numerous sutures are planned, numbered hemostats can help maintain organization.

10.4 Positioning and Setup

For inside-out meniscus repair, it is very helpful to use a leg holder to drape the operative leg free. This allows the assistant to easily gain access to the posterior medial aspect of the leg. A thigh-high tourniquet is placed on the operative extremity to assist with visualization, and the nonoperative leg is placed in a lithotomy stirrup leg holder abducted away from the surgical field.

10.5 Repair Technique

10.5.1 Exposure

The standard anterolateral and anteromedial arthroscopy portals are created, and a full diagnostic arthroscopy is performed. Next, depending on the laterality of the meniscus being repaired, the posterolateral or posteromedial capsule must be exposed.

10.5.2 Posteromedial Approach

The following palpable landmarks should be identified: medial tibiofemoral joint line, posteromedial edge of the tibial plateau, and the adductor tubercle. The arthroscopic probe can be sounded off of the posteromedial capsule to help identify the joint line. A longitudinal incision is centered over the level of the joint line, with the adductor tubercle as the proximal extent and a point approximately 2 cm distal to the joint line over the posteromedial tibial plateau edge as the distal extent. Sharp dissection is carried through the subcutaneous fascia and sartorius fascia. A triangular space can be identified deep to the sartorial fascia. This space is bound anteriorly by the joint capsule, posteriorly by the medial head of the gastrocnemius, and inferiorly by the semimembranosus (Fig. 10.1) [2].

Using a 10 blade scalpel or Mayo-type scissors, this fascia is divided longitudinally and spread apart. A Cobb elevator and finger can be used to gently release adhesions between the gastrocnemius and posteromedial capsule. The arthroscopic probe is placed into the joint and palpated along the posteromedial joint line to confirm adequate pericapsular exposure and posterior retraction of the neurovascular bundle. With the Cobb elevator still in place posteriorly, insert the preferred retractor to retract the posterior tissues. Figure 10.2 demonstrates the plane of the retractor to protect the posterior structures.

10.5.3 Posterolateral Approach

The lateral tibiofemoral joint line, Gerdy's tubercle, and posterior border of the iliotibial (IT) band are identified. An arthroscopic probe can be used to assist with localizing the joint line. A longitudinal incision is made coursing along the posterior edge of the iliotibial band (ITB) and centered over the joint line. Sharp dissection is carried down to the level of the superficial fascia of the ITB. The posterior margin is incised in line with the wound, leaving a small cuff of tissue posteriorly for repair. The fibular head and lateral head of the gastrocnemius can be palpated. The dissection interval is between the ITB and the biceps femoris tendon. The peroneal nerve lies posterior to the biceps femoris tendon. The posterior neurovascular structures (popliteal vein, artery, and tibial nerve) lie adjacent to the lateral head of the gastrocnemius posteromedially. Blunt dissection is used to release adhesions between the lateral gastrocnemius and posterior capsule. The arthroscopic probe is used to confirm adequate pericapsular exposure (Fig. 10.3).

10.5.4 Preparing the Tear

Once the capsule has been exposed posteriorly, the tear is prepared for repair. An arthroscopic shaver is used to debride the edges and remove fraying. An arthroscopic rasp or burr can then be passed along the tear edges to freshen the tissue and parameniscal synovium to stimulate bleeding. Similarly, the surgeon can use a spinal needle to stimulate bleeding.

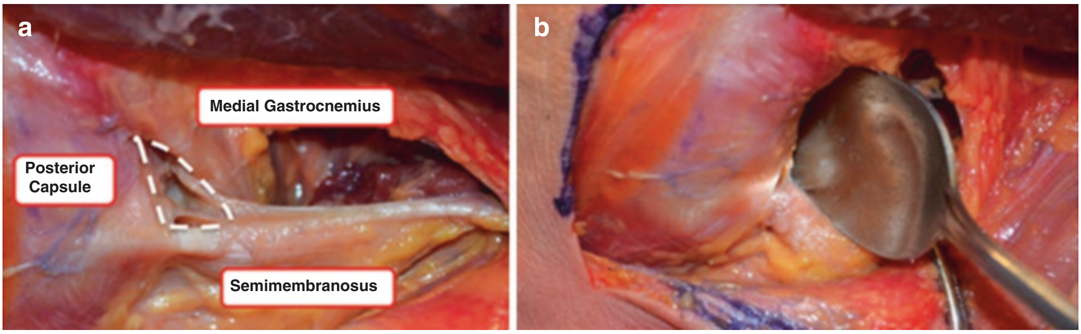

Fig. 10.1 A triangular interval can be identified in the posteromedial approach. The posterior retractor is placed in this interval (Published with permission from Ref. [2])

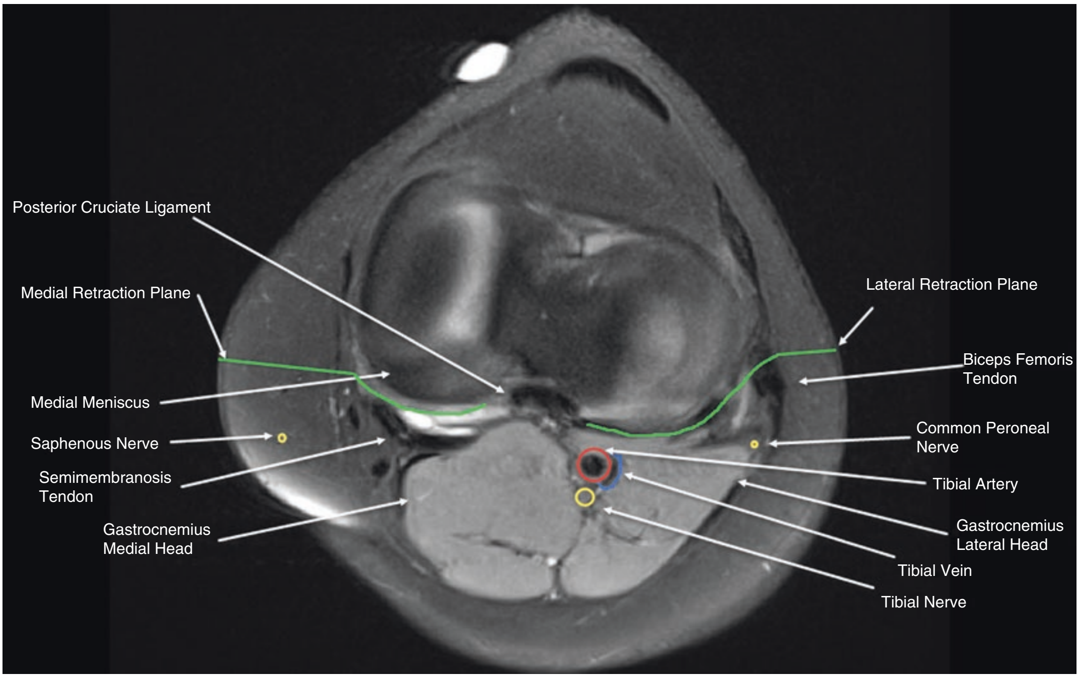

Fig. 10.2 The placement of the concave retractors is illustrated in *green* in this axial MRI image. The important neurovascular and other pertinent anatomic structures are labeled. The tibial or popliteal artery is *red*, the vein is *blue*, and the tibial nerve is marked in *yellow*. It is helpful in either the medial or lateral approach to use an arthroscopic probe to confirm that the important neurovascular structures are posterior to the retractor

10.6 Repair Principles

1. Place as many sutures as necessary to create a stable, anatomic repair. Sutures should be placed 4–5 mm apart.
2. Vertical suture orientation is more biomechanically favorable, with cadaveric and animal studies demonstrating increased stiffness and failure strength [4–6]. These findings seem to coincide with the circumferentially oriented type I collagen fibers that compose the majority of the menisci [7]. However, some tears (radial, flap) may be better suited with horizontal or oblique suture patterns.
3. The best stability and reduction is often achieved with combined, stacked superior and inferiorly placed sutures. Placing superior sutures only may evert the meniscus

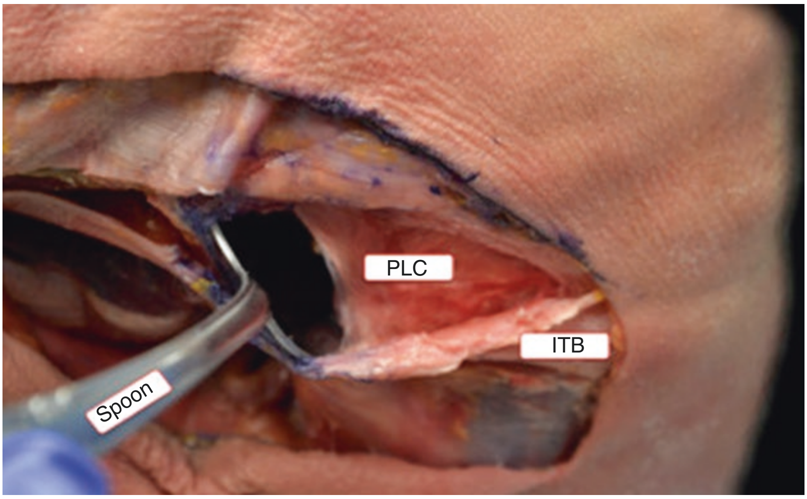

Fig. 10.3 The Iliotibial band is split along its posterior border. A space for the retractor is created by bluntly releasing adhesions between the gastrocnemius head and posterolateral corner (*PLC*) (Published with permission from Ref. [2])

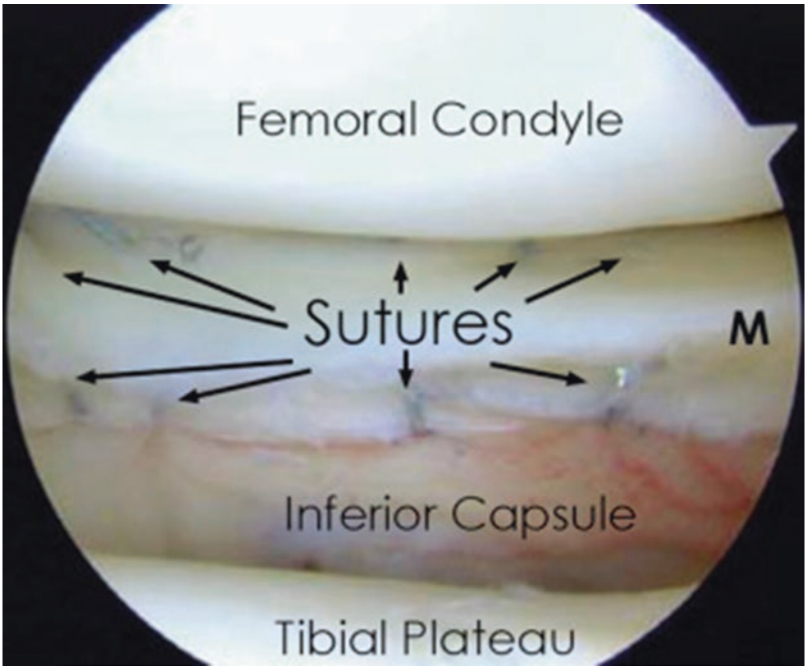

Fig. 10.4 Stacked superior and inferior sutures provide optimal strength and prevent abnormal gapping of the meniscus from unbalanced suture placement (Published with permission from Ref. [2])

and cause gapping on the tibial surface. In order to achieve a balanced repair, both superior and inferior sutures should be placed when possible. Because of the puckering effect, placing the superior suture first improves exposure of the inferior surface and is often a logical sequence for repair (Fig. 10.4).

10.7 Passing the Suture

A large spoon or the bottom half of a vaginal speculum is placed posteriorly, anterior to the (lateral or medial) gastrocnemius head to protect the neurovascular bundle. The knee is placed in 30 degrees of flexion, and the needle cannula is positioned onto the meniscus central to the tear.

Typically, the cannula is placed through the portal opposite to the side being repaired to avoid having to make a sharp turn of the needle. An assistant loads the needle into the cannula, and the suture is passed through the capsule either manually with a needle driver or using a gun-type suture shuttling device. The needle tip can be advanced through the cannula end to prevent the cannula or meniscus from slipping away as suture passing begins. This can also function as a spear and help to stabilize and reduce an unstable meniscus prior to suture passing.

Both the surgeon and assistant must coordinate their actions to ensure that the flexible needle is aimed toward the retractor as it exits the capsule posteriorly. The assistant retrieves the needle and suture from the posterior wound using a needle driver, and the needle is removed from the suture end. The second needle is loaded through the cannula and passed in similar fashion. The needles are carefully removed, the suture ends are tagged with a small clamp, and the process is repeated.

Sutures should be placed in a vertical mattress fashion on both the tibial and femoral surfaces to secure the meniscus to the peripheral capsulomeniscus tissue. Only placing sutures on the femoral side will leave a significant area of the tear unsecured.

10.8 Suture Tying

Throughout the suture passing process, the assistant is charged with suture management and preventing tangles. Once all sutures have been passed, the knee is flexed to 90°. Each suture is tied in a manner to not break the suture or pull through the soft tissue (Fig. 10.5).

10.9 Repair Assessment

After all sutures have been tied and cut, the repair is assessed by probing arthroscopically. Anatomic reduction and stability of the repair should be confirmed through visualization and careful probing.

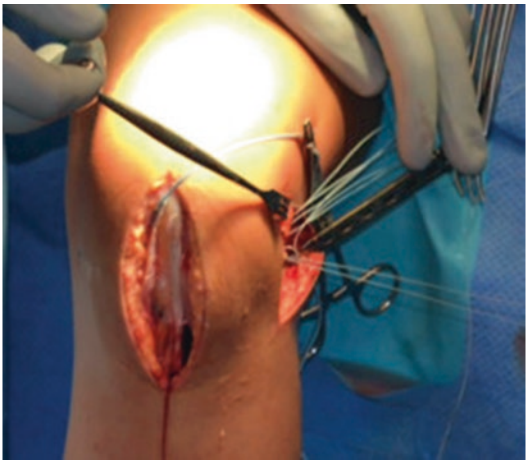

Fig. 10.5 The assistant retracts and receives the needle posterior as it is deflected out of the wound off of the retractor. When multiple sutures are placed, numbered hemostats can facilitate suture management (Published with permission from Ref. [2])

10.10 Closure

The wounds are irrigated thoroughly. On the medial side, the gastrocnemius fascia and sartorius fascia are closed independently. Laterally, the iliotibial band is closed in a running fashion.

10.11 Adjuncts

Several biologic adjuncts to meniscal repair have been investigated with limited and inconsistent efficacy. Enhanced healing has been demonstrated with the use of exogenous fibrin clots [8, 9]. We do not routinely use biologic adjuncts, including fibrin clots. However, if the meniscal repair is performed in isolation (without concurrent cruciate ligament reconstruction), we use a microfracture pick to create 3–4 awl holes in the non-articulating intercondylar notch surface of the lateral femoral condyle.

10.12 Outcomes

Although partial meniscectomy has a lower rate of reoperation, the long-term subjective and radiographic outcomes are inferior to that of meniscal repair [10]. Meniscal repair also has improved results with regard to return to sports activity [11]. Long-term retrospective studies have characterized the success of the inside-out repair. In a series of approximately 50 isolated arthroscopic meniscal repairs, Johnson et al. found the intervention to be nearly 80 % successful after an average 10 years of follow-up. A successful result was determined based on the absence of mechanical symptoms, instability, pain, degenerative joint disease, and reoperation [12]. Horibe et al. evaluated 132 inside-out meniscal repairs with second-look arthroscopy. At an average of 8 months after the initial surgery, 93 % of patients had excellent clinical outcomes (lack of pain, swelling, mechanical symptoms). On second-look arthroscopy, 74 % of the repairs had healed completely with little or no visible unhealed area. Only 9 % of repairs were found to be unhealed and with some persistent instability. Interestingly, 25 % of the patients with excellent clinical outcomes had signs of incomplete healing [13]. Other studies have acknowledged the success of inside-out meniscal repair [14–16].

10.13 Complications

The inside-out technique is safe and reliable. The most feared complication is an injury to the popliteal artery or common peroneal nerve, either of which can be devastating. While both complications have been reported, the incidence is low [17, 18]. Other complications include saphenous vein and nerve injury, inferior lateral genicular artery injury, and repair failure (persistent symptoms or re-tear). The risks of any knee arthroscopy include superficial (portal site) infection, deep infection (septic arthritis), deep vein thrombosis, painful hemarthrosis, and chondral injury.

10.14 Pearls

- Place the sutures in a stacked, femoral, and tibial suture configuration when possible.
- Only pass the needle 1–2 cm beyond the cannula. If the needle is passed more than 2 cm, it has likely deflected beyond the retractor and will put neurovascular structures at risk of injury.
- After the needle has been advanced through the meniscus and capsule, flexing the knee will make needle retrieval easier for the assistant.
- For posterior horn tears of the medial meniscus, the cannula should be passed through the anterolateral portal to allow the needle to be angled away from the neurovascular bundle.
- When passing multiple sutures, use numbered hemostats to aid in determining the location of each suture.
- When passing sutures at the midbody of the meniscus, the suture will exit very anterior in the wound and may pierce the skin. Instead of repositioning the suture, deliver it completely and remove the needle. Use a pointed hemostat to find the suture in the subcutaneous tissue and pull it retrograde into the surgical field.

10.15 Pitfalls

- Avoid making an incision too anterior because this will be difficult to retract the soft tissues.
- In the setting of cruciate ligament surgery, perform the meniscus repair prior to doing drilling cruciate tunnels as this will maintain better arthroscopic visualization and avoid suture entanglement.

Conclusion

The inside-out technique for meniscus repair is comparably inexpensive, biomechanically superior, and versatile in its ability to be applied to a variety of tear types and anatomic locations. Angled cannulas, concave popliteal retractors, an experienced assistant, and an understanding of the anatomy facilitate a successful and safe repair. Mid- and long-term results support the use of the inside-out technique for meniscal repair.

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The Role of Alignment in Meniscal Tears and the Role of Osteotomy

11

Aad Dhollander and Alan Getgood

Contents

11.1 Introduction

The meniscus has an important role of reinforcing and stabilizing the incongruity of the femur and tibia and is responsible for transmitting 40–60 % of stress to the knee when standing and 85 % when at 90 degrees flexion [1, 2]. Medial meniscus tears are more frequently reported since the medial structures are more firmly attached to the tibia, compared to the lateral meniscus which has a relatively free range of motion [3]. In a large-scale study targeting the middle aged or the elderly, a maximum of 35 % showed meniscus injury and the prevalence increased with age [2].

Meniscal tears are not always the result of trauma. Ferrer-Roca and Vilalta stated that it was of interest that only 35 % of their patients whose menisci had been removed had a history of trauma [4]. Therefore, it has been stated that other factors play an important role in the pathophysiology of meniscal tears [2, 5]. In this chapter, we focus on the role of axial alignment of the lower limb and its relationship with meniscal tears and degeneration. Furthermore, we will outline the biomechanical principles of realignment osteotomy, provide evidence for the role of osteotomy with meniscal pathology, and outline the surgical technique utilized at our institution.

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_11

11.2 How Does Alignment Relate to Meniscus Tears and Degeneration?

The knee joint is the largest and most complex joint in the human body and has the longest lever arms. The joint transmits muscle forces into motion, with large lever arms producing substantial load moments across the joint due to the ground reaction force acting about the center of rotation of the knee, creating adduction and abduction moments in the varus and valgus knee, respectively (Fig. 11.1). Axial load causes high mechanical stress in the respective joint compartments, with mechanical load during walking on even ground amounting to 3.4 times body weight and as much as 4.3 times when climbing stairs [6, 7].

The most frequent leg deformities occur in the coronal plane (varus–valgus deviations). Malalignment can be defined as a deviation of the mechanical axis. A significant deviation in the coronal plane is diagnosed when the weight-bearing axis of the lower extremity lies more than 15 mm medial to the center of the knee joint (varus deviation) or more than 10 mm lateral of the center (valgus deviation) [8]. To differentiate between a femoral and a tibial cause of malalignment, the mechanical lateral distal femoral angle (mLDFA, standard value 87° ± 3°) must be considered. If the mLDFA value is smaller than the standard value, the cause of the valgus deformity is femoral based. If the mechanical medial proximal tibial angle (mMPTA) is increased, the valgus malalignment is due to a tibial deviation. Conversely, an increased femoral angle (mLDFA) indicates a femoral cause of varus malalignment, whereas an mMPTA < 87° ± 3° indicates a tibial cause [8] (Fig. 11.2a).

In the presence of tibial or femoral deviations in the frontal plane, forces can no longer be transferred uniformly at the knee joint. Instead, nonphysiological load distribution with mechanical stress occurs in the medial or lateral compartment. Teichtahl et al. reported that for every 1° of varus alignment, articular cartilage loss increased by 0.44 % per year, as measured on MRI [9]. It is therefore clear that mechanical overload of a joint compartment correlates with cartilage damage and either promotes the development of degenerative joint disease or accelerates its progress [10–12].

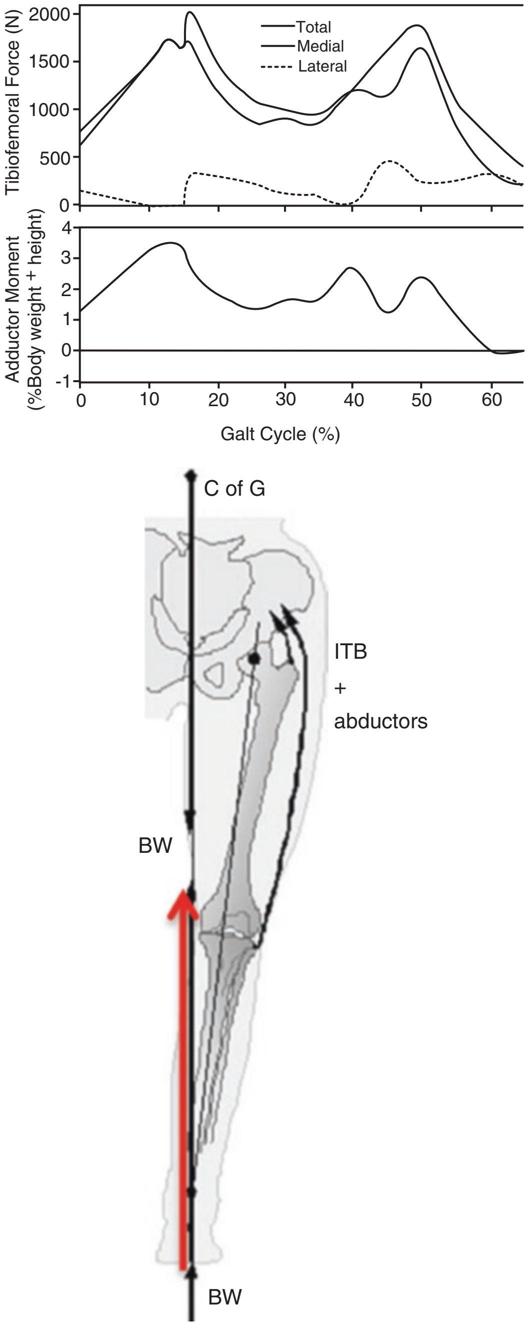

Fig. 11.1 Adduction moment (*red arrow*) as a result of ground reaction force placed medial to center of rotation in varus lower limb

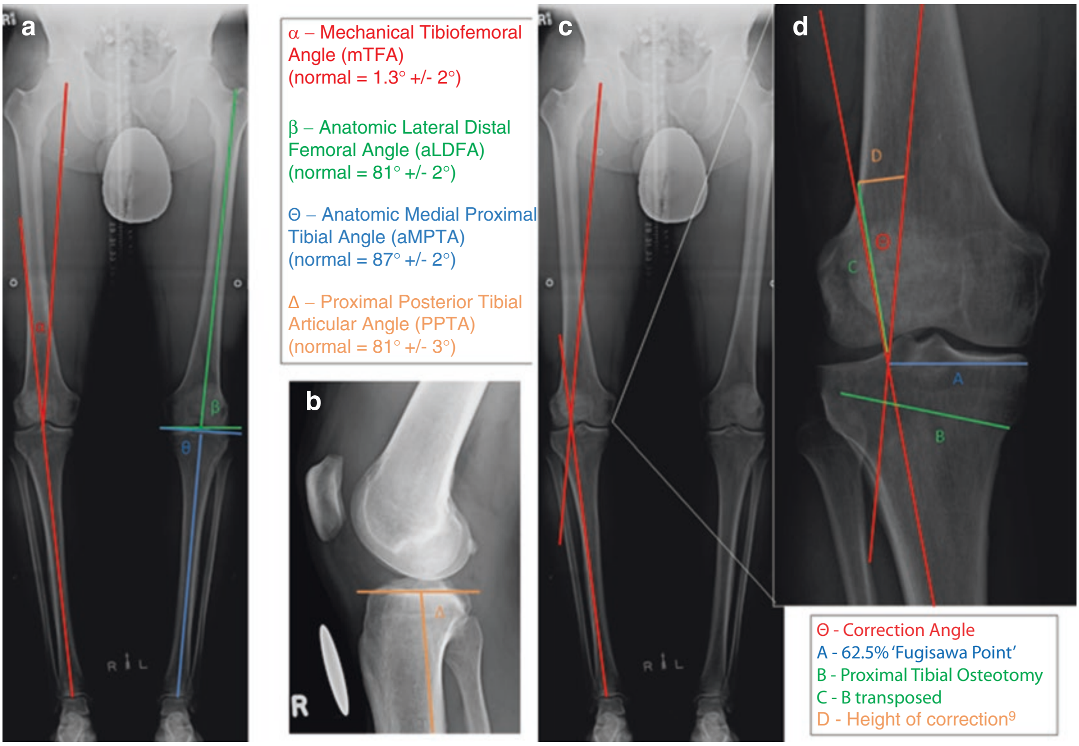

Fig. 11.2 (**a**, **b**) normal alignment indices of the distal femur and proximal tibia (**c**, **d**) preoperative correction planning for MOWHTO as per Dugdale et al. [36]

In many studies, the increased degree of lower limb varus is reported to be related to the progression of osteoarthritis due to medial meniscus injury and articular cartilage injury [1, 13–15]. It has been reported that the axial alignment of the lower limb in patients with isolated tears of the medial meniscus without obvious trauma is varus. The alignment is almost normal in those with obvious trauma. Therefore, it seems that a varus deformity of the knee is closely related to the occurrence of a medial meniscal tear [5]. This is not the case for the lateral meniscus, since the axial alignment of the lower limb does not appear to have a relationship with the occurrence of lateral meniscal tears, because the alignment of the lower limb was normal in these patients [5].

In summary, even without obvious trauma, the load stress to the knee produces degeneration of the medial meniscus in the varus knee, potentially leading to a later meniscal tear.

The medial meniscus is closely attached to the deep layer of the medial collateral ligament at its middle segment, resulting in relatively low mobility. In comparison with the lateral meniscus, the medial meniscus is broad and thick, particularly in the posterior segment. These conditions may explain why the medial meniscus is more prone to be influenced by load stress than the lateral meniscus [5].

11.3 Principles of Realignment Osteotomy

Osteotomies around the knee that alter the weight-bearing axis of the lower extremity have a substantial effect on the load balance and distribution of pressure at the knee joint [16]. Birmingham et al. demonstrated that valgus medial opening wedge high tibial osteotomy (MOWHTO) resulted in substantial and clinically important reductions in the load on the medial tibiofemoral compartment as measured by reductions in knee adduction moment on 3D gait analysis, with associated improvement in patient reported outcomes [17]. A similar result was found in a study by Collins et al. concerning the varus lateral opening wedge HTO [18]. Femoral and tibial osteotomies facilitate the restoration of the physiological axes of the lower limb.

To achieve the desired off-loading of the compartment, the mechanical axis is moved to a predetermined position in the knee. The most common deformity is varus malalignment in the face of medial compartment osteoarthritis. Many surgeons aim to move the axis beyond the center of the knee, to the Fujisawa point. This is 62.5 % of the medial–lateral width of the knee joint from the medial edge [19]. Fujisawa fails to provide a mechanical rationale for using this point. Rather, it appears to have been a subjective judgment based on the results of chondral biopsies in a small series of HTOs [19]. It is therefore unclear from the current literature whether Fujisawa's desired correction is optimal for biological augmentation. Agneskirchner et al. investigated the effect on the tibiofemoral articular contact pressures by moving the resultant force vector from medial to lateral during sequential medial opening wedge osteotomy in cadavers [20]. They found that the contact pressure in the lateral compartment was already 70 % higher than that in the medial compartment when the load vector passed through the center of the knee and that it continued to increase as the valgus angulation increased [21]. Therefore, it is therefore suggested that a desired correction would be between 50 % and 62.5 % medial to lateral in order to achieve the appropriate degree of compartment unloading. The same principles may be applied to the valgus knee, where correction in alignment should aim to be either neutral or slight varus; however, no studies have determined the optimal alignment for longevity of successful treatment outcomes.

11.4 Evidence for Realignment Osteotomy with Meniscal Deficiency

The goals of treatment of patients with symptomatic meniscal deficiency are primarily to provide symptomatic relief during daily activities with subsequent improvements in patient function and quality of life; relief with higher-level activities tends to be less predictable. Ideally, treatment would prevent further progression of osteoarthritis, although the current literature has not reliably demonstrated this [22]. Surgical treatments, including meniscal allograft transplantation (MAT), synthetic segmental meniscus replacement, and realignment osteotomy, are options that attempt to decrease the loads on the articular cartilage of the meniscus-deficient compartment by replacing meniscal tissue or altering joint alignment. In this section we focus on the existing evidence concerning different types of osteotomy as a treatment option for meniscal deficiency.

High tibial osteotomy (HTO) presents as an option for patients suffering from unicompartmental post-meniscectomy degeneration with tibial-based malalignment. This is the most common varus deformity because of a reduced medial proximal tibial angle. A medial opening wedge high tibial osteotomy (MOWHTO) (Fig. 11.3) has become the most common procedure to deal with this deformity due to the ease of angular correction and the maintenance of proximal metaphyseal bone stock. The lateral tibial closing wedge osteotomy was also common in the treatment of varus malalignment, but has fallen out of favor due to the higher risk for complications and imprecision in achieving the desired angle of correction. The dome osteotomy is not commonly performed, because it is more technically demanding to create a curved osteotomy; it is more indicated for a larger correction [22, 23].

Isolated lateral compartment osteoarthritis can occur also after meniscectomy. Due to the joint geometry and lack of congruity in the lateral compartment, resection of the lateral meniscus causes a much greater increase in contact stresses in the lateral compartment, and therefore the articular cartilage is at much greater risk of degeneration in these knees. As such, it is critical to assess the alignment of patients who have undergone lateral meniscectomy as they will be at significant risk of developing early chondrosis and subsequent OA. In this scenario, if the mechanical malalignment is femoral based, then a distal femoral varus osteotomy (DFVO) is an option to treat these patients [24] (Fig. 11.5). If, however, the valgus alignment is secondary to cartilage and meniscus loss, a tibial-based correction in the form of a lateral opening wedge HTO is a great option, because it affects the mechanical axis of the joint throughout a complete range of motion (Fig. 11.4). DFVO is only efficient in extension, whereas a tibial-based correction will also off-load the desired compartment in flexion too.

The success of HTO slowly diminishes with time. The mean range of effectiveness is more than 7 to 10 years. In this way, an HTO can win valuable time before placing a unicompartmental or total knee arthroplasty [23, 25]. Inaccurate correction of preoperative deformity is the biggest contributor to HTO failure. If inaccuracy occurs, overcorrection is more desirable than under correction [22, 26, 27]. The survival of isolated HTO gradually declines over time up to a 20-year follow-up. This was found in a review of 57 studies (4344 knees) of isolated HTO [25]. The respective survival rates were 92.4 %, 84.5 %, 77.3 %, and 72.3 % at 5, 10, 15, and 20 years of follow-up. This review also included four studies that directly compared medial opening wedge osteotomy with lateral closing wedge osteotomy, with no difference in survivorship or clinical outcomes in follow-up of more than 2 years [22, 25]. Luites et al. compared 42 patients treated with either a medial opening wedge or lateral closing wedge osteotomy in a randomized clinical trial [28]. They reported no difference in recovery period and bone healing. Song et al. similarly retrospectively compared outcomes of both medial opening and lateral closing osteotomy techniques at 3-year follow-up and found no significant difference in anterior knee pain, patellar alignment, or patellofemoral arthritis [29]. Another study observed that 90 % of patients after an HTO were engaged in sports at the same intensity as preoperatively [30].

DFO has been established for treatment of isolated lateral compartment arthritis in select patients, with a mean survivorship of 80 % at a 10-year follow-up [24].

In general, osteotomies are an effective procedure for the young patients allowing them to return to impact activities with less discomfort, with no significant differences observed between medial opening wedge and lateral closing wedge osteotomies.

11.5 Surgical Technique of Osteotomy

11.5.1 Patient Assessment

Important factors regarding osteotomy include patient comorbidities and smoking status. A study looking at the complications of HTO in our institution found that diabetics and smokers were associated with an increased risk of postoperative complications [31]. Gait assessment is important to check for a dynamic varus or valgus thrust (coronal plane movement during stance phase). An added hyperextension moment on heel strike is indicative of a further posterior soft tissue attenuation issues, usually in the opposite corner to the involved compartment.

Assessment of prior skin incisions, if present, is important, because this may dictate the surgical approach both at the current and for potential future operations. Assessment for all other pathologies that may be also addressed – either concomitantly or as a staged procedure – must be undertaken. These include stiffness, instability, malalignment, meniscal pathology, and chondral/osteochondral involvement.

Radiological assessment specific to osteotomy considerations includes anteroposterior, Rosenberg, lateral, and hip-to-ankle double-leg standing alignment radiographs. Varus/valgus or kneeling posterior stress views may be considered if dealing with complex instability patterns.

11.5.2 Osteotomy Planning

The following flow decision-making algorithm can be used to determine the type of osteotomy required to address the presenting pathology:

1. Site of correction – tibia or femur?

2. Degree of correction required – to neutral or overcorrection?
3. Single or biplanar correction – is there associated anteroposterior instability?
4. Opening or closing wedge – dependent upon the approach used and surgical preferences.
5. Hardware choices – ensuring that the hardware is not prohibitive of further procedures.
6. Concurrent vs. staged procedures – dependent upon the surgeon's skill, the duration of the procedure, and hardware interference.

In the varus knee, a medial opening wedge HTO (MOWHTO) is the author's first choice due to the ability to correct both coronal and sagittal planes, the ability to easily titrate the degree of correction, and the lack of disruption to the proximal tibial anatomy as seen in lateral closing wedge procedures [32]. The choice of the site of correction in the valgus knee is dependent upon the site of the deformity. If the valgus is secondary to cartilage and meniscus loss, with only a small degree of valgus, a lateral opening wedge HTO (LOWHTO) is the procedure of choice, because it addresses the problem throughout the range of flexion and extension [18]. Great care must be taken not to increase the proximal tibial joint line obliquity by more than 10°, as this has been presumed to be associated with poor outcomes [31, 33, 34].

If the deformity is primarily in the femur, i.e., if the anatomic lateral distal femoral articular angle (aLDFA) is abnormal (<80°), then a femoral-based correction is preferred. In this instance, the medial closing wedge distal femoral varus osteotomy (MCWDFVO) is our procedure of choice, due to the ease of approach, the stability of the construct, and good healing potential. A lateral opening wedge DFVO is an alternative option.

11.5.3 Degree of Correction

Fujisawa indicates that moving the mechanical axis into the opposite compartment is beneficial in isolated HTO [35]. The optimal degree of correction – whether neutral or overcorrection – is unknown. It is the authors' preference to correct the mechanical axis of the varus knee to the downslope of the lateral tibial eminence while in the valgus knee to correct to neutral. The method of Dugdale et al. [36] is used to calculate the correction for the MOWHTO (Fig. 11.2c, d), which may be modified for the LOWHTO and the MCWDFVO.

11.5.4 MOWHTO Technique (Fig. 11.3)

Approach – an oblique skin incision is prepared to ensure that as much soft tissue as possible overlies the hardware in order to try and reduce the incidence of infection. A distal MCL release is performed to prevent a tension band on the medial side when opening the wedge. A blunt retractor is then placed posteriorly after elevating the posterior periosteum to protect the neurovascular structures.

Osteotomy and wedge opening – the desired level of the osteotomy is marked so as to ensure that there is enough room for hardware proximally in the metaphysis. A guide pin is placed from medial to lateral, making sure that the lateral hinge point is 1.5 times the distance from the lateral joint line to the lateral tibial cortex. The osteotomy is initiated with an oscillating saw and is continued with an osteotome under fluoroscopic control, with the posterior retractor in place at all times, leaving a lateral hinge. The wedge is then opened slowly, taking care not to fracture the lateral hinge. Due to the geometry of the anteromedial wall of the proximal tibia, the wedge should open approximately double the distance posteromedially as anteromedially so as to ensure that the tibial slope is not inadvertently altered.

Fixation – once the desired correction is achieved, based on preoperative calculations, the hardware is applied as per the manufacturer's

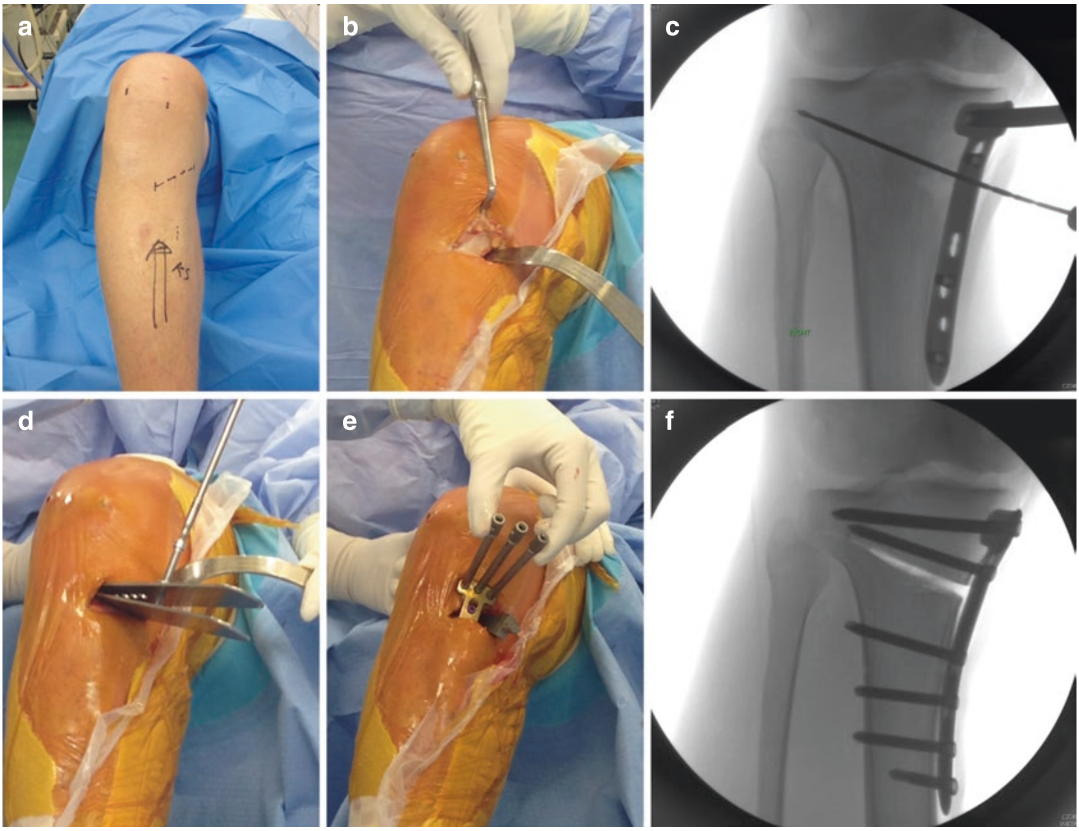

Fig. 11.3 Surgical technique for medial opening wedge high tibial osteotomy (MOWHTO). This is a right knee undergoing MOWHTO. A tourniquet is applied with lateral post and foot roll to support the knee held at 90° of flexion. (**a**) Oblique skin incision over pes anserinus allows a greater soft tissue envelope over the plate, helping to reduce wound infection and reduce risk to sartorial branch of saphenous nerve. (**b**) The sartorius fascia is split, and a blunt retractor is placed posteriorly protecting the neurovascular structures. The MCL is then cut at the level of the osteotomy. (**c**) A guide pin is placed in the line of the osteotomy, stopping at the level of the proximal tib/fib joint. The lateral hinge should be at least 1.5 times greater the distance from the lateral joint line than to the lateral cortex to help avoid intra-articular propagation of the osteotomy. (**d**) Following creation of the osteotomy with oscillating saw and osteotome, the wedge is opened with a spreader. (**e**) The osteotomy is held open with a wedge or laminar spreader and the plate is applied. (**f**) The screws are inserted percutaneously and the locking plate internal fixator is fixed in place as shown

guidelines. The proximal screws are inserted first, followed by one distal screw. At this stage, the knee can be brought out to extension in order to attempt to close the wedge down anteriorly, thereby reducing the chance of increasing tibial slope.

Rehabilitation – this generally entails touch weight-bearing for 4 weeks, with range of movement limited to 0–90°. At 4 weeks, patients may weight-bear as tolerated.

11.5.5 LOWHTO Technique (Fig. 11.4)

A similar process regarding the order of HTO is followed:

Approach – a lateral–longitudinal skin incision is made centered between the tibial tubercle and the anterior border of the fibula head. The tibialis anterior is elevated off the bone and

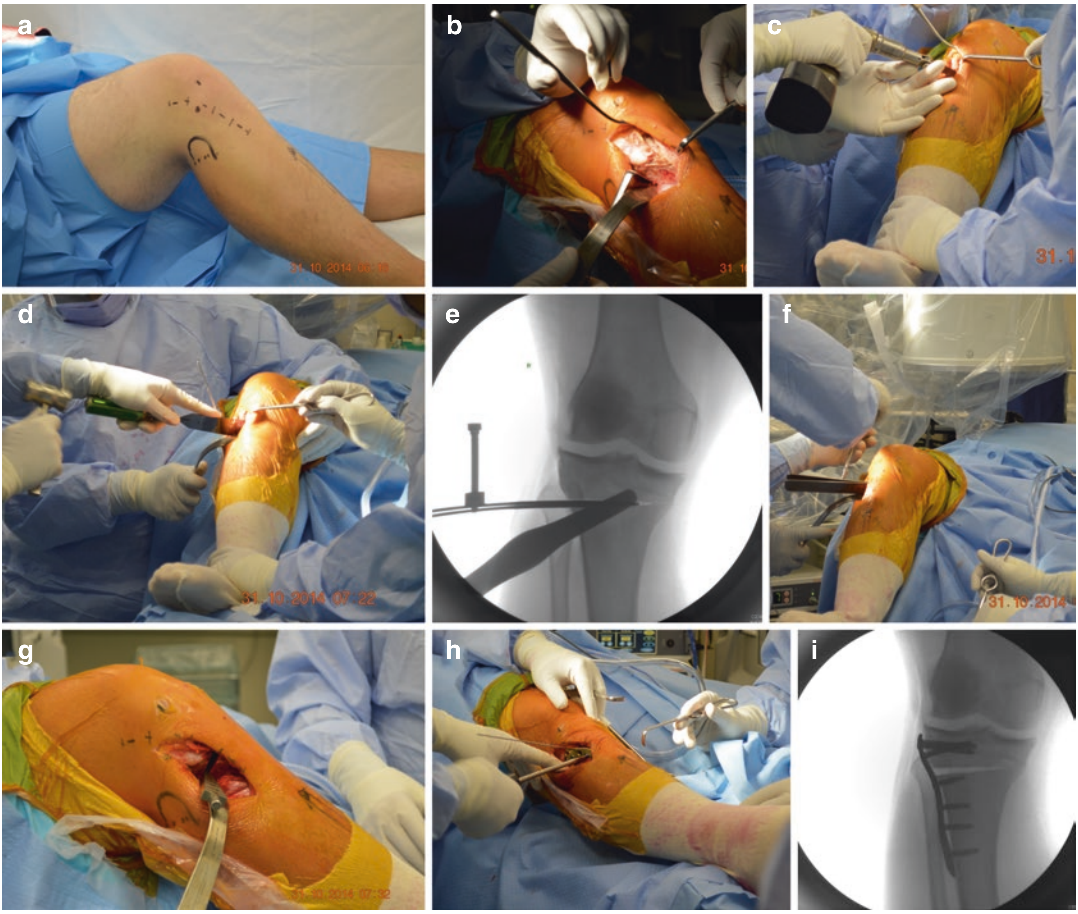

Fig. 11.4 Surgical technique for lateral opening wedge high tibial osteotomy (LOWHTO). This is a right knee undergoing LOWHTO. A tourniquet is applied with lateral post and foot roll to support knee held at 90° of flexion. (**a**) Curvilinear skin incision on lateral side of the knee midway between lateral border of patella and anterior border of fibula head. This may be extended if a lateral MAT is being performed and an arthrotomy is required. (**b**) Tibialis anterior is elevated off the proximal tibia and a blunt retractor is placed posteriorly to protect the neurovascular structures. Another blunt retractor is placed under the patella tendon to allow visualization of the anterior interval. (**c**, **d**) The osteotomy is performed with oscillating saw and osteotome under fluoroscopic guidance. (**e**, **f**) The spreader is inserted and the osteotomy is opened to the desired correction. (**g**) The osteotomy is held open with a wedge and the correction/alignment is checked. (**h**, **i**) The lateral plate is bent to fit the lateral cortex and applied in a standard method using locking screws

retracted posterolaterally, taking the nerve with it. The dissection is carried on to the anterior capsule of the proximal tibiofibular joint, which is opened and mobilized, negating the need for a fibular osteotomy. A blunt retractor is then placed posteriorly after elevating the posterior periosteum to protect the neurovascular structures.

Osteotomy and wedge opening – a similar process is followed as per the MOWHTO, except that the pin is placed from lateral to medial, and the wedge should have equal posterior and anterior gaps. This is again due to the proximal tibial geometry, which is more uniform on the lateral side than on the medial side.

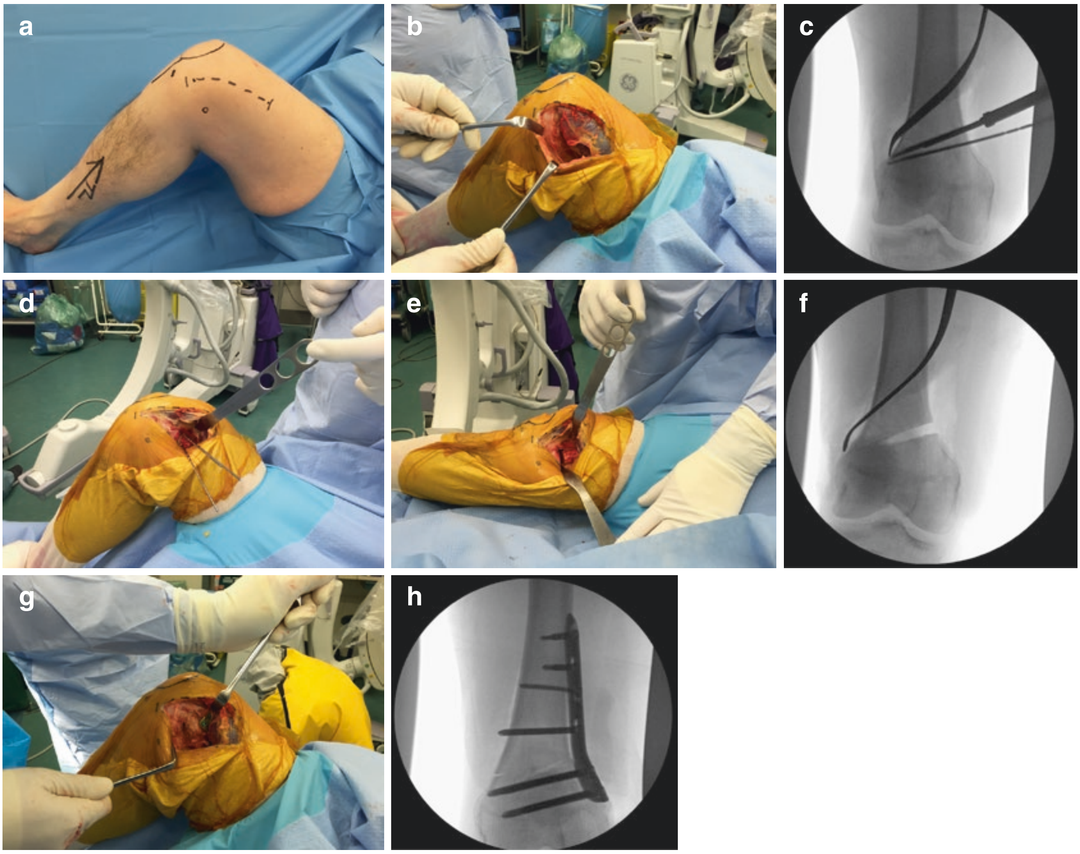

Fig. 11.5 Surgical technique for medial closing wedge distal femoral varus osteotomy (MCWDFVO). This is a right knee undergoing MCWDFVO. A tourniquet is applied with lateral post and foot roll to support knee held at 90° of flexion. (**a**, **b**) Medial incision to the knee followed by a subvastus approach to distal femur. (**c**) A guide pin is inserted in an oblique fashion, proximally on the medial cortex so that when the wedge closes, there is no step in the cortex. The pin is aimed for the medial cortex, just at the level of the radiographic "scar" of the posterior condyle. (**d**) A further two pins are inserted to allow for planning of a closing wedge, as well as a biplane anterior cut in the coronal plane. This adds a greater degree of stability to the construct when closing and fixing. (**e**, **f**) The corticocancellous wedge is removed. (**g**, **h**) The plate is applied and fixed with locking screws

Fixation – a lateral locking plate is utilized to maintain the correction.

Rehabilitation – similar as above.

11.5.6 MCWDFVO Technique (Fig. 11.5)

Approach – a longitudinal paramedian skin incision is made over the distal femur and a subvastus approach is made. The distal femur is exposed, the neurovascular structures are elevated away from the posterior femur, and a blunt retractor is placed for protection throughout the procedure. A further blunt retractor is placed anteriorly under the vastus medialis.

Osteotomy and wedge opening – a biplanar closing wedge osteotomy is planned and measured out as per the preoperative planned correction. The biplane cut helps control coronal and sagittal displacement during wedge production and closure. A guide pin is inserted from the medial cortex to a position on the lateral side, just superior to the subchondral density of the posterior condyle. A further three pins may be inserted to mark out the size of the wedge, all culminating at a similar point on the anteroposterior fluoroscopic view, 5 mm from the cortex. The osteotomy wedge cut is then completed with an oscillating saw and an osteotome, and the wedge is removed. The wedge is then closed with a varus force applied to the leg and a medial locking plate applied.

Fixation – the distal metaphyseal screws are inserted first, followed by a proximal non-locking screw to achieve compression at the osteotomy site. The other holes are then filled with locking screws.

Rehabilitation – similar as above.

Conclusion

While different techniques for meniscal substitution exist, it is generally accepted that they should not be performed in a knee where the mechanical axis runs through the affected compartment. The biomechanical rationale for an unloading realignment osteotomy is clear. It results in a reduction of articular contact stress and in a resultant reduction of chondral wear.

There are a number of surgical options available when realignment osteotomy is indicated. It is important that a thorough examination and radiological assessment of the patient are performed, paying close attention to the site of deformity so as to best select the most appropriate method of correction for that individual patient to result in optimal clinical outcomes.

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12

Outside-in Meniscal Repair: Technique and Outcomes

Jorge Chahla, James Gannon, Gilbert Moatshe,
and Robert F. LaPrade

Contents

12.1 Introduction

The menisci play a critical role in the health and longevity of the knee joint. Injuries to the menisci are extremely common, with some attributing it to 75 % of internal knee complications [6]. Historically, meniscus tears were treated by excising part or all of the meniscus. While meniscectomy still remains a viable treatment option in selected cases where a repair is not possible, vast evidence supporting a link between meniscectomy and increased osteoarthritis has prompted further development of repair techniques [13]. Contact pressure in the condyles has been shown to increase by 165 % and 235 % following a partial and total meniscectomy, respectively [9, 13]. This is especially problematic for high-level athletes. Using data from 5047 NFL players from the years 1987 to 2000, Brophy et al. reported that meniscal tears were the fifth most common injury affecting quarterbacks, receivers, offensive line, defensive line, and kickers [2]. While meniscectomies have been found to significantly reduce the career lengths of professional athletes [4], repairs carry high success rates at long-term follow-up. Stein et al. reported on a cohort of 81 athletes that 96.5 % returned to their pre-injury sports activity and expressed significantly less signs of osteoarthritis compared to patients having undergone meniscectomies. They also found a startling contrast between repair and meniscectomy patients, and 96.5 % of repair and 50 % of meniscectomy patients were able to

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_12

regain their pre-injury level of activity at a long-term follow-up of 5–8 years [9].

The anterior horn of the medial meniscus has been reported to be particularly important for stabilizing external rotation when the knee is fully extended [3] and also in preventing anterior femoral displacement [12]. In addition, the anterior horn tears of the lateral meniscus were reported to significantly increase tibiofemoral contact pressures in both compartments of the knee [7]. Studies have reported that repair of these tears restores condyle contact pressures to normal values [7]. Consequently, surgical repair is indicated whenever possible for all anterior horn tears. It is also important to recognize and treat anterior horn meniscal cysts, primarily of the lateral meniscus, as complete meniscal tears because solely debridement of anterior horn tears can destabilize the meniscus and lead to pain and decreased function. Current literature regarding the treatment of tears of the anterior horn of the menisci is very limited.

Commonly used techniques for meniscal repair include the inside-out, outside-in, and all-inside techniques. Warren et al. first described the outside-in meniscus repair in 1985, having been prompted to develop a technique that avoids the knee's critical neurovascular structures, specifically the peroneal nerve and saphenous nerve for the lateral and medial meniscus, respectively [1, 4, 8, 10]. Thirty-one years later, the technique has greatly evolved, with improved surgical technique and instrumentation being widely used presently (Fig. 12.1).

This procedure has the benefits of small incisions, low neurovascular risk, and high success rate [1, 4]. The outside-in repair technique is ideal for anterior horn tears because it allows for adequate access to the anterior horn of the meniscus, provides a stable fixation construct, and avoids leaving prominent intra-articular material with a minimal approach. The purpose of this chapter is to describe the surgical technique of outside-in repair of anterior horn meniscal tears, rehabilitation, and outcomes of this procedure.

12.2 Surgical Technique

A diagnostic arthroscopy is first performed through standard anterolateral and anteromedial portals to confirm and evaluate the meniscal pathology, as well as any concurrent pathology. After confirmation of the anterior horn tear, the arthroscope should be placed through the contralateral portal of the compartment of the involved meniscus to visualize the extent and characteristics of the tear. A 3 cm vertical incision is made in line with the portal on the same side of the knee as the anterior meniscal tear. Careful dissection is performed through the subcutaneous tissues to expose the underlying anterior joint capsule (Fig. 12.2).

To begin the outside-in repair, a spinal needle is introduced by piercing the overlying capsule, advancing it under the anterior edge of the medial or lateral meniscus (depending on the case), and through the body of the anterior horn, thus traversing the area of the tear (Fig. 12.3).

The inner cannula of the needle is removed, and a #1 PDS suture (Ethicon, Inc., Johnson & Johnson, Somerville, NJ, USA) is placed through the needle and into the joint (Fig. 12.4).

Similarly, a second needle is passed through the capsule, underneath the anterior edge of the meniscus, and through the body of the anterior horn. The inner cannula is again removed, and a looped suture retriever is passed through the second needle and into the joint. The free end of the previously passed PDS suture is then pulled through the looped retriever using a grasper and the suture pulled back out of the knee creating a mattress suture construct to secure the anterior horn (Fig. 12.5).

Multiple sutures are added to strengthen the construct (Fig. 12.6). Either a horizontal or vertical mattress suture configuration can be utilized, depending on the nature of the tear and the surgeon's preference.

Once the repair is complete, the sutures are tied to the anteromedial/lateral capsule with the knee flexed to 90° (Fig. 12.7). The arthroscope is inserted again, and the final construct is probed and assessed to confirm stability of the repair construct.

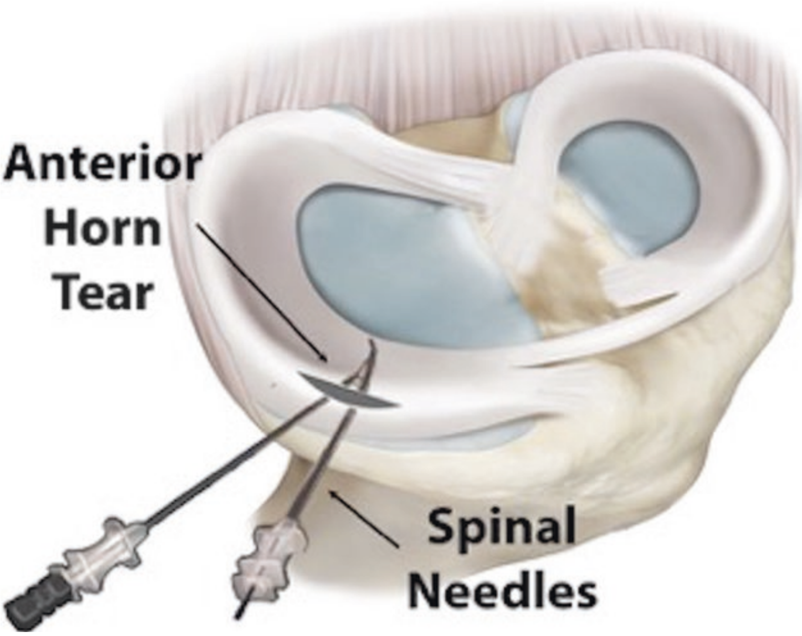

Fig. 12.1 Schematic diagram of a left knee (disarticulated from the femur) demonstrating an anterior horn tear of the medial meniscus being repaired with an outside-in technique with spinal needles

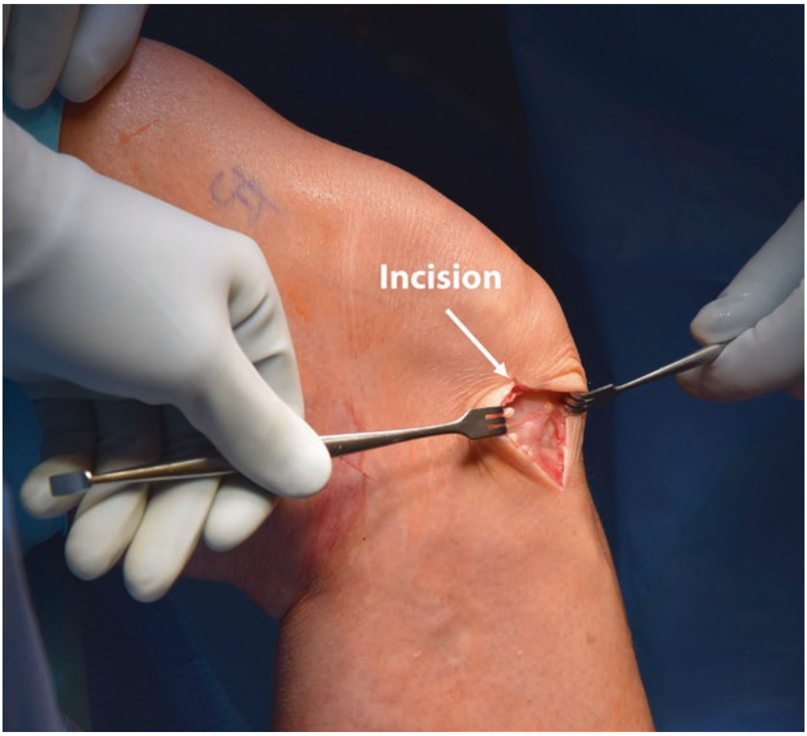

Fig. 12.2 A vertical incision (*arrow*) is made through the skin and subcutaneous tissues on a right knee to expose the joint capsule by extending the lateral portal incision 2–3 cm, which is on the ipsilateral side of the affected (lateral) meniscal tear

Postoperative Recovery and Rehabilitation For repairs performed in isolation, the patient is placed in a knee immobilizer in full extension and allowed partial weight bearing with crutches for the first 6 weeks. Physical therapy is initiated on postoperative day #1 to begin working on passive range of motion exercises. Knee flexion is limited to 0–90° for the first 4 weeks and then progressed

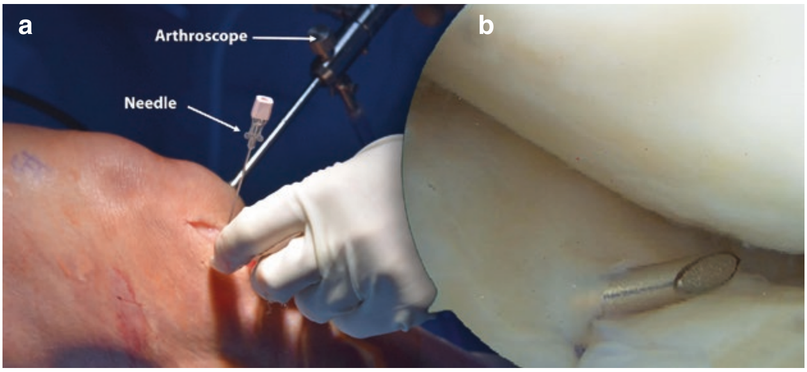

Fig. 12.3 (**a**) Intraoperative and (**b**) arthroscopic view. A spinal needle (*arrow*) is advanced through the lateral capsule, under the anterior edge of the torn lateral meniscus, and through the meniscal body on a right knee. A 30° arthroscope (*arrow*) is placed through the contralateral medial portal for adequate visualization

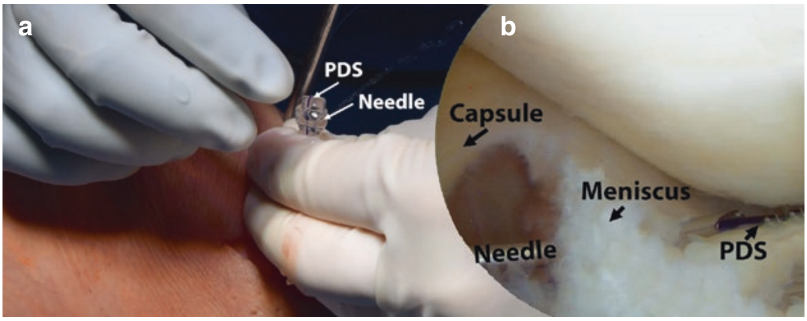

Fig. 12.4 The inner cannula of the needle (*arrow*) is removed, and a PDS suture (*arrow*) is passed through the needle, thus traversing the anterior lateral meniscal tear as visualized using a 30° arthroscope through the contralateral medial portal of a right knee

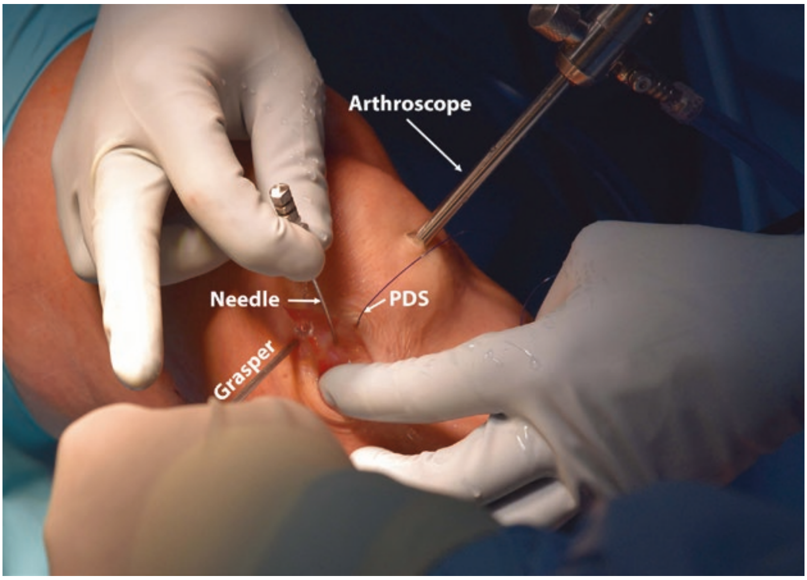

Fig. 12.5 The spinal needle (*arrow*) is passed a second time in a similar manner as before through the lateral incision of a right knee, and the free end of the previously passed PDS suture (*arrow*) is retrieved through the spinal needle using a grasper (*arrow*) and looped suture retriever. The grasper is placed through a second lateral working portal. This creates a horizontal or vertical mattress suture across the anterior horn of the lateral meniscus, depending on the type of tear and surgeon preference. A 30° arthroscope (*arrow*) is present in the medial portal

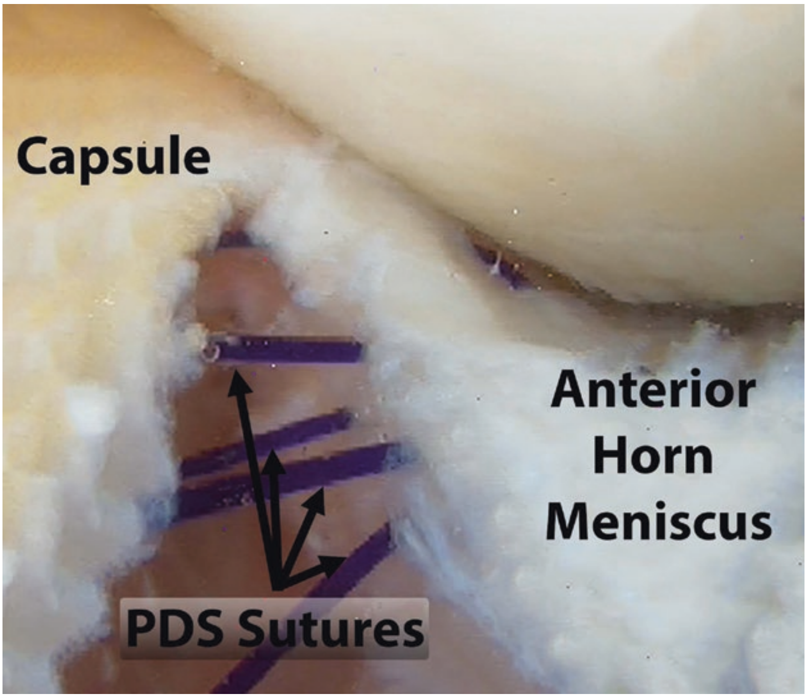

Fig. 12.6 Two PDS sutures (*arrows*) have been passed in a horizontal mattress configuration to repair the lateral meniscal tear of a right knee as viewed with a 30° arthroscope through the medial portal

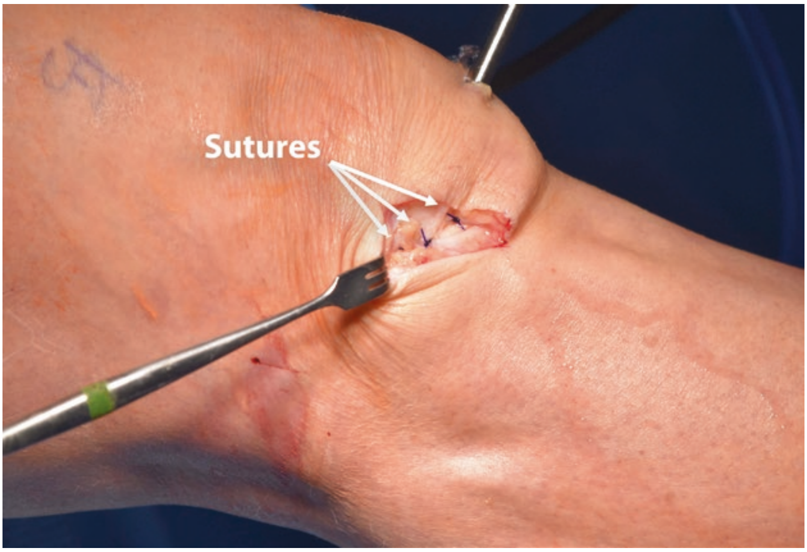

Fig. 12.7 The suture tails (*arrows*) are appropriately tensioned and tied over the lateral joint capsule of a right knee, thus securing the anterior horn of the lateral meniscus to the capsule to allow healing of the tear

as tolerated. Any significant squatting, lifting, or sitting cross-legged is prohibited for a minimum of 4 months to avoid excess stress on the meniscal repair.

12.3 Outcomes

Due to the prevalence of meniscal injuries, many studies have investigated the outside-in technique and how it compares to other repair procedures.

Van Trommel et al. reported a success rate of 76 % with their cohort of 51 patients treated with outside-in meniscus repair, using a combination of radiographs, second-look arthroscopy, and MRI. Patients without these records were excluded. Despite a 76 % reported success rate, only 45 % of these patients had complete meniscal healing, while 31 % had partial healing at the time of follow-up [10]. Morgan et al. found similar results, citing an 84 % success rate out of 74 repairs evaluated by second-look arthroscopy. All 84 % were asymptomatic at final follow-up. The average time from surgery to repair was 8.5 months. Similar to Van Trommel, only 65 % of the repairs completely healed, while 19 % partially healed. It is worth noting that the average time from repair to follow-up for the partially healed group was approximately half of the length of time for the entire cohort. The authors strongly believe that this influenced their results [6]. Abdelkafy et al. reported on a cohort of 41 meniscal repairs at a mean follow-up of 11.71 years (range 2–19 years), using standard clinical evaluation techniques, such as radiographs, to assess knee health. Five of the 41 procedures failed, meaning they received revision repair or meniscectomy [1]. Hantes et al. evaluated 17 outside-in repairs at a mean follow-up of 23 months. Patients were evaluated for joint effusion, sensitivity, and a negative McMurray test, and if these test were negative, the meniscus was considered healed. Based on this scoring system, 100 % of the repairs were successful [5]. Venkatachalam et al. used a cohort of 62 repairs in 59 patients from the years 1994 to 1999. Successful repair in their study had to meet the following criteria: the patient had little to no pain, no locking, and no revision surgeries. The average time until follow-up was 21 months. No clinical evaluation was used. Instead, patients were mailed a self-examination, which they filled out and sent back. The overall reported success rate is 66.1 %, a value we believe to be more realistic than other studies [11]. Lastly, Dave et al. conducted a literature review of outcome studies of the outside-in technique and found that reported success rates ranged from 50 to 91 % [4]. One potential explanation is the varying definition of success.

Meniscal repair outcomes are assessed in a heterogeneous manner. A “failure” does not necessarily imply that the patient is symptom free or that the meniscus completely healed. A failed procedure commonly refers to a patient that received no alleviation of symptoms postsurgery and likely required either a revision repair or a meniscectomy. Upon second-look arthroscopic examination, partial healing usually presents with a mostly healthy appearance but with repeated high-signal intensity in MRI. It is still to be determined what is clinically relevant since many partially healed menisci are asymptomatic [8].

12.4 Discussion

Since its inception in 1985, the outside-in repair technique has become a landmark procedure in the treatment of meniscal tears. The small incisions, low risk of neurovascular injuries, and high success rate make it a reliable method of repair, particularly for tears in the anterior two-thirds of the meniscus. Anterolateral and anteromedial meniscus tears have been shown to drastically increase contact pressure throughout both compartments of the knee, making this technique particularly valuable.

Conversely, success rates for tears to the posterior meniscus are not as high. Several studies have commented on the increased failure and complication rate with tears to the posterior horn [1, 4, 6, 10], which some believe to be due to the difficulty in accessing the region [8]. The outside-in repair has also been recognized as an effective alternative to the meniscectomy, which significantly increases condyle contact pressure and leads to osteoarthritis in the long term [13]. Furthermore, repair has proven to be more effective at returning patients to sport and pre-injury activity level [4, 9]. However, particularly debilitating tears, including radial tears, displaced tears, and tears in avascular zones, may be technically challenging to repair. Due to the deleterious effects of meniscectomy, a meniscal repair should always be attempted first.

Reported outcomes of the outside-in repair are consistently high; however, various authors disagree on how clinical relevance should be defined. But while an exact estimate of success with the outside-in repair is difficult to find, the technique is still highly effective at alleviating symptoms and returning patients to their pre-injury level of activity [1, 4–6, 8, 10, 11].

Conclusion

Meniscal tears are one of the most common knee injuries. If left untreated, this condition can have long-lasting impacts on a patient's knee health and overall activity level. Since 1985, the outside-in repair has been a reliable tool for the treatment of anterior horn meniscal tears. It is our belief that any practicing sports medicine surgeon should be comfortable with this procedure, as it will ensure the best possible short- and long-term outcomes for patient health and quality of life.

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Biological Augmentation of Meniscal Repairs

13

Adam William Anz

Contents

13.1 Introduction

Basic scientists, orthopedic clinicians, and the lay public have all recently become fascinated with biologic therapies. The interest has been stoked by the pursuit of science in animal studies and early clinical studies and by clinicians utilizing a broad spectrum of predominantly underdeveloped biologic treatments. The term biologics refers to natural products which are harvested and used to augment a medical process and/or the biology of healing. Biologics can be divided into three categories: growth factor therapies, which leverage chemokine and cytokine function such as point-of-care blood-based products; cell-based therapies which leverage cell function such as bone marrow aspirate; and tissue-based therapies, which utilize the structure of tissue to produce function such as allograft meniscal transplant. Investigators have been studying the biology of meniscal healing for many years, examining mechanical methods, methods involving growth factors, point-of-care blood-based augments, scaffolds, and stem cell therapies. This chapter will review the orthopedic pursuit of improving the healing of the meniscus.

13.2 Healing and Vascular Anatomy

Healing is divided into three phases: inflammation, repair, and remodeling. These phases are dependent on the delivery of cells and mediators

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© ISAKOS 2017
R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_13

of healing, the removal of injured tissue, and a structural framework for the wound healing process. The movement and components of blood provide the building blocks necessary to start and complete the healing process, a premise which has been observed in meniscal healing studies in animals [1, 2]. Platelets and fibrin are both vital, because fibrin provides a scaffold for the healing process. Platelets are important signaling molecules, providing chemotactic and mitogenic stimuli for the repair process [3–5]. When exposed to these normal mediators of healing, meniscus fibrochondrocytes are capable of proliferation and extracellular matrix synthesis [5].

While first described by Policard in 1936, Arnoczky and Warren produced the most widely recognized study on the blood supply of the meniscus [6, 7]. Blood arrives via two mechanisms: a perimeniscal capillary plexus which penetrates the meniscus with radial branches and areas of synovial covering which are highly vascular. These sources provide blood supply to roughly the outer 25 % of the meniscus [7]. This peripheral supply tapers to an avascular internal section. Meniscal healing studies in canines have illustrated good healing potential in vascular areas and little healing potential in avascular sections [2]. The structure of the vascular anatomy and clear lack of healing in the avascular zones have led surgeons to divide the meniscus into three anatomic sections when evaluating tears: an outer peripheral one-third with excellent to good healing potential, a middle one-third with moderate healing potential, and an inner central one-third with poor healing potential.

13.3 Vascular Access Channels and Synovial Abrasion

Studies quantifying the vascular supply and illustrating healing in vascular regions were followed by studies into techniques aimed at increasing the blood supply available to the entire meniscus. Initial canine studies focused on creating vascular access channels from the central avascular portion to the peripheral vascular portion and illustrated improved healing potential [2, 8]. A needle, blade, or trephine was a simple method to make a vascular access channel from the central region to the peripheral region. In 1993, a prospective study evaluating trephination of incomplete tears with an 18-gauge needle found 90 % of 30 patients were determined to have a good to excellent outcome based upon a subjective patient assessment score [9]. A next theoretic step to improve vascular presence was to create a larger vascular access channel with an implanted, absorbable porous structure. Preclinical animal study around a cylindrical device composed of poly-L-lactic acid illustrated promise with a 71 % healing rate of avascular tears in canines [10, 11]. However, after acquisition of the technology by an orthopedic implant company, developmental steps in humans were stopped after beginning a clinical study for undisclosed reasons.

In addition to creating conduits for blood flow, increasing the synovial attachment to the meniscus also increases the blood supply. Synovial abrasion involves roughening the synovium with an instrument such as a rasp adjacent to a meniscal tear (Fig. 13.1). In animal studies, this improves the healing potential of the middle third of the meniscus which normally has a marginal blood supply but does not improve the healing potential of the central avascular third [12, 13]. A clinical comparative study with this method includes one case-control study, illustrating a decrease in failure rate from 22 to 9 % after the authors began adding synovial abrasion to their

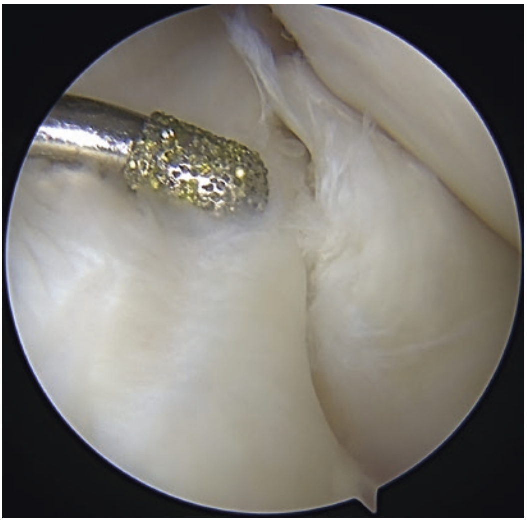

Fig. 13.1 Synovial abrasion performed arthroscopically

meniscus repairs [14]. It has been theorized that synovial abrasion is effective by itself to heal meniscus tears rather than as a method to augment meniscal suture repair [15]. A retrospective cohort study evaluating 47 patients who underwent synovial abrasion without suture repair found 71 % of the patients had complete meniscal healing, 21 % incomplete healing, and 8 % no evidence of healing when the sites were evaluated with second-look arthroscopy. The authors reported that stable tears illustrated the highest healing rate with this method [16].

13.4 Point-of-Care Blood Products

In addition to improving the blood supply of meniscal tissue, delivering various components of blood to meniscal tissue has also been studied including fibrin and platelets. Fibrin carries two properties which can be leveraged to improve meniscal healing: structural support of a clot and the chemokine properties of fibrin degradation products. Animal studies have varied; initial study of a fibrin clot in canines involved 2 mm meniscal defects, which when filled with fibrin clot healed with the formation of fibrocartilage [17]. Further study with a goat model of longitudinal tears found no benefit of a fibrin clot upon healing [13]. Tears repaired with sutures found a healing rate of 17 % with a fibrin clot augment and a healing rate of 87.5 % with synovial abrasion augment [13]. Low-level clinical studies have supported the use of fibrin clots to improve meniscal healing rates [18–20]. However, a randomized prospective study of horizontal tears reported that fibrin clot as an adjunct to repair produced inferior results when compared to repair with vascular access channels and when compared to a partial meniscectomy [21]. Synthesizing these studies suggests that fibrin clot can be useful when used as a scaffold or to protect healing tissue from the caustic healing environment of the joint but should not be interposed when adequate tissue is available for repair (Fig. 13.2).

While isolated and combined growth factors have proven effective for the enhancement of meniscus tissue regeneration in benchtop and animal studies [22–24], growth factors are not commercially available for clinical use with the exception of bone morphogenetic proteins, which have not been studied clinically in meniscus repair. However, point-of-care blood products such as platelet-rich plasma (PRP) are available to clinicians. Platelets contain a number of chemokines and cytokines which are released upon activation, including both anti-inflammatory and pro-inflammatory molecules [25–27]. While the exposure of tissues to pro-inflammatory molecules, such as TNF-alpha and IL-1, has inhibitory effects upon healing [28, 29], studies exposing cells from the

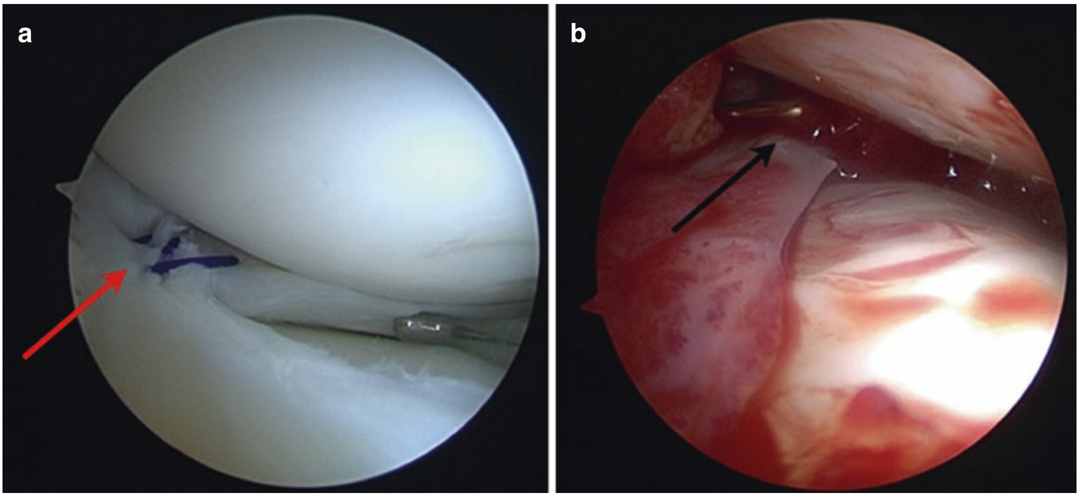

Fig. 13.2 A radial tear is repaired (**a**), protected by a fibrin clot loaded with bone marrow aspirate (**b**)

avascular meniscus zone to IGF, FGF, and PDGF have illustrated new matrix formation and fibrochondrocyte proliferation [30–32]. In a benchtop study, cell proliferation and extracellular matrix synthesis were stimulated by exposing cultured fibrochondrocytes to PRP [33]. These same authors investigated a PRP gelatin hydrogel (GH) which eluted PRP in a slow fashion, 4 weeks on average, in a rabbit model. Comparison included GH alone, GH with PRP, or GH with platelet-poor plasma to treat a punch defect. The group treated with the GH with PRP illustrated the best tissue upon histologic review [33].

Clinical data evaluating the efficacy of PRP to augment meniscal repair is limited to two studies. In a retrospective comparative study, the clinical outcomes of 15 isolated meniscus repairs augmented with a leukocyte-rich PRP matrix were compared to 20 repairs performed without PRP augmentation. Outcomes were similar regarding reoperation rate and clinical outcome scores. This study was underpowered with a post hoc power calculation suggesting that a similar study with approximately 200 patients in each arm would be necessary to answer the clinical question [34]. Another study evaluated 17 patients treated with open meniscal repair of a horizontal meniscus tear alone to 17 patients treated with open meniscal repair and an in injection of leukocyte-rich PRP into body of the meniscus repair. Outcomes assessed with MRI and clinical outcome scores were similar with the exception of a significant difference between two subsets of KOOS scoring, pain, and sports activities. These two subsets of the KOOS score favored the PRP group [35]. These studies suggest that the clinical benefit of current PRP technologies to meniscal repair at this time is marginal.

13.5 Scaffolds

For tissue regeneration to occur, it is theorized that three principle components are necessary: a scaffold, cells, and the appropriate cell signaling molecules. Meniscal injury can permanently damage tissue such that repair is not always possible, and tissue may not be available to provide cell incorporation and extracellular matrix formation. In some instances replacement tissue is necessary. For meniscal applications, replacement scaffolds come in three types: allograft meniscal tissue, xenograft collagen-based scaffolds, and synthetic scaffolds. Allografts are covered in a subsequent chapter and are indicated in scenarios of near-complete meniscal injury. Collagen-based scaffolds and synthetic scaffolds are typically used to fill segmental meniscal deficits.

The Collagen Meniscus Implant (CMI) (Ivy Sports Medicine LLC, Montvale, NJ) is a xenograft collagen-based scaffold manufactured from highly purified type 1 bovine collagen. In a developmental histologic study, the CMI was implanted in nine canines [36]. The implant underwent an active integration in the majority of cases over the course of 18 months, with four cases illustrating a mild chronic inflammatory response and one giant-cell engulfment of the scaffold in 3 weeks [36]. In clinical application, outcomes at 5 years and 10 years have illustrated superiority when compared to partial meniscectomy for medial meniscus injury [37–42]. Monllau et al. reported on a case series of 25 patients with 10-year follow-up. At final follow-up, clinical scores sustained improvement including Lysholm scores and mean pain scores on a visual analog scale (VAS). MRI analysis with Genovese scores found 64 % of cases as nearly normal and 21 % of cases as normal. There was an 8 % implant failure rate [37]. In a case-control study of 33 patients, Zaffagnini et al. compared CMI implantation with partial meniscectomy alone for medial meniscal injury [42]. Lower VAS scores and higher objective IKDC, Tegner index, and SF-36 scores were observed in the CMI group. Radiographs revealed less medial joint space narrowing in the CMI group [42]. A lateral meniscus study has recent 2-year outcomes which mirror the results of the medial meniscus experience [43]. Despite improvement in clinical outcome scores, implant absorption has been observed in 6–12 % of cases [42–44].

Synthetic meniscal scaffolds are under development with early encouraging results. Implant design involved optimizing pore number, pore size, inter-pore connectivity, compressibility, ingrowth, and degradation time [45–47]. Development has continued with biomechanical analysis of a degradable synthetic porous scaffold, illustrating improvement in contact mechanics after implantation [48]. Implantation studies in canines and humans have illustrated replacement of the scaffold with vital material with limited to no signs of inflammatory reaction [49, 50]. Twenty-four-month data was encouraging, with significant improvements in all clinical outcome scores and an incidence of treatment failure of 17.3 % [51]. At 5 years, the clinical improvement maintained, but only 62.2 % of the implants survived upon MRI evaluation, questioning the complete efficacy of the implant [52].

13.6 Stem Cell Therapy

Cells are integral to tissue healing and regeneration, because they are necessary for the production and maintenance of extracellular matrix. Stem cells have garnered an exploding interest primarily due to their ability to self-renew and to differentiate into distinctive end-stage cell types. Potential mechanisms of action applying stem cells have focused on the ability of these cells to differentiate into a number of different cell types of orthopedic interest, i.e., cultured cells from bone marrow can be differentiated into chondrocytes, adipocytes, or osteocytes. Recent interest has grown concerning the additional abilities of these cells to mobilize, monitor, and interact with their surrounding environment [53–55] (Fig. 13.3). Stem cells are able to release a broad spectrum of macromolecules with trophic, immunomodulatory, and anti-inflammatory potential, which allows them to participate in injury response, tissue healing, and tissue regeneration. These cells are innate to the body's maintenance, repair, and stress response systems. Basic science and animal study have illustrated the potential of cells with stem potential regardless of their environment/source of harvest, and the interplay of cells

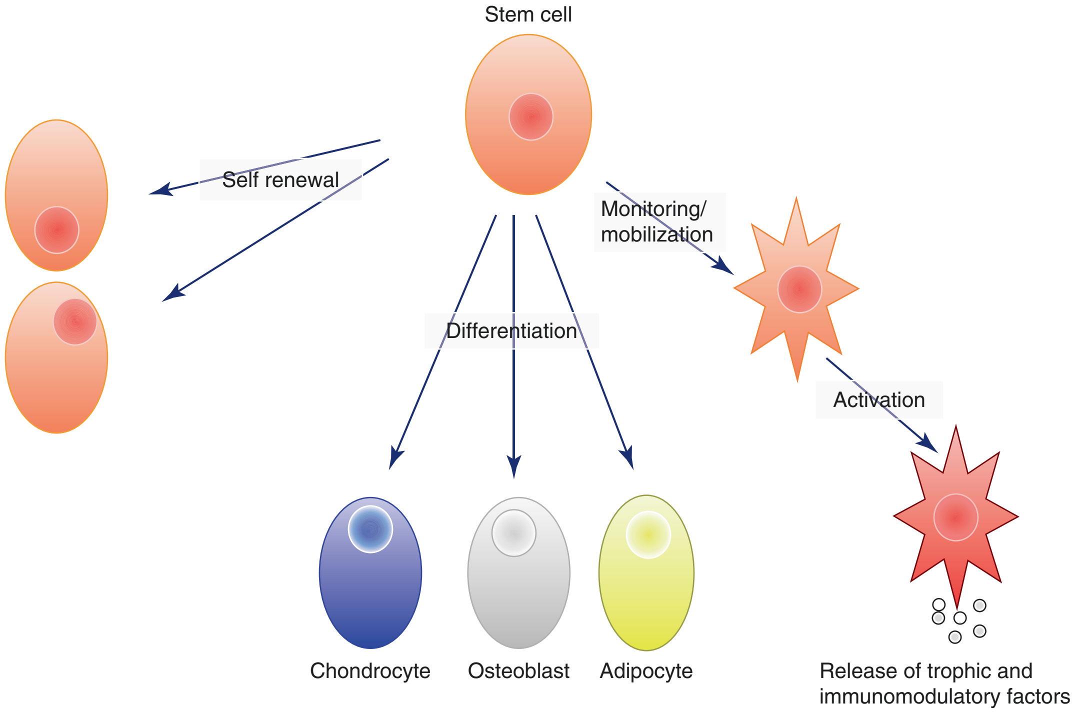

Fig. 13.3 The four cardinal properties of stem cells: proliferation, multipotentiality, monitoring/mobilization, and paracrine function

based upon which environment they reside is not fully understood.

Cells with stem properties are present in many environmental niches, including the bone marrow, adipose tissue, synovial tissue, muscle tissue, and tendon tissue. Two stem cell types, the hematopoietic stem cell (HSC) and perivascular stromal cell (PSC), can be aspirated from bone marrow. The interplay, interaction, and superiority between these two cell types are complex and incompletely understood, and it is unclear which of these cells is the parent cell upon culture [56–59]. Both of these cells have stem properties and have been shown to differentiate to tissues of orthopedic interest [60]. To utilize these cell types, the orthopedic community primarily utilizes point-of-care bone marrow aspiration and concentration, while the hematology-oncology community mobilizes these cells from the bone marrow to the blood stream with pharmaceutical agents and harvests via apheresis. Bone marrow aspiration produces variable numbers of stem cells, with studies ranging from 1 stem cell per mL of tissue collected to 300 thousand stem cells per mL of tissue collected [61]. Mobilization and apheresis can produce large volumes of peripheral blood-derived cells with 600 thousand HSC per mL and 2.32 million PSC per mL of tissue collected [62]. These cells can be stored for serial injections.

In adipose tissue, cells adherent to the abluminal side of blood vessels, known as pericytes, also carry stem qualities. Aspiration and processing of adipose tissue can access these stem cells, producing a product often referred to as stromal vascular fraction (SVF). Processing of lipoaspirate to create stromal vascular fraction requires mechanical or enzymatic processing. This produces variable numbers of stem cells, with quantitative studies ranging from 5 thousand to 1.5 million stem cells per mL of tissue collected [61]. Similar to adipose-derived stem cells, synovial-derived and muscle-derived stem cells also require mechanical or enzymatic processing. For applications involving large numbers of cells, investigators often utilize culturing techniques for all sources with the exception of mobilization and apheresis harvest. As clinicians, three challenges have proven more important than which cell type to utilize: (1) patient-care logistics regarding collection and application, (2) the undefined dose-response curve regarding stem cells, and (3) government/community regulation.

Stem cell studies and the meniscus are currently limited to preclinical animal study and should be divided into studies investigating tissue regeneration and studies investigating methods to improve meniscal repair. Meniscus regeneration studies have evaluated autologous bone marrow-derived cultured mesenchymal stem cells (bMSCs) and synovial-derived cultured mesenchymal stem cells (sMSCs), determining that stem cells carry substantial regeneration potential [63, 64]. The application of meniscus regeneration study to clinical practice requires further development, and review of these studies helps us preview where cell therapy is heading.

One of the earliest studies evaluated the implantation of bMSCs in a hyaluronan/gelatin scaffold into a segmental meniscal defect in rabbits, with integration and meniscus-like fibrocartilage in 8 of 11 rabbits treated with bMSCs and 2 of 11 rabbits treated with a scaffolds alone [63]. This group investigated further whether culture was necessary and whether differentiation of cells was necessary in a similar follow-up study using hyaluronan-collagen matrices and bone marrow aspirate in one group, undifferentiated bMSCs in another group, and bMSCs that had been cultured in a chondrogenic medium to differentiated them toward the fibrochondrocyte lineage [64]. Marrow aspirate did not improve healing. The non-differentiated cultured bMSCs produced the best results with meniscus-like tissue that was fully integrated into the surrounding tissue, while the differentiated bMSCs produced a moderate improvement in healing [64]. This

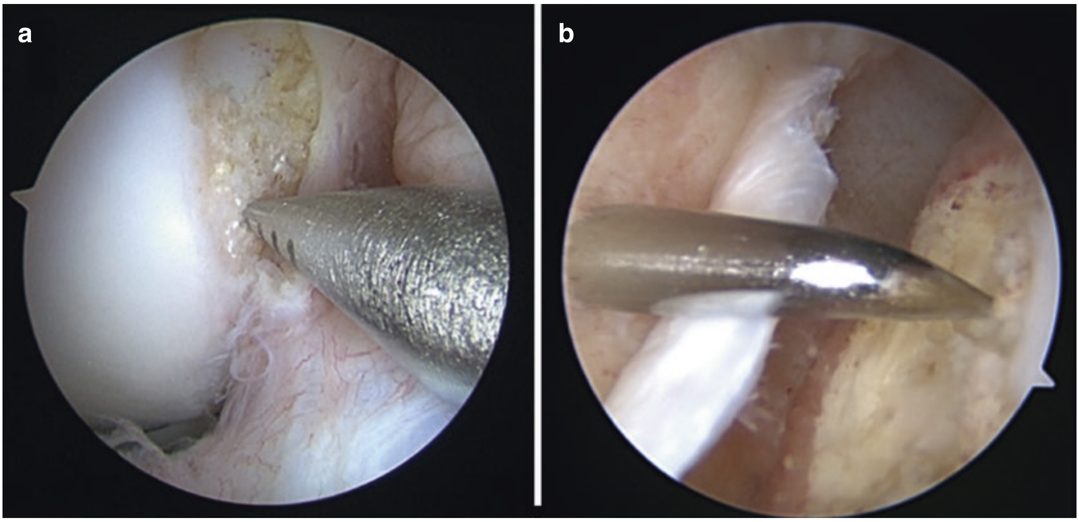

Fig. 13.4 Marrow stimulation is performed at the intercondylar notch (**a**) and outer side of the femoral condyle (**b**) to augment meniscal repair

study leads the authors to theorize that preimplantation differentiation of stem cells may not be necessary. Studies involving sMSCs have involved cultured synovial stem cells injected intra-articularly as opposed to implanted in a scaffold [65–68]. An initial study in rabbits found that labeled sMSCs injected intra-articularly after creation of a cylindrical meniscal defect adhered to the site of the defect, differentiated into cells resembling fibrochondrocytes, and enhanced the quality of meniscal regeneration [65]. This was followed by a massive meniscal defect study illustrating improved regeneration of tissue after one injection of sMSCs compared to a control [66] and a similar massive defect study with three serial injections in a porcine model [67]. An additional group has applied these concepts to a primate model providing histologic evidence of improvement with stem cells in a model more closely resembling humans [68].

There have been two studies regarding cell therapies and the augmentation of meniscal repair. One study evaluated the use of marrow stimulation to improve meniscal healing after the creation of a cylindrical defect (Fig. 13.4). Marrow stimulation of the intercondylar notch improved the quality and quantity of the healing tissue in a rabbit model [69]. Another study which evaluated the use of adipose-derived cultured mesenchymal stem cells (aMSCs) to improve healing rates of longitudinal meniscus tears treated with suture repair in a rabbit model illustrated increased healing rates in the groups treated with aMSCs [70].

Conclusion

The primary challenges of meniscal repair are the limited blood supply, the harsh nature of the biochemical and mechanical nature of the joint, and instances where injury destroys meniscal tissue. As knowledge of the anatomy and biochemistry of the meniscus have improved, biologic options to augment repair have progressed. Synovial abrasion and marrow stimulation are mechanical methods with clear support (Fig. 13.5). Scaffolds have a clearly defined role, while blood- and cell-based products require further refinement before wholehearted, evidence-based use is advocated.

Fig. 13.5 Apheresis allows for the mobilization, harvest (**a**), and storage of a large quantity of stem cells (**b**) which allows serial injection throughout the healing phase of the meniscus. This process is currently under development with an FDA observed trial

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14

Meniscal Repair Outcomes: Isolated Versus Combined with Other Procedures

Mark R. Hutchinson, Mitchell Meghpara,
Danil Rybalko, and Garrett Schwarzman

Contents

14.1 Introduction

The meniscus plays an important function in knee load bearing, shock absorption, joint lubrication, and joint stability [1]. In light of the important functions of the meniscus, a number of studies have shown that a lack of a functional meniscus may accelerate progression to osteoarthritis. As such, every reasonable effort is made to preserve the meniscus by repairing it, when indications are appropriate.

A number of meniscus repair techniques have been described, including inside-out, outside-in, all-inside, and combined.

The inside-out technique (Fig. 14.1) remains to be the standard for meniscal repair, offering stable fixation of tears and reproducible results. It is primarily used for tears in the posterior and middle thirds of the meniscus [2].

The outside-in technique allows for repair of tears in the anterior and middle thirds of the meniscus. Both inside-out and outside-in techniques can be done relatively rapidly [2].

All-inside technique was first introduced in 1991 to decrease surgical time, technical difficulty, and risk to neurovascular structures. This technique and associated devices have evolved over time. While early all-inside repairs have had inferior results compared to other techniques, more recent reports are showing comparable early results [3]. Boenisch et al. and Bryant et al. reported on clinical outcomes of all-inside repair and have shown no significant differences in short-term failure rates [4, 5].

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_14

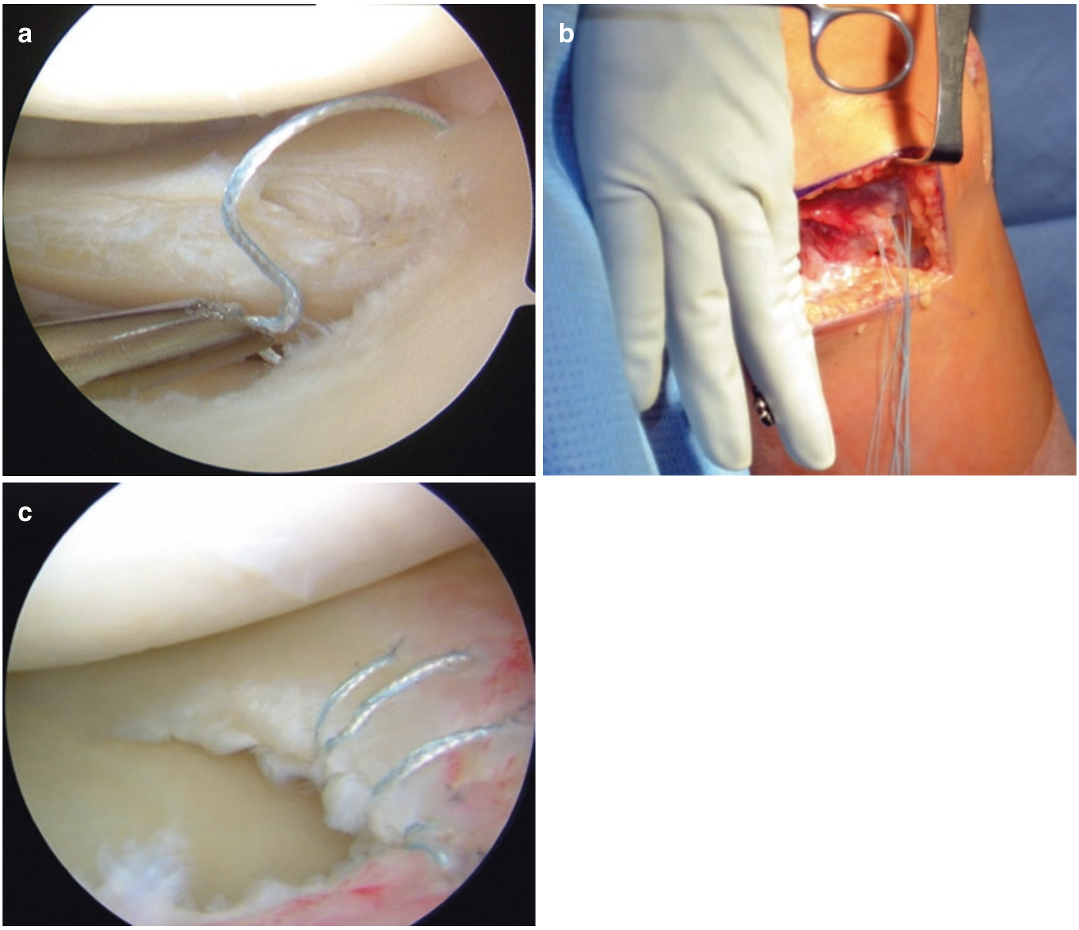

Fig. 14.1 Inside-out repair technique. (**a**) Degenerative horizontal cleavage tear is identified. (**b**) Sutures pulled through the knee. (**c**) Completed repair with vertical mattress sutures (Images courtesy of Dr. Robert LaPrade)

14.2 Overall Results

Several studies have reported the success rate of meniscus repair to be anywhere from 70 to 90 % [6–20]. Failure is typically defined by continued pain at the tibiofemoral joint, likely from an unhealed repair, requiring subsequent meniscectomy. In a systematic review at a 5-year minimum follow-up, failures ranged from 20.2 to 24 % (mean 23.1 %) that required meniscectomy [21]. Other studies have shown failure rates ranging from 5 to 43.5 % (mean 15 %) [22].

However, even if failures do occur, there has been evidence to show meniscal preservation following a repair that required subsequent meniscectomy. Pujol et al. [22] indicated the amount of meniscus needed for resection following repair was either lower (35 % of cases) or equal (52 % of cases) to the amount of resection that would have been needed at the time of primary surgery, if no repair was done.

The benefits of cartilage preservation and long-term protective effects following meniscal repair have been well documented. Postoperative analysis of osteoarthritis after meniscal repair compared with meniscectomy shows a positive cartilage protection in patients undergoing repair. Rockborn et al. demonstrated increased Fairbanks changes in patients undergoing meniscectomy (60 % stage 0–1, 27 % stage 2) versus repair (20 % stage 0–1, 4 % stage 2) [23].

A systematic review evaluating radiographic changes demonstrated 78 % of meniscal repairs had no degenerative changes versus 64 % of partial meniscectomies [24]. Additionally, when degenerative changes were seen, 97 % of meniscal repairs had one grade change or less compared with 88 % of partial meniscectomies [24].

14.3 Factors Affecting Outcomes after Meniscus Repair

Many factors have been associated with the success of meniscus repair. These include tear location, whether the tear is acute or chronic, vascular zone of injury, rim width, tear length, and patient age. Additionally, stability and anterior cruciate ligament (ACL) laxity significantly influence the outcome of meniscal repairs [2]. Differences in outcomes have been noted when isolated meniscus tears were repaired in stable knees compared to knees that also required a concomitant ligament reconstruction, most commonly the ACL [25, 26]. Table 14.1 summarizes recent studies reporting on outcomes after isolated meniscal repair. Table 14.2 summarizes recent studies reporting on meniscal repair with ACL reconstruction and tibial plateau open reduction internal fixation (ORIF).

Multiple reports in the literature have demonstrated better clinical success and healing of the lateral meniscus when compared to the medial [27–32]. Logan et al. showed that medial meniscal repairs were significantly more likely to fail than lateral meniscal repairs, with a failure rate of 36.4 % and 5.6 %, respectively [27]. One possible reason for this is the nature of the injury may be different. Injuries to the lateral meniscus tend to be more acute, whereas injuries to the medial meniscus commonly occur from recurrent instability and are chronic in nature [33]. Additionally, with the posterior horn of the medial meniscus relatively immobile, as the knee flexes, more pressure is exerted on the medial repair [25].

Table 14.1 Outcomes after isolated meniscal repair: literature review

Author	Year	Level of evidence	Technique	No. patients	Follow-up (mo.)	Success rate (%)
Fillingham et al. [44]	2016	IV	Inside-out; all-inside	555	57	89
Steadman et al. [43]	2014	III	Inside-out	40	120	95
Nepple et al. [21]	2012	IV	Open; inside-out, outside-in, all-inside	278	60	77.3
Stein et al. [45]	2010	III	Inside-out	42	105	85.70

Table 14.2 Outcomes after meniscal repair with combined procedures: literature review

Author	Year	Level of evidence	Surgical technique	No. patients	Follow-up (mo.)	Success rate (%)	Combination
Ra et al. [46]	2013	IV	Inside-out	12	30	92	ACL
Song et al. [47]	2014	IV	All-inside	15	24	87	ACL
Pujol et al. [48]	2015	IV	All-inside	41	114	87	ACL
Thaunat et al. [49]	2016	IV	All-inside	132	27	93	ACL
Westermann et al. [50]	2014	Meta-analysis	All-inside, inside out	286	72	84, 90	ACL
Bogunovic et al. [51]	2014	IV	All-inside	49	84	84	ACL
Walter et al. [52]	2014	IV	All-inside	104	13.5	85	ACL
Ruiz-Iban et al. [53]	2012	IV	All-inside	15	58	92	Tibial fracture

Lastly, asymptomatic failed lateral meniscus repairs can occur [34], and without anatomic assessment, this can underestimate the amount of failed lateral repairs.

Arnoczky and Warren [35] reported only the outer 10–30 % of the medial meniscus, and 10–25 % of the lateral meniscus is vascular in an adult. Consequentially, peripheral tears have superior healing rates. In a second look study by Asahina et al. [36], tears of the peripheral one third of the meniscus had a significantly higher rate of healing (87 %) compared to only a 59 % healing rate in central third tears.

Tenura and Arciero [37] reported rim width to have a significant role in healing. Patients who satisfactorily healed their repair had an average rim width of 2.2 mm versus a 3.3 mm average rim width in the unhealed group [37]. Moreover, none of the repairs healed with rim widths >4 mm [37]. Similar results were found by Bach et al. whereby meniscal tears with larger rim widths had a shorter time to failure [38].

Tenura and Arciero [37] also reported on tear length. Despite not being significant, they showed an 80 % healing rate for tears measuring up to 3 cm versus a 64 % healing rate for tears 3–4 cm in length. Other studies have also demonstrated a relationship between tear size and healing [11, 39]. Cannon and Vittori showed 94 % of repairs healed with tear lengths <2 cm, 86 % healed with lengths 2–4 cm, and only 50 % healed with tear lengths >4 cm [39].

Unlike the factors described above, patient age has been shown to have varying results in the literature on healing. Bach et al. [38] showed a significantly longer time to failure in older patients, suggesting a longer survivorship of repair in this patient population. Barrett el al [40]. studied repairs in an older patient population with mean age of 44 years and reported 87 % of patients had good clinical results at a minimum of two-year follow-up. Similarly, Noyes and Barber-Westin [41] had a series of 29 patients with mean age of 45 years and reported 87 % of patients were asymptomatic at a mean of 33 months follow-up.

However, other studies have shown decreased healing rates in patients aged >30 years or that patient age was not predictive of outcome [11, 37, 42]. Steadman et al. compared two cohorts, first with patients younger than 40 years of age and a second with patients 40 years and older. He found no difference in outcomes by age group with an overall failure rate of 30 % and mean time to failure of 4.9 years [43].

14.3.1 Outcomes After Isolated Repair

The generally reported healing rate of isolated meniscal repair has been reported at 60 % for complete healing. However, partially or incompletely healed menisci have been reported to be asymptomatic in the short-term studies [22]. The rate of partial healing has been reported at 25 %, and a failure to heal occurred 15 % of the time [22]. While the various studies have used a number of different methods to evaluate healing such as CT arthrogram, MRI, and second-look arthroscopies, they have consistently shown similar outcomes [43].

In a systematic literature review by Nepple et al. of 13 studies reporting on outcomes in isolated meniscal repair at 5 years follow-up and beyond, the pooled rate of meniscal repair failure was 22.7 % (63 of 278) [21]. While location of the meniscus tears did not show significant difference in failure between the lateral and medial meniscus, there was a trend toward slightly lower failure rate in the lateral meniscal repairs [21]. The technique of repair did not appear to make a difference. When broken down by repair type, the study showed a meniscus repair failure rate for open repair of 26.8 %, outside-in technique of 23.9 %, inside-out technique of 25.3 %, and all-inside technique of 23.3 % [21]. In a similar study of isolated meniscus repairs, Fillingham et al. reported a clinical failure rate of 11 % [44].

Clinical outcome scores were consistently high following isolated meniscal repair and were independent of the repair technique. In a systematic review of 481 studies, Fillingham et al. reported mean Lysholm and Tegner scores of 88 and 5.4 for the inside-out repair and 90.4 and 6.3 for the all-inside repair technique, respectively [44]. Another study reported that 96 % of patients were able to reach preinjury sports activity level in the repair group, compared to 50 % in the meniscal resection group [45].

14.3.2 Outcomes After Meniscus Repair Combined with Other Procedures

Meniscus repairs are often performed concomitant with other injuries. Most commonly associated with ACL injury, meniscal injuries can also be present with tibial plateau fractures, PCL tears, MCL tears, and other injuries to the knee. Given the associations of meniscus tears with other knee injuries, a number of studies have analyzed results of meniscus repair when done in combination with other procedures.

Combined repair of the meniscus, when associated with another injury around the knee, appears to have a more favorable outcome when compared to just an isolated meniscus repair. Studies have shown success rates with a combined procedure ranging from 84 to 100 % [46, 47, 49–56] compared to 70–90 % in isolated repairs [6–20].

Greater success in the reconstructed ACL knee can be attributed to positive effect of initial hemarthrosis and subsequent fibrin clot. Also, with a more stable knee and minimal laxity, the integrity of the meniscal repair is preserved. When an ACL graft is ruptured, Westermann et al. reported a doubling of failures of (27.3 %) [50]. Feng et al. [57] found a strong correlation between failures of ligament reconstruction and meniscal repair. They noted a 100 % failure rate of repairs when the KT-1000 laxity was greater than 5 mm [57].

The literature has a wide breath of studies evaluation concomitant ACL and meniscal repair; however, relatively few studies have focused on associated injuries other than an ACL rupture. A major reason for the high prevalence of meniscal and ACL combination studies can be attributed to the fact that just over one third of the meniscus tears were associated with an ACL injury [21].

Outcomes of combined reconstruction of the ACL and repair of the meniscus are well reported in the literature. Studies have analyzed both the inside-out and all-inside technique for combination repairs. The highest-level study analyzed was a cohort series by Westermann et al. that showed a failure rate of 14 % in meniscus repair with ACL reconstruction [50]. This is consistent with the other all-inside studies for combination repair that showed failure rates ranging from 6.8 to 16 % [44, 45, 47, 50, 52, 54]. Of note, the inside-out combination repair appeared to show better outcomes than the all-inside technique. The success rates of the inside-out studies analyzed were 92 % and 100 %, respectively [46, 49].

Stahl et al. [56] examined a combination of tibial plateau ORIF and concomitant meniscal tears. Given the high association between tibial plateau fractures and meniscal tears, possibly as high as 30 % [56], it is important to consider the outcomes of this combination repair. Ruiz-Iban

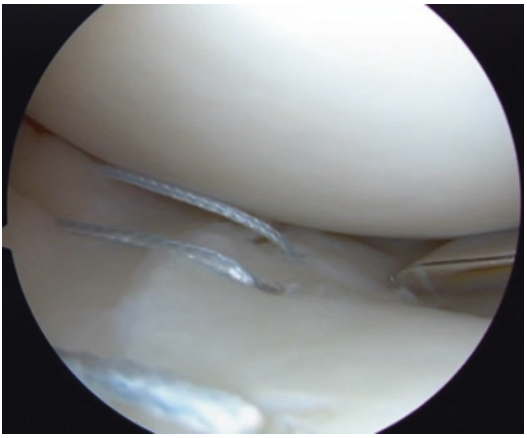

Fig. 14.2 Photograph of an inside-out medial meniscus repair in a left knee

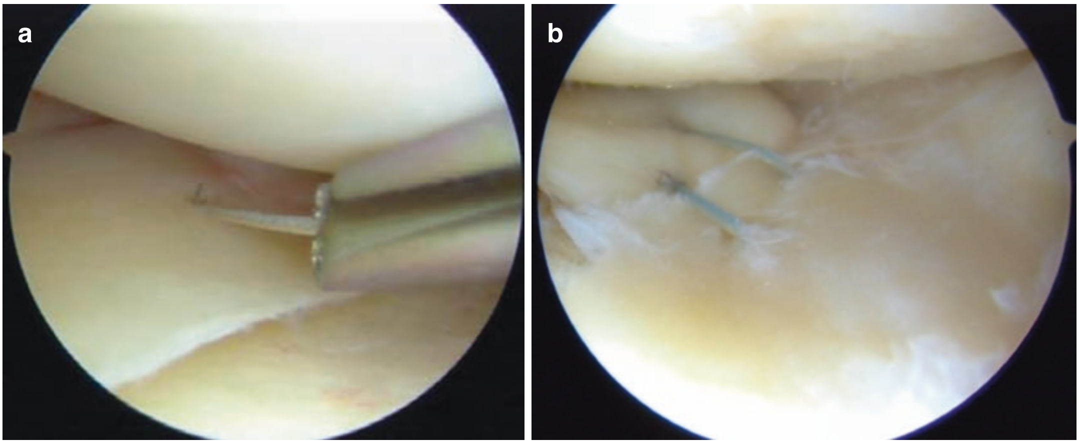

Fig. 14.3 Photograph of suture placement for an inside-out medial meniscus repair in a left knee

et al. [53] analyzed 15 cases of concomitant tibial plateau ORIF and meniscal repair. They found that there was a 92 % success rate with the all-inside technique [53]. Although there are limited studies regarding this procedure, it is important to note that the outcome appears to be consistent with combination repairs seen with ACL reconstruction.

There is more information needed regarding meniscal repair combined with other procedures, however, given that all but one of these studies analyzes a meniscal repair combined with ACL reconstruction. Therefore, further research is required to examine the relationship between meniscus repair and other injuries around the knee (Figs. 14.2 and 14.3).

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Treatment of Meniscus Degeneration and Meniscus Cysts

15

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15.1 Introduction and Outline

Meniscal tears are usually classified into two main categories: traumatic and degenerative (non-traumatic). However, degenerative meniscal lesions can be subdivided into primary degenerative meniscal lesions and meniscal lesions in osteoarthritic knees [1].

Meniscal mucoid degeneration (MD) – a condition that has generally been ignored – is likely to be responsible for the primary meniscal degeneration. Myxoid or cystic degeneration is also used for the same pathologic entity. Mucoid degeneration deserves special attention because it may be seen at a younger age, and it may be responsible for a non-traumatic tear of the meniscus which is not repairable; the process may end up with the loss of the meniscus at a young age. In our series of consecutive patients, the average age of the patients with meniscal mucoid degeneration was 28 years (range 16–68); 17 of 23 patients were under 40 years [2].

Meniscus degeneration in osteoarthritic knees usually occurs in middle and advanced ages; it is assumed that the prevalence increases with age. The prevalence in women aged 50–59 years and in men aged 70–90 could reach 16 and 50 %, respectively [3]. Once the meniscus loses some of its critical function due to degeneration, the increased biomechanical loading patterns on joint cartilage may result in accelerated cartilage loss [4, 5].

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_15

Meniscal cysts are associated with meniscal mucoid degeneration [2, 6, 7]. These cysts are commonly found in young and middle-aged patients [8]. Therefore, it is an important clinical entity.

One of the aims of this chapter is to draw attention to mucoid degeneration of the meniscus due to its serious implications in younger patients.

15.2 Meniscal Mucoid Degeneration and Cysts

15.2.1 Definition and Etiology of Meniscal Mucoid Degeneration

The most decisive feature of meniscal MD is the increase of mucoid ground substance created by mucoprotein and glycoprotein in connective tissue; proteoglycans accumulate in the interstitial area [6]. Mucoid degeneration may occur in two different forms in meniscal tissue; the degenerative process starts primarily around the cells and extends to the interstitial space in the stromal type. In the second type, cystic parameniscal degeneration, the degenerative process settles in the parameniscal field, and united cracks and pseudocysts are typical [6, 7]. Although the exact etiology is unknown, trauma (endogenous and exogenous), endothelial inclusion in cartilage tissue, chronic infection, and bleeding into the parenchyma have been implicated as etiologic factors [9–13]. The potential effect of chronic bacterial infection was not accepted in one study [2]. Similarly, degeneration caused by apoptotic cell death leading to suppression of collagen and proteoglycan synthesis does not seem to play a role in the etiology of meniscal mucoid degeneration [14, 15]. Mechanical stresses can induce an increase in proteoglycan synthesis by chondrocytes and may be responsible in the etiology of physiological stromal meniscal mucoid degeneration [6, 15, 16].

As in other tissues, aging is a physiological condition that can be seen in the meniscus; however, it has different pathological characteristics [17]. Knee joint overloading caused by obesity and malalignment may also create degenerative changes in the meniscus matrix via disrupting the structure and function [3, 18–20].

15.2.2 Clinical Features of Meniscal Tears due to Mucoid Degeneration and Cysts

Meniscal degeneration is a slowly developing process likely to involve progressive mucoid degeneration and weakening of the meniscus ultrastructure. Therefore, the resultant tears are typically non-traumatic [1, 2]. The duration of symptoms before presentation is long, meaning that such tears are usually not seriously symptomatic [2]. Although patients with meniscal tear due to MD have pain, it is usually not serious, at least for some time despite having known that they had complex tears on magnetic resonance imaging [2]. In our study, the mean duration of symptoms was 11.6 months (range 1–36 months). A history of trauma was present in only three of 24 knees (13 %), and the mean Tegner activity level was 4 (range 1–7). Pain was common in all knees. Giving way, swelling, catching, and difficulty in squatting were detected in a small number of patients [2].

Meniscal cysts are usually seen in the lateral meniscus; they present as palpable tender cystic masses on the middle third of the lateral joint line. The cyst often becomes prominent at 45° of knee flexion and disappears at further flexion and extension (Pisani’s sign) [21]. At 45° of flexion, the cyst typically becomes more prominent with external rotation and disappears with internal rotation (Fig. 15.1a, b) [22]. Medial cysts rarely present as cystic masses, because mucoid degeneration is usually confined to the body of the meniscus. If a cyst develops, it usually involves the posterior horn and is palpated posteromedially. Catching or locking caused by a medial meniscal lesion associated with a cyst seems to be less common [23].

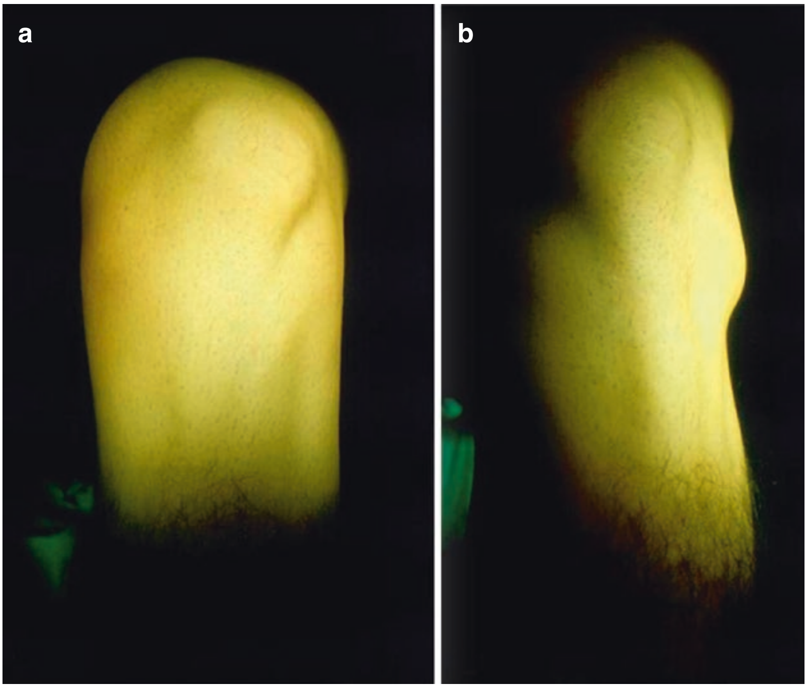

Fig. 15.1 Lateral meniscal cyst, left knee. Internal rotation (**a**), external rotation (**b**)

15.2.3 MRI Findings

Meniscal structure is well evaluated on proton density and T1 sequencing, while pathology is best identified on T2 sequencing [24]. In adult patients, increased abnormal signal in the meniscal structure indicates mucoid degeneration. There are three stages; stages 1 and 2 are differentiated by morphological features (oval, linear), and abnormal signal is confined to the meniscus structure. However, abnormal signal extending to the joint surface in stage 3 is diagnostic for meniscal tears [25]. Sometimes increased signal intensity can occupy the whole meniscal body. The meniscal outline may seem intact in some images, and the signal may reach the surface in others. The meniscus looks as if it is “empty,” or it resembles a triangular “frame” (Fig. 15.2) [2].

On magnetic resonance imaging, meniscal cysts can be seen as hyperintense on T_2-weighted images. A hypointense appearance is possibly due to cystic fluid loss or bleeding into the cyst. On T1-weighted images, the intensity of the cyst is determined by its fluid protein content; if protein content increases, the cyst becomes isointense with skeletal muscle (Fig. 15.3a, b) [26].

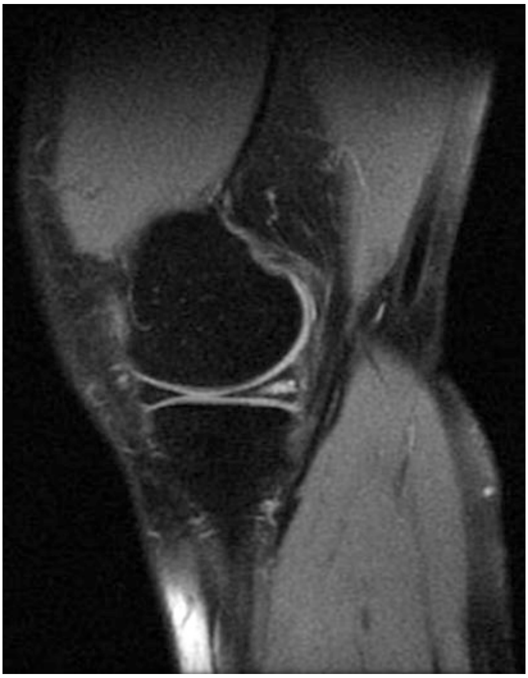

Fig. 15.2 “Empty” meniscus

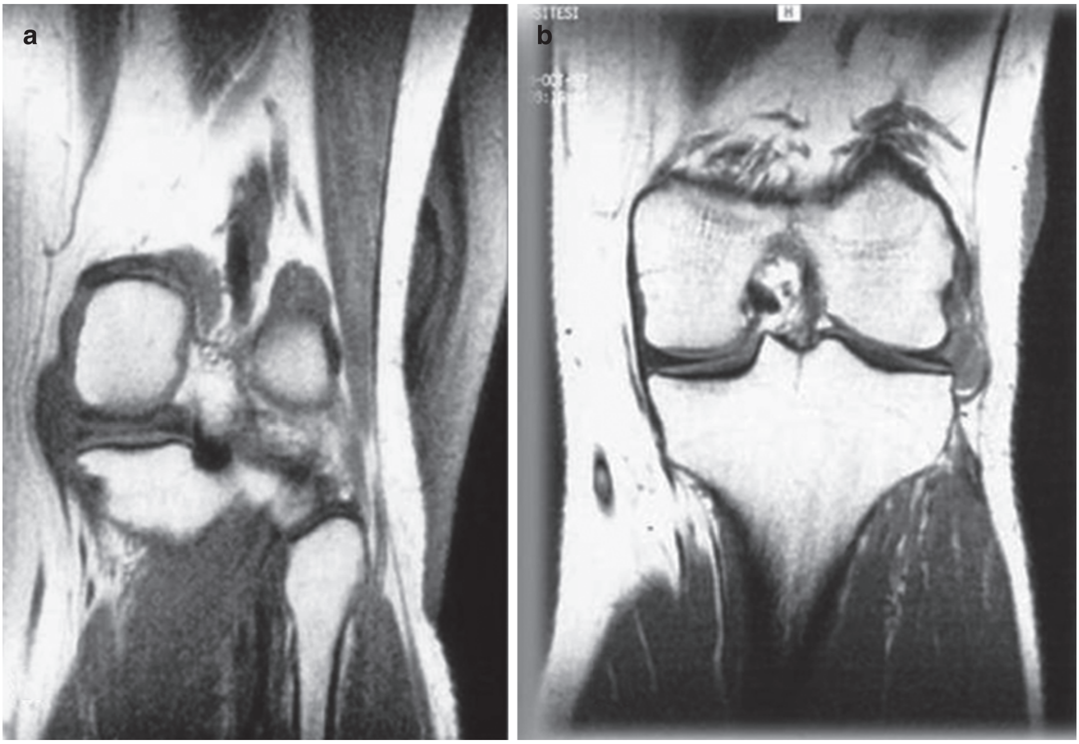

Fig. 15.3 Medial meniscal cyst (**a**), lateral meniscal cyst (**b**)

15.2.4 Arthroscopic Findings and Tear Types

If the meniscus is not torn, it is almost impossible to think that it is affected by mucoid degeneration unless a preoperative MRI is obtained; the meniscus may seem intact during arthroscopy. Horizontal, flap, radial, and complex tears are typical. As the surgeon proceeds with meniscectomy, the characteristic yellow color of the meniscal substance becomes apparent (Fig. 15.4a, b). Meniscal cysts are usually accompanied by horizontal cleavage tears [27]. Besides these, the abovementioned tear types are usually encountered [2].

15.3 Treatment

15.3.1 Treatment of Degenerative Meniscal Tears

The most critical issue in the treatment of degenerative meniscal tears is to evaluate the tear in accordance to the age of the patient and radiologic findings. For the patients who have meniscal tears accompanying radiological osteoarthritis grade ≤II, there is a tendency toward planning the treatment according to the osteoarthritis level. If all therapeutic modalities fail and the patient presents with considerable mechanical symptoms, arthroscopic partial meniscectomy can be considered, although mechanical symptoms cannot be clearly defined by the patient. Other than these patients, even for the younger patients who have no or low-grade radiological osteoarthritis, there is a conflict about the treatment regimen in the literature. In this chapter, we have focused on both degenerative meniscal tears in the degenerative knee in older patients and meniscal tears accompanying meniscal mucoid degeneration including meniscal cysts in younger patients.

In 2002, when Moseley et al. [28] have published their controlled clinical trial, arthroscopic treatment of degenerative menisci and knees has been paused by many arthroscopists, and some reviews have supported this finding in recent years although arthroscopic debridement has

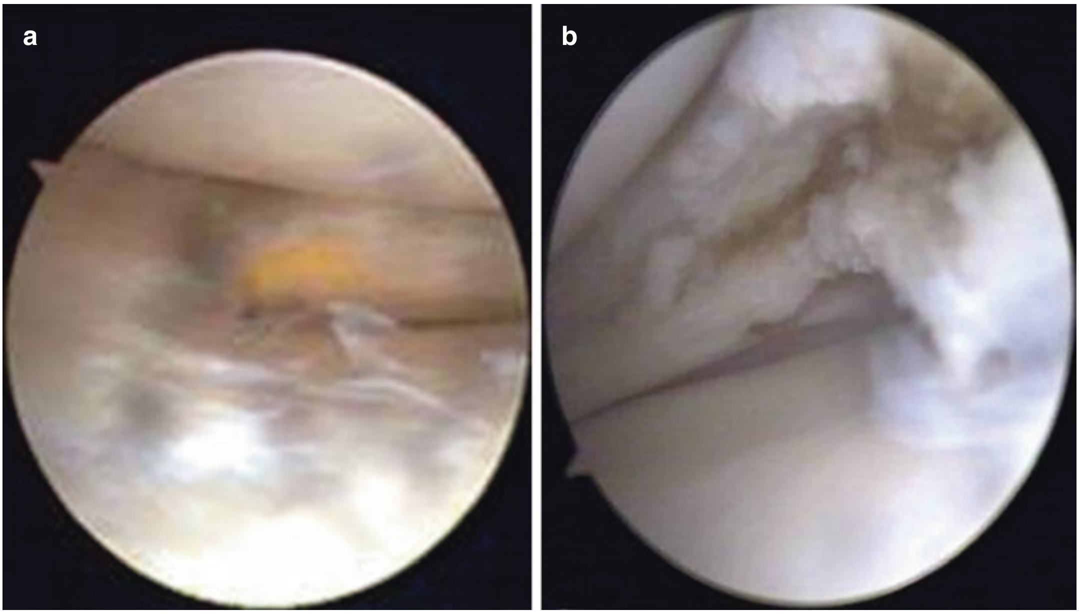

Fig. 15.4 Mucoid degeneration: the characteristic *yellow* color of the meniscal substance (**a**). Another case: *dark yellow-brown* color as meniscal resection proceeds toward the periphery (**b**)

been acquitted in a most recent meta-analysis [29–32]. In spite of these findings, arthroscopy of the knee in elderly patients is still an applied but declining procedure today [33].

In a prospective study, where middle-aged patients with radiological osteoarthritis grade ≤1 were randomly assigned either to arthroscopic meniscectomy and exercise regimen or to only exercise regimen, the findings showed that none of the treatment modalities showed a difference among the patients' results after a 5-year follow-up [34]. Contrary to this study, another one, with the same demographic features, demonstrated that middle-aged patients with meniscal symptoms might benefit from arthroscopic surgery [35].

In another study, Sihvonen at al. have randomly assigned middle-aged patients with no osteoarthritis to arthroscopic meniscectomy and sham surgery including only lavage and reported that the outcome after arthroscopy was no better than the sham procedure after 12 months [36]. A randomized controlled trial has shown no significant differences between the patient groups (standardized physical therapy regimen vs. surgery and postoperative physical therapy) after a 6-month follow-up, although 30 % of the patients who have received physical therapy alone have undergone arthroscopic meniscectomy within 6 months [37].

According to a systematic review including all these studies, there is a moderate evidence to suggest that there is no benefit to arthroscopic meniscal debridement for degenerative meniscal tears in comparison with nonoperative or sham treatments in middle-aged patients with mild or no concomitant osteoarthritis [38]. It is rational that arthroscopy will have relatively better results for traumatic meniscal tears than for non-traumatic degenerative tears [39].

Since these types of tears mostly exist in the avascular part of the menisci, they are considered to be an indication for partial or subtotal meniscectomy. However, in recent years, there is an increasing interest to repair such lesions due to deleterious effects resulting from meniscal loss.

Degenerative horizontal cleavage tears are another issue that differs from other degenerative tears as regards treatment alternatives. Accepted treatment modalities include arthroscopic partial meniscectomy [40], arthroscopic partial meniscectomy of the inferior fragment [41], open repair [42, 43], arthroscopic repair (Fig. 15.5),

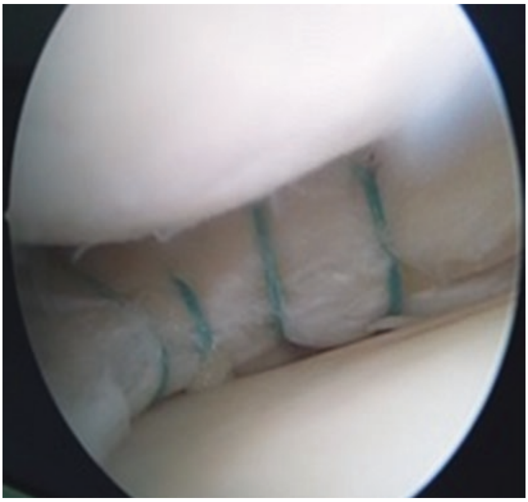

Fig. 15.5 Long horizontal cleavage tear repaired by inside-out sutures

and arthroscopic repair augmented by a fibrin clot [44].

In the study of Kim et al. [40], patients under 40 with an isolated horizontal tear were operated by arthroscopic partial meniscectomy, and the functional scores postoperatively were improved after a follow-up of more than 2 years.

In horizontal cleavage tears, during partial meniscectomy, the inferior or the superior fragment can be spared, while the other is excised. However, in a biomechanical study on sheep knees, it was demonstrated that sparing one fragment offered no benefit over resecting both in extensive horizontal tears [45].

An inframeniscal portal was used for horizontal tears of both menisci for partial meniscectomy in 40 patients, and after a follow-up of 2 years, the authors concluded that this portal was effective for accessing this type of tears, but they had a grade 1 medial collateral ligament injury in two cases [41].

In a study [42] that stressed the difference between degenerative meniscal tears of over 50 patients and complex horizontal tears in young and active patients, the authors preserved the meniscus by open repair of horizontal tears in 80 % of patients. The authors [43] have recently published the results of a longer follow-up and reviewed nine patients with the same issue for 10 years. They concluded that they could recommend open repair for such tears in young patients. The incidence of radiological osteoarthritis was low after 10 years. The success rate for 98 repaired horizontal cleavage tears was found to be 77. 8 % in a systematic review [46].

Kamimura and Kimura [44] have used a vertical inside-out suturing technique with fibrin clot in 18 degenerative horizontal cleavage tears with a mean age of 35.8 followed for 40 months, and follow-up arthroscopies showed 70 % complete and 30 % incomplete healing. Marrow-stimulating techniques have been used for the repair of horizontal meniscal tears of the avascular zone in addition to arthroscopic repair [42, 46, 47]. In the series of Ahn et al. [47], 11 of 32 repairs for whom second-look arthroscopy was performed, 73 % showed complete healing after a follow-up of 45 months.

15.3.2 Treatment of Meniscal Cysts

Starting from the 1950s, the accepted treatment modality for meniscal cysts was open excision of the cyst and open total meniscectomy [48–51]. Percutaneous needle aspiration of the cyst under ultrasound guidance and isolated excision of the cyst mostly result in the recurrence of the cyst and the physical findings [52, 53]. But, due to the importance of the menisci for the knee, a total meniscectomy is no longer an accepted procedure today. So, the currently recommended treatment modality for the meniscal cyst accompanying a tear is arthroscopic partial meniscectomy followed by cyst decompression.

Percutaneous needle aspiration under ultrasound guidance has been accepted as a simple and valid method in the middle term with a high recurrence rate because of leaving the tear [52, 53]; so it can be used for the patients who reject the operation or who cannot be operated because of various reasons [54].

The most widely accepted treatment alternatives are partial meniscectomy [55], open cystectomy with arthroscopic management of the tear

[56–58], and arthroscopic partial meniscectomy with intra-articular decompression of the cyst [8, 59–61]. In some cases, an extensive meniscectomy is performed to decompress the cyst intra-articularly [62–64]. A limited meniscectomy (if not reparable), by creating a 5-mm channel from the joint into cyst, is the ideal procedure [54].

After debriding the meniscal lesion arthroscopically, the cyst can be decompressed both from inside and percutaneously from outside with the help of a motorized instrument introduced through a transmeniscal approach [65].

Ahn et al. [47] have described an outside-in suturing technique for a vertical repair of the anterior horn of the meniscus after arthroscopic decompression of a large cyst. The authors have mentioned that the large gap between the meniscus and the joint capsule was closed after tying the sutures post-decompression. After following four patients for about 12 months, they have concluded that this kind of suturing can also be applied to the longitudinal tear of the anterior horn. If the size of the meniscal detachment is more than 2 cm, the meniscus should be repaired to prevent instability [47].

There was no difference between the entirely arthroscopic treatment and arthroscopic examination combined with open excision of the cyst in two series [61, 66]. In Sarimo's series [61] where 86 % had excellent or good results, decompression was performed with a small curette by inserting its tip through the rupture into the meniscus and probing the way toward the cyst with the help of simultaneous palpation of the cyst from the outside.

Recently, in a study [67] comparing the recurrence risk of parameniscal cysts between arthroscopic meniscectomy with open cystectomy and an entirely arthroscopic technique with intra-articular cyst decompression, after a follow-up period of 26 months of 241 young patients, arthroscopic decompression group had a sixfold higher recurrence risk than open cystectomy group. They have mentioned that the recurrence was strongly related to large cystic lesions and large meniscal tears.

In the technique of Howe et al. [68] which they called internal marsupialization, a 5-mm channel was created in the capsule adjacent to the cyst arthroscopically for decompression of the cyst content into the joint equalizing the pressure between the intra-articular compartment and cyst cavity while preserving the meniscal tissue. In eight patients with a mean follow-up of 39 months, no recurrence was shown.

For a meniscal cyst at the posterior horn of the medial meniscus, Ohishi et al. [69] have used a posterior transeptal approach. An alternative approach was described by Haklar et al. [70] for the lateral parameniscal cyst, where the authors have decompressed the cyst via the anterolateral portal and through the intra-articular portal with the arthroscope in the superomedial portal. They advocate that visualization of the entire cyst is better from the superior portals and handling the instruments is easier from the anterior portals (Fig. 15.6).

15.3.3 Authors' Method

- Arthroscopic surgery is of little or no benefit for older patients with advanced osteoarthritis and is not recommended.
- Surgery can be proposed for patients with degenerative meniscal tears with persistent pain and mechanical symptoms after 3 months.
- For a horizontal cleavage tear without a meniscal cyst in the younger patient without radiological osteoarthritis, we usually excise the free superior and inferior edges with the help of mechanical instruments until a stable edge is achieved – with maximum care not to reach the periphery of the meniscus. If the quality of the meniscal tissue is sufficient, following minimum edge resection, we perform repair with inside-out vertical sutures (Fig. 15.5).
- For a lateral meniscal cyst with a concomitant meniscal tear, we perform arthroscopic partial meniscectomy by using mechanical instruments and a motorized shaver. Then, through an accessory portal over the cyst, we debride the periphery of the meniscus and the cyst content with a motorized shaver (Fig. 15.7).

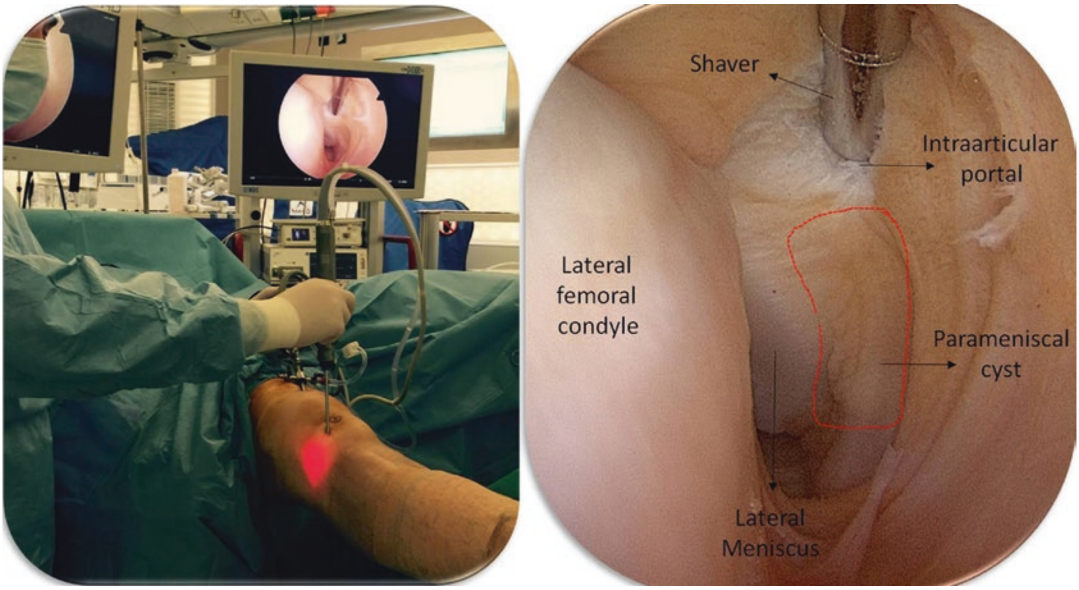

Fig. 15.6 Lateral parameniscal cyst decompression via intra-articular portal (shaver in anterolateral portal and through the intra-articular portal with the arthroscope in the superomedial portal) (Courtesy of Uğur Haklar)

Fig. 15.7 Intracystic portal

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Discoid Menisci and Their Treatment

16

Chih-Hwa Chen and Chian-Her Lee

Contents

16.1 Introduction

Discoid lateral and medial menisci were first described in cadaver specimens [1, 2]. Discoid meniscus is an abnormal congenital variant of the fibrocartilaginous meniscus of the knee [3–7]. The discoid shape results in a membrane barrier that prevents normal contact between the articular surfaces of the femoral condyles and tibial plateau resulting in a high incidence of mechanical deformation [8–11]. The meniscal anomaly differs in size, shape, coverage of tibial plateau, extent of peripheral rim instability, and meniscal attachment. A discoid meniscus is thicker and covers nearly the entire tibial plateau, which alters the stability and mobility of the meniscus [12, 13]. A discoid meniscus with thicker meniscus substance, unstable attachment to the tibial plateau, and poor vascularization of central region increases the susceptibility to mechanical and shear stress of the discoid-shaped meniscus to injury and a subsequent tear [14, 15, 16].

16.2 Anatomy

A discoid meniscus is a rare anomaly attributed to a persistence of fetal anatomy. The congenital theory proposes the discoid meniscus is an anatomical variant and suggests that increased shear stress causes meniscocapsular separation and secondary hypermobility [17]. In adults, the medial meniscus covers 50 % of the medial tibial

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_16

plateau and is attached firmly to the joint capsule tissues with coronary, meniscotibial, and deep medial collateral ligament. The lateral meniscus covers 70 % of the lateral tibial plateau and has firm anterior and posterior attachments with augmentation posteriorly by the anterior and posterior meniscofemoral ligaments. A discoid meniscus is a thicker meniscus that covers nearly the entire tibial plateau. The lateral meniscus is most commonly involved.

16.3 Incidence

The reported incidence of a discoid meniscus ranges from 0.4 to 17 % for the lateral side [4]. A discoid medial meniscus is a rare abnormality, with incidence estimated at 0.06–0.3 % [5, 6, 18]. The incidence of bilateral lateral discoid meniscus is up to 20 % of the cases, whereas bilateral medial discoid menisci are quite rare [18]. Coexistence of both medial and lateral discoid menisci in the same knee has been reported only twice [19]. The reported incidence of a discoid meniscus shows a wide geographical variation. In Europe, it is rather rare, with an incidence between 1.2 and 5.2 % [20–22]. In East-Asian countries, such as Japan, Korea, and China, it is seen more frequently, with an incidence between 13 and 46 % [23–26].

16.4 Classifications

Watanabe et al. classified various types of lateral discoid menisci based on the arthroscopic appearance [27]. Discoid menisci with intact peripheral attachments were labeled as type 1 or 2 according to the degree of coverage of the lateral tibial plateau:

Type I (complete): Complete discoid meniscus covering the entire plateau with intact peripheral attachments (most common occurrence)
Type II (incomplete): Incomplete discoid meniscus with intact peripheral attachments Type III (Wrisberg ligament type): Absent posterior meniscotibial attachments with only the ligament of Wrisberg remaining for stability (least common occurrence) [28] The Wrisberg type may be of normal shape rather than discoid. The general configuration produces an unstable or hypermobile lateral meniscus. Although this is the most frequently used classification system, its value for the purposes of treatment decision-making is questionable. The traditional classification was expanded with adding a fourth type to describe a ring-shaped meniscus characterized by a ring-shaped morphology with a normal posterior tibial attachment [9].

Classification of a discoid meniscus tear includes simple horizontal, complicated horizontal, longitudinal, radial, degenerative, and complex by arthroscopic findings. This classification method is useful for treatment planning [29].

Jordan et al. based their classification on both clinical and intraoperative findings [3, 7]. They defined the meniscal type (complete or incomplete), its peripheral rim stability, and the presence or lack of symptoms and tear. The most common tear pattern is that of a horizontal cleavage tear, which comprises 58–98 % of all cases of symptomatic discoid meniscus tears [30–32].

16.5 Diagnosis

Clinical symptoms are nonspecific and include snapping, intermittent locking, or chronic pain [3, 10, 11]. Children and adolescents may present with a palpable or perceptible snapping on the lateral joint line. The symptoms are variable, depending on the type of the discoid meniscus, the medial or lateral side, the presence of tear, and the status of rim stability [33–36]. A stable discoid meniscus is often an incidental finding in asymptomatic patients. It can become symptomatic in the presence of a tear. An unstable discoid meniscus may produce the classical “snapping knee.” It is usually related to the Wrisberg ligament type. A discoid meniscus tear may occur after an injury or may be insidious without an acute trauma.

A torn stable discoid meniscus may become unstable due to spread of a tear to the posterior tibial attachment. An audible, palpable, or visible snap on terminal extension with pain swelling and locking, in the absence of a traumatic cause, is the chief presentation of young children with this syndrome. The patient may present with an effusion, limited full extension, an anterolateral bulge at full flexion, pain, and tenderness at joint line.

A positive McMurray test is not a typical presentation. A true locking of the knee is also an uncommon presentation. Pseudo-locking of the knee may occur without a specific maneuver and recover into the normal range of motion. The variation in symptoms, descriptions on intermittent occurrence and vague, insidious onset, and physical examination all contribute to inconsistencies in the clinical presentation and diagnostic examination. A patient may become symptomatic due to instability of the meniscus and a new tear of the discoid meniscus or as the result of accompanying lesions, such as osteochondritis dissecans on the lateral joint compartment.

16.6 Imaging

Radiographic evaluation is often helpful to aid in the diagnosis. Plain radiographs, ultrasonography, and magnetic resonance imaging present characteristic findings for suspect and final diagnosis.

16.6.1 Radiography

Standard plain radiography of both knees should be obtained, including anterior-posterior, lateral, tunnel, and Merchant views which can contribute significantly to the establishment of diagnosis. Lateral joint space widening, squaring of the lateral femoral condyle, cupping of the lateral tibial plateau, tibial eminence hypoplasia, and fibular head elevation may be demonstrated [13]. Cupping is a transformation of the normally flat to convex bony shape into a more concave shape on the lateral tibial plateau.

16.6.2 Ultrasonography

Ultrasonographic imaging of the menisci may demonstrate a wide and irregularly shaped lateral discoid meniscus in type 1 and 2 discoid menisci. The sonographic criteria for a diagnosis of a discoid meniscus include the absence of a normal triangular shape, the presence of an abnormally elongated and thick meniscal tissue, and the appearance of a heterogeneous central pattern. Discoid meniscus tears are well demonstrated on ultrasonography. Ultrasonography is a reliable technique for the screening diagnosis tool for a discoid meniscus in an experienced specialist.

16.6.3 Magnetic Resonance Imaging

On magnetic resonance imaging (MRI), a discoid meniscus is seen as three or more successive sagittal slices with continuity between the anterior and posterior meniscal horns or a transverse meniscal diameter of greater than 15 mm or greater than 20 % of the tibial width on transverse slice images. The diagnostic criteria of a discoid meniscus are a ratio of the minimal meniscal width to the maximal tibial width on the coronal slice of more than 20 % and a ratio of the sum of the width of both lateral horns to the meniscal diameter on the sagittal slice of more than 75 %. Both ratios had a sensitivity and specificity of 95 and 97 %, respectively, even when torn menisci were present [37]. Other less precise criteria were a minimal meniscal width on the coronal slice of more than 15 mm and three or more consecutive sagittal slices showing continuity between the anterior and posterior horns of the meniscus. MRI can also provide information on intra-substance tissue quality, meniscal tear, and the presence of associated osteochondritis dissecans lesion. Incomplete, Wrisberg ligament type or unstable normal menisci are much more difficult to diagnose [38]. A ring-shaped meniscus is not easily distinguished from a bucket handle tear of the normal lateral meniscus using MRI [24]. The reparability of the lateral discoid meniscus cannot be reliably predicted from MRI imaging and can usually best be decided under arthroscopic checkup during operation.

16.7 Associated Pathology with a Discoid Meniscus

A discoid lateral meniscus was reported to be associated with high fibular head, fibular muscular defects, hypoplasia of the lateral femoral condyle, hypoplasia of the lateral tibial eminence, abnormally shaped lateral malleolus of the ankle, and an enlarged inferior lateral geniculate artery [7, 10, 15]. One of the most important clinical associations is the connection between a discoid lateral meniscus and an osteochondral lesion of the lateral femoral condyle.

Osteochondritis dissecans of the lateral femoral condyle is relatively rare. The presence of a discoid lateral meniscus was reported to commonly occur in a most of the osteochondritis dissecans lesions that occurred on the lateral femoral condyle [39]. It was suggested that existence of a discoid meniscus itself might produce an abnormal contact force onto the lateral femoral condyle even if the meniscus is not torn. This abnormal contact force may lead to an osteochondritis dissecans lesion in the lateral femoral condyle. A discoid lateral meniscus tear, young age and high activity, and valgus alignment were reported to be predisposing factors for osteochondritis dissecans of the lateral femoral condyle [40]. Discoid meniscus surgery was shown to allow the healing of an osteochondral fragment. Discoid meniscus surgery should be the recommended approach for osteochondritis dissecans of the lateral femoral condyle when combined with a lateral discoid meniscus tear [41].

16.8 Treatment

The treatment methods depend on various factors: clinical symptoms, patient age, tear pattern, and chronicity [42].

16.8.1 Conservative Treatment

If the discoid meniscus is detected incidentally during arthroscopy, no treatment is needed. This type of meniscus is considered to provide excellent cartilage protection. An incidentally found discoid lateral meniscus with no symptoms or physical signs should not be treated surgically. Snapping knee with no other symptoms and no radiographic signs of accompanying articular lesions can be followed-up and then subsequently treated should it become symptomatic. An otherwise asymptomatic knee with the incidental finding of discoid meniscus is a contraindication for surgical treatment.

16.8.2 Partial Meniscectomy and Meniscoplasty (Saucerization)

Central tears with unstable meniscal fragments are treated by partial meniscectomy with saucerization (Figs. 16.1, 16.2, and 16.3). Any effort should be made to leave a stable meniscal rim while preserving as normal of a meniscal configuration as possible. Arthroscopic partial meniscectomy with saucerization is the treatment of choice for symptomatic stable, complete, or incomplete discoid lateral meniscus tears [4, 32, 42]. The width of the remaining peripheral rim should be between 5 and 8 mm to prevent impingement and instability of the remaining part of a discoid lateral meniscus that may lead to future secondary meniscal tear [43].

16.8.3 Partial Meniscectomy and Meniscus Repair

Treatment of a peripheral tear of a discoid meniscus is usually a partial meniscectomy with meniscoplasty (saucerization) and repair of peripheral tear (Figs. 16.4, 16.5, and 16.6). Combined peripheral and central tears are treated by combining resection of the central tear and meniscoplasty with repair of the

Fig. 16.1 Magnetic resonance image of a central tear of a discoid lateral meniscus

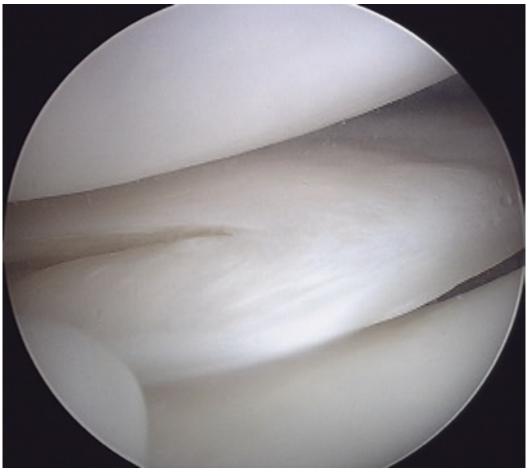

Fig. 16.2 Central tear of a discoid lateral meniscus

meniscal peripheral rim (Figs. 16.7, 16.8, 16.9, and 16.10). Meniscus-conserving therapy is strongly indicated for peripheral tears and especially for longitudinal tears of the posterior horn, middle third, or anterior horn. The younger the patient is, the greater the importance of attempting a repair, even if repair may not seem to be possible initially during surgery. Any repair techniques should be tried to preserve as much of the lateral meniscal tissue as possible. A chronic tear is likely to be associated with the extensive destruction of the meniscal tissue. In patients with a symptomatic tear, for months or even years, there is likely to be retraction and heaping of the meniscal tissue, which can make it difficult or impossible to perform a repair [44, 45].

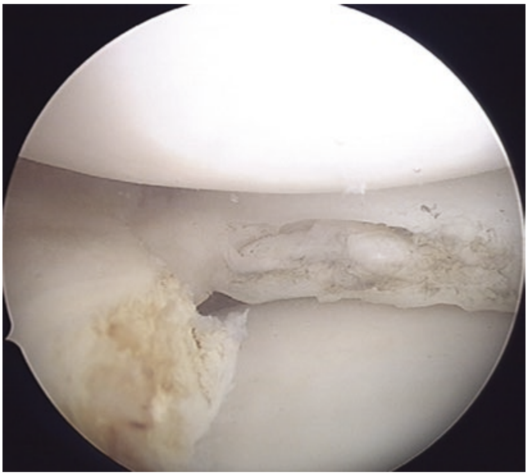

Fig. 16.3 Partial meniscectomy with saucerization

Fig. 16.4 MR image of peripheral tear of discoid lateral meniscus

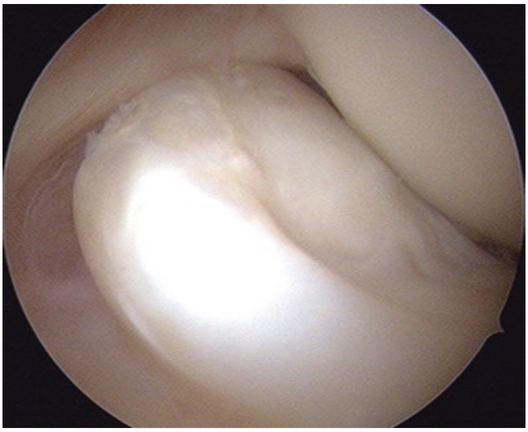

Fig. 16.5 Peripheral tear of discoid lateral meniscus

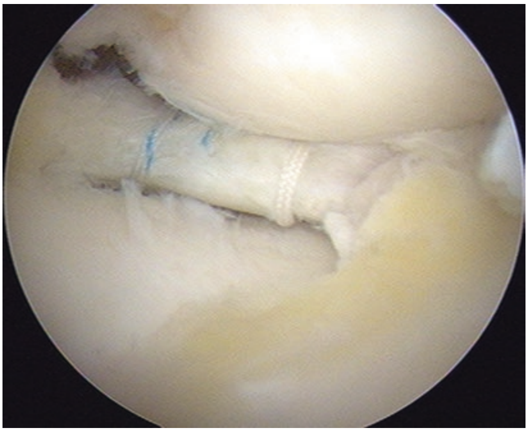

Fig. 16.6 Partial meniscectomy with saucerization and repair of the peripheral tear

Fig. 16.7 Magnetic resonance image of a combined central and peripheral tear of a discoid lateral meniscus

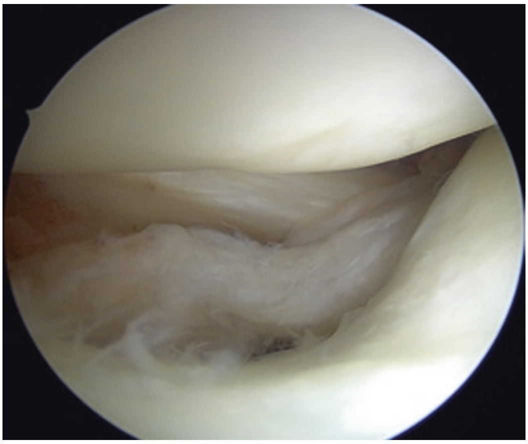

Fig. 16.8 Combined central and peripheral tear of a discoid lateral meniscus

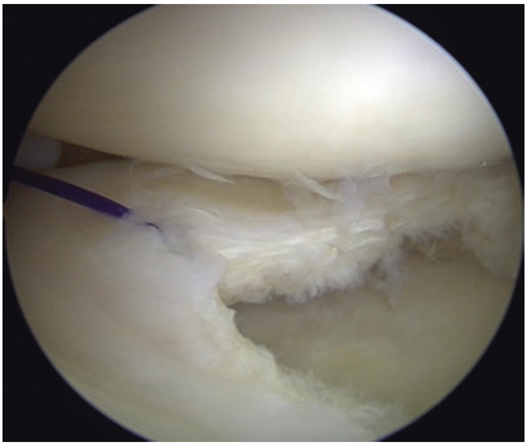

Fig. 16.9 Partial meniscectomy with saucerization to treat the central tear

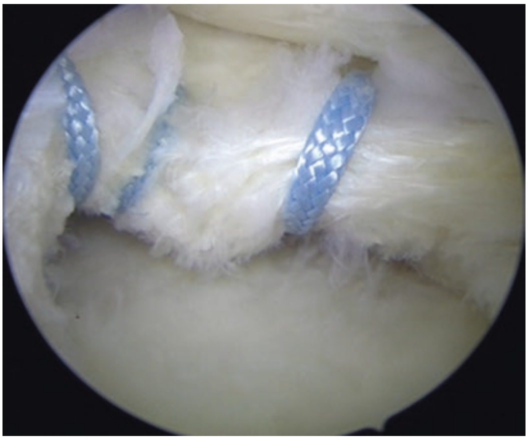

Fig. 16.10 Suture repair for the peripheral tear of the discoid meniscus

Postoperatively, protected motion and weight bearing followed by progressive mobilization and rehabilitation is necessary to restore the best knee function.

16.9 Treatment Outcome

Saucerization of discoid lateral meniscus tears can lead to excellent long-term functional results despite signs of osteoarthritic changes in the lateral compartment of the knee [46]. Arthroscopic partial meniscectomy with stabilization of the unstable remnant rim was effective in preserving knee function with few early degenerative changes during a midterm follow-up period. Subtotal meniscectomy is probably the only option for unsalvageable cases. There was no difference in outcomes among the partial meniscectomy, partial meniscectomy with suture repair, and subtotal meniscectomy groups. Less satisfactory functional outcomes may follow in children aged 10 years or older or when a reoperation has been performed [47].

Ten-year follow-up results of arthroscopic meniscectomies for symptomatic discoid lateral menisci presented no correlation between the type of meniscectomy (partial or total) and the clinical and radiographic results. Development of radiographic changes, such as minor osteophytes in the lateral compartment and less than 50 % narrowing of the lateral joint space, was found in 47–64 % of the patients. The reported clinical results were excellent or good in most of the patients [20]. However, most of these patients are very young and are faced with decreased function in early adulthood.

A long-term clinical and radiographic follow-up outcome of arthroscopic reshaping with or without peripheral meniscus repair for the treatment of symptomatic discoid lateral meniscus in children has been reported. Arthroscopic reshaping for symptomatic discoid lateral meniscus in children led to satisfactory clinical outcomes after a mean of 10.1 years. They found that progressive degenerative changes appeared in 40 % of the patients. The subtotal meniscectomy group had significantly increased degenerative changes compared with partial meniscectomy with or without repair [48].

High awareness of the clinician to the possibility of a discoid meniscus tear, its variable clinical presentations, and treatment considerations may improve its therapeutic outcome.

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Meniscal Allograft Transplantation: Updates and Outcomes

17

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© ISAKOS 2017
R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_17

17.1 Introduction

Osteoarthritis after removal of the medial meniscus was demonstrated in dogs in the 1930s [44] and in humans in the 1940s [24]. During the following decades, the important role of the menisci was confirmed in several clinical and experimental studies. The first animal studies on meniscal transplantation were carried out in the 1980s [8, 15]. Milachowski performed the first human MAT in 1994 together with anterior cruciate ligament (ACL) reconstruction in 22 patients from 1984 to 1986. This was an open surgery, and either gamma-sterilized lyophilized or deep-frozen grafts were used, and long-term results were published in 2002 [89]. In Belgium, Rene Verdonk started performing meniscal allograft transplantation in 1989, and his group has published important studies in this field [82, 84–86]. In the Netherlands, Herman de Boer and Ewoud van Arkel have published several studies on the outcome of MAT [77–79]. In the USA, John Garret started with MAT in 1986 [26]. Other important contributors in this field in USA have been Frank Noyes, Robert F. LaPrade, Bill Garret, Steve Arnoczky, Marlow Goble and Brian Cole. In Canada, Allan Gross and John Cameron started early with osteochondral and meniscal allografts [95]. From South Korea a large number of studies have been published [38, 40, 41, 46–48]. The list of contributors listed here is not complete, and many others have contributed in the evolving research on MAT.

After being originally regarded as experimental surgery, MAT has today become an established treatment method [58]. However, there are no randomized clinical trials (RCTs) or other comparative studies with a control group of conservatively treated post-meniscectomy patients. Several case series have shown good results following the procedure in the short and midterm, while long-term results are not well documented. Particularly, a preventive effect on the development of osteoarthritis (OA) has not been shown. The outcomes are less favourable with increasing cartilage degeneration at implantation, and the availability of meniscal grafts is limited. Proper patient selection is important to obtain optimal improvement in the patient's function and to ensure that the available meniscal allografts are reserved for patients with the highest potential benefit from the procedure. Studies are still lacking to determine the best way to perform graft processing, handling, surgery, and rehabilitation.

17.2 Graft Procurement

17.2.1 Laws and Regulations

The use of musculoskeletal tissue from donors for transplantations is regulated in detail in the USA and in Europe. In the USA, the Food and Drug Administration (FDA) sets the requirement for the tissue banks: All tissue banks have to be registered with the FDA, donor testing must be performed by screening and testing for communicable diseases and current good practice must be followed during the tissue processing (Food and Drug Administration 21 CFR Parts 207, 807, and 1271). In addition to the FDA regulations, the American Association of Tissue Banks (AATB) has accredited most of the musculoskeletal tissue banks in the USA. AATB has established further recommendations for the handling of allograft tissue (AATB Standards for Tissue Banking 14th Edition).

In the European Union (EU), the use of musculoskeletal tissue for transplantation is regulated by the European parliament through EU directives. However, national regulations may differ from these. The European Council representing 47 countries and the WHO have also provided guidelines for tissue transplantations, and national and international association of tissue banks all over the world has their own guidelines and ethical rules.

17.2.2 Donor Selection and Suitability

17.2.2.1 Eligibility

The first step in the process is to obtain consent from the potential donor's family. Most European countries have developed a so-called presumed consent from the donor, but require an additional consent from the family. In the USA persons who want to become donors provide their written consent before death. The next step is to assess the suitability of the donor. This includes a medical history where systemic autoimmune diseases, neurological disorders, genetic diseases, chronic infection, alcoholism and malignancy are general contraindications. There is no upper age limit regulated by law. The European guidelines have an upper age limit for meniscal allografts of 45 years. One US tissue bank (Joint Restoration Foundation) uses only donors under 35 years for meniscal allografts.

17.2.2.2 Physical Examination

A physical examination of the donor is an important step to identify donors with an increased risk for transmitting disease. Five percent of donors are excluded at this step.

17.2.2.3 Testing

The minimum requirements for biological tests of the donor include anti-HIV-1, anti-HIV-2, NAT HIV, HBs Ag, total anti-HBc, antibodies to HCV, NAT for HCV, antibodies to HTLV types I and II and syphilis which all must be negative for the donor tissue to be released.

17.2.3 Graft Harvesting

17.2.3.1 Time Limits

In the USA harvesting must be performed within 24 hours if the body has been cooled and within 15 hours if not and in Europe within 12 hours without cooling and 48 hours with cooling.

17.2.3.2 Facilities and Personnel

Graft harvesting should be performed in an aseptic environment. The handling personnel must have the appropriate training. Sterile draping and instrumentation must be used. After opening the knee, the menisci are inspected for damage. If suitable for transplantation, the meniscus is taken out with 2–3 cm section of the corresponding tibia plateau. The graft must be wrapped in an aseptic way and transported to the tissue bank. In the USA, further processing before freezing must be completed within 72 h.

17.2.4 Graft Treatment

17.2.4.1 Primary Processing of the Meniscal Allograft

The tissue must be tested for bacterial contamination by culture. Further processing includes physical debridement, mechanical agitation, ultrasound processes, alcohol solutions, rinses and antibiotic treatment [53] with the aim to remove blood and lipids and minimizing the risk for disease transmission and immunological reactions.

17.2.4.2 Graft Sterilization

All allografts have a potential for disease transmission, but the risk for transmission has been estimated to be very low, with between 1 in 173,000 and 1 in 1 million for HIV and 1 in 421,000 for hepatitis C for unprocessed grafts [53]. Different methods have been investigated to minimize this risk without hampering the properties of the graft. Cells will be destroyed by such methods, so fresh viable grafts and cryopreserved grafts are not sterilized.

Gamma radiation at 2.5 mrad or higher has been shown to negatively affect the biomechanical properties of menisci [90, 91]. It has been debated whether a lower dose could give sufficient sterilization with no or acceptable harm to the tissue. A recent experimental rabbit study showed a negative effect also with 1.5 mrad on scanning electron microscopy, but no difference in histology compared to non-radiated grafts [94]. Ethylene oxide has been shown to induce a persistent synovitis [32] and is not currently used. Peracetic acid sterilization has also been used but has been shown to harm the biomechanical properties and inhibit remodelling of ACL grafts in an animal model [66]. The same has been demonstrated for electron beam radiation which has been proposed as an alternative to gamma-radiation [67].

In summary, all secondary sterilization methods with sufficient virucidal and bactericidal effects are harmful to a meniscal allograft. Secondary sterilization is therefore no longer used by most tissue banks.

17.2.5 Graft Storage

There are four methods for graft storage: fresh viable grafts, cryopreserved grafts, lyophilized grafts and fresh-frozen grafts. The latter is the graft most commonly used today.

17.2.5.1 Fresh Viable Grafts

These grafts contain viable cells which in theory would be an advantage [83]. However, clinical studies have not reported better results with these grafts. Harvesting must be performed as soon as possible (varying from 4 to 12 h according to different authors). The graft must be kept at 4 °C for 10–14 days in the patient's serum while necessary donor testing and planning are performed. This short time frame poses a challenge in finding a suitable recipient and transporting of the graft to a distant hospital if needed. The risk of disease transmission is also regarded as higher compared to other methods.

17.2.5.2 Cryopreserved Grafts

With this technique the graft is immersed in a cryoprotective agent (usually glycol), a culture medium and an antiseptic agent. The graft is then slowly cooled to −196 °C. The cryoprotective agent stops the formation of ice crystals, and the grafts have been reported to have viable cells after thawing. The collagen network seems to be better preserved with this technique. However, the method is quite complicated and costly. Experimental [23] and clinical outcomes [30] have not been reported to be better with this method compared to others, and the method is little used today.

17.2.5.3 Lyophilization

This is a so-called freeze-dried meniscus. The tissue is frozen in a vacuum and dehydrated. The graft is thawed and rehydrated before implantation. It can also be stored at room temperature and the process allows long storage. There may be a negative effect on biomechanical properties [27], and clinically there seems to be a higher risk for effusion and synovitis [57]. Of note, this method is no longer used.

17.2.5.4 Fresh-Frozen Grafts

This is by far the most common method to store meniscal allografts today. The method is simple and possibly less immunogenic. After the initial processing, the graft is quickly frozen to −80 °C. Donor cells are destroyed by the freezing process. Grafts can be stored for up to 5 years. The lack of viable cells has not been reported to have a negative effect on the clinical outcome. The graft must be transported from the tissue bank to the implanting hospital as fast as possible in insulating package while keeping the graft frozen. At arrival the graft must immediately be placed and kept in a freezer at −40 °C or below until implantation.

17.2.6 Sizing of the Meniscus

17.2.6.1 Sizing of the Donor Meniscus

During the initial processing of the meniscus, the anteroposterior and mediolateral distances are measured. These are the most important measurements. In addition, the width of the meniscus itself at the anterior, middle and posterior parts can be measured (not all tissue banks do this).

17.2.6.2 Sizing of the Recipient

Several methods have been proposed for best possible sizing of the recipient. The sizing can be based on plain radiographs, CT, MRI of the same or contralateral knee or anthropometric measurements. Radiographs must have a calibrating sphere or a similar marker to obtain correct measurements. According to Pollard's method, the distance between a vertical line lateral/medial to the tibial eminence and a vertical line at the lateral/medial margins of the tibial plateau is measured in the coronal plane and the anteroposterior distance between a vertical line at the tibial tuberosity and the posterior tibia plateau in the sagittal plane. The width of the meniscus in the coronal plane corresponds to the measured distance, while the length of the meniscus in the sagittal plane is 80 % of the measured distance for the medial meniscus and 70 % for the lateral meniscus [62]. Yoon et al. found that this method overestimated the anteroposterior length of the lateral meniscus and suggested another formula: 0.52 × Tibia AP length (in mm) + 5.2 mm [92]. The measurements for the Pollard method can also be obtained with more exact results by CT scan but includes a higher radiation risk. MRI is regarded the gold standard and is widely used. Using MRI of the contralateral knee has also been advocated [93]. Van Thiel has recommended the use of the patient's gender, weight and height in a formula to estimate the size of the meniscus [81]. In a recent article by Yoon's group, they concluded that MRI is the best option to size a meniscus transplant graft. For the lateral side of the knee, anthropometric measurements according to van Thiel is an alternative, while the Pollard method is an alternative on the medial side [34].

17.3 Indications for Meniscal Allograft Transplantation

17.3.1 Indications

The ideal candidate for meniscal allograft transplantation is a patient with a painful knee following a total or subtotal meniscectomy with no symptoms of instability and with normal cartilage and normal alignment. The symptoms should be severe enough to justify a large operation with potential complications, including the risk of an inferior result. This usually means that the patient should have pain during daily activities and pain making sport activities impossible or difficult. In addition, the symptoms must correspond to the clinical findings, i.e. in the case where the medial meniscus has been resected, the symptoms should be located to the medial joint line. Other symptoms may be swelling or locking. The duration of symptoms should be of at least 6 months. The patient must be willing and capable to follow the rehabilitation programme following surgery. The patient should also do "prehab" which means training of knee function before surgery, preferably guided by a physiotherapist with the necessary knowledge and interest. This will make him/her better prepared for surgery, and in some cases the patient will improve so well that MAT may no longer be indicated at that point in time.

When there are cartilage injuries/defects present, MAT may still be indicated, but the prognosis is somewhat less favourable with a higher failure rate, and the patient needs to be informed about this [36]. In the authors' opinion, one can accept quite severe cartilage changes in a young patient, but should be more "strict" in patients over 40 years of age.

In the case of varus alignment in a medial meniscus-deficient knee, a valgus high tibial osteotomy is preferred as the first-line treatment. In most cases, this will relieve symptoms enough so a later MAT is usually not needed. Similarly, in the case of valgus alignment in a lateral meniscus-deficient knee, a distal varus osteotomy of the femur is usually the first treatment of choice, or it can be performed concurrently [45]. Some authors perform HTO together with MAT [35, 36, 85].

In cases of instability, this is usually corrected before or concurrent with a MAT. In failed ACL-reconstructed knees with deficient medial meniscus and no other obvious causes of graft failure, a concomitant ACL revision and medial MAT may be indicated.

17.3.2 Contraindications

MAT is usually not indicated in patients over age 50, although case series of MAT including patients in this age group have been reported [74]. In many patients over 40, there will be degenerative changes that contraindicate a MAT. Kellgren-Lawrence grade 2 and more (osteophytes and joint space narrowing) are also contraindications. Other contraindications are signs of infection, inflammatory joint disease and BMI above 35 [14].

17.4 Preoperative Issues

17.4.1 Examinations and Investigations

The first step is to obtain a thorough history from the patient. When did the injury occur? What are the symptoms today? What can the patient do and what can he/she not do? It is very important to ask the patient what he/she wants to do and what his/her expectations following surgery are. If there is a discrepancy between the patient's expectations and what can be obtained with surgery, it is very important to help the patient to have realistic expectations, by providing thorough information. Previous surgical reports from other hospitals should be collected. The patient should fill in an appropriate patient-reported outcome measures (PROMs) like Lysholm score, Cincinnati score, KOOS score, or others. An activity score like the Tegner score or similar should also be used. This will help in the preoperative evaluation of the severity of the symptoms, will help in the decision for surgery, and can be compared with post-operative scores at a later stage as part of the quality control of the results of MAT in the institution.

The clinical exam must include a thorough inspection of the limb axis, gait and other factors. The knee is inspected for swelling and muscle atrophy and examined for laxity, direction of possible laxity and tenderness, particularly along the joint lines. All patients where MAT is considered should have standing x-rays with 30° of knee flexion to evaluate the joint space and osteophytes. Long-standing radiographs from the hip to ankle with extended knees should be obtained to evaluate alignment. Recent MRIs should be evaluated or new MRIs obtained to evaluate the status of the menisci, cartilage, ligaments and other structures. The authors prefer in most cases to perform a diagnostic arthroscopy to obtain a complete status of the knee to confirm that the meniscus status is not better than anticipated and that the condition of the cartilage and ligaments does not contraindicate a MAT before a meniscus allograft is ordered from the tissue bank.

17.4.2 Obtaining a Meniscus Allograft

For most surgeons a fresh-frozen meniscus allograft is ordered from a certified tissue bank. The surgeon should have good knowledge about their tissue bank, the procedures around the harvest of the graft and how the graft is processed, stored and transported. He/she should also have good knowledge of the rules and regulations related to tissue transplantation. The sizing of the graft is based on MRI or radiographs with a size marker [69, 93]. This is usually done by the tissue bank. Once the tissue bank has a meniscus of suitable size for the patient, an offer is sent to the surgeon. The surgeon should check and compare the given measurements of the donor graft and the recipient, verify it is the correct side and then accept or not accept the graft. Usually a size mismatch up to 5 % is regarded as acceptable [93]. Once the graft is received, the identification should be checked and the graft stored at –40 °C or below until implantation.

17.5 Surgery

The surgery is usually performed under general anaesthesia. Epidural or peripheral (femoral-ischial) nerve blocks are often used in addition for post-operative pain control. The leg is draped in a standard fashion for knee surgery. Some surgeons prefer a Gilchrist holder around the thigh with a hanging lower leg; others place the leg on a flat table with a foot support and side support to the lateral side of the thigh. A tourniquet may be used to control bleeding. Systemic prophylactic antibiotics are administered to the patient intravenously according to the local recommendations for the hospital.

17.5.1 Surgical Technique

Many different techniques have been described for MAT. Open, arthroscopic and partly open/partly arthroscopic methods are used. Bony or soft tissue fixation is used with or without bone tunnels. There are no RCTs or other studies that have shown that one technique is superior to others. Therefore, the technique will be the preferred choice of the surgeon, often with personal modifications. Most surgeons would start the procedure with an arthroscopic examination of the knee. Then the remnants of the meniscus are removed by a basket punch and/or shaver. It is important to preserve the outer fibrous rim to maintain the "barrel band" function of the meniscus.

17.5.2 Medial Meniscus Allograft Transplantation: Bone-Plug Technique

17.5.2.1 Graft Preparation

The graft comes with the meniscus attached with its posterior and anterior roots to the tibial plateau bone block. This technique, with small variations, has been described by several authors [1, 21, 39, 42, 45]. The bone blocks are prepared by drilling a pin through the bone block exiting through the meniscal root attachments. Then a collared guide pin (Fig. 17.1) is inserted into the hole created by the pin which is then over-drilled with a 9 mm coring reamer to prepare the two bone plugs. The plugs should not be too long, with the posterior bone plug around 8–10 mm in length to facilitate the later introduction into the joint. Non-absorbable sutures are placed in the posterior and anterior root and through the central pin hole in the bone blocks. Sutures are also placed in the posterior and anterior part of the meniscus (Fig. 17.2). The authors prefer 4 non-absorbable vertical sutures in the posterior part and anterior part, each 5 mm apart. This leaves a part in the middle without sutures. Usually the meniscal allograft is immersed in an antibiotic bath or swab. The type of antibiotics should be selected in cooperation with local microbiologists/infection specialists.

17.5.2.2 Placement of the Meniscus Allograft

Using arthroscopic technique, the posterior root attachment site is visualized. Careful use of shaver, radiofrequency and a mini "notch plasty" under the PCL can create the necessary space and visibility. Perforating the MCL with a needle while holding a valgus pressure can open up the medial compartment slightly and thereby increase visualization and enhance access. The posterior tunnel is drilled by placing an ACL-tibial guide (or similar specially designed "meniscal root" guides that are available) at the posterior root attachment, drilling a guide pin, and a 9 mm tunnel is drilled over the guide pin. A small longitudinal arthrotomy is made medial to the patellar tendon continuous with the medial arthroscopy portal. The ante-

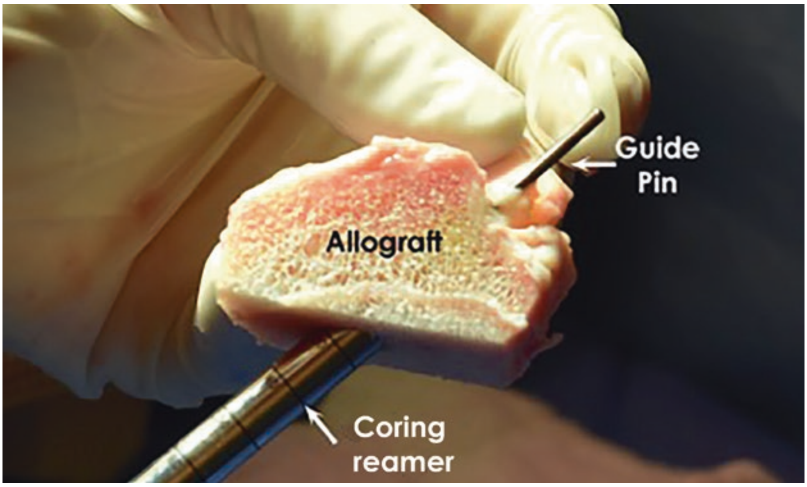

Fig. 17.1 Figure showing the creation of bone plug using a coring reamer over a collared pin

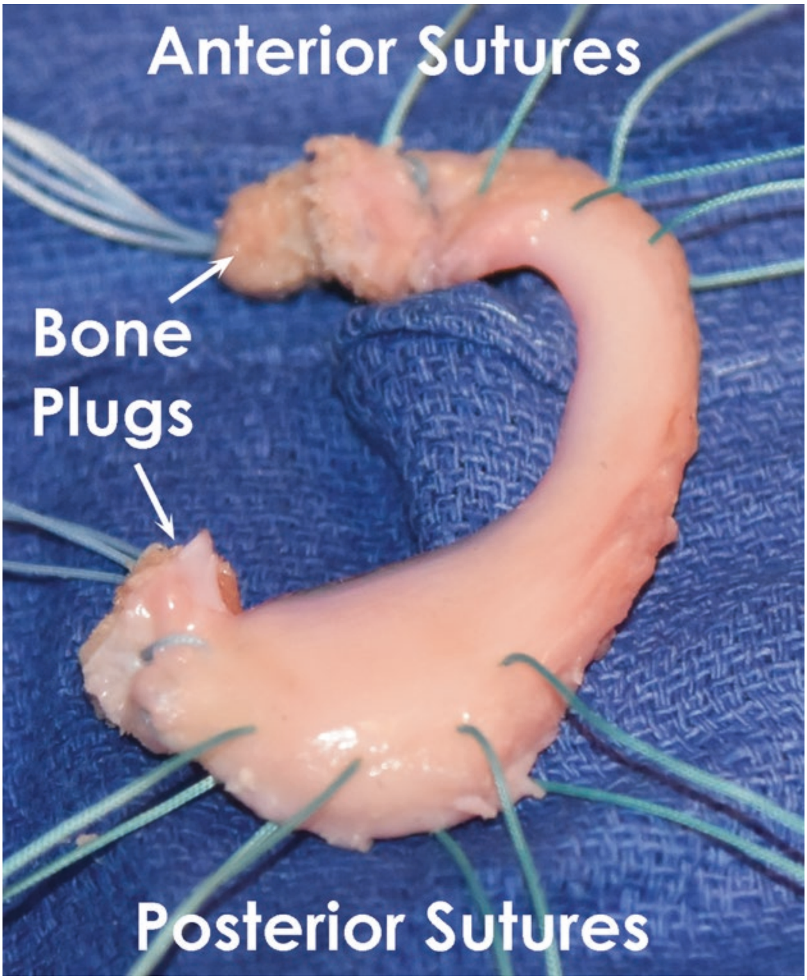

Fig. 17.2 Medial meniscus allograft with bone plugs and sutures placed in posterior and anterior horns

rior root attachment is exposed, and an 8 mm blind tunnel is drilled over a guide pin placed central in the root attachment. Usually, this tunnel is reamed after the MAT is placed into the knee in case the native root attachment location does not precisely match the MAT. By the use of a drill or awl, a small canal from distal and into the bottom of this tunnel is created for the passage of sutures. A posteromedial longitudinal incision is made and the posteromedial capsule is exposed by creating a space between the medial gastrocnemius muscle and the capsule. A spoon or similar instrument is used to protect the posterior structures. Four passing sutures are passed from inside in the posterior part of the joint space corresponding to the sutures placed in posterior part of the allograft, through the capsule and out in the posteromedial incision using a clamp or a suture passer. Then the meniscus graft is introduced into the joint by first pulling the posterior sutures through the bone tunnel and the posterior capsule with the first placed passing sutures. Numbered hemostats can facilitate future tying of the sutures. Then the meniscus is gently pulled in place. The insertion of the posterior bone plug into the tunnel may be facilitated by the use of a hook or a grasper. The anterior bone block is inserted into the anterior tunnel. The sutures are tied against the capsule posteriorly. The anterior part of the meniscus is sutured to the anterior capsule by open surgery with free needles. The sutures from the bone blocks are sutured over a button or the bone bridge between the tunnels. Finally, the middle part of the meniscus without preplaced sutures is sutured by vertical mattress sutures with inside-out sutures with long needles.

17.5.2.3 Variations of This Technique

Some surgeons use one bone plug in the posterior end and only soft tissue in the anterior end. This will allow for adjustment of the meniscus tension in cases of size mismatch [51, 76]. The suture placement can also vary. Some use fewer preplaced sutures in the graft and more inside-out sutures after placement of the graft. Some surgeons use all-inside suture systems [4]. The external tunnel opening in the tibia can be anteromedial or anterolateral depending on the surgeon's preference. The bone plugs may also be created with the use of other techniques.

17.5.3 Medial Meniscus Allograft Transplantation: Soft Tissue Technique with Bone Tunnels

In many of the steps, this method is similar to the bone-plug technique [1, 6, 65, 72]. When using only the meniscus root attachments without bone, it is important that these attachments in the allograft are well preserved and of good quality. The sutures need to be placed in a fashion to ensure a secure hold in the anterior and posterior roots of the meniscus. According to surgeons using this technique, this allows for adjusting the tension/outer diameter of the meniscus to fit with the condyles. With this technique the meniscus can be introduced into the joint through a smaller opening without an arthrotomy.

17.5.4 Lateral Meniscus Allograft Transplantation: Bone Bridge Techniques

The root attachments of the lateral meniscus are very close to each other. By keeping the roots of the allograft attached to a bone bridge, the correct distance between these attachments can be maintained with the root attachments connected by the bone block. As with a medial MAT, the first part of the operation is a diagnostic arthroscopy, followed by removal of meniscus remnants with care to preserve enough of the outer fibrous rim. The bone bridge technique with variations has been described by several authors [17, 43].

17.5.4.1 Graft Preparation

With the dove tail technique [17], the bone block is prepared by the use of a specially designed cutting system (Fig. 17.3) creating a trapezoid-shaped (viewed in the anterior-posterior direction) bone block. The block is trimmed so that it fits into the corresponding "sizer" (Fig. 17.4). Sutures are placed in the meniscus substance in the similar way as in the bone-plug technique above.

17.5.4.2 Placement of the Meniscus Allograft

A posterolateral longitudinal skin incision is made just posterior to the fibular collateral ligament (FCL), the iliotibial tract is opened in the direction of the fibres and the capsule is exposed by creating a space between the capsule and the lateral gastrocnemius muscle. A spoon or similar instrument is placed between the capsule and the posterior structures to protect the neurovascular structures. Four passing sutures are placed in the same way as described for the medial side bone-plug technique.

An anterolateral arthrotomy is performed through an incision lateral to the patellar tendon as an extension of the lateral arthroscopy portal.

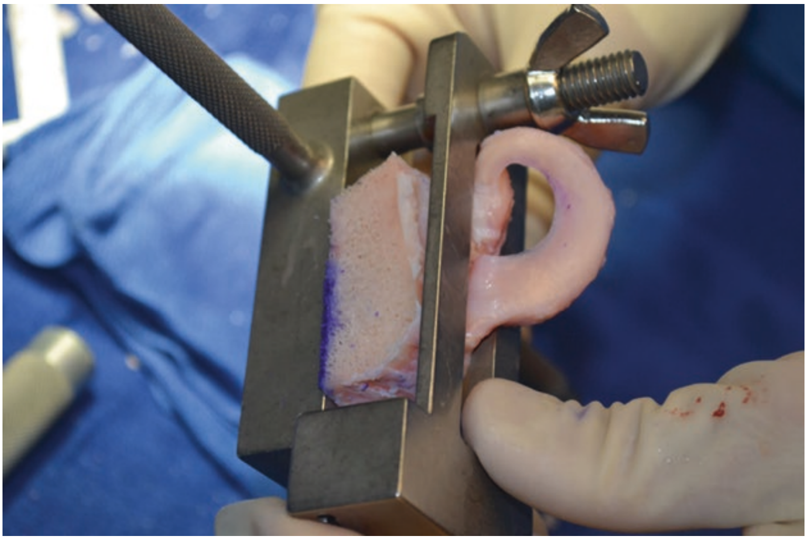

Fig. 17.3 Lateral meniscus allograft bone block in work station for cutting

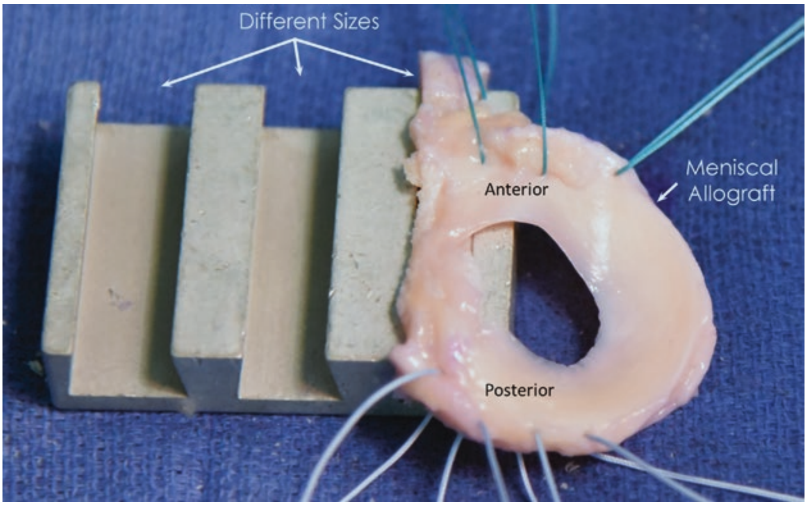

Fig. 17.4 Measurement of bone block of lateral meniscal allograft. Three sutures (*green*) have been placed through the anterior horn and four sutures through the posterior horn

A similarly trapezoid-shaped trough is created in the tibia in the anterior-posterior direction through the root attachments. This is done by first removing the protruding tibial spine between the roots and then tapping in a chisel with a guide pin on top to achieve the correct depth. The rest of the remnant bone in the trough is removed first by drilling and then shaped by the use of trapezoid-shaped rasps of similar size as the bone block. The posterior cortex of the tibia is preserved. The meniscus is introduced by first pulling the pre-placed sutures in the posterior part of the meniscus through the capsule, then passing the bone block into the trough and simultaneously pulling gently in the sutures till the meniscus is in place. With a bone block that fits well into the trough, the bloc will now be stable. The sutures are tied and placed in the same fashion as for the medial meniscus bone-plug technique.

17.5.4.3 Variations of This Technique

Some authors prefer a rectangular-shaped bone block and securing the block with sutures in the anterior and posterior end through bone tunnels [68]. A technique using an interference screw for fixation of the bone block has also been described [25]. With these techniques the stability of the bone block is less dependent on an exact fit into the trough.

17.5.5 Lateral Meniscus Allograft Transplantation: Soft Tissue Technique

Several authors have published the use of soft tissue fixation of the anterior and posterior horns through bone tunnels and suturing the meniscus to the capsule as described for the medial meniscus soft tissue technique [2].

17.5.6 Lateral Meniscus Allograft Transplantation: Bone-Plug Technique

Lateral MAT is most commonly performed with a bone bridge or soft tissue fixation of both horns in tibial tunnels. The proximity of the root attachments makes it difficult to use two bone plugs, but this technique has been presented by some authors [2].

17.5.7 Open Technique for Meniscal Allograft Transplantation

Meniscal allograft transplantation started with an open technique in the 1980s, but is now less common. For the both lateral and medial side, an arthrotomy is performed with bony detachment of the ligamentous complex from the femur for access. The detached ligament with bone is refixated to the femur at the end of the procedure. Soft tissue fixation of the anterior and posterior horns can be performed with sutures through tibial tunnels [22, 87] or with fixation of the roots to the remnants of the original meniscal root attachments without tunnels [85].

17.5.8 Combination with Other Procedures

MAT can be performed in combination with other procedures in the same knee either concomitantly or as a separate procedure. The most common procedures are ACL reconstruction, ACL revision and tibial or femoral osteotomy. In selected cases cartilage procedures as autologous chondrocyte implantation or osteochondral transplants can be performed. Describing these techniques is beyond the scope of this chapter.

17.5.9 Discussion of Differences Between the Techniques

As mentioned, there are no RCTs comparing different techniques, and the preferred technique will be the personal preference of the surgeon with soft tissue techniques usually regarded as quicker and easier to perform. However, there are some issues to be discussed regarding choice of technique.

17.5.9.1 Clinical Outcome

Most published studies in clinical outcome are case series with no control group. In general, the clinical outcome using PROMs is good both in the short and midterm for all techniques. In a study of patients with lateral MAT, patients with a graft fixed with the bone bridge technique had significantly better range of motion compared with patients having the graft fixed with soft tissue sutures in bone tunnels [68].

17.5.9.2 Graft Extrusion

Graft extrusion means that the implanted meniscus is displaced externally leaving more of the joint surface exposed. This will in theory increase the risk for later OA, but a negative effect of extrusion on clinical scores has not been demonstrated to date. One study compared bony versus soft tissue fixation in bone tunnels and found no difference in clinical outcome, but more graft extrusion in the soft tissue group [1]. Another study showed a higher extrusion rate in patients treated with an open technique with soft tissue fixation without bone tunnels compared to arthroscopic soft tissue fixation in bone tunnels [20]. In a multivariate study of graft extrusion in a series of lateral MAT with bone bridge technique, significant risk factors for the major graft extrusion (more than 3 mm) included delayed time from previous meniscectomy to MAT and increased axial plane trough angle measured on MRI [3].

17.5.9.3 Radiological Outcome

In the prospective study by Abat et al. [2], there was no significant difference in radiological outcome regarding joint space narrowing between the bone-plug group and the soft tissue fixation in bone tunnel group at mean 5 years.

17.5.9.4 Complications, Failures and Reoperations

The same study by Abat et al. reported 33 % complications and 9 % failure rate in the soft tissue fixation group and 16 % complications and 3.6 % failures in bone-plug group [2].

17.5.9.5 Experimental/Biomechanical Studies

Some studies have reported that bone-plug fixation in tunnels restores tibial contact pressure better than soft tissue fixation in bone tunnels or with a bone bridge [7, 19]. In a later similar study, only a slight advantage for the bone plugs on contact pressure was found [54]. In a study of pull-out strength, no difference was found [31].

17.5.10 Conclusion

Medial meniscal allograft transplantation is today most commonly performed with two bone tunnels with either soft tissue fixation or bone plugs. On the lateral side, the most common technique is either a bone block connecting the anterior or posterior horns or soft tissue fixation in two bone tunnels. No technique has been shown to be superior regarding clinical outcome. Soft tissue fixation seems to give more extrusion of the meniscus than bony fixation in post-operative MRIs.

17.6 Rehabilitation Following Meniscal Allograft Transplantation

The aim of the rehabilitation is to get the patient as soon as possible back to his/her preinjury functional level without compromising the healing of the implanted graft.

17.6.1 Factors Influencing the Rehabilitation Programme

Animal studies have demonstrated that vascular ingrowth in an injured native meniscus is impaired by immobilization and that early mobilization leads to a stronger repair tissue [13]. Clinical studies support these findings [55, 70]. In a sheep study, Milachowski showed complete healing of lyophilized and fresh-frozen meniscal allografts at 48 weeks with remodelling occurring only in the lyophilized menisci and less vascular ingrowth occurring in the fresh-frozen menisci [57]. Fresh and cryopreserved meniscal allografts in a goat model showed peripheral healing, revascularization, cellularity and incorporation at 6 months [33]. From these studies we can assume that complete healing of a human meniscus allograft may take between 6 months and 1 year.

Both the peripheral capsular fixation and the meniscal root fixations are at risk for reinjury postoperatively. Weight bearing with an extended knee imposes load on the meniscal roots which increases through flexion up to four times at 90° of knee flexion [9]. In open kinetic chain exercises, high tibial contact forces have been estimated [56]. Repetitive low loading of meniscal transtibial root repairs has been reported to increase displacement of the repaired roots [63]. Applying moderate tensile forces at repaired medial meniscal roots has been reported to easily reach a magnitude that exceeds the strength of fixation [73].

These and other biomechanical studies support that rehabilitation following MAT should include restricted weight bearing, restricted ROM and restricted use of open chain exercises. Even though a high risk of allograft loosening may be feared from these experimental studies, the clinical experience is that a total loosening of an implanted meniscal allograft is rare. However, extrusion, which is common, may be a result of displacement of the meniscal root fixation.

17.6.2 Rehabilitation Programme

Rehabilitation programmes have traditionally been divided into phases.

Rehabilitation protocols following orthopaedic interventions are progressed through sequenced phases and include active interventions aimed at addressing body impairments and functional limitations [11]. The primary aim is to timely progress the patient towards participation in their desired physical activity and sport, while simultaneously protecting the healing tissue from premature overloading. Current orthopaedic post-operative rehabilitation is progressed through the different phases based on sound clinical reasoning, sequenced functional achievements and the completion of functional milestones. At the same time, knowledge on tissue-specific biologic healing processes must be respected and will guide the early timeline of advancement [28]. Four rehabilitation phases are traditionally outlined:

1. The acute post-operative phase aiming at minimizing impairments
2. The rehabilitation phase aiming at restoring normal activities of daily living
3. The return to sport phase aiming at resuming desired sports activities
4. Prevention of reinjuries:
    - Most surgeons performing MAT recommend a rehabilitation protocol in line with the following restrictions [45] with some local modifications. Toe touch weight bearing in a brace locked in extension for the first 6 weeks with gradual transmission to full weight bearing from week 6 to 8.
    - Straight leg exercises in the brace are allowed from day 1.
    - The knee brace is locked the first week. From week 1 to 3, passive and active flexion and extension exercises without external load are allowed as tolerated between 0 and 90 degrees. From week 4, gradual increase to full range of motion is encouraged without application of external force.
    - Cycling is initiated after 8 weeks provided unrestricted knee flexion of 100°.
    - No open chain muscle strengthening exercises before 3 months after surgery.
    - No running or other activities with impact before 6 months after surgery.
    - Activities involving pivoting motions and pivoting sports are generally advised against and should under no circumstances be initiated before 9 months after surgery.

Rehabilitation following a MAT first and foremost consists of a targeted exercise programme. Phase 1 is prolonged compared to most other surgical procedures due to restricted weight bearing and ROM. The principles within the acronym POLICE (protection, optimal loading, ice, compression and elevation) are primary tools following any orthopaedic surgical procedure [12]. However, exercise therapy has effects both at a local tissue level and in the central nervous system and should be used as a direct tissue healing stimulation (mechanotherapy) [37]. Concurrently, general conditioning and optimization of function within the allowed load and movement limitations is performed. Patients are guided by physiotherapists to perform daily home-based exercises involving isometric muscle activation and active low-load ROM mobilization exercises. Restoring passive and active knee extension is imperative during this phase. Electrical neuromuscular stimulation is frequently administered to enhance active muscle contractions. Active rehabilitation exercises are often supplemented with medical and manual therapies that may enhance the effects of exercise through pain management and improved tissue adaptations. The success of rehabilitation is dependent on introducing the most effective intervention at the correct time in adequate dosage [11].

In Phase 2 of the rehabilitation, the focus will shift from joint and muscle impairments to gradually increase the complexity of movements from single joint controlled actions to more complex tasks, including movements through several biomechanical planes. During the initial full weight-bearing period, the programme will mainly incorporate elements to improve motor control and muscle strength [61]. Specifically, exercises to regain motor control of weight-bearing single-leg stance and terminal knee extension (0–20°) are emphasized to facilitate normalization of walking. Furthermore, quadriceps and hamstring muscle strengthening is focused in combination with gluteal and adductor closed chain exercises. Additional sessions of no-impact cardiovascular training should be incorporated to continue healing of the implanted tissue, with the additional benefit of an increased fitness level.

For a large proportion of patients undergoing a MAT procedure, returning to high-impact or pivoting sports is not realistic [60]. Most patients will experience the short- and long-term benefits of symptom relief and improved function in activities of daily living. However, some may improve substantially and want to pursue high-impact and/or pivoting sport activities. Then, more traditional strength and conditioning training will be incorporated in the weekly rehabilitation programme. The focus on more complexity, velocity and jumping and landing tasks will increase. A higher rate of force development and introduction of sport-specific exercises is emphasized with a gradual progression into on-field training. However, close monitoring of residual symptoms such as joint effusion and/or pain must be continued. Reappearance of symptoms should lead to a discussion on abandoning the aim of resuming strenuous sport activities, which in itself may be the most important action for prevention of a failed meniscus allograft (Phase 4).

17.7 Outcomes of Meniscal Allograft Transplantation

The role of the meniscus in joint preservation, load distribution, lubrication and kinematics has been thoroughly studied [49, 50, 59]. Meniscectomy is reported to increase contact pressures in the condyles by 235 % and partial meniscectomy increases condyle pressures by 165 %. Increased contact pressures and joint instability have a negative effect on the longevity of the knee joint. In recent years there has been an increasing interest in meniscus preservation procedures. Despite improved techniques, the meniscus is not always amendable to repair, and hence a meniscectomy is inevitable.

Meniscus allograft transplantation has been introduced to address the problems associated with meniscectomy. Several studies are published on the outcomes of meniscal allograft transplantation (MAT), but most studies are of low quality (retrospective studies with few patients). In a systematic review by Rosso et al. [64] considering 55 articles, none of the studies were level 1, 2 studies were level 2, 7 as level 3 and 46 as level 4. The mean Coleman methodology score of the 55 included articles was 49.7 (24–81). The reported clinical outcomes using patient-reported outcomes (Lysholm, Tegner, IKDC), return to sports and activity after MAT, radiographic outcomes and complication will be discussed.

17.7.1 Patient-Reported Outcomes

Several knee scoring systems are reported in the literature including the Lysholm score, Tegner, visual analog scale for pain and/or overall knee function, International Knee Documentation Committee (IKDC) subjective and objective forms, Knee Injury and Osteoarthritis Outcome Score (KOOS), Short Form-12 (SF-12) or SF-36, Noyes sports and symptoms score, the modified Cincinnati score, the Fulkerson knee score, the Hospital for Special Surgery score, the Western Ontario and McMaster Universities Osteoarthritis Index 7 (WOMAC), the Knee Assessment Scoring System and the Knee Outcome Survey.

Rosso et al. [64] reported in a recent systematic review that the knee function evaluated by the weighted average Lysholm score improved from 55.5 ± 2.1 to 82.7 ± 2.7 and the weighted average pain VAS decreased by 4 points from 6.4 ± 0.4 to 2.4 ± 0.4. All studies reported an improvement at follow-up, suggesting good clinical outcomes at short-term to midterm follow-up. In their systematic review of the 18 studies that compared outcomes for medial and lateral MATs, there were no significant differences except in two studies that reported shorter survival for medial MAT. There was no significant difference between isolated MATs and MATs combined with other procedures and between fixation methods (soft tissue vs. bone block). Some authors have reported an increased risk of meniscal extrusion with soft tissue fixation [1].

In a recent systematic review, Smith et al. evaluated outcomes after MAT in 35 studies including 1332 patients (1374 knees) with a mean follow-up of 5.1 years [71]. The mean Lysholm score improved from 55.7 to 81.3, IKDC scores from 47 to 70 and Tegner activity score from 3.1 to 4.7. A Lysholm score of 65–83 is defined as fair [75]. In the same systematic review, Smith et al. [71] reported failure rates of 10.6 % at 4.8 years and complication rates of 13.9 % at 4.7 years.

17.7.2 Survival Rates

Verdonk et al. reported a survival time of 11.6 years using the cumulative Kaplan-Meier survival rate in 100 patients treated with MAT [85]. There was no difference in failure rates between the medial and lateral meniscus. Failure rates have been reported to increase with time, with van der Wal et al. [80] reporting a 52 % survival rate at 16 years. There are conflicting results on the success rate and survivorship depending on the side. Verdonk et al. reported a cumulative 10-year survival rate of 74 % for the medial side and 70 % for the lateral side [85]. However, van Arkel et al. [78] reported higher success rates for the lateral side (88 %) compared to the medial side (63 %) in a follow-up of 63 patients with a mean follow-up of 60 months.

17.7.3 Radiologic Outcomes

Smith et al. reported a weighted mean joint space narrowing of 0.032 mm across all studies at a mean follow-up of 4.5 years in their recent systematic review. These changes were not significant. Most studies report meniscal extrusion on MRI, but the correlation of meniscal extrusion to clinical outcomes is not clear. Most studies report no correlation, but Yoon et al. found an association between meniscal extrusion and Lysholm score. The grading of meniscal extrusion differs between studies. While some studies report the relative percentage of extrusion of the meniscus allograft extending beyond the edge of the tibial plateau, some studies report absolute measurement of extrusion in millimetres. Some studies use the 3 mm cutoff to describe extrusion, with <3 mm defined as minor extrusion and >3 mm as major extrusion. Regardless of the grading system, most studies report meniscal extrusion on MRI follow-up. There are conflicting reports in the literature on which meniscus allograft has a high risk of extrusion (medial vs lateral), but there seems to be no significant difference. Only a few studies have evaluated the progression of meniscal extrusion on MRI over time. Verdonk et al. [86] reported progressive meniscal extrusion from 1 year to 12 years in 59 % of the patients. Another study reported increase in meniscal extrusion from 2.7 mm at 6 months to 3.6 mm at 4.4 years follow-up [65].

Whether MAT is chondroprotective is still a subject of debate. Most studies on this topic have small cohorts and short follow-up and might not be able to detect the chondral changes of osteoarthritis that happen over time. Chalmers et al. [18] reported no change in Kellgren-Lawrence (K-L) grading in 5 of 10 patients (50 %) at 3.3 years, while Ha et al. [29] reported no change in K-L grade in 78 % at 2.6 years and worsening in 22 %. Vunderlinckx et al. [88] reported no change in K-L grade in 58 % after a mean follow-up of 8.8 years.

The radiographic changes depend on the imaging modality, grading system and the follow-up time. Carter et al. [16] reported no change in 94 % of the patients at 2 years, while there were degenerative changes at 10 years. In a long-term follow-up study of 23 patients, six patients had grade 2 degenerative changes, and five patients had grade 3 degenerative changes at 14 years. All patients with degenerative changes had received lyophilized grafts, and the mean Lysholm score was 75 at 14 years [89].

Good healing rates are reported based on MRI and second-look arthroscopy. Van Arkel et al. reported higher healing rates evaluated by arthroscopy than MRI, suggesting that MRI may underestimate healing of the meniscal allograft [79]. Some studies reported up to 100 % healing evaluated on MRI [10, 47, 52]. Ha et al. reported a 72 % healing and 28 % partial healing, while van Arkel reported complete healing in 63 %, partial healing in 26 % and no healing in 11 %. On second-look arthroscopy, the patients evaluated as partially healed on MRI were healed, and those evaluated as no healing were partially healed.

17.7.4 Return to Sports

Few studies address the issue of return to sports after MAT. There is still no consensus as to when players can return to preinjury activities. There is also a debate whether a patient should return to sport at all after MAT. Alentorn-Geli et al. reported an 85.7 % return to sports after 15 MATs on soccer players [5]. Chalmers et al. [18] have also reported high rates of return to sports, with a 77 % rate of return to preinjury level of performance in 13 high-level athletes. As with several other MAT studies, the limitation is the sample size and the retrospective nature of the studies.

17.7.5 Complications

The complication rates vary a lot in the literature depending on the authors' definition of failure. Rosso et al. reported a weighted average complication rate of 10.6 % in their systematic review, with tear of the graft being the most common (60 %) of all complications. Higher failure rates are reported in the cryopreserved meniscus allografts than the fresh-frozen grafts. Some authors have argued that the fixation type on the medial side, soft tissue versus bone block, could affect the observed results. Bone block fixation theoretically provides better fixation, improved healing potential and a reduced risk for extrusion. This is important in restoring the joint biomechanics and loading. However, Rodeo reported higher histological scores in suture only MATs compared to bone plugs. Clinical studies have not reported any difference in patient-reported outcomes between the two fixation methods. However, suture technique was associated with higher failure rates including meniscus extrusion and high complication rates [1].

Conclusion

In summary, the studies reporting results after MAT are mostly level 3 and 4 studies (case series). Clinical results are good in the short and midterm. Radiological studies show a high percentage of meniscal extrusion on MRI, but this does not correlate with clinical outcome. Bony fixation is associated with less extrusion than soft tissue fixation. There is little joint space narrowing in the short and midterm, but significant after 10 years. Complication rates are around 10 %, with graft tear being the most common [45].

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Erratum to: All-Inside Meniscal Repair: Updates on Technique

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Erratum to:
Chapter 9 in: R.F. LaPrade et al. (eds.),
***The Menisci*,**
DOI 10.1007/978-3-662-53792-3_9

In the original version of chapter 9, the chapter author's last name was wrongly given as Cardoso, but it should be given as Pereira Cardoso. The name of the author should be read as Tulio Pereira Cardoso.

The updated original online version of the chapter can be found at DOI 10.1007/978-3-662-53792-3_9

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3_18

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R.F. LaPrade et al. (eds.), *The Menisci*, DOI 10.1007/978-3-662-53792-3