Meniscal Allograft Transplantation

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Contents

26.1 Introduction

Meniscal tears are the most common knee injuries, with a reported annual incidence of 61 per 100,000 people [1]. For years meniscectomy has been considered the gold standard treatment for meniscal lesions, due to the lack of knowledge regarding the role of the meniscus and the long-term effects of its deficiency. In fact nowadays, it is well known that even partial deficiency of the meniscus could be destructive for knee joint at long term. It is reported that meniscectomy increases the risk of developing knee osteoarthritis after 10 years of about 20 % for medial meniscus and 40 % for lateral meniscus [2] (Fig. 26.1). This is due to its important and irreplaceable functions, such as increasing congruity of the joint, reducing contact stresses, shock absorption, stabilization, proprioception, and cartilage lubrification and nutrition [3, 4]. For these reasons the management of meniscal tears changed

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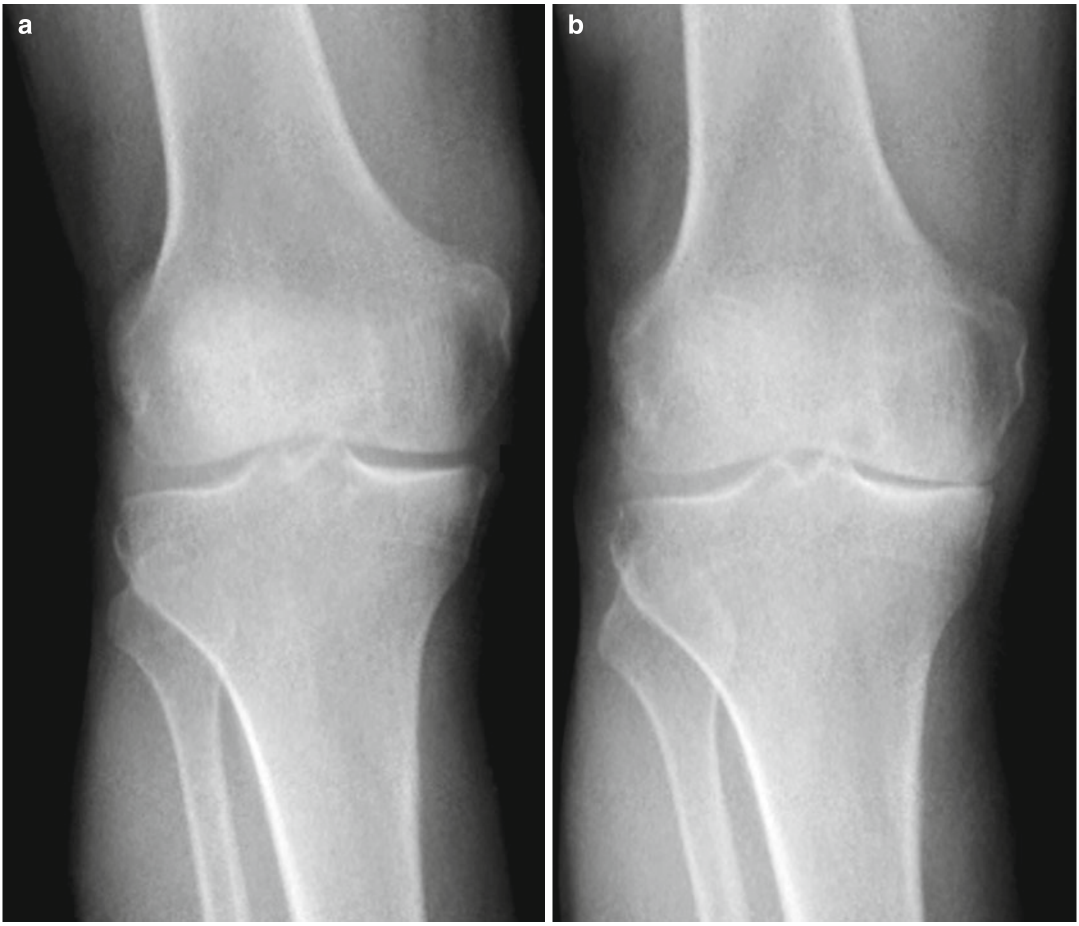

Fig. 26.1 Anteroposterior radiographs of the knee before (**a**) and 10 years after a medial meniscectomy (**b**). Reducing of medial joint space is evident

dramatically over the years, from aggressive toward more conservative strategies. In this background meniscal substitution with allograft and more recently with scaffolds has been proposed in case of irreparable lesions.

The first meniscal allograft transplantation (MAT) was performed in 1984 by Milachivski, who reported after 5 years the results of 23 MAT associated with anterior cruciate ligament (ACL) reconstruction [5].

Since then, huge progresses have been made regarding techniques, graft processing, patient selection, and evaluation, and thousands of patients have been treated with MAT in about 30 years [6]. Although there are a high number of studies reporting good outcomes and acceptable incidence of minor complications of this treatment, there is still controversy in considering MAT as experimental or gold standard treatment for postmeniscectomy symptomatic patient, as recently proposed [6].

Moreover, there is not a standard technique to perform MAT, and various authors supported by experimental and in vitro studies proposed different options to process, size, and fix the graft. Most of the authors proposed also different indications to MAT, associating or not associating concomitant surgeries.

As we can see the meniscal allograft transplantation is still a controversial issue that needs more accurate and high-quality studies in order to clarify its real benefits and its potential chondroprotective effect.

26.2 Patient Selection and Preoperative Evaluation

Surgery for the meniscus-deficient knee should be considered only after exhausting all nonsurgical measures. Nonsurgical treatments of patients who have undergone meniscectomy include unloading braces, encouraging nonimpact activities, and medications. When these measures fail to provide relief of symptoms or to prevent joint space narrowing, MAT may be considered [7].

Accurate selection of patients and both clinical and radiological evaluation are mandatory in order to obtain a good result and prevent early failure.

26.2.1 Indications

The indication for meniscal allograft transplantation has yet to be comprehensively defined. There is no consensus regarding inclusion or exclusion criteria; therefore, MAT could be suggested in a patient that meets all the following features:

- Young age (<55 years)
- History of meniscectomy
- Pain localized to the meniscus-deficient compartment
- Stable knee joint
- No malalignment (<2° of deviation toward affected compartment, as compared with the contralateral mechanical axis)
- Articular cartilage with minor evidence of degenerative changes (<grade 3 according to International Cartilage Repair Society classification or <III° according to Outerbridge classification) (Table 26.1)

MAT could also be performed in ACL-deficient patient with history of medial meniscectomy in conjunction with concomitant ACL reconstruction, as it has been reported that associated MAT improves laxity when compared to isolated ACL reconstruction [8].

Table 26.1 Description of Outerbridge grading for cartilage damage

Grade	Description
Grade 0	Normal cartilage
Grade 1	Cartilage with softening and swelling;
Grade 2	Partial thickness that do not reach subchondral bone
Grade 3	Fissuring to the level of subchondral bone
Grade 4	Exposed subchondral bone

26.2.2 Contraindications

Generally the most common contraindication to MAT is advanced chondral degeneration, characterized by cartilage wear and radiographic evidence of osteophytes or femoral condyle flattening. It is reported that a better outcome is achieved in patient with mild unicompartmental arthritic changes, while higher risk of graft extrusion and rupture in knees with advanced osteoarthritis. Localized chondral defects may be addressed concomitantly with chondrocyte transplantation, osteochondral grafting, or synthetic scaffolds.

Also malalignment is reported to cause abnormal pressure on the meniscal allograft resulting in impaired revascularization that could lead to degeneration and loosening of the graft. Therefore, a corrective osteotomy should be considered in case of greater than 2° of deviation toward the involved compartment, as compared to contralateral mechanical axis [9].

Obesity, synovial disease, inflammatory arthritis, untreated instability of knee joint, and previous joint infections represent other contraindications to take into account. The lack of symptoms remains a controversial issue, as prophylactic meniscal transplantation is not routinely recommended. In fact MAT is not without risks and current evidence has yet to demonstrate long time prevention of arthrosis. On the other hand, meniscal transplantation could be performed prior to symptom onset in young, athletic patients with complete meniscectomy, as better outcomes are reported in knees with less degenerative changes.

26.2.3 Clinical Evaluation

In order to satisfy the inclusion criteria, an accurate history of knee trauma, injuries, and surgical procedure should be obtained. Knee pain, swelling, and mechanical symptoms exacerbated by physical

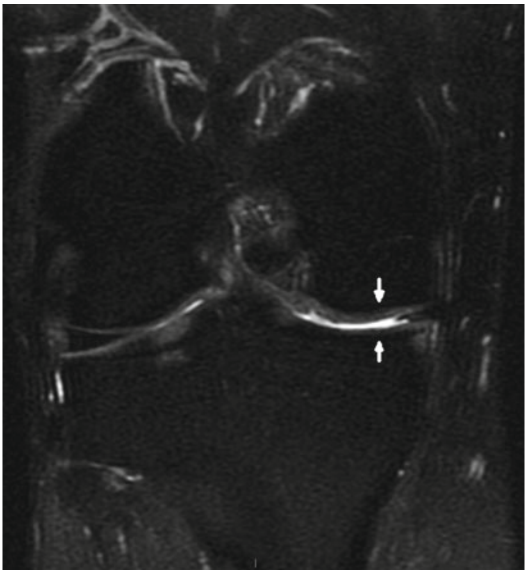

Fig. 26.2 MRI appearance of medial meniscus-deficient knee (*white arrows*)

activity are often complained after several years of adequate knee function after a meniscectomy.

A targeted physical examination should be performed and height, weight, and BMI collected as well. With the patient standing, lower limb alignment is evaluated. Then range of motion and ligamentous stability are assessed both for affected and contralateral knee. Pain and tenderness should be reported exclusively to the affected compartment and ipsilateral quadriceps strength, and circumference reduction could be noted as consequence of knee pain.

26.2.4 Radiological Evaluation

An accurate radiological planning is mandatory to correctly address the surgery. Weight-bearing AP radiographs of bilateral knees in full extension and a non-weight bearing 45° of flexion lateral radiography are required. Rosenberg view (45° flexion weight-bearing PA radiograph) could be helpful to detect subtle joint space narrowing, while long-view mechanical axis radiography is necessary in case of low limb malalignment. MRI should be performed whenever possible, as it

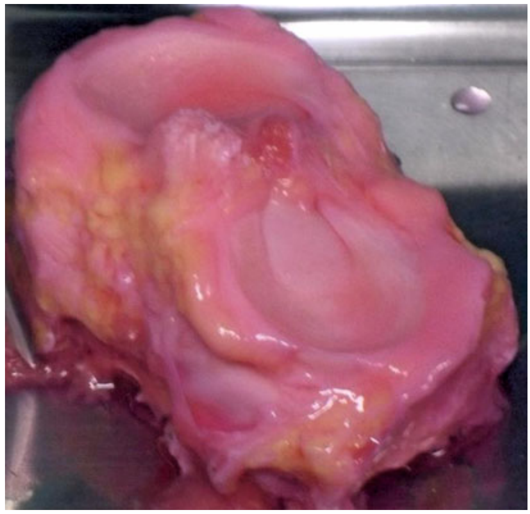

Fig. 26.3 Fresh meniscal allograft

allows to evaluate the meniscal defect (Fig. 26.2), ligament lesions, subchondral bone pathologies, and cartilage status.

26.3 Graft Choice

The correct choice of the graft plays a crucial role in the good results of the procedure. In particular, the type of preservation and the sizing method could highly influence the outcomes of the transplantation, even causing early failure or rupture.

26.3.1 Graft Preservation

After the harvesting, different methods for graft preservation are available, with specific biologic implications, risks, and results.

Fresh Allograft

This preservation technique is obtained, keeping the graft at 4 °C in sterile tissue culture medium for 7 days without loss of viability (Fig. 26.3). Fresh allografts are thought to be the ideal type of transplant, because fresh tissue contains large number of cells. However, despite the viable chondrocyte population may have a beneficial effect in maintaining the mechanical integrity of the graft after the transplantation [10], the replacement of 95 % of donor cells by host cells is reported at 1 year after the transplantation [11], making the cell's viability a questionable issue. Furthermore, due to the short time of viability, it is quite impossible to match the meniscal size of donor and receiver. The lack of the sterilization process that would damage the cell's viability increases the risk of disease transmission, contributing to the restricted use of this method of graft preservation.

Lyophilization

It consists of a dehydration process that destroys all viable cells of the graft and denatures histocompatibility antigens as well. These features make the graft less likely to provoke immune response. On the other hand, lyophilized allografts are reported to have high risk of shrinkage, disruption, synovitis, and effusion [5]. These findings suggest that lyophilization may not be an appropriate processing method for meniscal allografts [12].

Cryopreservation

It is accomplished by storing the graft at −180 °C, usually with dimethyl sulfoxide or glycerol. This method partially allows the cell membrane integrity, but the percentage of viable cells is reported to decrease with storage time [13]. Furthermore, sterilization techniques that affect cells viability cannot be performed. As similar results have been described with normal and cryopreserved menisci, no evidences support the additional cost of this method.

Deep-Frozen (Fresh-Frozen)

This method consists in the graft storage at −80 °C (Fig. 26.4). Similar to lyophilization, deep-freezing destroys viable cells and denatures histocompatibility antigens, and sterilization is allowed as well. However, in this case, mechanical proprieties are not significantly altered by freezing process. The lower costs and the lack of evidences of inferior outcomes of deep-frozen allografts make this method the most commonly used [9].

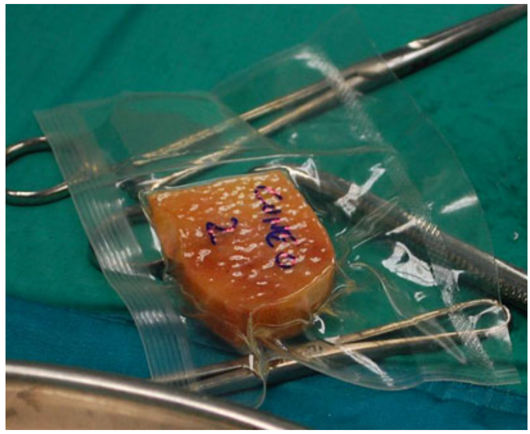

Fig. 26.4 Fresh-frozen meniscal allograft

26.3.2 Graft Sizing

Sizing of the graft plays a crucial role in the success or failure of the implant. In fact undersized grafts result in poor congruity with the femoral condyle and may produce excessive load [14], while oversized grafts may be predisposed to extrude from the compartment, causing inadequate load transmission [9]. The tolerance for size mismatch is estimated to be within 5 % of the original meniscus [15].

Various sizing methods have been proposed in order to obtain the correct size and maximize the graft's successful healing and functionality.

Intraoperative Sizing

In the first meniscal transplantation studies, allografts were shaped with the scalpel and then placed on the tibial plateau [5]. However, this procedure destroys the collagenous network and alters the graft mechanical proprieties [16].

MRI and CT Sizing

Several studies reported MRI as more accurate than radiography in preoperative sizing of the menisci for allograft transplantation [17, 18]. On the other hand, MRI and CT have been shown to underestimate the size of menisci [12]. MRI and CT have been used to estimate the graft size considering the contralateral meniscus as well, even if considerable

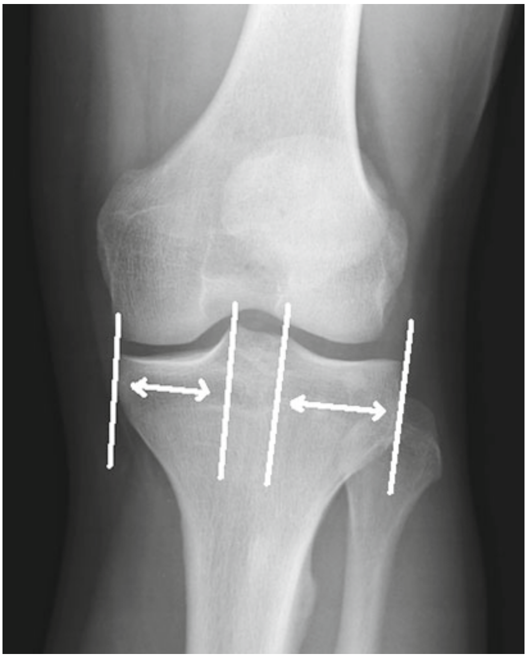

Fig. 26.5 The meniscal width is obtained measuring the distance from the peak of the tibial eminence to the periphery of the tibial metaphysis on anteroposterior films

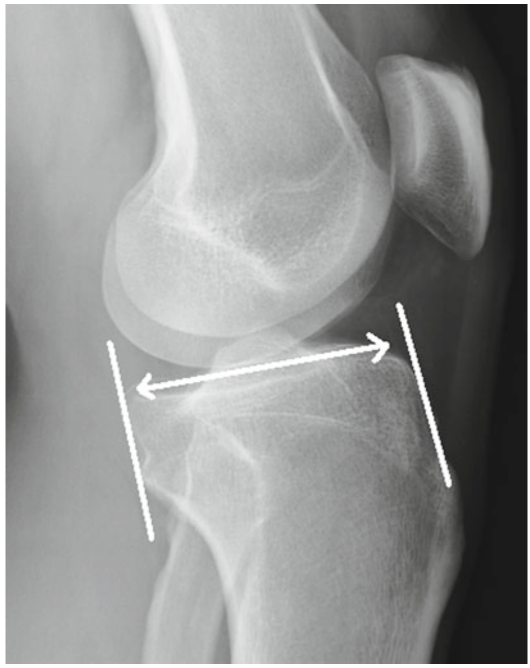

Fig. 26.6 The meniscal length is the 70 % of and the distance measured at the joint line between a line running parallel to the tibia's anterior and posterior margins on lateral films from the lateral meniscus and 80 % for medial meniscus

anatomical variability and asymmetry between right and left meniscus have been described [19].

Radiographic Sizing

Plain radiographies have been widely used as gold standard of preoperative graft sizing [9]. The common method has been developed by Pollard [20]. The correct graft size is obtained from plain films corrected for magnification, measuring the distance from the peak of the tibial eminence to the periphery of the tibial metaphysis on anteroposterior films and measuring the distance at the joint line between a line running parallel to tibia's anterior and posterior margin on lateral films. The first measure represents the meniscal width (Fig. 26.5), while meniscal length is the 70 % of the second measure for lateral meniscus and 80 % for medial meniscus (Fig. 26.6). Width matching using plain radiographs has been reported to be more reliable than length matching when it is sought to assure adequate positioning of meniscal transplants, and width mismatch has showed to predict graft subluxation [21]. Recently a modified Pollard method, consisting of reducing the total size of the graft by 5 %, has been proposed in order to decrease the percentage of meniscal extrusion [22].

Anthropometric-Based Sizing

As height, weight, and gender have been found to correlate to meniscal tissue dimensions [23], Van Thiel proposed a validated regression model that uses these variables to accurately predict required allograft meniscal size, with slightly more accuracy compared to radiographic and magnetic resonance imaging sizing techniques [24].

26.4 Techniques

A large number of techniques of meniscal allograft transplantation have been proposed by various authors, ranging from open, arthroscopically assisted, and arthroscopic techniques, each one with its own pros and cons. Although a wide range of options are available, a primary issue of each technique is the graft fixation. Two types are distinguished: bony fixation of the meniscal horns to the tibia and capsular fixation of the peripheral margin of the allograft.

- *Meniscal Horns Fixation*. This objective can be achieved with the use of soft tissue attachments, bone plugs or bridge, and suture anchors. Evidences are controversial regarding which method guarantees adequate fixation, as cadaver studies showed how bone-to-bone fixation is required to restore optimally normal contact mechanics of the transplant [25, 26], while clinical practice showed how difficult it could be achieving the perfect size match of donor and recipient and obtaining an optimal position of the graft, reporting altered contact pressure distribution in cases of nonanatomic placement of the graft [27]. Furthermore, histological evaluation showed significantly better results in bone-plug free transplants, and animal studies reported less immunogenic effect as well [28]. Besides bone-plug fixation, good clinical results have been reported also suturing meniscal horns to the ligamentous tibial bone attachment [29] and using transosseous sutures tied over a bony bridge over the anterior aspect of the proximal tibia [30]. Recently, posterior horn fixation with transosseous suture and anterior horn fixation to the capsule with an out-in stitch has been described [31].
- *Capsular Fixation*. The graft must be securely sutured to the capsule using standard meniscal repair techniques, as peripheral capsular fixation is an indispensable requisite for graft healing and vascularization. The lack of clinical controlled studies comparing different fixation techniques does not allow to determine the best suture method; thus, nonasorbable or nonasorbable sutures, vertical stitches, or all-inside devices could be used on the base of surgeon preferences [12].

26.4.1 Open Techniques

Open techniques for meniscal allograft transplantation are first described in the late 1980s. Nowadays, these have been almost completely replaced by arthroscopical or arthroscopically assisted techniques because of less soft tissue disruption, the possibility to avoid collateral detachment, decreased morbidity, and early rehabilitation. However, some believe that an open surgical procedure may enable more secure peripheral suturing or bony fixation of the graft allowing greater precision and stability [9].

Double Bone-Plug Technique

The open approach to meniscal transplantation is performed with knee at 80° of flexion. A paramedial parapatellar incision is made in case of medial meniscus transplantation. Using a curved 1 in. osteotome, the origin of medial collateral ligament on the femoral epicondyle is removed. The medial compartment is exposed using valgus stress. Two 10 mm holes are prepared directly at the anatomic site of each horn's bony insertion. The graft, prepared leaving two bone blocks attached to meniscal horns, is placed on the tibial plateau. The middle of each of the graft's bone plugs is secured with 20 mm long, 4 mm cancellous screw, or in alternative a bioabsorbable 7 mm diameter interference screw is inserted alongside the bone block. Then the meniscal edge is sutured to the joint capsule. Finally reattachment of the medial epicondyle to the femur is achieved by a staple or screw [15].

A lateral double bone-plug technique could be performed in a similar manner, although the "trough" technique is preferred because of the closeness of the anterior and posterior lateral meniscus insertions.

Trough (Bridge-in-Slot) Technique

This technique could be performed for both meniscal transplantations, although it is almost exclusively reserved to lateral meniscus transplantation, because the distance between the anterior and posterior horns of lateral meniscus is often 1 cm or less. For this reason the graft is prepared incorporating both insertions on a single bone bridge. Then a paramedial parapatellar incision is made and a rectangular bone trough is prepared at the lateral meniscal anterior and posterior tibial attachment sites to match the dimensions of the prepared lateral meniscal transplant. Then the allograft is inserted into the trough and secured using a no. 2 braided suture [15].

This technique could be used for combination of medial and lateral meniscal transplantation, implanting the allograft with a common bone bridge that contains both menisci attachments [14].

Soft Tissue Fixation

Medial or lateral parapatellar incision is performed depending on the interested compartment. The collateral ligament is released with a bone plug from the epicondyle to open up the compartment and allowing the suture fixation of all the allograft to meniscal rim. In addition, the meniscal soft tissue at the anterior and posterior horns may be fixed with transosseous suture [32].

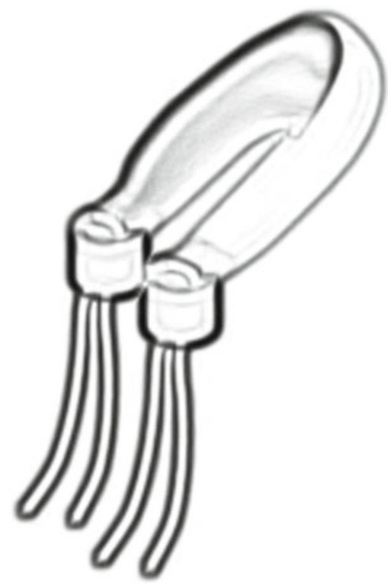

Fig. 26.7 The allograft is prepared leaving two bone plugs at the posterior and anterior horns, with sutures passing trough each bone plug

26.4.2 Arthroscopically Assisted

With the advent of arthroscopic era, open techniques were modified and adapted in order to be partially assisted form arthroscopy, reducing the extent of accesses and soft tissue disruption and trying to improve surgical outcomes.

Double Bone-Plug Technique

Due to menisci anatomy, this technique is reserved to medial meniscal transplantation. The patient is placed in the supine position on the operating room table with a tourniquet applied with a leg holder, and the table was adjusted to allow 90° of knee flexion. Diagnostic arthroscopy is done to confirm the preoperative diagnosis and articular cartilage changes. Then the allograft is prepared leaving two bone plugs as follows: the posterior bone plug was 8 mm in diameter and 12 mm in length. The anterior bone plug was 12 mm in diameter and 12 mm in length. Three 2-0 nonabsorbable sutures were passed retrograde trough each bone plug, with two additional locking sutures for secure fixation of the bone plugs within the tibial tunnel (Fig. 26.7). A 4-cm skin incision was made on the anterior aspect of the tibia adjacent to the tibial tubercle and patellar tendon. A second 3-cm posteromedial incision was made. A guide pin was placed adjacent to the tibial tubercle and was directed to the anatomic posterior meniscal attachment, and a tibial tunnel was drilled over the guidewire to a diameter of 8 mm. At least 8 mm of opening was required adjacent to the posterior cruciate ligament in the femoral notch to pass the posterior osseous portion of the graft . In tight knees, a subperiosteal release of the long fibers of the tibial attachment of the medial collateral ligament could be required.

The meniscal bed is prepared by removing any remaining meniscal tissue while preserving a 3-mm rim when possible. A 3-cm medial arthrotomy was used to pass the posterior bone portion of the graft. The posterior attachment guidewire is retrieved, and the sutures attached to the posterior bone are passed. Then the optimal location for the anterior meniscal bone attachment was identified and a 12-mm rectangular bone attachment was fashioned to correspond to the anterior bone portion of the meniscal graft. A 4-mm bone tunnel is placed at the base of this bone trough. The sutures are passed trough the bone tunnel, and the anterior horn is seated (Fig. 26.8). Tension is applied to the anterior bone sutures and inside-out suture repair is per-

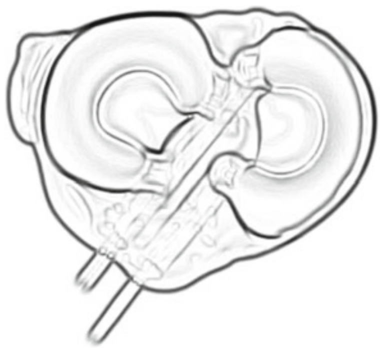

Fig. 26.8 The sutures locked in the bone plugs are passed trough the corresponding tibial tunnels and the graft is positioned on the tibial plateau

Fig. 26.9 Once the graft is in the correct position, it is secured tying the sutures on the anterior aspect of the tibia

formed after closing the anterior arthrotomy. Finally sutures are tied on the anterior aspect of proximal tibia [33] (Fig. 26.9).

Trough (Bridge-in-Slot) Technique

This technique is almost exclusively reserved for lateral meniscus transplantation. The graft is prepared with the central bone portion incorporating the anterior and posterior meniscal attachments and measuring 8–9 mm in width and 35 mm in length (Fig. 26.10). A limited 3-cm lateral arthrotomy is made just adjacent to the patellar tendon. A similar 3-cm posterolateral longitudinal approach is performed. A rectangular bone trough is prepared at the lateral meniscal anterior and posterior tibial attachment sites to match the dimensions of the prepared lateral meniscal transplant (Fig. 26.11). A 4-mm anterior tibial tunnel is drilled into the bone trough, exiting just distal to the joint line, and two sutures are passed over the central bone area of the transplant for fixation of the graft to the tibial trough. The allograft was inserted into the trough (Fig. 26.12) and the knee is flexed, extended, and rotated to confirm correct allograft placement. Finally the central bone attachment sutures are tied, the arthrotomy closed, and the inside-out meniscal repair performed [33].

Fig. 26.10 The graft is prepared with the central bone portion incorporating the anterior and posterior meniscal attachments

Fig. 26.11 A rectangular bone trough is prepared at the lateral meniscal anterior and posterior tibial attachment sites to match the dimensions of the prepared lateral meniscal transplant

Fig. 26.12 The bone plug is inserted into the trough and the meniscal graft is placed in the correct position

Keyhole Technique

This technique can be considered as a variation of the trough technique performed creating a round trough that narrows at the surface of the tibial plateau, allowing the bone bridge to lock into the tibial bone trough. This method should be reserved to lateral meniscal transplantation. The technique is performed making a 3–4-cm parapatellar incision with dissection to the joint capsule. The tibial guide from the keyhole instrument set is used for guide pin placement parallel to the horn attachments. An 11-mm reamer is drilled over the guide pin and subsequently a rongeur or burr is used to make a 6-mm-wide slot connecting the superior aspect of the 11-mm tunnel to the tibial eminence groove. It is necessary to perform an arthrotomy when making the keyway slot, but when preparing the slot posteriorly, a dry arthroscopic technique is very helpful for visualization. The tibial slot sizer is used to assure the keyway is completely prepared, and then the preparation of the allograft can be performed. The graft is mounted on the workstation and anchored by 2 posts and the cylindrical section of the graft is prepared by advancing the handheld, slotted, coring reamer over one half of the graft and subsequently completed from the opposite end. An oscillating saw is used to make vertical cuts down the long axis of the graft to prepare the slot portion of the graft. A “reduction” suture is placed in the posterior corner of the allograft and passed trough the knee at a position approximating that of the graft, and with light tension on the suture to assist in graft reduction, the graft is inserted using a collared pin. Initially, horizontal sutures should be placed in the superior aspect of the graft, starting from the posterior and then the middle section of the graft. Once the preliminary sutures are placed, the capsule is closed and the repair is completed using arthroscopic techniques. Vertical mattress sutures are commonly used due to their greater strength, while all-inside methods are often used at the most posterior aspect to avoid neurovascular injury. Routinely, 8–10 sutures are all that are needed to secure the graft [34].

26.4.3 Arthroscopic Techniques

The most recent techniques described in the field of meniscal allograft transplantation are performed completely arthroscopically. To allow graft fixation without performing arthrotomic accesses, bone-plug free grafts are used. This offers advantage as less morbidity, early rehabilitation, and easier matching to compartment size [30, 31, 35].

Double Tibial Tunnel

After a complete diagnostic arthroscopy, debridement of meniscal remnants is done to achieve a good bleeding bed. Then, two 6-mm bone tunnels are drilled at the anatomic sites of meniscal insertion. The allograft is prepared placing sutures with Krackow mattress at both horns. One additional vertical mattress suture is placed from 1.5 cm of the posterior horn in order to aid in situating the graft. The posterior horn suture is used to pull the meniscal allograft in place. Then an inside-out technique with vertical mattress sutures is used to fix the graft to the rim. Finally the sutures placed in the anterior and posterior horns are tied together over the tibia cortical surface [35] (Fig. 26.13).

Single Tibial Tunnel

After removing the remnant of the native meniscus and creating a bleeding bed at the periphery, the graft is prepared by removing bone plugs and fixing one nonabsorbable suture to the posterior meniscal horn in a modified Mason-Allen fashion and an absorbable one to the anterior meniscal horn in a modified Kessler fashion (Fig. 26.14). The superior portion of the meniscus is marked with radial signs with a surgical marker to prevent mismatching and twisting during arthroscopic insertion. A 3-mm drill is used to prepare one tibial tunnel with the entrance on the medial side of the tibia. For medial meniscal transplantation, the posterior tunnel is placed behind the medial tibial spine and in front of the PCL tibial insertion site. For lateral meniscal transplantation, the tunnel is placed behind the ACL tibial insertion. A knot pusher was used to pass a "shuttle suture" trough the posterior tibial tunnel. The "shuttle suture" was tied to the nonabsorbable suture placed into the posterior horn and passed trough the posterior tunnel, acting as a transport suture from inside to outside (Fig. 26.15). The graft is introduced in the joint space with a fine, smooth Klemmer forceps trough the arthroscopic portal (enlarged to 1 cm) and located correctly by pulling the suture fixed to the posterior meniscal horn. Then, the graft is fixed to the capsule with a mean of 5 "all-inside" stitches, keeping under desired tension the 2 meniscal horn-fixing sutures (Fig. 26.16). The anterior meniscal horn is then fixed to the capsule by the previously placed absorbable suture trough the corresponding working arthroscopic portal

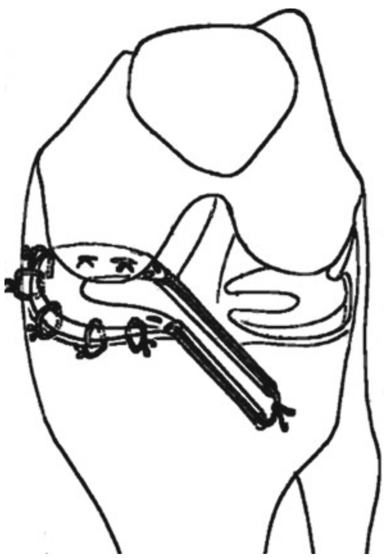

Fig. 26.13 Final aspect of the double-tunnel arthroscopic MAT. The graft is secured to the tibia trough two sutures and to the capsule with inside-out vertical mattress sutures

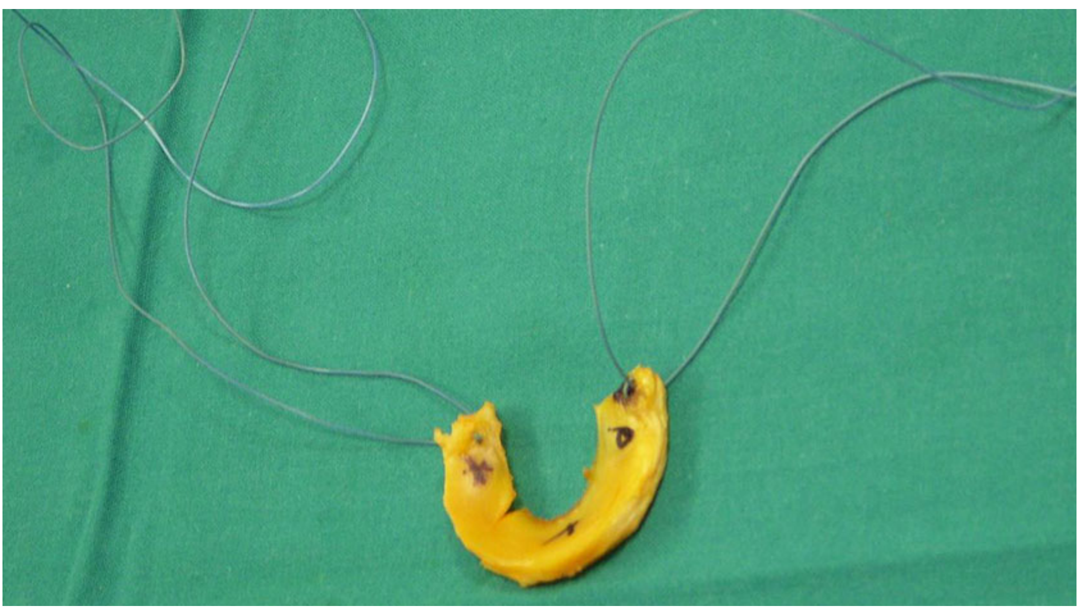

Fig. 26.14 The graft is prepared by removing the bone plugs and fixing one nonabsorbable suture to the posterior meniscal horn in a modified Mason-Allen fashion and an absorbable one to the anterior meniscal horn in a modified Kessler fashion

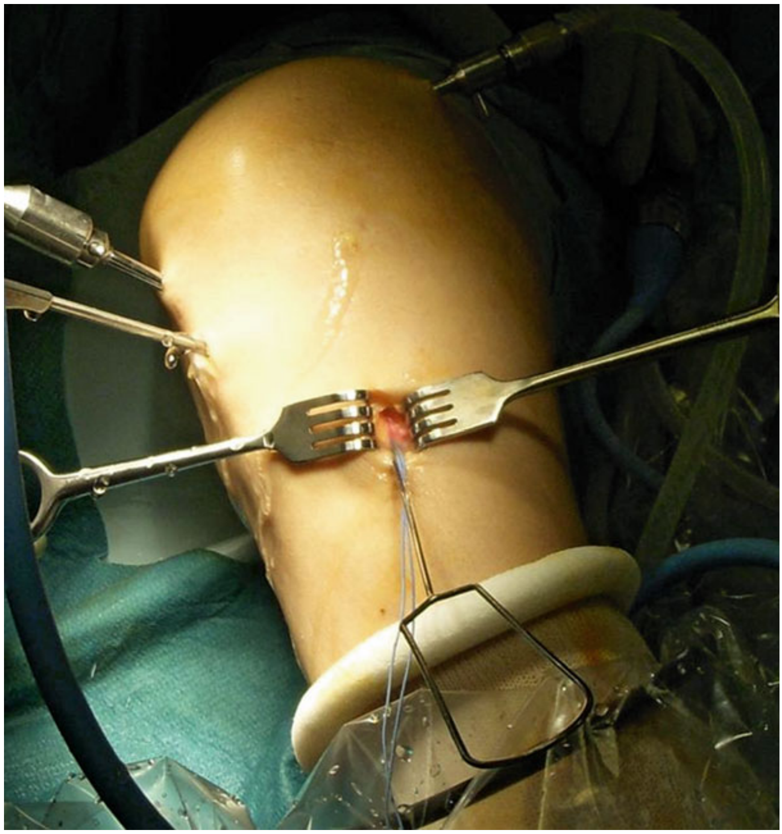

Fig. 26.15 A knot pusher is used to pass a "shuttle suture" trough the posterior tibial tunnel. The "shuttle suture" is tied to the nonabsorbable suture placed into the posterior horn and passed trough the posterior tunnel, acting as a transport suture from inside to outside

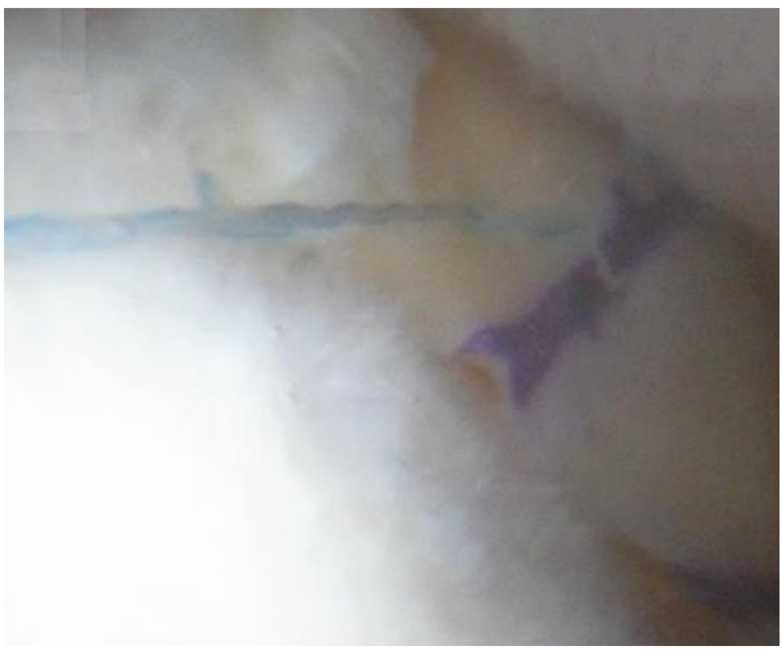

Fig. 26.16 Arthroscopic capture of single-tunnel MAT. The graft is fixed to the capsule with a mean of 5 "all-inside" stitches, keeping under desired tension the 2 meniscal horn-fixing sutures

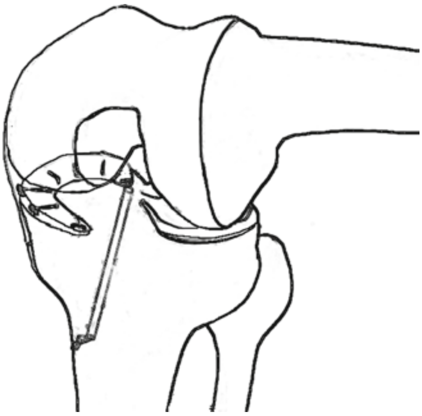

Fig. 26.17 Final aspect of the single-tunnel arthroscopic MAT

(Fig. 26.17). Finally, after the transplanted meniscus is checked for stability and matching, skin suture, a compressive bandage, and a full extension brace are placed [31].

26.5 Associated Procedures

Associated procedures are very common when MAT is performed, as only 36 % of all transplantations described in literature are isolated and only three trials present data of isolated MAT [36–38]. The percentage most commonly performed in association with MAT is ACL reconstruction (42 % of associated procedures and 30 % of cases), while the second most common concomitant surgery is cartilage treatment (31 %). Also corrective osteotomy is performed frequently, in 19 % of MAT. Other procedures performed rarely comprise osteotomies of the tibial tuberosity, retinacular releases, adhesiolysis, capsular placation, hardware, and loose body removals [6].

26.5.1 MAT and ACL

Meniscal transplantation combined with ACL reconstruction is performed in knees with ACL insufficiency and meniscal deficiency. In fact it is reported better KT-1000 arthrometer results in patients treated with ACL reconstruction and medial MAT compared to ACL reconstruction alone [8]. Different techniques of ACL reconstruction are used, comprising single or double bundle and hamstrings, patellar tendon, or allogeneic grafts. Usually ACL tunnels are performed before meniscal allograft insertion. Then MAT is completed. When performing MAT with bone plug or trough technique, special care is required because the ACL tibial tunnel often encroaches on the bone trough. To avoid this problem, the ACL graft passage and femoral fixation should be done before placing lateral meniscal allograft bone bridge [7]. Graf et al. [39] reported good clinical results at mean 9.7-year follow-up, with stable knees and patient satisfaction. Radiographic evaluation showed abnormal IKDC grade in 88 % of patients, due to significant degenerative arthritis at the time of transplantation.

26.5.2 MAT and Cartilage Treatment

As chondral damage is considered a negative prognostic factor in meniscal allograft transplantation, cartilage repair and restoration techniques are becoming a necessary adjunct to meniscus transplant for optimal biological joint preservation. The combination of these two surgical techniques has been shown to have the same outcomes as either technique was performed individually [40]. The options available include autologous chondrocyte implantation (ACI), microfractures, osteochondral allograft, and bioengineered scaffolds. Improving in clinical objective and subjective scores is reported at 1–4.5 years follow-up. Although 50 % of patients is reported to require 1 or more subsequent surgeries from 2 to 4 years after combined MAT and cartilage treatment (most of which was debridement of ACI hypertrophy), failure rate is 12 %. Most of the failures are due to MAT (85 %) versus the cartilage techniques [40].

26.5.3 MAT and Osteotomies

Even if osteotomy is a very common procedure associated to MAT, no studies report the results of these two procedures alone. Most of the time the treatment with osteotomy and MAT represents the subgroup of a wider group of patients treated with the combination of different techniques. The high number of osteotomies performed is due to the necessity to correct the axial malalignment in order to prevent the overload on the graft and avoid early failure. Usually closing wedge high tibial osteotomy is performed with medial MAT in case of varus malalignment, while open wedge distal femoral osteotomy is performed with lateral MAT in case of valgus malalignment [31]. In fact axial malalignment is frequently present in patients treated with total or subtotal meniscectomy several years before the onset of symptoms; in this scenario MAT and osteotomy appear the only biological solution available in order to correctly address the meniscus deficiency. The debate of which of the two procedures really improve pain and symptoms is unknown, unless controlled trial comparing osteotomy alone and MAT plus osteotomy in homogeneous groups of patients is performed.

26.6 Rehabilitation

Rehabilitation after MAT is a still debated and controversial issue, as the effects of loading on the new meniscal graft are not well understood. Different rehabilitation regimens have been proposed in clinical practice, but there is still lack of consensus, similarly to meniscal repair [9]. Good results have been reported with immediate full range of motion and unlimited weight bearing, while other studies recommended full extension and non-weight bearing even for 6 weeks [41]. A prudent approach to rehabilitation after MAT is represented by initially limiting flexion, as after 60° anterior translation of the meniscus and increased stress on posterior repair begin. Also weight-bearing restriction is suggested, to not compromise the graft healing and fixation during the early postoperative revascularization. Isometric exercises are recommended to prevent muscle atrophy. The expected time to sport activity resumption ranges from 4 to 12 months [9].

As a sample, the rehabilitative protocol proposed by Marcacci et al. [31] (Table 26.2) consists of 4 weeks with a full extension knee brace. The brace immobilizer is removed two times a day to perform knee mobilization with motorized hardware. Starting the day after surgery, patients begin progressive range of motion from 0° to 45° over the first 2 weeks and 0° to 90° over the next 2 weeks, after which full motion is progressively allowed. At week 6 postoperatively, patients are allowed to fully bend the knee involved in transplantation. Over the first 4 weeks, patients are allowed to walk without weight bearing with 2 crutches. At week 4 postoperatively, patients start to bear weight as tolerated and wean off 1 crutch. At week 6 postoperatively, full weight bearing is started. Quadriceps-setting exercises and straight-leg raises begin from the second day after surgery. After 2 weeks, patients start stationary bike exercises and are allowed to perform swimming pool exercises (after stitches are removed). Only at week 4 the rehabilitation of the musculature trough isotonic exercises is initiated. Return to noncontact sports is not allowed until the fourth month, and patients are advised not to resume contact sports until 8 months postoperatively.

Table 26.2 Rehabilitation protocol after MAT proposed by Marcacci et al. [31]

Time	Motion	Weight bearing	Exercise
Weeks 1–2	Full extension (brace), passive mobilization 0–45°	No weight bearing (2 crutches)	Quadriceps strengthening (isometric)
Weeks 3–4	Full extension (brace), passive mobilization 0–90°	No weight bearing (2 crutches)	Cyclette, water gym
Weeks 5–6	Complete	Partial weight bearing (1 crutch)	Quadriceps strengthening (isotonic)
Week 7–month 4	Complete	Full weight bearing	Progressive return to sport (noncontact)
Month 5–8	Complete	Full weight bearing	Progressive return to sport (contact)

Otherwise, standardized rehabilitation protocols are not applicable in every patient, as the rehabilitative programs are often determined by the very frequent concomitant procedures performed at the time of MAT, in particular cartilage treatment. Thus, a correct one should be tailored considering age, expectation, and associated surgeries.

26.7 Risks and Complication

Although meniscal allograft transplantation is considered a safe procedure, it is not totally free of risks. In addition to the usual potential complications of surgery and anesthesia, other risks are related to the allograft tissue and to the surgical technique.

26.7.1 Immunological Reaction

Although meniscal allografts have been demonstrated to express class I and II histocompatibility antigens and to present the possibility to produce host immune response (in particular regarding bone-plug grafts) [42], it is reported only one case of frank immunologic rejection of a cryopreserved graft, based on histologic and clinical evidence [43]. Furthermore, fresh meniscal allografts are reported to not elicit significant immune response at mean 4.5-year follow-up [9]. Only subclinical immunoreactivity is demonstrated in deep-frozen allografts [44], with unknown effects on graft health and outcomes.

Considering these findings, in general MAT is considered safe, with no evidence of failure or rejection due to immunological response [12].

26.7.2 Disease Transmission

The use of meniscal allograft creates a risk of transmission of diseases. As MAT is not a lifesaving measure, this risk is justified only if it is exceedingly small. The different methods of preservation and processing do not present the same risks of disease transmission. In fact, as deep-freezing and lyophilization cannot destroy human immunodeficiency virus (HIV), grafts treated with these methods present a risk of HIV transmission of 1 in 8 million. HIV and other transmissible life-threatening viral diseases like hepatitis B made sterilization techniques a crucial issue in the graft management. Gamma irradiation is the most common secondary sterilization method. The dosage of 3.6 mrad, necessary to inactivate all but 1/1,000,000 HIV-infected bone cells, is reported to produce significant changes in the mechanical proprieties of meniscal tissue, compromising its survival [45]. Regarding fresh and cryopreserved allograft, nonsterilization methods are possible without compromising the cells viability and the potential advantage of these conservation methods. Nevertheless, controversies are present regarding cell viability issues and the advantage of nonsterilized meniscal allografts.

Given the pitfalls associated with graft processing techniques, stringent donor selection and screening are mandatory in order to make graft processing techniques as safe as possible [12].

26.7.3 Failure

A common definition of failure is (sub)total destruction/removal of the graft with or without conversion to arthroplasty. Using this definition, the failure rate is reported to be 10.6 %. If the need for partial meniscectomy or a subsequent procedure is considered as a failure criteria, the percentage rises. The most commonly reported cause of failure is the tearing of the graft [6]. The reasons of graft rupture are various.

Uncorrect Position of the Graft

Hoop stress transmission and functional load transmission across the knee depend upon correct position and fixation of the anterior and posterior horn attachment sites. When the allograft's posterior horn is fixed in an excessively anterior position, proper load sharing is not reestablished, while an excessively anterior position of medial meniscal transplant may result in excessive compressive forces and meniscal damage [25].

Uncorrect Size of the Graft

Also the sizing of the graft plays a crucial role in the success or failure of the implant. Undersized grafts result in poor congruity with the femoral condyle and may produce excessive loads [14], while oversized grafts may be predisposed to extrude from the compartment, resulting in inadequate transmission of compressive loads across the knee [14]. Furthermore, improper sizing may exacerbate biological or immune responses, which could potentially compromise the outcome of the allograft.

Graft Extrusion

Meniscal allograft extrusion (Fig. 26.18) could be caused by preoperative sizing mismatch due to technical problems in examining radiography, over-tensioning of the meniscal suture during surgery, overstuffing with expulsion of part of the meniscal body out of the knee joint cavity, loss of fixation of both horns of the transplanted meniscus, nonanatomical position of the insertion site of the graft, and resection of too much native tissue [31]. Marcacci et al. [31] reported a 72 % of partially extruded grafts after a minimum FU of 3 years, while Verdonk [46] found a similar percentage at 10-year minimum FU. Lee et al. [47] founded a 40 % extruded allografts, but they also reported that the extruded grafts tend to be stable over the long term. Gonzales-Lucena et al. [35] reported an extrusion of 36.3 % with regard to the global allograft size in a series of 33 grafts from 5 to 8 years FU. Although these findings, no significant correlations are reported between meniscal extrusion and various clinical and radiologic outcomes at 3-year FU [31, 48]. Even if the extrusion phenomenon does not appear to influence the clinical results, it could compromise the long-term outcome and beneficial effect since an extruded graft has different biomechanical effect and predicts the increase of subchondral bone lesions and tibial plateau bone expansion [49].

26.8 Results

At the state of the art, the knowledge of MAT outcome is confounded by patient- and surgeon-specific variables, like degree of preoperative arthrosis, graft processing, surgical technique, associated procedures, and clinical and

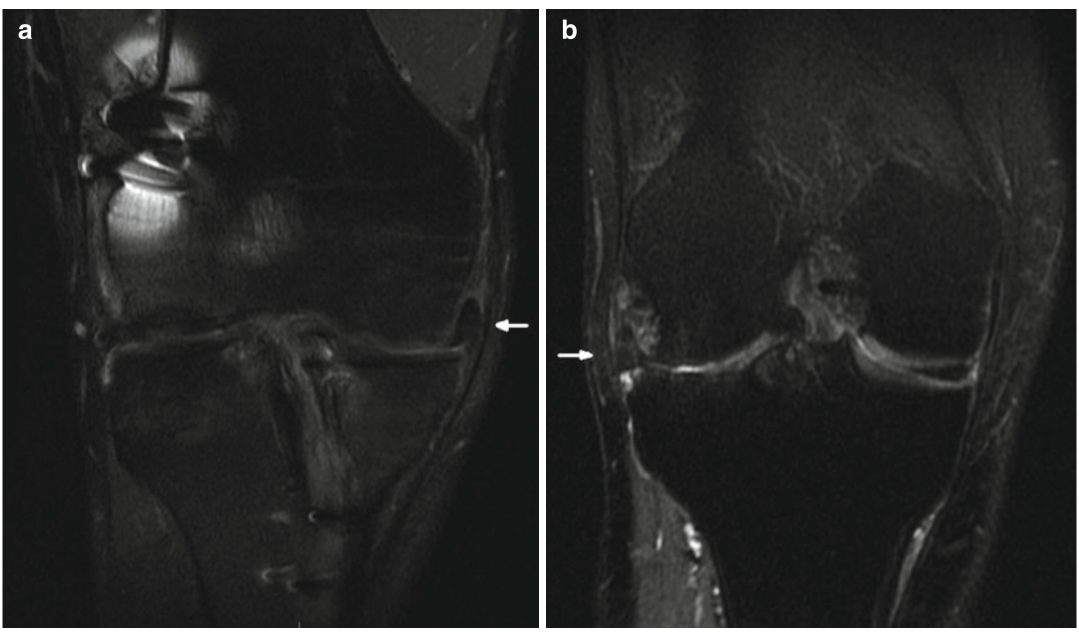

Fig. 26.18 MRI showing extrusion (*white arrows*) of medial (**a**) and lateral (**b**) meniscal allograft

radiological outcome measures. Furthermore, the quality of the studies on this controversial topic is poor, as stated in a recent meta-analysis [6]. Thus, the real effect of MAT, especially regarding long-term outcomes and chondroprotective effect, is yet to be defined.

The most important finding of more than 20 years of MAT is that this procedure is safe and reliable and should no longer be considered experimental [6].

Most of the trails present short- or medium-term outcomes, showing excellent/good results in 84 % of patients; however, the improvement of clinical scores showed a tendency to slowly decrease over time [6]. The long-term results of a case series of 100 MAT show that pain relief and functional improvement persist in approximately 70 % of patients at 10-year follow-up [50]. Generally, similar results have been reported both for medial and lateral MATs and also when the transplantation is performed alone or with concomitant procedures.

Regarding chondroprotective effect of MAT, the lack of control group consisting of conservatively treated symptomatic postmeniscectomy patients limits the power to detect it. Currently it has not yet been shown that MAT prevents or delays the degenerative process derived from meniscal deficiency over time, although various findings suggest a trend in this way.

No progression of joint space narrowing in a considerable number of patients has been reported at long-term follow-up [46]. Some authors even showed joint space gain in some patients, especially with lateral MAT [38, 39]. These promising findings obtained with radiographic evaluation seem supported by MRI evaluation as well. In fact improvement in cartilage status at 3-year follow-up [31] and potential chondroprotective effects over 10 years in a subgroup of patients [46] have been reported. On the other hand, shrinkage, extrusion, rupture, and altered signal of the graft were reported as well, both with MRI and second-look arthroscopy. Several authors documented arthroscopically good healing and incorporation of the graft and normal appearance of cartilage [6], while others reported histological evidence of viable cells in the graft periphery, neovascularization from the synovial lining and variable collagenous architecture. No evidence of immunologic rejection was documented [6].

Considering the removal of the graft or conversion to TKA as failure criteria, the overall mean failure rate is 10.6 %. If extended to MRI evidence of rupture or the need for subsequent procedures as wall, the rate increases [6]. Giving the complexity of this kind of surgery, in particular when MAT is associated to other procedures, the overall complication rate is 21.3 % and includes manipulation under anesthesia and graft rupture [6].

In conclusion, MAT is a safe and reliable procedure that enables the symptomatic patient after a meniscectomy to resume high levels of activity and works as a long-term “bridging” procedure before arthroplasty.

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