Meniscal Preservation is Important for the Knee Joint

Abstract

Native joint preservation has gained importance in recent years. This is mostly to find solutions for limitations of arthroplasty. In the knee joint, the menisci perform critical functions, adding stability during range of motion and efficiently transferring load across the tibiofemoral articulation while protecting the cartilage. The menisci are the most common injury seen by orthopedicians, especially in the younger active patients. Advances in technology and our knowledge on functioning of the knee joint have made meniscus repair an important mode of treatment. This review summarizes the various techniques of meniscus tear repair and also describes biological enhancements of healing.

Keywords: *Meniscus repair, partial meniscectomy, root tear, scaffolds, tissue engineering*
MeSH terms: *Knee joint, arthroscopic surgical procedures, review literature, menisci, medial, lateral*

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Introduction

Native joint preservation has always been an area of research and innovation in spite of the remarkable strides in the field of arthroplasty. The knee joint is extremely prone to trauma resulting in degeneration. Every structure in the knee joint is important and the menisci are the bulwark against the destruction of the joint.

The menisci of the knee joint are fibrocartilaginous semilunar tissues that perform the critical functions of stabilizing the joint and aiding in efficient load transfer as a shock absorber.[1] They are integral to overall function of the knee and play a key role in shock absorption, joint stabilization, and possibly proprioception.[2,3] At least 70%–90% of the axial load transmitted through each compartment is dissipated by its meniscus and affords the articular cartilage the protection from injury.[4] The menisci were once thought to be vestigial remnants and thus disposable. Surgical excision was promoted as a benign procedure, and as late as 1975, complete excision was advocated for a complete recovery.[5] The functions of the meniscus were recognized much earlier[6] and eventually the potential harms of its excision started gaining attention.

In this review article, we will focus on the various methods of repairing the meniscal tears, meniscal transplants, biological therapies, and partial meniscectomy as a salvage procedure.

Meniscus Tears

Meniscal tears are very common injuries of the knee for which patients seek treatment, with an estimated incidence of 61/100,000 population per year.[7] The cross section of the meniscus reveals three distinct layers: a superficial layer on both tibial and femoral surfaces, a lamellar layer with radial arrangement of collagen, and a central region where the fibrils are along the long axis of the meniscus in a circular fashion. The circular arrangement of the collagen bundles is probably why tears frequently have a longitudinal orientation.[8] Acute tears are more common in the younger population, with medial meniscus tears twice as common as lateral ones. Multiple classifications of the meniscal tears have been described. The acute tears are described as the tear pattern with respect to the meniscus collagen fibril arrangement. This descriptive classification includes radial tears - perpendicular to the long axis of the meniscus, vertical longitudinal - parallel to the long axis, oblique tears, horizontal cleavage tears, and complex tears with a mixed morphology. Of these, radial tears of the posteromedial compartment are the most common, and longitudinal tears are most often associated with acute anterior cruciate ligament (ACL)

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tear. Degenerative tears are usually complex in their morphology.[9]

As arthroscopy techniques, implants, and understanding of the anatomy, biomechanics, and biology of the meniscus continue to evolve, there is increasing evidence now to support repair of the meniscus.

Meniscus Repair

Suitability of a tear for repair must be assessed before planning the surgery. A tear which is within the peripheral red-red zone, longitudinal in orientation, and up to 3 cm long is most amenable to repair.[10] The main principles to be followed during any meniscal repair surgery are as follows:

- Adequate visualization of the entire torn meniscus must be achieved to accurately diagnose the tear morphology and determine the feasibility of repair. A controlled deep medial collateral ligament release by the pie-crusting technique just below the joint line helps in visualizing posterior meniscal tears[11]
- Creating the favorable biological environment to potentiate healing is a vital step. This involves debridement of granulation tissue to freshen the tear edges, peri-meniscal and meniscal synovial abrading, and trephination so as to create vascular channels[12,13] [Figure 1a and b]. A fibrin clot from the patients' own blood can also be introduced at the repair site[14]
- A limited notchplasty or microfracture of the lateral femoral condyle to deliver marrow elements into the joint during isolated meniscal tear repairs also helps augment biological healing.

The three basic techniques of meniscus repair include outside-in, inside-out, and all-inside, and each has its indications, advantages, and pitfalls.

Inside-out repair

Henning first described the inside-out technique of meniscus repair. He described the use of cannulae for precise placement of suture needles in the meniscus, performance of meniscal and synovial abrasion to open vascular channels, and "safety incisions" placed posteromedially for medial or laterally for lateral meniscus repair needle retrieval.[15]

An inside-out meniscus repair can be safely performed for the central and posterior third tear of both the menisci.[16] Although the inside-out repair has been the gold standard for posterior third longitudinal meniscus tears, newer implants and improved techniques for all-inside repair have now become the preferred method.[17] Middle third tears, however, are readily amenable to repair by the inside-out technique without significant risk to neurovascular structures and possibly, without the need for a safety incision [Figure 2a and b]. Radial tears are also better repaired by an all-inside figure-of-8 with horizontal construct than an inside-out technique, with the former having significantly higher failure loads and higher stiffness values.[18]

A recent systematic review compared the all-inside with inside-out isolated meniscus repairs. The study noted that the failure rates, functional outcomes, and the complications between the two methods were similar.[19] However, the inside-out techniques have some distinct advantages. A variety of straight or curved, single- or double-lumen suture needle delivery cannulae are available to allow accurate and controlled suture placement.[14] These needles are less traumatic than the bulkier all-inside implant devices causing less iatrogenic damage to meniscus tissue. This becomes critical when repairing a complex tear where the tissue might be friable. By allowing a greater number of fixation points, these needles capture more collagen tissue as well. Another important advantage is that these suture needles are significantly less expensive than all-inside repair devices, thus reducing the cost to the patient and health-care delivery system. Details of surgical technique are described by various authors and are beyond the scope of this review.[20,21]

The techniques for repairing the medial and lateral meniscus are similar with the exception of small modifications on the lateral side. A safety incision on the lateral knee is always advocated to safeguard the common peroneal nerve from

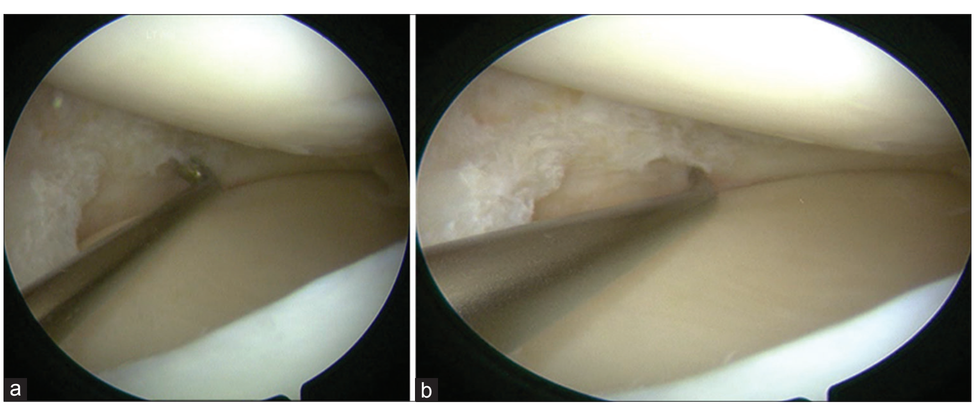

Figure 1: Arthroscopic views showing that abrading the meniscus and adjacent synovium using a specially designed rasp (a) and trephination, i.e., making small puncture holes in the capsule, using a microfracture awl (b) are mechanical methods of enhancing the healing response

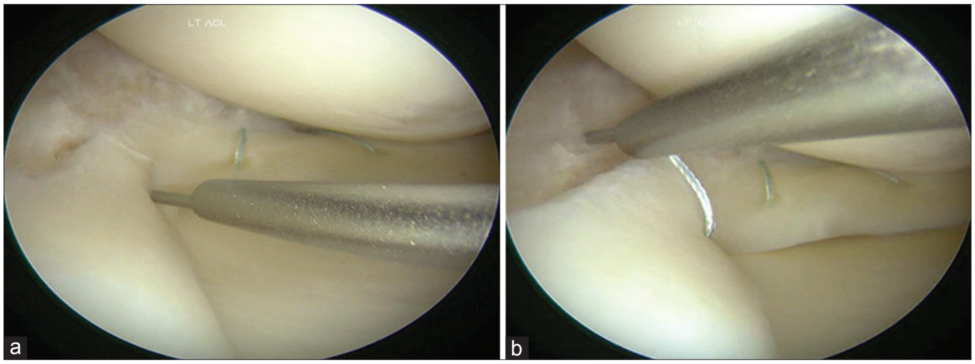

Figure 2: Arthroscopic views showing that inside out meniscus repair of left knee medial meniscus: a suture-loaded needle being passed through the meniscus using a single-slotted straight cannula (a) and then through the meniscocapsular junction superiorly (b), to obtain a vertical mattress configuration

the needle trajectory. Some of the commonly encountered complications and safe surgical practices to avoid them are noted.

Complications and problems

There exists a potential to injure anatomic structures in the needle trajectory. Saphenous nerve injury can be avoided by the medial safety incision and retracting the nerve behind the pes tendons as it lies posterior to the sartorius tendon. Laterally, the common peroneal nerve lies posteromedial to the biceps femoris. Injury is avoided by making the lateral skin incision in flexion and carefully developing a plane between the biceps femoris and iliotibial band. Popliteal vessels are at highest risk while performing a posterior third lateral meniscus repair. Careful placement of a retractor and always passing suture needles from the anteromedial portal avoid injury to the vessels. If the medial side sutures are tied in flexion, a flexion contracture can develop due to overtightening the posteromedial capsule. Needlestick injury to the surgeon or assistants is very possible and must be avoided.[22] The inside-out technique also increases operative time by about 50%, compared to all-inside technique.[23]

Outside-in repair

The outside-in technique of meniscus repair entails passage of a suture from outside to within the joint through the meniscus, shuttling of this suture outside, and tying of a knot over the capsule, although various modifications of the exact technique exist [Figure 3]. The biggest advantage of this technique is the nonrequirement of any special device or implant to perform the repair. One requires only an appropriate suture material such as polydioxanone or No. 0 FiberWire (Arthrex, Naples, FL, USA) which can be inserted inside the joint using special needles or a spinal needle.

Since the technique involves insertion of a sharp instrument inside the joint without visual control, the ideal and safe indications are anterior horn tears and vertical longitudinal tears in anterior two-third of meniscus. Posterior horn tears tackled by outside-in technique have a high risk of neurovascular injury. This absence of control over the exact site of needle exit within the joint is the biggest limitation of this technique.

Multiple modifications of the technique have been described in literature.[24-27] This has helped in making the technique safer and reducing complications while at the same time simplifying surgery. There is a longer learning curve, and it is challenging to get the needles in the exact position of the meniscal tear to pass the sutures.

Complications and problems

The neurovascular structures in the needle trajectory remain at the same peril as in the inside-out technique. Chondral damage during insertion of needles into the joint is a well-known complication. This can be avoided by carefully placing the needles while visualizing the meniscus arthroscopically and not thrusting them in.

Intraarticular knots which are used to secure the repair in some techniques are also a cause of problems. Kelly and Ebrahimpour carried out a second-look arthroscopy in patients who had synovitis after meniscal repair with mulberry knot technique. They found out the prevalence of aseptic synovitis and evidence of chondral damage. The synovitis and clinical symptoms subsided after partial meniscectomy.[28]

All-inside repair

While the standard inside-out suture repair remains the gold standard, evolving technology has allowed for adapting the suture anchor concept to the meniscus repairs. The all–inside technique has evolved over the years resulting in increased ease and reduced surgical times and neurovascular risks.[29] The initial devices were cumbersome to use and that led to development of the second-generation devices with the suture anchor concept. The next iteration introduced bioabsorbable rigid materials which however failed and had greater complication rates in comparison to the prevailing standards. Most of these were made of rigid poly-l-lactic acid (PLLA) or polylactic acid (PLA) which can retain its strength beyond 24 weeks before reabsorption.

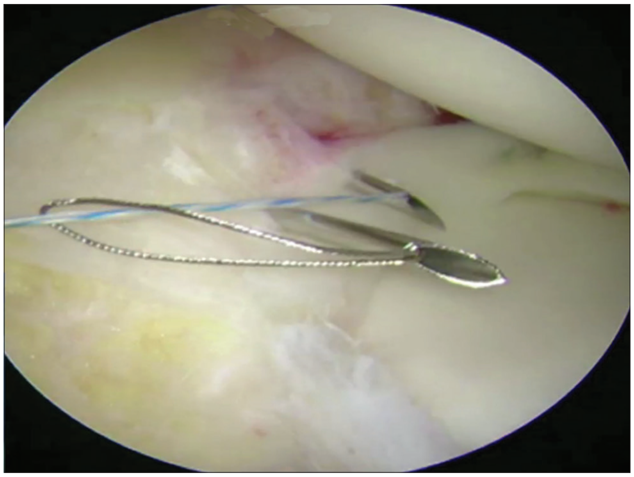

Figure 3: Arthroscopic views showing that outside in meniscus repair of anterior horn knee medial meniscus of left knee. The suture is introduced through the needle placed posteriorly and is shuttled across a wire loop passed through another needle anteriorly. This suture can be retrieved outside the capsule and a knot tied

Inflammatory reaction, transient synovitis, and breakage of the device also lead to chondral damage. The devices were also unable to achieve and adjust the compression and tension across the repair. The current fourth-generation devices are flexible, sutures based, and allow variable compression and tensioning across the tears. There are multiple devices available in the market, each with their own technical nuances and features. They can allow for vertical mattress, horizontal mattress, or continuous suture placement. The mode of suture deployment also varies. Active deployment devices are triggered to fire the implant into position while passive deployment devices depend on the surgeon to essentially push the device in place across the capsule and deployment of the anchor upon withdrawing the inserter.

The new devices have newer complications that include "misfiring" of the implant, breakage or migration of the anchors, and entrapment of the popliteus, collaterals, or iliotibial band. Iatrogenic chondral damage rates are lower. A unique application of the all-inside devices is for the repair of medial meniscus ramp lesions [Figure 4a-c]. Radial tears are also better repaired by an all-inside figure-of-8 with horizontal construct than an inside-out technique, with the former having significantly higher failure loads and higher stiffness values.[18]

Complications and problems

Overall, the active deployment devices are more reliable and more precise regarding location and depth. They have less misfires or "air balls" as compared with the passive devices, especially when tensioning of the repair is attempted. Active deployment devices have a bit of "kick-back" when fired. The user of the device must be aware of this to prevent inappropriate depth of placement or misfire.

Biological Enhancement of Meniscal Repair Healing

Given the poor vascularity and limited healing ability of the meniscus, multiple methods have been proposed to augment the healing potential of the repaired meniscus.[30]

Growth factors delivered to the site of repair have also shown to have a role. Fibroblast growth factor (FGF) stimulates type II collagen and aggrecan mRNA production in cellular development. FGF-2 stimulates proliferation of chondrocytes, mesenchymal stem cells, and osteocytes. Transforming growth factor beta I, bone morphogenetic proteins (BMPs), insulin-like growth factor I (IGF-I), vascular endothelial growth factor, platelet-derived growth factor-AB all play a role in upregulating collagen and cell proliferation and in promoting angiogenesis. Interleukin-1 and epidermal growth factor have been shown to stimulate meniscal cell migration, whereas BMP-2 and IGF-1 have been shown to stimulate fibrochondrocyte migration from the middle to avascular zone.[31] These growth factors are not easily available for commercial use and hence we rely on release of these factors during the fibrin clot formation. Fibrin and fibrin degradation products attract leukocytes to site of the injury and initiate healing response with release of multiple growth factors.[32] This is the basis for use of platelet-rich plasma (PRP) and fibrin clots as an adjunct to meniscal repair.

There are numerous PRP preparation kits and each of them produces varying proportions of growth factors, leukocyte concentration, activating agents, PRP volume, and concentration of platelets. This variation in the qualitative and quantitative product delivered to the repair site prevents us from generalizing the results published. Basic research in animal models is suggestive of enhanced healing with the use of PRP.[33] However, in the absence of large randomized controlled trials, no categorical conclusion can be arrived at in support of its use.

Tears and Repair of Non-Red-red Zone

There is general consensus in literature that tears in the red-red zone of the meniscus must be repaired, but management of tears in the red-white zone is still controversial.[34] Arnoczky and Warren in their seminal work on meniscal vasculature demonstrated that there was variable vascular penetration in the medial meniscus, but this was not correlated with age, sex, or anatomic location.[35] Healing in the peripheral vascular portion of the meniscus has greater potential than in the central avascular zones. There are multiple strategies that can be employed at the time of repair to enhance this healing response.[36] Noyes *et al*. have demonstrated that 62% of meniscus tears of the red-white zone healed with normal or near-normal characteristics in all the parameters assessed by them at minimum 10 years followup. Of the

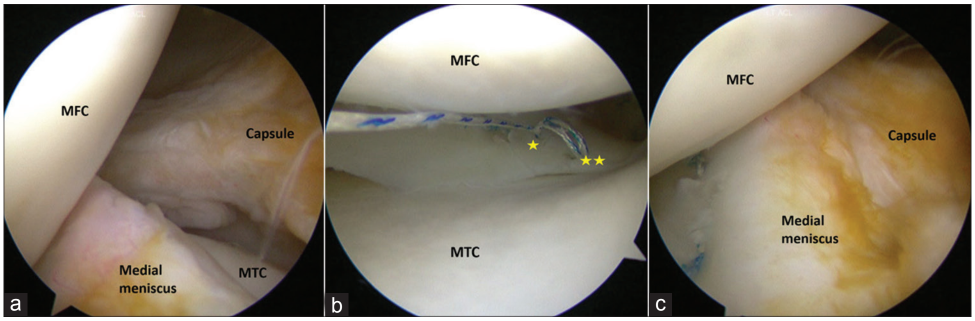

Figure 4: Arthroscopic views showing that ramp lesion of the left knee medial meniscus (a). Repair performed using an all-inside device shown by the two bites (single star and double star) on the superior surface of the meniscus (b). The rent is closed after tensioning the suture (c). MFC = Medial femoral condyle, MTC = Medial tibial condyle

11 failures in their cohort of 33 patients, six required arthroscopic resection of unhealed meniscus, two had apparent joint space reduction, and the patients were asymptomatic in spite of failed healing.[37] Gallacher *et al*. reported that outcomes following white-white zone isolated meniscal repairs at mean followup of 49 months, where criterion of failure was reoperation for excision or re-repair. They reported a success rate of 68% with significant improvement in the Lysholm score after surgery.[38] Barber-Westin performed a systematic review to analyze healing of repairs in the red-white zone of the meniscus repaired by all-inside and inside-out techniques. Approximately 83% tears were considered clinically healed based on the criteria of the absence of meniscal symptoms and when no additional surgery was required. Data were insufficient to assess healing based on the type of meniscal tear. Age, gender, chronicity of injury, involved tibiofemoral compartment, and concomitant ACL reconstruction were not found to adversely affect healing rates.[39]

Partial Meniscectomy as Salvage

Not all tears are suitable for repair and at least a partial meniscectomy might be indicated to alleviate the patients' symptoms. Cadaver studies to assess the effects of meniscectomy on stability and intraarticular pressures using pressure-sensitive films show that there is almost 75% decrease in the contact areas following medial meniscectomy leading to more than two-fold increase in peak contact pressures.[40] The higher load on the articular cartilage leads to disruption of the proteoglycan matrix resulting in swelling and inflammation throughout the joint. The increased hydration and catabolic state causes the collagen matrix to breakdown and accelerates the normal wear and tear within the joint.[41]

Partial versus total meniscectomy

With the advances in arthroscopy and widespread performance of meniscal repairs, it is uncommon to perform a total meniscectomy today. Partial meniscectomy, however, has a crucial place in arthroscopic surgery of the knee. If a meniscus tear is not suitable for repair, either due the site or size or tissue quality, partial meniscectomy is a valid surgical option. The basic principles for this were described by Metcalf.[42] These are as follows: removal of all mobile fragments; avoiding sudden changes in rim contour; a perfectly smooth rim is unnecessary as some remodeling occurs; repeated probing to evaluate the tear; avoiding damage to the meniscocapsular junction to avoid the loss of hoop stresses; using both manual and motorized instruments to maximize efficiency; and when uncertain about removal or retrieval, err on the side of preserving as much meniscus tissue as possible rather than further compromising biomechanical properties.[42]

Patients undergoing total meniscectomy as compared to partial showed a significantly higher risk of developing radiographic osteoarthritis (OA).[43] In a randomized study of patients who underwent either partial or total meniscectomy, similar early clinical results were reported, there was no significant difference in the radiographic outcomes although the total meniscectomy group had greater mediolateral instability at median followup of 7.8 years.[44]

There is a direct correlation between the amount of the meniscal tissue retained and peak contact stress on the tibial surface following partial meniscectomy.[45] A finite element study quantifying peak pressures to amount of meniscus tissue resection showed that even a 20% resection of meniscus causes a detrimental increase in forces which may hasten osteoarthritic changes. A 65% partial meniscectomy causes maximum shear stress in the articular cartilage.[46]

The tibiofemoral articulations on the medial and lateral side are different, and the absence of menisci leads to a higher contact pressure due to increased point loading on the cartilage. The convex lateral condyle of the femur rolls on a flat or convex lateral tibial condyle, leading to worse outcomes after a lateral meniscectomy. There is a much higher functional deterioration and decreased stability in patients who have undergone a lateral meniscectomy as compared to the medial side.[7,44,47]

Radiological changes

The radiological changes in the knee joint following medial meniscectomy were described by Fairbank half a century ago.[48] He described joint space narrowing, flattening of the marginal part of the medial femoral condyle, and sclerosis of the articulating condyles in patients who had undergone meniscectomy. These radiological signs indicate early osteoarthritic changes in the knee. At least three patients' groups are at higher risk of developing osteoarthritic changes after a meniscectomy: those with ACL deficiency; those with a pre existing chondral lesion; and obese or overweight patients with a high body mass index.[49-52]

Summary

There is abundant literature available on the consequences or outcomes of meniscectomy. However, most of these data are either incomplete or inaccurate or not homogenous to accurately compare and conclude about specifics. The functional and radiological outcomes do not necessarily correlate in most studies. The multiple imaging modalities provide data which are not uniform for comparison. The lack of standardization of methodology and heterogeneous data makes it difficult to conclude if the findings represent true differences or are bias or other errors.[52]

It is prudent to assume that careful selection of patients who really need a meniscectomy, precise arthroscopic surgical technique to preserve as much meniscus as possible, and concomitant management of ligamentous and chondral pathology will reduce the incidence of arthritic changes, when compared with open and radical procedures of the past.

Meniscal Root Tears

In addition to meniscocapsular attachments, there are four meniscal roots that firmly anchor the medial and lateral menisci to the anterior and posterior tibial intercondylar region.[53,54] The biomechanical integrity of the meniscal roots is vital for the proper function of the menisci.[55,56]

All direct avulsions off the tibial plateau and radial tears adjacent to the meniscal roots on either medial or lateral meniscus are defined as root tears.[57] These tears left untreated, result in loss of hoop tension and altered tibiofemoral contact forces. There is accelerated cartilage degeneration seen in such knees which effectively act as a meniscectomized knee.[4,54,56] Improved ability to detect them, and an increased understanding of their biomechanical consequences, has prompted a lot of research in the field of root tears and their management.

The posterior root tear of the medial meniscus is most common as it is the least mobile of all the meniscal roots.[3,58] Posterior horns bear most of loads especially in deep flexion and thus are more likely to get injured.[59] A higher prevalence has been noted in Asian countries where the lifestyle leads to increased squatting and kneeling, especially in the older populations.[60] Individuals with a higher body weight index, lower activity level, and varus malalignment and females are at an increased risk.[61]

Anterior root tears are rare and are usually seen as a complication following improper tunnel placement in an ACL reconstruction or poor placement of entry point for tibial intramedullary nailing.[62,63]

Meniscal root injuries are notoriously difficult to diagnose due to their unusual clinical presentation. The patient may not recollect a specific traumatic occurrence. Patients with an acute posterior tear usually report a popping sensation followed by severe knee pain. Although there is symptomatic relief over a period of time and ambulation is possible, some amount of pain, especially while sitting cross-legged, is reported by these patients. A magnetic resonance imaging scan is the gold standard for diagnosing these lesions [Figure 5a-c].

Treatment

The treatment options for meniscal root tears include conservative management, partial meniscectomy, and repair. The decision-making process is influenced by the age of the patient, symptoms, cartilage status, presence or absence of meniscal extrusion, and type, location, and chronicity of the root lesion.

Conservative treatment

Certain patients may be amenable to treatment with the nonsurgical option. Symptomatic treatment with nonsteroidal anti-inflammatory drugs, bracing to unload the affected side, and activity modification are helpful, especially in patients with advanced age, multiple comorbidities, and severe OA.[64]

Partial meniscectomy

In chronic root tear patients who fail to respond to conservative treatment, and those with partial root tears with preexisting chondral lesions, a partial meniscectomy is the treatment of choice.

Advantages of partial meniscectomy over repair include reduced operative time, easier postoperative rehabilitation, and faster return to activities and sports. These gains and improved short term subjective scores must be read cautiously, knowing that patients undergoing root repair have better improvement in scores and less progression of arthritic changes over time.[2,61,65,66]

Root repair

The recognition that a complete root tear resembles a meniscectomized knee biomechanically has led to an increased preference to repair the lesion than excision of the meniscus.[55,67] Surgical repair is reserved for patients with: (i) acute symptomatic root tears with minimal arthritis, (ii) chronic symptomatic root tears, having failed conservative treatment, without significant preexisting arthritis or varus mal alignment, and (iii) lateral meniscus root tears concomitant with ACL injuries.[2,52,55,57,68,69]

There are multiple surgical techniques and fixation methods that have been described for repairing the medial or lateral root tears.[53] The surgical techniques fall into two broad categories: pull-out suture repairs and suture anchor repairs. Recent description of surgical landmarks has facilitated accurate identification of the roots and the key is anatomic repair irrespective of the technique used.[70,71] Nonabsorbable high strength sutures or tapes are used to grasp the root tissue and anchor to its anatomic bed to allow healing [Figure 6a and b].

Treatment Outcomes

Short term symptomatic relief is seen in patients undergoing either conservative management or partial meniscectomy. However, the progressive deterioration of the chondral surfaces is not prevented.[3,72] To restore hoop stress and improve the clinical and radiographic scores, an anatomic medial meniscal root repair is essential.[2,4] There is no evidence to prove that root repairs retard the progression of arthritis, though it has been reported that repairs do better than partial meniscectomy in this regard.[73] Both methods of root repair (pull-out suture and suture anchor) result in improved functional scores.[74-76] The optimal technique is yet to be determined, though it seems that that suture anchors provide superior biomechanical properties compared with pull-out sutures.[75] Complete healing of the repaired root

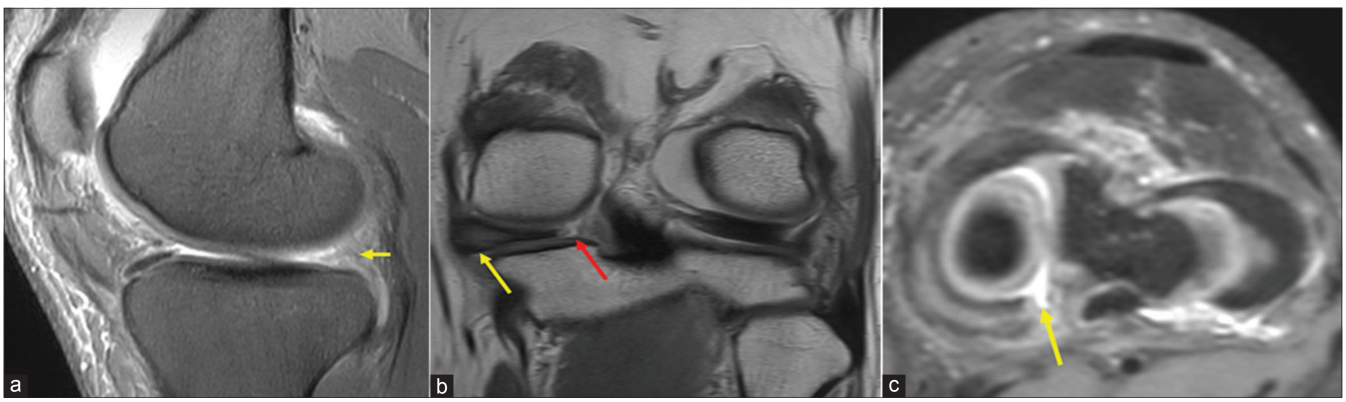

Figure 5: Magnetic resonance imaging diagnosis of medial meniscus posterior root tear – (a) The "ghost meniscus" sign, i.e., absent posterior horn of medial meniscus (yellow arrow) in Proton Density Fat Saturated [PDFS] sagittal section. (b) T1-weighted coronal section showing the site of root tear (red arrow) and extrusion of meniscal tissue outside the joint line (yellow arrow). (c) Axial section across the meniscus demonstrating the site of tear (yellow arrow)

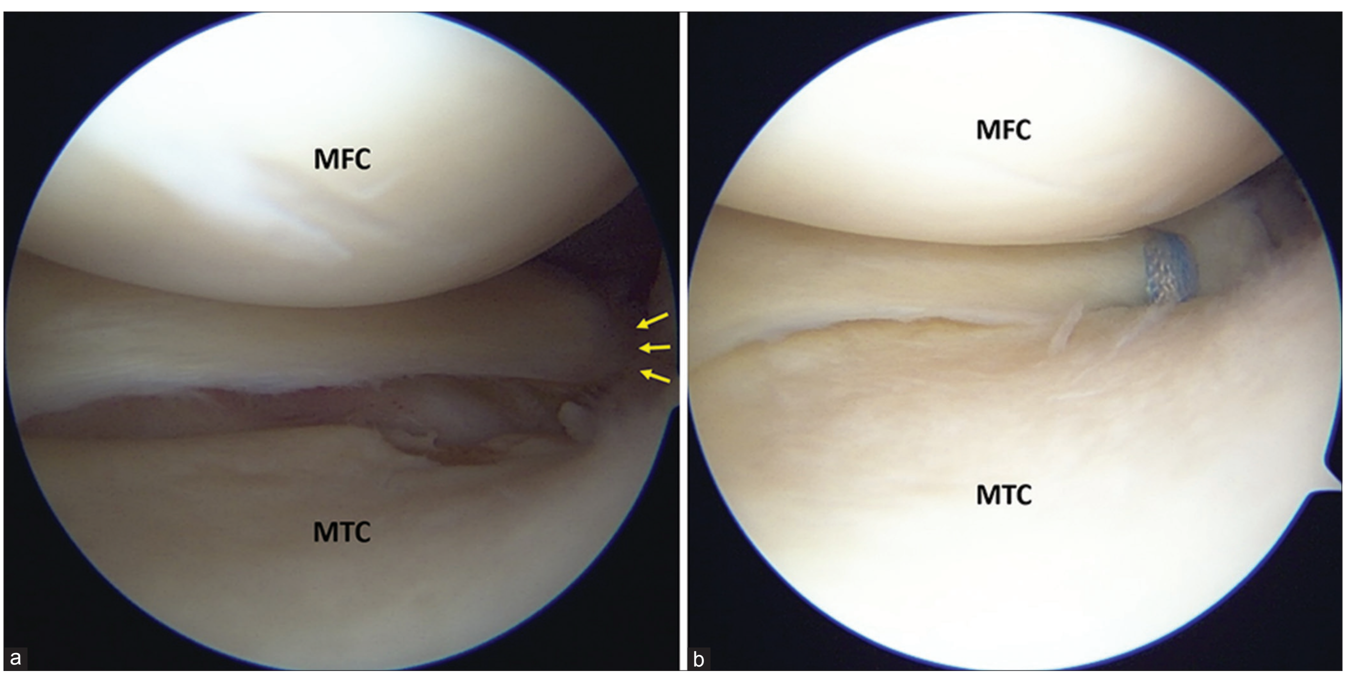

Figure 6: Arthroscopic views showing (a) Left knee medial meniscus posterior root tear (yellow arrows). (b) The meniscus is reduced anatomically after repair using high strength suture tapes. MFC = Medial femoral condyle, MTC = Medial tibial condyle

and reduction of meniscal extrusion are less predictable.[75] Posterior root tears of lateral meniscus have been treated conservatively and with root repair, with low-level evidence justifying either line of management.[72]

Complications

Most intraoperative complications are related to surgical technique and include iatrogenic damage to ACL or cartilage of the ipsilateral compartment and injury to posterior neuro-vascular structures.[57] Meniscal root repair is a technically demanding surgery primarily due to difficulty in accessing the tear and optimal site of repair. Insufficient tension on the repair, inadequate tissue-bite or quality, and nonanatomic fixation may not restore joint biomechanics.[77,78]

Rehabilitation

The rehabilitation following meniscectomy is simpler and faster than following a repair, as there is no "protection" that is required. After an isolated meniscectomy, rehabilitation basically involves advancing activities progressively as the patient tolerates them. The first 2 weeks is for achieving range of motion, quadriceps, hamstring, and core strength and weight bearing without restriction. Sports specific exercises are begun after 2 weeks, and patients are usually able to return to sports at about 6 weeks.[79] Return to sports is also faster in younger patients and in elite athletes.[80]

Rehabilitation after meniscus repair is gradual and there is some disagreement on whether this must be a slow or accelerated protocol. Control of pain and effusion can be done with cryotherapy in the initial weeks. In initial period, protection in terms of weight bearing, and range of motion is generally followed. Richards *et al*. found that compressive loads as in weight bearing applied in full knee extension following repair of longitudinal tears allow reduction and stabilization of the repair.[81] A brace must be used for weight bearing as tolerated ambulation for the initial 4 weeks. However, weight bearing must be delayed after repair of a radial tear or posterior root to prevent hoop stresses from distracting the repair and compromise healing.[82] Knee flexion is detrimental to the repair, as the meniscus translates posteriorly with flexion, especially beyond 60° and the stress rises as well.[58] Hence, active assisted range of motion beyond 90° must be avoided in the first 4 weeks following a repair. For posterior repairs, knee flexion is limited to 70° and active or resisted knee flexion is avoided.[83] An early goal is to establish quadriceps control followed by reestablishment of nonantalgic gait pattern, which in turn also helps improve the range of motion. A phased rehabilitation schedule is recommended with adherence to the rules of rehabilitation as described by Gray.[83,84] Return to sports with accelerated rehabilitation protocols is now advocated and been shown to be successful when compared with more restrictive regimens.[85-87]

Meniscal Allograft Transplantation

Meniscal allograft transplantation (MAT) emerged as a potential treatment option for restoring knee biomechanics, improving and/or delaying the post meniscectomy early onset of arthritis in the knee.[88] There is extensive evidence proving the safety and reliability of the procedure in properly selected patients with acceptable clinical and functional outcomes.[89-92] Most studies have shown an improvement in quality of life with return to recreational as well as competitive sports.[88,92-96] Although the rates of survival for medial and lateral allografts vary, a mean survival rate of 70% at 10 years can be expected.[97,98] Meniscal allografts are fresh, fresh frozen, lyophilized, and cryopreserved, with fresh frozen and cryopreserved allografts used more commonly.[88,92,99] Improperly sized grafts can cause higher forces across the graft and the surrounding articular cartilage. While a 10% mismatch may be tolerated, more research into consequences of mismatch is necessary.[100] The technique of MAT and fixation methods are beyond the scope of this review. However, it must be emphasized that it is critical in preventing early and midterm complications. Suture-only peripheral fixation can lead to extrusion.[101] Bony fixation for the meniscal horns is different for medial and lateral meniscus, with a bone plug for medial meniscus and a bone bridge for the lateral side as the preferred method. The clinical and functional outcomes for bone-to-bone as well as peripheral suturing techniques are similar.[93,97,102] The most common complications of MAT are graft tear, shrinkage, extrusion, and knee stiffness, especially if other procedures are performed to address mechanical misalignment. Failure of MAT can either lead to removal of the allograft with or without conversion to arthroplasty.[88] The goal of MAT is to restore knee biomechanics by optimizing the load distribution of the tibiofemoral forces in the affected compartment, thus retarding the degenerative changes in cartilage. However, conclusive evidence of this has not been documented except in animal models and most human studies report progression of radiological changes.[103-108]

Tissue Engineering Approach

In nonrepairable damaged menisci, partial meniscectomy followed by transplanting a graft is an option. A regenerated, remodeled meniscus can be produced by introducing a graft which acts as a template for matrix synthesis and cellular infiltration along with growth mediators. At present, these include allografts: collagen based scaffolds and artificial biodegradable scaffolds.

Allografts have been in clinical use for a long time and have reported 10-year survival rates of up to 98% and 15-year survival rate of 93.3%.[109,110] These rates go down dramatically in the presence of limb malalignment and articular cartilage damage. The International Meniscus

Reconstruction Experts Forum has proposed the three main indications for MAT:[111] (i) unicompartmental pain in the presence of total or subtotal "functional" meniscectomy, (ii) as a concomitant procedure to revision ACL reconstruction to aid in joint stability when meniscus deficiency is believed to be a contributing factor to failure, and (iii) as a concomitant procedure with articular cartilage repair in a meniscus-deficient compartment.

Although a limited number of scaffolds have made it into the preclinical and clinical studies, there is a huge amount of literature pertaining to *in vitro* tissue engineering.[112] Scaffolds made from synthetic, extracellular matrix constituents (ECMs), tissue derived, and hydrogels have their inherent advantages. An advantage of using synthetic scaffolds is the ability to change its biomechanical properties, whereas the natural scaffolds are better for cellular interaction. Use of electrospun synthetic scaffolds with poly-E-caprolactone (PCL) to provide the appropriate microarchitecture for meniscal cell seeding, coupled with the biomechanical advantage of three-dimensional organization, is an exciting development in recent years.[113] Most naturally derived scaffolds from ECM or hydrogels fall short of the native meniscus in terms of mechanical strength. Tissue-derived scaffolds from porcine small intestine submucosa and silk are also being investigated.[114] Xenogeneic meniscal scaffold of bovine origin may provide options for a partial meniscal replacement.

The native meniscus with its anisotropic features may eventually turn out to be impossible to replicate or regenerate in the laboratory. To achieve the increased level of *ex vivo* maturation of the cell laden scaffolds, the engineered grafts require complex mechanobiological culture modalities over prolonged durations and will be reflected in higher manufacturing costs. While there is great potential for biological augmentation in meniscus surgery, greater translational efforts to link the *in vitro* and preclinical biological and tissue engineering data to the clinical scenario are the need of the hour.

Conclusion

The importance of native joint preservation cannot be stressed enough, in spite of great strides in functional and clinical outcomes after total joint arthroplasty. Although arthroplasty techniques and implant materials have improved over the past decades, the increasing longevity of the general population makes it necessary to delay the primary surgery as long as is feasible. The meniscus plays a vital role in maintaining the stability of the knee joint along with optimizing the tibiofemoral load transfer and distribution. This also helps in preserving the health of the articular cartilage. With all the knowledge gained over the years, it is vital to try and preserve the meniscus by repairing it in appropriate indications. This will hopefully prevent the early development of OA or at least slow down the progressive degeneration of the articular cartilage. In extreme conditions, a partial meniscectomy might be unavoidable and may be carried out by attempting to preserve as much meniscus as is feasible. Biological enhancements of meniscal healing and MAT are other options in the surgeon's armamentarium to aid in joint preservation.

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Conflicts of interest

There are no conflicts of interest.

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