Review Article

Meniscal Root Injuries

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Abstract

Meniscal root tears are an increasingly recognized injury leading to notable functional limitations, potential rapid cartilage deterioration of the affected compartment, and subsequent risk of total knee arthroplasty if left untreated. Repair of these tears is advised when articular cartilage remains intact because both medial and lateral meniscus root repairs have demonstrated favorable results. Recent literature demonstrates decreased rates of osteoarthritis and arthroplasty after medial meniscus root repair compared with partial meniscectomy and nonsurgical management. The transtibial pull-out repair technique is most commonly used and provides a biomechanically strong suture construct with standard and familiar knee arthroscopy portals. Furthermore, repair has recently been shown to be economically effective by decreasing overall societal healthcare costs when compared with more conservative management strategies. This review outlines the evaluation, treatment, and documented outcomes of meniscal root repair, which is imperative to the preservation of knee function and maintaining quality of life.

Meniscal tears are one of the most common knee injuries, accounting for 12% to 14% of orthopaedic presentations involving the knee, with an estimated prevalence of 60 to 70 persons per 100,000.[1–3] Tears can affect various portions of the native meniscus, including the medial and lateral roots which function to anchor the anterior and posterior meniscal horns to the tibia, providing critical maintenance of proper contact stresses, joint stability, and kinematics.[4–6] Meniscal root tears were first described in 1991 by Pagnani et al[7] and are defined as either radial tears located within 1 cm of the meniscal attachment or a bony/soft-tissue root avulsion.[8] The prevalence of posterior root tears identified during knee arthroscopy has been reported to be 7% to 9% overall, with roughly two-thirds located medially and one-third located laterally.[9,10] Interest in diagnosis, management, and surgical technique has continued to grow, with root injuries being increasingly recognized as a cause of early and rapid knee osteoarthritis.[8,11,12] In 2008, Allaire et al[5] demonstrated that avulsion of the medial meniscus posterior horn is biomechanically equivalent to a complete meniscectomy, with resultant abnormal high-peak tibiofemoral contact pressures and decreased contact areas. Similarly, Schillhammer et al[13] demonstrated in 2012 that lateral meniscus posterior horn detachment also increases peak tibiofemoral contact pressures while decreasing contact areas. Subsequently, other studies have associated root tear–associated meniscal extrusion with degenerative cartilage damage, particularly in the setting of increased tibiofemoral stresses during axial loading.[12,14–19]

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Lateral meniscus root tears occur often in young patients with concurrent anterior cruciate ligament (ACL) and multiligament knee injuries.[20] More specifically, patients with lateral meniscus root tears have been demonstrated to be 10 times more likely to have associated ACL tears, whereas patients with medial meniscus root tears were six times more likely to have knee articular cartilage defects with an Outerbridge grade of two or higher.[10] In addition, medial meniscus root tears are commonly chronic and degenerative in nature and occur in middle-aged women, which may account for a subset of over 21% of medial root tears.[8]

Historically, meniscal root tears were treated with partial or total meniscectomy. However, the well-established degenerative "Fairbank's[21]" changes that follow meniscectomy including joint space narrowing, flattening of the femoral condyles, and subsequent generalized osteoarthritis are undesirable in meniscal tear management. As recognition of root tears continues to increase, growing consideration is given to preservation and restoration of meniscal function to prevent degenerative outcomes associated with conservative management and partial meniscectomy.[17,20,22] Subsequently, meniscal root repair has demonstrated improved joint kinematics, patient-reported outcomes, and overall decreased healthcare costs, thus becoming an increasingly commonly used treatment method.[8,15,16,18,23] This review outlines the evaluation, treatment, and documented outcomes of meniscal root repair, which is imperative to the preservation of knee function and maintaining quality of life.

Root Anatomy and Biomechanics

The meniscal roots have been well described and contain native and supplemental fibers that markedly increase the area, strength, and stiffness of the meniscal roots.[24] The medial meniscus anterior root attachment has the largest footprint, inserting along the anterior intercondylar crest on the anterior slope of the tibia.[25] A cadaver study demonstrated the center of the medial meniscus anterior root attachment to be 9.2 mm anteromedial from the ACL and 27.5 mm anterolateral from the apex of the medial tibial eminence.[26] The lateral meniscus anterior root attachment is 5.0 mm anterolateral from the center of the ACL, 14.4 mm from the apex of the lateral tibial eminence, and 7.1 mm from the lateral articular cartilage.[26] It has also notable overlap with the ACL footprint (88.9 mm^2) and is at high risk of iatrogenic injury with nonanatomic tibial tunnel reaming during ACL reconstruction.[27]

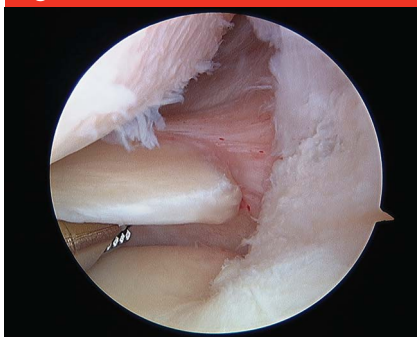
The medial meniscus posterior root attachment has been demonstrated to be 9.6 mm posterior and 0.7 mm lateral to the apex of the medial tibial eminence, with a center point 8.2 mm anterior to the most proximal aspect of the posterior cruciate ligament attachment.[28] By contrast, the lateral meniscus posterior root attachment is 4.2 mm medial and 1.5 mm posterior to the apex of the lateral tibial eminence, with a center point 12.7 mm directly anterior to the most proximal posterior cruciate ligament tibial attachment.[28]

Biomechanically, the meniscal roots convert and disperse axial tibiofemoral loads as hoop stresses and are critical to meniscal function, with 50% to 70% of medial and lateral compartment loads absorbed by the meniscus.[5,29] Disruption of meniscal root integrity results in loss of both hoop stresses and meniscal function, exposing the articular cartilage of the knee to supraphysiologic loads, decreased tibiofemoral contact area, and increased peak contact pressures similar to that of a total meniscectomy.[5] In the cadaver biomechanical series by Allaire et al,[5] complete posterior medial meniscus root tears increased peak contact pressures by 25% (2.8 to 4.2 MPa, $P < 0.001$). After medial root repair, peak contact pressures were restored to similar values (2.9 MPa, $P > 0.05$) compared with intact meniscus controls. In terms of the lateral compartment, similar trends have been observed, with Schillhammer et al[13] reporting 50% increases in peak contact pressures after lateral meniscus posterior horn detachment ($P < 0.03$) and recreation of native contact pressures ($P > 0.99$) after meniscal root repair. Similarly, in a serial sectioning and repair study, Ode et al[30] demonstrated 49% increases in peak tibiofemoral contact pressures with complete radial transection of the posterior lateral meniscus ($P < 0.001$) and subsequent recreation of native peak contact pressures after repair with either inside-out or all-inside suture techniques ($P = 0.2595$).

Clinical Presentation and Diagnosis

Meniscal root tears are generally classified into the following two clinical categories: (1) traumatic tears, which typically occur in younger active patients and are often lateral and associated with concomitant ligamentous injury, and (2) degenerative tears, which are often medial, make up approximately 70% of posterior root tears, and result from chronic, often low-energy attritional mechanisms such as standing from a deep-seated position in older adults.[8] Traumatic tears are more commonly true avulsions of the posterior horn of the meniscus (Figures 1 and 2) and should be repaired at the time of knee ligament (ie, ACL) reconstruction, whereas degenerative tears are often full-thickness radial tears near

Figure 1



Arthroscopic view of an acute traumatic posterior medial meniscal root tear with avulsion of the posterior horn attachment.

Figure 2

Coronal T2-weighted MRI showing the appearance of an acute, traumatic radial tear near the medial meniscus posterior horn–root junction (arrow) with associated meniscal extrusion (**A**). Sagittal T2-weighted MRI images demonstrate a "ghost sign" (arrow) with a missing meniscus at the posterior aspect of the tibia corresponding to the root attachment (**B**).

the root junction and are often not true avulsions from bony meniscal attachments.

As most degenerative meniscus root tears lack a traumatic event, clinicians should have a high degree of clinical suspicion when evaluating the patient with atraumatic knee pain, especially as it relates to the medial meniscus. Risk factors for posterior root tears are well documented and include varus malalignment, older age, increased body mass index (BMI), female sex, and increased Kellgren-Lawrence grade.[31,32] The most common physical examination findings associated with meniscal root tears are joint line tenderness, pain with full knee flexion, and a positive McMurray test.[33] Prototypical meniscal symptoms such as catching, locking, or giving way may be less common in these tears; however, patients with meniscal root tears often have posterior knee pain as a primary report.[8] In addition, Seil et al[34] reported that pain with the application of a varus stress test in full knee extension to be a clinical indicator of medial meniscus posterior root avulsion.

Imaging and Classification

MRI remains the diagnostic modality of choice for meniscal root tears because of the absence of highly sensitive or specific findings in the patient history and physical examination.[29] When reviewing MRI, meniscal root injury is best assessed using T2-weighted sequences, evaluating for three key findings as follows: (1) linear high signal intensities perpendicular to the meniscus (radial tear) at the meniscal root in the axial plane, (2) a vertical linear defect of the meniscal root (truncation sign) on coronal series, often associated with concurrent meniscal extrusion, and (3) the absence of normal meniscal signal in the sagittal plane (ghost sign) (Figure 2 and Video, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A416).[35]

Meniscal extrusion is defined as a substantial (≥3 mm for medial tears) outward radial displacement of the meniscus from the tibial articular cartilage and has been identified to be strongly, albeit noncausally, associated with [medial] meniscal root pathology and joint degeneration.[36,37] Given that the truncation sign may be difficult to visualize, extrusion may be the only sign suggestive of a meniscal root tear observed in coronal series. Furthermore, although not all cases of meniscal extrusion are due to root tears, root tears have been demonstrated to be rare in isolation without associated meniscal extrusion on MRI.[38]

In terms of tear configuration and terminology, LaPrade et al[39] have provided a classification system based on the arthroscopic assessment of tear morphology. Type 1 tears represent partial but mechanically stable tears (7% of tears), type 2 tears consist of a complete radial tear occurring within 9 mm of the bony root attachment (68% of tears), type 3 tears are formed by a complete root detachment with an associated ipsilateral bucket-handle tear (6% of tears), type 4 tears consist of a complex oblique tear with complete root detachment (10% of tears), and type 5 tears demonstrate a bony avulsion fracture of the root attachment (9% of tears).

It is worth noting that MRI evaluation of the meniscal roots must be viewed in light of certain limitations and augmented by physical examination and history. A blinded review by LaPrade et al[9] reported preoperative MRI detection of medial and lateral

meniscus posterior root tears to have a sensitivity of only 82% and 60%, respectively. In addition, Krych et al demonstrated that the rate of preoperatively identified posterior root tears on MRIs read by fellowship-trained musculoskeletal radiologists was only 33%, with only 50% of missed tears clearly evident when retrospectively reviewing known tears.[22]

Natural History and Clinical Outcomes

Natural History

Given that avulsion of the meniscal root is functionally equivalent to complete meniscectomy, the natural history of meniscal root tears is particularly poor, with up to 28% of patients undergoing total knee arthroplasty (TKA) at a mean of 3.2 years after initial diagnosis.[5] In parallel, the role of tear-associated extrusion and subsequent osteoarthritis and spontaneous osteonecrosis of the knee (SONK) has also been the subject of ongoing investigation.[40–42] Previously been thought of as an idiopathic process, SONK has been associated with posterior meniscal root tears in up to 80% of patients, providing mounting evidence that SONK embodies subchondral insufficiency fractures because of biomechanical loss of meniscal root competence.[42]

In terms of progression of osteoarthritis, it had been previously noted that the degree of radial displacement (extrusion) of menisci that had not undergone meniscectomy, as measured on MRI, was strongly correlated with the degree of osteoarthritic changes observed on radiographs.[43,44] For patients with high-grade root tear–associated articular pathology (ie, SONK), multiple series have suggested that nearly all patients have substantial extrusion on preoperative imaging.[45,46] In a series by Yasuda et al,[46] all 18 knees evaluated with SONK had substantial ≥3 mm extrusion of the medial meniscus. However, it remains to be determined whether meniscal extrusion is a risk factor or downstream consequence of root tear–related osteoarthritis.

Root Repair Versus Meniscectomy

The role of root repair over meniscectomy, when technically possible, is increasingly supported by the available literature. Chung et al[15] compared 37 root repairs with 20 partial meniscectomies at a minimum of 5 years of follow-up and observed superior objective knee function scores in the repair group. Furthermore, 35% of the partial meniscectomy group underwent conversion to TKA compared with 0% of the repair group. These findings were mirrored by Krych[20], who demonstrated that patients undergoing partial meniscectomy for symptomatic medial meniscus posterior root tears demonstrated no substantial benefit in patient-reported outcome scores, and furthermore, 52% of meniscectomy patients progressed to arthroplasty at a mean of 4.5 years. More recently, the long-term results of meniscal root repair have been reported, demonstrating good results in 96% of patients and mean postoperative improvements of 30.2 points on the Lysholm scale.[23] It is noteworthy that the studies presented represent retrospective series and may be subject to a degree of selection bias, with patients undergoing meniscectomy being less healthy and poorer candidates for joint preservation compared with their peers undergoing meniscal repair.

Root Repair Outcomes and Risk of Articular Cartilage Degeneration

Outcomes of meniscal root repair have been promising and support surgical intervention for the maintenance of function and prevention of arthritis.[15,16,23] A a mean follow-up of 6 years, Chung et al[15] demonstrated that only 14% of 37 meniscal root repair patients demonstrated ≥2 unit progression of the Kellgren-Lawrence grade. In a follow-up study of 91 patients, only 1 patient (1%) converted to TKA at a mean follow-up of 7.1 years.[23]

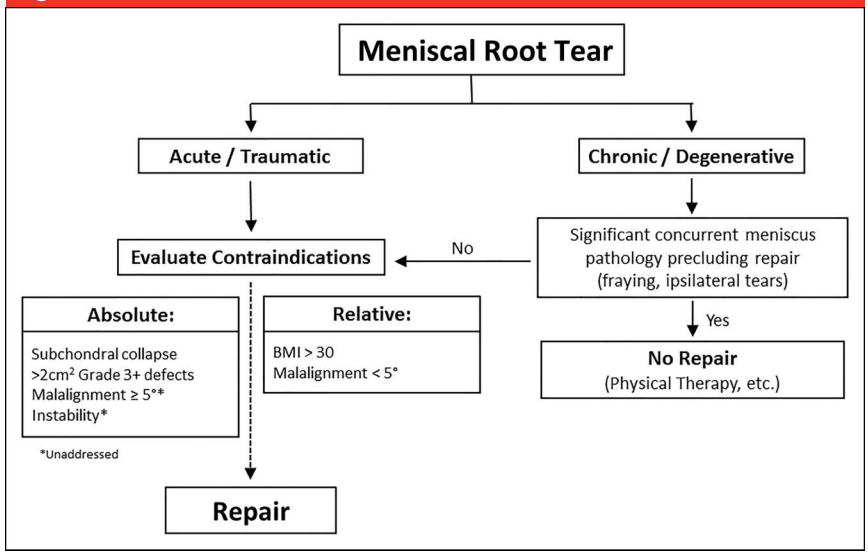
Although root repair has demonstrated decreased rates of progressive osteoarthritis and conversion to arthroplasty, various underlying factors remain important in determining the success of root repair procedures. In particular, Brophy et al[47] demonstrated that at minimum 2-year follow-up, patients with a BMI greater than 35 kg/m^2 had a higher rate of repeat surgery (25% versus 0%) and a higher proportion of patients with clinical OA at the time of the final follow-up (75% versus 29%, P = 0.04). Although BMI and osteoarthritis risk likely exist on a continuum, outcomes such as this highlight the importance of patient counseling and the role of BMI in indicating patients for root repair. In addition, previous studies have established that complete structural healing of root tears is correlated with notable improvements in meniscal root extrusion, with those patients with incomplete healing and associated high-degree extrusion going on to early progression of cartilage degeneration at 2 years of follow-up.[33] Therefore, all efforts should be made intraoperatively to reduce the extruded meniscus to support both anatomic tear healing and restoration of native joint biomechanics.

Economic Considerations

In addition to providing a potential opportunity for surgical intervention and joint preservation, recent studies have established the economic effectiveness of meniscal root repair. In a recent meta-analysis, meniscal repair, meniscectomy, and nonsurgical

management were compared using a Markov cost model–based meta-analysis.[18] Knee osteoarthritis rates of 53.0%, 99.3%, and 95.1% were observed at 10 years for the repair, meniscectomy, and conservative management groups, with associated 33.5%, 51.5%, and 45.5% rates of TKA, respectively, highlighting the protective effect of root repair. In further cost-based analyses, meniscal repair was found to be both cost effective and superior in terms of patient-experienced quality-adjusted life years. As such, we think that meniscal repair is not only surgically feasible but also clinically and economically justified.

Figure 3



Flowchart showing indications and contraindications for meniscal root tear repair.

Clinical Management

We believe repair should be attempted in young patients with an otherwise healthy knee and strongly advocate for concurrent assessment of alignment, cartilage, and ligamentous factors because failure to address underlying pathology has been demonstrated to be one of the most common reasons for revision after knee preservation surgery.[48] Specific indications for meniscal repair consist of acute tears and chronic/degenerative tears without substantial concurrent meniscal pathology occurring in active patients without generalized osteoarthritic changes (ie, Kellgren-Lawrence grade ≤2). Contraindications to meniscal root repair include subchondral bone collapse, substantial malalignment (≥5°), and notable degenerative pathology of the affected knee compartment, which must be comprehensively assessed at the time of presentation (Figure 3). In addition, increased BMI (ie, >30 kg/m^2) and milder forms of malalignment (<5°) serve as relative contraindications given the increased stress on the repair construct.[47]

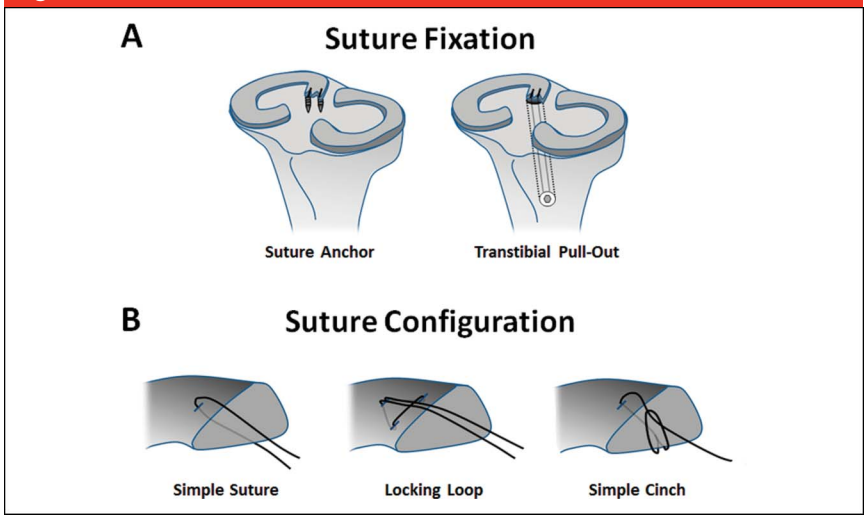
Recent literature supports the repair of radial meniscus tears, as is sometimes the case for degenerative tears, with similar patient-reported outcome scores and revision surgery–free survival at 5 years.[49] However, nonsurgical management or partial meniscectomy should be considered in patients with notable underlying meniscal pathology and suboptimal substrate for repair (ie, accompanied by complex, degenerative meniscus pathology and fraying) and in those patients with notable coexisting chondral pathology. Partial meniscectomy can still serve a role in patients with irreparable tears in the setting of mechanical symptoms such as locking or pain refractory to a comprehensive trial of nonsurgical management and physical therapy. Indications for repair of degenerative tears are evolving, and the optimal candidate for older patients with such pathology has yet to be definitively established.

Biomechanics and Suture Constructs

The biomechanics of various suture devices and configurations (Figure 4) have been previously described and assessed.[12,33,50] In terms of the described suture anchor and transtibial pull-out techniques, only one article to date has directly compared the two techniques.[33] Kim et al[33] reported in 2011 that both techniques demonstrated significant and similar reductions in medial root tear gap distances (pull-out: 3.2 mm preoperative to 0.5 mm postoperative, P = 0.031; suture anchor: 2.9 mm preoperative to 0.6 mm postoperative, P = 0.041) and similar improvements in meniscal extrusion. Furthermore, the 2 groups demonstrated similar rates of complete structural healing (pull-out: 11 of 17, suture anchor: 12 of 14, P = 0.45), albeit with a suggestion of higher rates of incomplete healing in the pull-out group (6 of 17 versus 2 of 14, P < 0.01). Further research directly comparing the two fixation methods is needed to evaluate the ideal fixation method for repair, with both widely reported on an individual basis in the literature.

When choosing suture constructs, both ultimate load to failure and

Figure 4



Schematic depiction of suture anchor and transtibial pull-out techniques for suture fixation (**A**) and simple suture, locking loop, and simple cinch suture configurations for meniscal fixation (**B**).

cyclic displacement during knee rehabilitation must be considered. A variety of suture configurations have been described, with simple sutures, locking loops, and [simple] cinches commonly used (Figure 4, B).[12] Multiple studies have demonstrated superior locking loop strength when compared with simple suture configurations.[51,52] However, the placement of sutures in the posterior meniscal horns can be clinically challenging, with locking loop constructs requiring multiple passes, placing nearby anatomic structures at risk.

The use of a cinch stitch is of clinical interest given that it requires only a single pass and has been suggested to have increased pull-out strength when compared with standard simple suturing methods.[53] When comparing a simple cinch and locking loop configurations, significantly less displacement was found in cinch sutures (3.3-mm displacement simple cinch versus 3.7-mm locking loop, $P = 0.001$ for medial meniscus and 2.7-mm displacement simple cinch versus 3.4-mm locking loop, $P < 0.001$), whereas ultimate load to failure was similar between the 2 groups. Considering that simple cinches have been found to be notably better at resisting displacement compared with locking configurations, we advocate for their use given easier, single-pass placement and fewer associated perforations of the meniscus tissue.

Given the clinical association of meniscal extrusion with degenerative cartilage pathology, recent interest has been shown in creating suture constructs, which can reduce or centralize meniscus tissue and potentially result in better approximation of native biomechanics and contact forces.[19,38,46] In an animal study involving meniscal destabilization through meniscotibial ligament transection in rats, Ozeki et al[54] demonstrated that the use of a peripherally applied transtibial centralization suture reduced extrusion and macroscopic and histologic cartilage degeneration at 8 weeks of follow-up. Subsequently, Daney et al[55] published a human biomechanical study describing a centralization suture placed at the midpoint between the posterior meniscal root attachment and posterior border of the medial collateral ligament to prevent extrusion after medial meniscus root repair. The authors observed that anatomic repair with the addition of the centralization suture was the only construct to significantly ($P < 0.05$) lower peak contact pressures across all knee flexion angles tested from 0° to 90°. However, it is noteworthy that no difference was observed when comparing analogous (ie, anatomic versus nonanatomic) repair techniques with or without the addition of a centralization suture, supporting the need for further research in these centralizing suture constructs.

Authors' Preferred Operative Technique

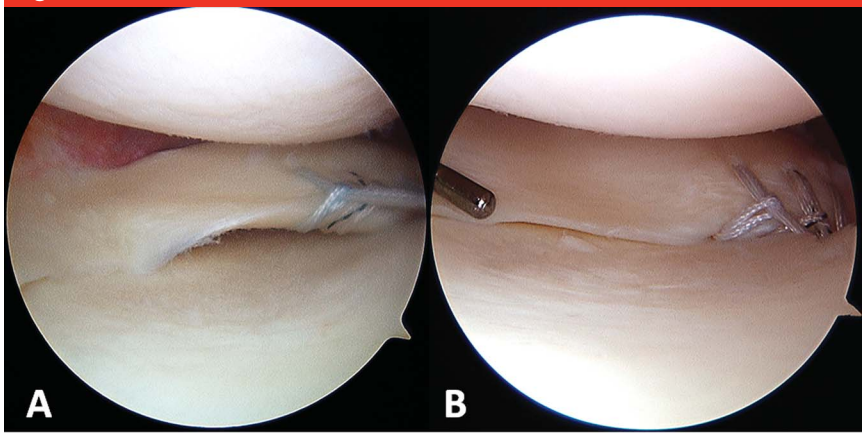
Repair of meniscal root tears has been described using sutures pulled through a transtibial tunnel and also using direct fixation with suture anchors. Although published outcomes support the efficacy of both suture anchor and transtibial constructs, with satisfactory and comparable structural healing and patient-reported outcome scores, the suture anchor technique is technically challenging, requires a posterior portal adjacent to the neurovascular structures, and uses specialized, curved suture-passing devices for constrained passing within the knee.[33,56] Given this, the authors are proponents of transtibial fixation using standard and familiar arthroscopy portals, which has an established record of positive midterm to long-term results.[15,23,57]

Our preferred technique of meniscal root repairs has previously been described in detail and is demonstrated in our associated Video, Supplemental Digital Content 1, http://links.lww.com/JAAOS/A416.[58] Standard knee arthroscopy portals are used, including a portal ipsilateral to

Figure 5

Arthroscopic view of suture passing with a self-retrieving device.

Figure 6



Arthroscopic views demonstrating locking loop suture tensioning (**A**) and subsequent meniscal root reduction to the native bony attachment, constituting the final repair (**B**).

the tear to allow for direct visualization of the posterior root. The attachment of the meniscal horn is inspected and palpated with a probe, which is of clinical significance because of the high rate of incomplete tear visualization on preoperative MRI.[59] In cases where it is difficult to obtain adequate visualization of the posterior meniscal roots and their respective compartments, we recommend consideration of (reverse) notchplasty or pie crusting of the medial collateral ligament to provide satisfactory arthroscopic access.[60] Given that meniscal root tears are challenging to identify preoperatively, including in the setting of both primary and revision ACL reconstruction, surgeons must always thoroughly inspect the meniscal attachments and be ready to repair detected root tears. For this reason, we recommend having meniscal suture-passing devices specialized for root repair available at the time of all knee cases.

After establishment of optimal portals and working space, attention is turned to tibial socket preparation. Given the importance of anatomic socket location, our preference is to use a root-specific tibial guide placed through the ipsilateral arthroscopy portal and centered on the meniscal root footprint. However, this can also be achieved with a standard ACL guide and drill. Subsequently, a 6-mm all-in-one guide pin/reamer is introduced into the joint through an incision on the proximal and medial tibia and deployed so that a shallow 6-mm socket is formed to provide fixation access to healing vascular subchondral bone. This can also be achieved with the standard 6-mm drill; however, this leads to greater bone loss along the length of the entire tibial tunnel compared with selective inside-out drilling with all-in-one instrumentation.

For meniscal fixation, a free No. 0 nonabsorbable suture is passed through the torn meniscus in a simple cinch configuration using a self-retrieving suture-passing device (Figure 5). A total of 2 to 3 locking sutures are placed, depending on the tissue size and quality and then individually tightened, with the knee cycled to remove creep from the system. Subsequently, the sutures are tensioned through the tibial socket to reduce the meniscal root back to the native bony root attachment (Figure 6). Tibial fixation is subsequently obtained using a 5.5-mm anchor or, as classically described, a tibial button, with the knee in 90° of flexion.

Postoperative Course and Care

Protection of meniscal repair is critical to healing and, consequently, successful clinical outcomes. During the first 6 weeks after surgery, weight bearing is limited to full knee extension with toe-touch weight bearing in the brace. Concurrently, overall knee range of motion is limited from full extension to 90° of flexion. After 6 weeks, the brace is discontinued, and patients may begin full progressive weight bearing and unrestricted knee range of motion when unloaded. Knee loading at flexion angles greater than 90° is not allowed until 4 months postoperatively. Clinically, a gradual increase in activities is allowed after 3 months of recovery, with gentle initiation of sporting activities at 4 to 6 months, once normal strength and gait symmetry has been achieved. This may be limited by concomitant surgical procedures, such as a ligament reconstruction, and is thus informed on an individualized basis by the treating surgeon. Of note, high-quality evidence comparing individual meniscal root–specific rehabilitation protocols and their respective duration

has yet to become available and merits further investigation.

Summary

Meniscal root repair is strongly preferred in well-selected patients, with decreased rates of osteoarthritis and TKA in comparison with patients managed with partial meniscectomy or nonsurgical management. Using a transtibial pull-out technique for meniscal root repair allows for a strong suture construct and a familiar arthroscopic approach, providing established, positive long-term outcomes. Given the high potential economic and quality-of-life advantages, we recommend meniscal root tear repair, when indicated, to best preserve knee function in patients presenting with meniscal root tears.

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