Meniscal Root tears: Repair and Salvage techniques

Morgan D. Homan, DO
Jacob Braaten, BS
Mark Banovetz, BS
Nicholas I. Kennedy MD
Robert F. LaPrade MD, PhD

1Twin Cities Orthopedics, Edina, MN
2University of Minnesota Medical School, Minneapolis, MN

Corresponding author:
Robert F. LaPrade MD, PhD
Twin Cities Orthopedics
Edina, MN 55435
Email: laprademdphd@gmail.com
Abstract

Recent interest has uncovered the importance of understanding meniscal root anatomy, its effect on biomechanics of the knee joint, and appropriate treatment modalities. Meniscal root tears may account for up to one fifth of all meniscal tears and have downstream consequences that can be as severe as total meniscectomy due to the unique force-dispersing properties of the meniscus. Meniscal biomechanics rely heavily upon the integrity of root attachments, and this historically overlooked etiology of knee pain and early onset osteoarthritis plays a vital role in maintaining the longevity of the knee joint. As meniscal root pathology becomes more commonly known and clinically assessed, an understanding of classifications, repair methods, and indications is important for surgeons.
Background (and epidemiology)

Historically overlooked as an etiology of knee pain and early onset osteoarthritis, the meniscal root plays a vital role in maintaining the longevity of the knee joint.\textsuperscript{1,2} Reported to affect nearly 100,000 patients annually, meniscal root tears account for up to 10-21% of all meniscal tears and have been labeled as a “silent epidemic” due to their widespread underdiagnosis and the rapid progression of untreated injuries to osteoarthritis.\textsuperscript{3-6} Demographic differences have been reported for types of meniscal root tears, with young male patients more likely to present with lateral meniscal root tears, often in the setting of multiple ligament knee injuries, knee trauma, or concomitant anterior cruciate ligament (ACL) tears.\textsuperscript{7} Medial meniscal root tears often occur via a low-energy mechanism and are more common in older patients with higher BMI and existing degenerative changes in the knee.\textsuperscript{8,9}

A meniscal root tear is defined as a complete bony or soft tissue avulsion of the root attachment or a radial tear that occurs within one cm of the meniscal root attachment.\textsuperscript{10-12} Recent studies have recognized the extent to which meniscal root tears disrupt the native biomechanical role of the meniscus.\textsuperscript{4,10,13-15} Meniscal root integrity is critical for the conversion of axial tibiofemoral loads into hoop stresses.\textsuperscript{2,12,16} A root avulsion alters the tibiofemoral load distribution across the tibial plateau because of meniscal extrusion, which increases the pressure on the articular cartilage. Past biomechanical studies have demonstrated changes in area and contact pressures across the tibiofemoral joint following a meniscal root tear are comparable with a meniscal deficient state.\textsuperscript{16} These altered tibiofemoral loads have been shown to intensify degenerative changes in the knee joint.\textsuperscript{9,17}
Past literature has reported a strong association between meniscal root tears and progression to knee osteoarthritis,\textsuperscript{1,7,17,18} and meniscal root tears often occur in the fourth or fifth decade of life. Early detection is crucial to restore native knee joint loading and for the prevention of articular cartilage degeneration.\textsuperscript{3,7,17,19} For decades, meniscectomy was the standard treatment following meniscal injury, and continues to be widely utilized. However, given the significant risk of progression to osteoarthritis, treatment by meniscectomy has come under scrutiny and current research emphasizes meniscus preservation with anatomically oriented meniscal root repair techniques.\textsuperscript{17,20} This article will review the anatomy and biomechanics of the meniscus root attachments, with diagnostic and surgical treatment pearls, and discuss the current state of meniscal root tear repairs and salvage techniques.

\textit{Anatomy/biomechanics}

\textit{Meniscus Anatomy: Structure is Function}

The medial and lateral menisci form two C-shaped borders filling the triangular space between the tibial and femoral articular cartilage surfaces and the joint capsule. The meniscus itself is roughly the shape of a collapsed triangle on cross section, with a broad, vascular outside body which thins to a less vascular and then ultimately avascular apical ridge between chondral surfaces. This unique space-filling shape leads to increased joint-surface contact area.\textsuperscript{17,23} The lateral meniscus is smaller and more circular with its anterior and posterior roots nearly meeting at the lateral intercondylar eminence. Both anterior and posterior medial meniscal roots lie peripheral to the lateral root insertions, forming more of a horseshoe or C shape.

The medial meniscus, perhaps due to the greater percentage of weightbearing through the medial femoral and tibial pillars, is more rigidly attached to the tibia and the surrounding capsule, and therefore, less mobile. The medial meniscus therefore provides a certain measure of stability for
the femoral condyle on the tibia—a sort of shallow, rounded cup holder. The lateral meniscus in comparison has more laxity allowing a small amount of anteroposterior glide along the tibial surface so as to better move with the lateral femoral condyle during natural axial rotation about the tibiofemoral joint. Much of the posterior horn of the lateral meniscus lacks meniscocapsular attachments, thereby allowing this increased mobility. However, the meniscofemoral ligaments, which course from the medial most extent of the posterior horn to their attachment sites in the femoral notch both anterior and posterior to the bundles of the PCL, both confer notable stability namely to internal rotation and anterior translational forces.

While the meniscocapsular attachments and meniscofemoral ligaments are both important for meniscal stability, the most biomechanically important connections are the meniscal root attachments.\textsuperscript{17,22,23} Further, meniscal root integrity is crucial to meniscal function as a whole, because the disruption of these anchoring sites releases the circular tension holding the meniscus between the tibiofemoral cartilages.\textsuperscript{17} The resulting axial compression through the tibiofemoral joint then pushes the meniscus out of the articular joint space, thereby diminishing the ability of the meniscus to adequately disperse axial tibiofemoral joint forces.

\textbf{Biomechanics, Stability, and Sequelae}

Foundational studies examining the biomechanical and structural characteristics of the menisci have established their critical role in modulating force transmission across the tibiofemoral articulation\textsuperscript{17,21,22}. Classically, the meniscus has been likened to a “shock absorber” in the knee\textsuperscript{17,23}. It functions in this capacity by converting axial compressive loads into radial tangential “hoop stresses.”\textsuperscript{17,22} In doing so, the menisci reduce the total compressive forces experienced by the chondral cartilage of the tibial plateau and femoral condyles\textsuperscript{17,22}. Furthermore, by increasing
the contact surface area of the tibiofemoral articulation, the menisci function to spread compressive loads over a larger surface area, thereby avoiding the phenomenon of “point loading.” This dispersion of axial compressive loads across the knee helps to provide long term protective effects to chondral surfaces and prevent progression of osteoarthritic changes. In addition, the loss of stability caused by root tears leads to increased instability and motion across the tibiofemoral articulation, which puts increased strain on stabilizing ligaments such as the ACL. It may also be that increased motion due to instability inferred by meniscal root pathology changes the biomechanics of the tibiofemoral joint to an extent that expedites the joint degradation sustained.

Pathology discussing diagnosis

LaPrade Classification of Meniscal Root Tears

The term meniscal root tear (MRT) is used to describe damage occurring to one of the meniscal attachment sites within 1 cm from the meniscal root insertion. Meniscal root tears can manifest in a variety of ways, necessitating the use of an appropriate classification system. The LaPrade Classification for MRTs classifies meniscal root tears based on the location and quality of the tear.

Unlike other proposed systems for classifying MRTs, the LaPrade Classification for MRTs applies to both the anterior and posterior roots and separates tears into 5 types. Type 1 describes an isolated, stable partial tear of the meniscal root. Type 2 describes a complete radial tear of the meniscal root and contains three subtypes which differ based on their location along the meniscal root relative to the center of the root insertion; Type 2A occurs at less than 3
mm from the center of the root attachment, Type 2B occurs from 3 to 6 mm from the center of the root attachment site, Type 2C occurs from 6-9 mm from the center of the root attachment site. Type 3 describes an MRT with a concomitant longitudinal/circumferential tear (commonly referred to as a “bucket handle” tear). Type 4 describes an oblique tear of the meniscus that extends into the meniscal root resulting in complete root detachment. Finally, Type 5 describes the case of a complete bony avulsion fracture of the root from its attachment to the tibial plateau.

![Figure 1: Graphic displaying an example of each type of MRT as described by the LaPrade Classification System. A Type 2A tear is depicted as an example for a Type 2 tear. Reproduced with permission from AJSM Vol. 43 Issue 2, pp. 363-369.](image)

**Extrusion and Nonanatomic Repair**

Many studies have shown that the meniscus-deficient knee (e.g. patients treated with meniscectomy or hemi-meniscectomy) almost always consistently and rapidly progresses to osteoarthritis. Furthermore, biomechanical models have shown the meniscal root-deficient
knee to be biomechanically equivalent to the meniscectomized knee, and therefore, pose a similarly significant risk of progression to fulminant osteoarthritis\textsuperscript{16,17}. Studies have further demonstrated that nonanatomic repair of an MRT functions biomechanically similar to leaving the root left untreated and thereby would have significant long-term degenerative effects\textsuperscript{26,27}. This is because the chondroprotective functions of the menisci are ultimately dependent upon their attachment to their respective anatomic root attachment sites\textsuperscript{17,21,28}. When the native menisci experience axial compressive forces, they are placed into circular traction\textsuperscript{17,22,28}. However, when the MRTs are compromised, the meniscus is unable to retain circular traction, and instead, extrudes out of the joint space\textsuperscript{17,21,28}. As a result, the meniscus is unable to disperse axial compressive loads, and point loading occurs\textsuperscript{15}. Point loading results in a phenomenon described previously as spontaneous osteonecrosis of the knee (SONK, now thought to be more appropriately referred to as “subchondral insufficiency fracture,” or SIFK), which is one of the identifiable signs of a meniscal root tear that can be found on magnetic resonance imaging (MRI)\textsuperscript{17,29}. Therefore, strategies to minimize meniscal extrusion following meniscal root repair have also become an area of great focus\textsuperscript{29-31}.

\textit{Diagnostic pearls}

Due to the acceleration of joint degeneration caused by meniscal root tears, early diagnosis and prompt treatment is paramount for good outcomes. The clinical diagnosis begins with a detailed patient history and physical exam, and while certain radiographic findings may raise clinical suspicion, the gold standard for diagnosis is ultimately MRI and arthroscopy. Regarding the notoriety of MRTs as missed diagnoses, high clinical suspicion is required for the diagnosis and clinician understanding of etiology and diagnostic signs is crucial.
History and Physical Exam

The difficulty of diagnosing meniscal root tears stems in part from the lack of similarity to injury of the meniscal body. It has been reported, for example, that only 10-15% of patients with medial posterior root tears exhibit signs of knee locking or giving way.\textsuperscript{32} Indeed, similar to the majority of chronic meniscal injuries in older populations, up to 70\% of patients cannot recall a direct inciting injury.\textsuperscript{33} When present, the mechanism of injury may lead to clinical suspicion of a root tear, such as a rotatory blow to a flexed knee which is assumed to be a common etiology. The presence of an ACL injury should also prompt examination for an MRT, most commonly in the lateral posterior root. Lateral meniscus root tears have been reported to have an incidence rate ranging from 2.65-16\% in ACL injuries.\textsuperscript{34,35} Physical exam is also limited in diagnostic utility, with some combination of pain with deep flexion (for posterior root tears), palpable meniscal extrusion, and a positive McMurray’s test being present in only 50-60\% of patients.\textsuperscript{36} Physician gestalt after history and physical should direct further diagnostic imaging.

Imaging

Plain film radiographs including Rosenberg view are commonly obtained in orthopedic clinics, these images are less helpful for characterizing type of meniscal pathology and instead more helpful with inferring chronicity and severity of degenerative changes. Because root tears are structurally comparable to meniscal deficiency, the onset of rapid arthritic changes and increased Kellgren-Lawrence scores, particularly in young patients, should provoke investigation for meniscal root tears. Long leg standing films should be acquired to assess coronal alignment as well. More recent literature has demonstrated that varus malalignment of >5 degrees is associated with slightly decreased outcome scores compared with neutral alignment.\textsuperscript{37} However,
patients still have low failure rate and good improvements in outcome scores with varus alignment following meniscal root repair. Further, concomitant osteotomy in this population was associated with significantly worse outcomes and therefore is no longer recommended in this patient cohort.

MRI is the most reliable non-invasive test for MRTs. Although in the past, studies had demonstrated specificity as low as 70\%\textsuperscript{38}, the literature now reports recent diagnostic advances have improved predictive values to over 90\%\textsuperscript{39-41} Signs of meniscal root tears on MRI include increased signal resulting from fluid collection near the meniscal roots (Figure 2), the ghost sign (sagittal cuts on which the meniscus is not identifiable in its normal position, Figure 3), and coronal views showing meniscal extrusion greater than 3 mm from the tibial articular cartilage (Figure 4).\textsuperscript{17} Axial cuts can similarly be quite telling and representative of a meniscal root tear if the imaging cuts demonstrated have a good on-profile view of the root attachment (Figure 5).

Associated SONK, a misnomer more properly replaced with SIFK, is bony edema of the femoral condyles or tibial plateau thought to be caused by increased point-loading due to lack of
meniscal support. This is another MRI finding that, in the absence of obvious causes, should prompt further investigation of an MRT.²⁸

Arthroscopic Assessment

Direct visualization under arthroscopy remains the gold standard for confirmation of MRTs, and due to increasing clinician awareness meniscal roots are commonly assessed with a probe on routine arthroscopy (Figure 6). They may be visualized and assessed from standard medial and lateral portals, or for optimal visualization a surgeon may drive through the intercondylar notch or (less commonly) use additional posteromedial or posterolateral portals.
posterolateral portals.\textsuperscript{42} Arthroscopic assessment should classify the tear type for determination of indicated fixation.

\textbf{Treatment options}

\textit{Nonoperative Treatment}

As awareness of meniscal root tears and the biomechanical significance of MRT repair grows, nonoperative treatment has fallen out of favor excepting surgical contraindications. These include advanced arthritis (Outerbridge or Kellgren-Lawrence 3-4), high BMI, and coronal malignment more than $3^\circ$.\textsuperscript{43,44} For those patients who are not good surgical candidates or for whom meniscal root repair would offer little benefit, the mainstays of treatment are weight loss, activity modification, and bracing.\textsuperscript{43} In particular, for patients with underlying varus alignment, the use of a medial unloader brace may prove very beneficial in reducing stresses upon the joint. Further symptomatic treatment with analgesics and ice may be recommended. For those with intractable pain failing nonoperative treatment, particularly in elderly patients, a total knee arthroplasty may be considered.

\textit{Meniscal Root Repair Techniques}

Numerous techniques exist to repair, augment, or reconstruct the meniscus, and there are many associated procedures that may aid in the long-term viability of the procedure, including repair or reconstruction of other stabilizing structures about the knee, or procedures aimed at ameliorating increased stress placed upon the meniscus. In last-resort cases, salvage procedures exist to offer the patient some form of relief. Meniscal root repair should be followed by a minimum of six weeks non-weightbearing with passive knee flexion to 90 degrees only for two weeks to avoid overstressing the new construct.
Side-to-Side Repair

Perhaps the most obvious technique to restore meniscal function is an all-inside direct end-to-end repair of a radial tear. In the meniscal root, specifically, this would manifest as a gray area between type 2 C tears and very posterior radial tears of the meniscal horn. This is because a significant (~10 mm or more) stump is required both for adequate tissue purchase, and because the device depth-limiter precludes use with anything less. This type of repair is more commonly used for lateral meniscal root tears due to their propensity to tear incompletely with a flap that needs to be realigned. There are a number of ways to address these tears in a “side-to-side” fashion. All-inside with arthroscopic knot tying, all-inside with meniscocapsular fixation devices and inside-out techniques have all been described and can be utilized for these tear types. Further, the described suture configurations themselves are highly variable. These configurations include: simple sutures across the tear, X type configurations, and rip-stop constructs combining horizontal mattress and vertical or simple suture patterns.

There are numerous things to consider regarding the ideal repair construct. The benefit of side-to-side repairs lies in their ability to incorporate existing meniscal tissue attached to the stump which provides an approximate restoration of native meniscal length and avoids the potential to shorten the meniscus (and thus overtighten it) which may occur with anchor or transosseous fixation. The size and quality of this stump is often less than ideal and therefore meniscal configurations that are the least damaging and help with load sharing are preferred. It is also important to consider needle size in the proposed construct because most all-inside devices are between 14-16 gauge compared with inside-out devices which are 23-25 gauge. This is a diameter difference of >0.6mm which is substantial and can lead to further damage to an already
compromised meniscal radial tear edge. Further, risk of suture pull-through failure is not low and therefore a rip stop technique, which helps distribute the load to meniscal tissue across the suture material, could be beneficial. One additional factor to consider regarding technique is the potential risks of iatrogenic injury to the popliteal vessels posterior to the lateral root if care is not taken while placing sutures.

**Suture Anchor**

Suture anchors may be utilized for repair of MRTs at the site of root attachment, often utilizing additional far anteromedial and posteromedial portals to allow for more vertical orientation of anchors while maneuvering around the femoral condyles. This technique uses two sutures per anchor to pull the root down to the anchor site, after which they are arthroscopically tied. A shaver may be used for bony bed preparation and/or shaving the underside of the meniscus to help with healing. Use of suture anchors may be considered in patients with a medial collateral ligament (MCL) tear which allows better access to the posteromedial root attachment, and also in patients undergoing concomitant procedures such as osteotomy in which there is concern for tunnel interference with the use of transtibial tunnels.

**Knotless Suture Anchor**

Knotless suture anchors make use of additional portals as mentioned above for better access and orientation of anchor placement, but use hardware designed to cinch the suture passed through the meniscus down to the anchor without need for tying knots arthroscopically, which reduces the technical challenge of using anchors for meniscus repair. The risks and benefits are similar to those stated for suture anchors in the previous section while adding the benefit of a knotless technique.

**Transosseous tunnels**
Transosseous tunnel root repairs are commonly used and have been reported to be superior to other techniques in terms of anatomic restoration of joint kinematics including contact pressures and hoop stresses.\textsuperscript{12,15,22,49} These techniques have been described previously with detailed steps.\textsuperscript{47,50} The essence of this procedure is one or two tunnels drilled from the anterior tibia and exiting through the anatomic root attachment site to which the root tear will be pulled with use of several sutures and ultimately fixed over the anterior tibial aperture through use of a cortical button, anchor device, or screw and washer fixation. The root attachment site is decorticated using a curette or a small socket to allow for a bleeding bony surface which facilitates bony healing into the root.\textsuperscript{51,52} Single tunnels are less technically challenging, but it has been shown that the double-tunnel technique, which is the preferred technique of the corresponding author, better approximates the root into an anatomic position due to the additional contact site which
increases the dispersion area of suture tension on the root, and also allows for orientation of root fixation.\textsuperscript{50,30} Many different suture configurations may be used to tie down the meniscal root including a luggage loop, vertical or horizontal mattress (Figure 7), or simple techniques. The preference of the corresponding author is for a vertical mattress suture which is relatively uncomplicated, reasonably quick to perform, and adequately disperses suture tension across the meniscus to avoid suture pull-through. The potential limitations of this procedure are the use of transtibial tunnels which may cause concern for tunnel convergence or interference in a patient with need for multiple concomitant procedures; but this can often be overcome with careful planning (Figure 8).

\textit{Meniscal Root Augmentation}

\textbf{Centralization}

\textit{Figure 7: Medial meniscal root repaired with a side-to-side technique.}
Despite repair of the meniscal root, it is common for meniscal extrusion to remain as identified on coronal MRI. It is assumed that the chronicity of meniscal extrusion due to undetected MRTs or delayed repair lead to scarring of the meniscal body to the capsule in an extruded position. A meniscocapsular release may be performed (alone, or in conjunction with stabilizing techniques described below) to provide mobility and anatomic restoration of the meniscal root to its attachment site.\textsuperscript{46} One such stabilizing technique is a centralization stitch and suture anchor to bring the meniscal body back over the tibial plateau.\textsuperscript{48,53} Such procedures may also may be performed without the use of a meniscocapsular release if the meniscal body is adequately mobile. This peripheral stabilization to centralize the meniscal body may also be achieved through use of a separate transtibial tunnel drilled laterally to pull the meniscal body down to bone similar to a transossseous pullout technique. The transtibial centralization suture has been reported to best minimize extrusion and restore tibiofemoral contact mechanics.\textsuperscript{30}

**Biologics Augmentation**

The use of biologics to stimulate meniscal growth and enhance meniscal healing has utilized a plethora of techniques with varying degrees of efficacy. Some ideas, such as injection of hyaluronic acid or various growth factors, have shown no ability to improve meniscal healing or have produced mixed results from varying authors. Other techniques, including the inhibition of known meniscal inflammatory factors such as matrix metalloproteases, were successful in stimulating meniscal healing, but ultimately caused musculoskeletal toxicity and did not clinically improve patient arthritis. Yet other techniques show promise of improved meniscal healing in preclinical trials, but have yet to be fully validated for clinical significance due to lack of high-quality evidence. These include use of platelet-rich plasma, fibrin clots, stem-cell...
therapy, and marrow venting (which originated when observation of meniscal healing after concomitant ACL repair was shown to improve meniscal healing rates).⁵⁴,⁵⁵

Concomitant procedures

Osteotomy

Due to the detrimental effect of varus and valgus malalignment on meniscal root mechanics—including repair—osteotomy is sometimes used to improve outcomes for meniscal root repair. Indications for osteotomy should be dictated by degree of malalignment, patient age, and demand on the knee. Specifically, greater than 10° of varus malalignment is an indication for concurrent open-wedge high tibial osteotomy with MRT, while less than 5° indicates meniscal root repair only. The 5-10° range is a gray zone requiring attention to patient needs. Correction of valgus malalignment may be approached by use of a distal femoral osteotomy. Closing wedge osteotomy may also be used in cases where increased posterior tibial slope (also a risk factor for failure of meniscal repair) is being addressed. When proximal tibial osteotomy is used concurrently with transtibial pullout repair, it is recommended the root repair be performed first, and that the cut be outlined ahead of the root repair to be positioned slightly lower than normal to allow for increased amount of proximal tibia for tunnel placement.⁵⁴ Inclusion of osteotomy has been correlated with decreased patient-reported outcomes and will affect patient rehabilitation by increasing the non-weight bearing post-operative period by two weeks.⁴⁷

Cruciate/Collateral Reconstruction

When concomitant cruciate or collateral ligament reconstruction is indicated, a good knowledge of anatomical and biomechanical relationships and the order of operative steps is critical to achieve the best outcomes. As described previously, there is a reciprocal relationship to
biomechanical knee function between the stabilizing ligaments of the knee and the meniscus. In active patients with tears of both the meniscal root and one or more stabilizing ligaments, simultaneous repair and reconstruction is preferred. The corresponding author prefers an order of operative steps in which the meniscal root repair is addressed first up until sutures have been passed and anatomic restoration of the root has been visualized with manual tension on the sutures. Fixation of the construct is delayed until after the other procedures have been prepared and are ready for tensioning. This delay avoids stress to the new and somewhat fragile root repair during flexion of the knee, such as occurs when drilling or fixating the femoral ACL tunnel. Concurrent meniscal repair will also affect tunnel placement for tibial ACL and PCL tunnels. Recent work by Chahla et al. demonstrated that risk of convergence between root tunnels and cruciate tunnels is notable, specifically between the lateral root tunnel and the ACL tibial tunnel. They assessed differing trajectories and found placement of root tunnels parallel in the sagittal plane to the ACL tunnel minimized convergence. Further, care should be taken specifically in double-bundle PCL reconstruction techniques to ensure the PCL tunnel is distal to the ACL and meniscal root tunnels and in line with the ACL tunnel in the coronal plane. Patient rehabilitation for cruciate and collateral ligament injury is slowed by concomitant meniscal root tear as patients must remain non-weightbearing for six weeks post-operatively.

**Chondral Procedures**

It is not uncommon for root tears to be associated with either traumatic or degenerative chondral defects, which can sometimes be significant and indicate one of various chondral procedures such as osteochondral autograft or allograft transplantation. Such repair of cartilaginous defects is typically reserved for lesions larger than two square cm, with smaller lesions having been shown to heal well with the use of less invasive techniques such as marrow venting.
Rehabilitation is dependent on size and location of the lesion, which may necessitate 6-12 weeks of non- or toe-touch weightbearing and limited flexion to 45° for 4-6 weeks, which creates potential extension of recovery time to those healing from concomitant meniscal root repair.\textsuperscript{54,57}

\textit{Salvage Techniques}

\textbf{Meniscal Root Reconstruction}

Reconstruction of the meniscal root may be indicated when there is little or no tissue of the meniscal root remaining for appropriate fixation, which would lead either to over-tensioning of the meniscus in order to gain an anatomic repair, or insertion of posterior meniscal horn into the bony attachment site instead of the more ligamentous tissue of the meniscal root which has better biomechanical properties for use as an anchoring material. Medial meniscal posterior root reconstruction using gracilis tendon autograft has been described.\textsuperscript{58} After harvest of a 4 mm diameter gracilis graft from the pes anserinus, the superficial MCL is released off the femur to increase working space. A tibial tunnel is drilled from the medial aspect of the tibial tuberosity to the prepared footprint of the medial meniscal root. A suture is then passed through the posterior horn remnant and used to shuttle the graft through the tunnel and ultimately provide end-to-end suture fixation of the posterior horn and gracilis tendon. The graft is fixed with a bioabsorbable screw with 30-45° knee flexion. Recovery and rehabilitation is similar to repair of MRT with the addition of possible donor-site morbidity.\textsuperscript{54,58}

\textbf{Meniscal Transplant}

Meniscal allograft transplantation may be used for selected meniscus-deficient patients, but has restrictive indications and is contraindicated in patients with instability, older ages, axial malalignment, and diffuse subchondral bone exposure. These conditions may be corrected and
render the patient into a suitable candidate for meniscal transplant, but although improved clinical outcomes have been reported with allograft transplantation there is a paucity of high-quality literature with adequate control groups. However, transplantation remains one of the few treatments for meniscus-deficient knees that may be considered before arthroplasty.19

**Mensical Scaffolds**
A wide variety of meniscal prosthetics has been investigated, with the most promising results occurring in porous, stiffer scaffolds that allow for the ingrowth of new cartilaginous tissue. This is usually achieved through seeding of the scaffold with fibrochondrocytes, autologous chondrocytes, hyaluronic acid, or human connective tissue growth factors. Other options have explored resorbable collagen meniscus implants made from bovine achilles tendons, and improved meniscal scaffold fit via three-dimensional (3D)-printing. These various meniscal replacements most often suffer from transplant tear, malposition, and misshape, and are almost universally inferior to native meniscal tissue in tensile strength and compression.55 Further comparative studies and improved methods are likely necessary in this field before it is widely used.

**Offloading Osteotomy**
In patients with irreparable meniscal root tears or meniscal-deficient knees in the presence of significant axial malalignment (>8°), the progression of degenerative changes may be slowed by offloading osteotomy. This may delay the need for knee arthroplasty for 15 or more years in 50-60% of patients.59 Patients with increased BMI are at higher risk for failure with offloading osteotomy, and patient body habitus should be considered carefully. Trial of an unloader brace to simulate the effects of surgery may be useful to determine which patients will best benefit from this procedure.54,59 It should be noted that use of osteotomy and associated hardware may
increase the complexity of future arthroplasty should such become necessary by adding a hardware removal stage to the surgery, as well as increasing the difficulty to balance the knee.

**Arthroplasty**

The final solution for degenerative and otherwise irreparable changes in the knee is replacement via uni-compartmental or total knee arthroplasty. Although this option is frequently utilized and results in profound lifestyle improvement for appropriate patients, the expected life-span of arthroplastic prosthetics is limited and thus arthroplasty should be delayed as long as possible. For this reason, it is increasingly recognized among the orthopedic community that prevention of degeneration via meniscal repair, reconstruction, and salvage techniques is preferable as first line-treatment, and attitudes are continually shifting from meniscectomy to repair.3,11,16,17

**Outcomes**

The primary goal of addressing meniscal root tears is ultimately longevity of the patient’s native knee function to maximize utility and quality of life while minimizing pain, instability, or mechanical symptoms. To that end, several subjective and objective outcome measures may be utilized including patient satisfaction, return to activities, progression of osteoarthritis, and need for future interventions. Unfortunately, our ability to definitively describe these outcomes is limited by the somewhat recent advent of meniscal root repairs as a more common procedure, and the lack of long-term follow up studies. What evidence does exist points strongly to the ability of meniscal root repairs to prevent further accelerated degeneration of the knee joint. Indeed, the results of several studies investigating transtibial repair outcomes estimated that progression of OA is halted in up to 84% of patients after transtibial repair.32,46,60 Other investigators have reviewed literature comparing surgical repair to meniscectomy and
nonoperative treatment over 39 months, and they similarly reported significantly less OA after surgical repair.\textsuperscript{61} The long-term success rate of transtibial root repairs is also satisfactory with a revision rate of just 6.7%.\textsuperscript{41,62} LaPrade et al. demonstrated that subjective measures also show general patient satisfaction as measured with significant postoperative self-reported improvement and improved Lysholm, Tegner activity scale, and Western Ontario and McMaster Universities osteoarthritis index (WOMAC score).\textsuperscript{62} Additionally, there was no reported difference in patient outcomes or satisfaction between medial and lateral root repairs, or for patients above or under the age of 50.\textsuperscript{62}

Meniscal root tears have a potentially devastating effects on rapid progression of tibiofemoral OA, as evidenced by up to 80% of SONK cases being associated with meniscal root tears.\textsuperscript{63} As previously mentioned, meniscal root repair results in slowed progression of OA compared to meniscectomy or nonoperative treatment. Indeed, Krivicich et al. conducted a systematic review of patients four years out from surgical repair or meniscectomy for treatment for meniscal root tears, and found that patients with meniscectomy were 300% more likely to both have progression of their previously documented OA and to convert to total knee arthroplasty compared to patients receiving meniscal repair.\textsuperscript{64} More data is still needed to determine long-term prognosis of meniscal root repairs however short and mid-term outcomes have provided fairly conclusive evidence that in that time frame repair is much more chondroprotective than meniscectomy or nonoperative treatment.

**Pearls and pitfalls**

1. MCL release may be performed when adequate visualization of the posterior horn is not possible, particularly in those with tight medial compartments. Release of the MCL...
allows for instrumentation and visualization to perform the repair without damaging
articular cartilage. The MCL is then treated nonoperatively.

2. Low profile tibial fixation devices such as the EndoButton are less invasive and lead to
fewer complications from symptomatic hardware then a screw and washer.\(^{36}\)

3. Decortication of the meniscal root attachment site prior to fixation aids in the growth of
the meniscal root into the bone, increasing strength of the final construct.\(^{51}\)

4. Residual extrusion on post-operative MRI is not an uncommonly reported finding. It is
thought to occur due to incomplete anatomic reduction of the root to its attachment site—
often because reduction is hindered by scarring to the capsule over time.\(^{66}\)

5. Peripheral release of the meniscus from the joint capsule is useful especially in cases
where chronic meniscal extrusion has led to scarring of the meniscal body to the capsule,
making it difficult to reduce to its anatomic location. Because the meniscus scars back to
the capsule after release during the non-weightbearing portion of patient recovery, this
technique is thought to be quite effective and safe.\(^{67}\)

6. A peripheral stabilization suture is thought to help reduce meniscal extrusion
postoperatively, aiding in scarring of the meniscus in a more anatomic location.\(^{29,30}\)

**Informed Patient Consent**

The author(s) should confirm that written informed consent has been obtained from the involved patient(s) or if
appropriate from the parent, guardian, power of attorney of the involved patient(s); and, they have given approval for
this information to be published in this case report (series).

Please refer to Elsevier's policy regarding written patient consent requirements
[https://www.elsevier.com/about/policies/patient-consent#text=That%20individual%2C%20legal%20guardian%20or%20writing%20of%20all%20such%20conditions](https://www.elsevier.com/about/policies/patient-consent#text=That%20individual%2C%20legal%20guardian%20or%20writing%20of%20all%20such%20conditions)

☐ Complete written informed consent was obtained from the patient for the publication of this study and
accompanying images.

☒ The authors declare that informed patient consent was not provided for the following reason:

| ☐ There is no patient information in this study which requires the need for informed consent. All
| images used for illustrative purposes are completely de-identified, and this review of current
| literature concepts did not utilize primary patient data. |

**Declaration of interests**

☐ The authors declare that they have no known competing financial interests or personal relationships
that could have appeared to influence the work reported in this paper.
The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:


