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Review

Meniscus Root Tears: Current Concepts in Anatomy, Diagnosis, and Treatment Strategies

Peri Kindan Baltaci, Mehmet Toker, Emre Anil Ozbek

Department of Orthopaedics and Traumatology, Ankara University, Ankara, Türkiye

ABSTRACT

Meniscal root tears are defined as radial tears or avulsions of the meniscal attachment within 1cm of its insertion on the tibial plateau. These injuries disrupt the meniscus' ability to convert axial loads into circumferantial hoop stresses, resulting in increased tibiofemoral contact pressure and accelerated osteoarthritis. Medial meniscus posterior root tears are the most commonly encountered type, generally associated with degenerative diseases. Lateral meniscus root tears (MRT), on the other hand, are mostly associated with acute injuries of younger patients. Diagnosis can be challenging due to nonspecific clinical symptoms, necessitating a combination of thorough physical examination, patient history, and high-resolution imaging. Treatment strategies have evolved from partial meniscectomy to MRT repair, which is now considered the gold standard. Techniques such as transtibial pullout and suture anchor repair aim to restore the native anatomy and function of the meniscus. Postoperative protocols are evolving, but typically involve restricted weight-bearing and range of motion for the initial weeks. As understanding of meniscal root pathology continues to grow, further research is needed to refine surgical techniques and establish evidence-based rehabilitation protocols.

Keywords: Hoop stress disruption, meniscal root tear, osteoarthritis progression, transtibial pullout repair

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Address for correspondence:
Emre Anil Ozbek.
Department of Orthopaedics and Traumatology, Ankara University, Ankara, Türkiye
E-mail: anl_ozbek@hotmail.com

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INTRODUCTION

MRTs are radial tears or avulsions occurring within 1 cm of the meniscal attachment to the tibial plateau, where the meniscus anchors to bone and transmits axial loads into circumferential hoop stresses to stabilize the joint structure.[1,2] The meniscal roots have an essential role for proper functioning of the menisci and, in turn, knee biomechanics.[3,4] A tear in meniscal roots leads to an increased tibiofemoral pressure and contact area.[5,6]

Failure of MRTs accordingly leads to progressive joint degeneration, as hoop stress dissipation becomes ineffective. It has been accepted in the literature that meniscal root tears are equivalent to meniscectomy biomechanically.[7] Long-term follow-up studies have demonstrated a significantly increased rate of osteoarthritis and need for total knee arthroplasty in patients with untreated root tears compared to those who underwent anatomical repair.[8] Furthermore, non-anatomic repair of meniscal roots induces similar results.[9] Therefore, treatment modalities for meniscal root pathologies have shifted focus towards preserving and repairing to return the menisci to their native origin.[10]

Anatomy of the Meniscus Root Attachments

The fan-shaped anterior horn of medial meniscus has been reported to have the largest and strongest footprint of any meniscus root

attachments.[1,11] It inserts in line with medial tibial eminence roughly 7 mm anterior to the anterior cruciate ligament (ACL) tibial insertion.[11] Berlet and Fowler described 4 different insertion types in this area, describing a potential link with the ACL.[12]

The posterior root attachment of the medial meniscus inserts anteromedial to the tibial attachment of the posterior cruciate ligament(PCL).[13] "Shiny white fibers", first reported by Anderson et al.[14], are supplemental posterior based fibers named after their brilliant appearance on arthroscopy. Early approximations of the attachment of the posterior root were 47.2 mm^2 and 80 mm^2, while recent studies reported areas of 30.4 mm^2 and 68 mm^2, a reduction caused by exclusion of the shiny white fibers from the root attachment.[8,11]

The anterior root of the lateral meniscus is smaller compared to that of medial meniscus. The attachment is found anterior to the lateral tibial eminence and laterally to the tibial insertion of the ACL.[8,15] An attachment between the anterior horn of the lateral meniscus with the bundles of the ACL was reported in previous studies.[11]

The attachment of the lateral meniscus posterior root is found directly anterior to that of medial meniscus posterior root.[8,11,16] The posterior root of the lateral meniscus was reported to be the smallest among all root atachments; however, with the exclusion of the shiny white fibers from the medial meniscus posterior root attachment, some studies suggested that the medial meniscus posterior root may have the smallest area.[8]

Epidemiology

MRTs hold particular clinical significance among all meniscal injuries, accounting for approximately 20% of all meniscal tears.[17] However, with growing interest in the diagnosis and treatment of meniscal root tears, it is increasingly believed that their true prevalence is significantly higher than what is currently reported in the literature.[1]

The anterior attachments of both roots are shown to be more mobile and therefore less susceptible to injury compared to the posterior attachments. Degenerative posterior root tears of the medial meniscus have been reported as the most common type of meniscal root tears, likely due to the limited mobility of the medial meniscal posterior root compared to other root attachments.[8] Studies have shown that individuals with certain risk factors—such as sedentary patients over the age of 50 and those with lifestyles involving prolonged sitting or frequent squatting with legs in a flexed position—are more prone to developing medial MRT.[1,8]

The lateral meniscus is nearly twice as mobile as the medial meniscus, resulting in a reduced role in knee stabilization and making it less susceptible to stress-related injuries.[18] However, participation in sports activities—particularly pivoting and contact sports—has been identified as a significant risk factor for lateral MRT.[19]

Clinical Features

Diagnosing MRTs requires a comprehensive evaluation that combines clinical signs and symptoms with a detailed patient history, as the presentation is often nonspecific and lacks high sensitivity.[20]

Clinical Presentation

MRTs often present with vague and nonspecific symptoms, making clinical diagnosis challenging. Patients typically report posterior knee pain exacerbated by deep flexion, squatting, or climbing stairs.[21] In degenerative cases, symptoms may have an insidious onset, whereas acute root tears may be associated with a sudden "pop" or giving-way episode.[22]

Physical Examinaton

Physical examination findings include tenderness along the joint line, a positive McMurray and Apley test, and pain during deep flexion. Effusion may be present but is often minimal in chronic tears. It is essential to perform a comprehensive physical examination, as meniscal root tears may be associated with other knee injuries.[8,21,22]

Radiological Imaging

X-Ray

The first recorded MRT in the literature dates back to 1935, when Weaver described ossification of the semilunar cartilage.[17] Despite advancements in radiology and the growing interest in advanced imaging techniques such as MRI, plain radiographs—including anteroposterior, lateral, Merchant view, and orthoroentgenograms—remain essential in the evaluation and preoprative planning of MRT.

Orthoroentgenograms are a fundamental component of preoperative evaluation in patients with suspected MRT for through assesment of the limb alignment, joint space, and intraarticular deformity.

The Kellgren-Lawrence (KL) grading system is commonly used to assess the severity of osteoarthritis, ranging from grade 0 (normal) to grade 4 (severe joint space narrowing and osteophyte formation).[23] Studies showed positive correlation between the KL grade and severity of the meniscus extrusion in the MRI.[23]

Mechanical tibiofemoral angle is the angle between mechanical axes of the femur and tibia. It is known that varus deformity increases load distribution to the medial meniscus.

Mikulicz line, a term used for the mechanical axis of the lower limb, is drawn from the center of the femoral head to the center of the ankle. Physiologically, this line runs 4±2mm medial to the center of the knee. Medial deviation indicates varus and lateral deviation indicates valgus of the knee.[24]

In knees exhibiting varus or valgus malalignment, several radiographic measurements are available to help determine the origin of the deformity, which is critical for accurate surgical planning.

Joint line convergence angle (JLCA) is the angle between the lines drawn between femoral condyles and tibial plateaus. It runs almost parallel in physiological condition. JLCA deviations indicate intra-articular origin of the malalignment, especially lateral laxity.[25] JLCA increases progressively with osteoartrhitis progression.[26]

The mechanical medial proximal tibial angle (mMPTA) and the lateral distal femoral angle (mLDFA) help determine whether the malalignment originates from the tibia or the femur. These angles are defined as the intersection between the respective joint line and the corresponding mechanical axis.[27] Normal values for these angles are 85°-90°. An increased mMPTA indicates that the varus deformity originates from the tibia and may suggest the need for a high tibial osteotomy(HTO).[24]

Precise preoperative calculation of these values is essential to avoid overcorrection or undercorrection and to optimize outcomes following meniscal root repair, especially when combined with alignment correction procedures.

Magnetic Resonance Imaging (MRI)

MRI remains the gold standard imaging technique for diagnosing MRTs, having the highest sensitivity and specifity.[8] The diagnosis is affected by the skill level of the radiologist as well as the quality of the MRI. There are direct and indirect signs that can guide specialists for the diagnosis. T2-weighted sections are considered to be the best section to detect a meniscal tear.[1]

Direct MRI signs of meniscal root tears include high signal intensity replacing the normally dark meniscal tissue in the root region on axial, the cleft sign on coronal (Fig. 1), and the ghost sign, which is the absence of an identibiable meniscus on sagittal T2-weighted images.[17,22]

Indirect signs include parameniscal cysts, subchondral bone marrow edema and meniscal extrusion of >3mm.[28] Meniscus extrusion is defined as a complete or incomplete detachment of meniscus from the tibial attachment site.[1]

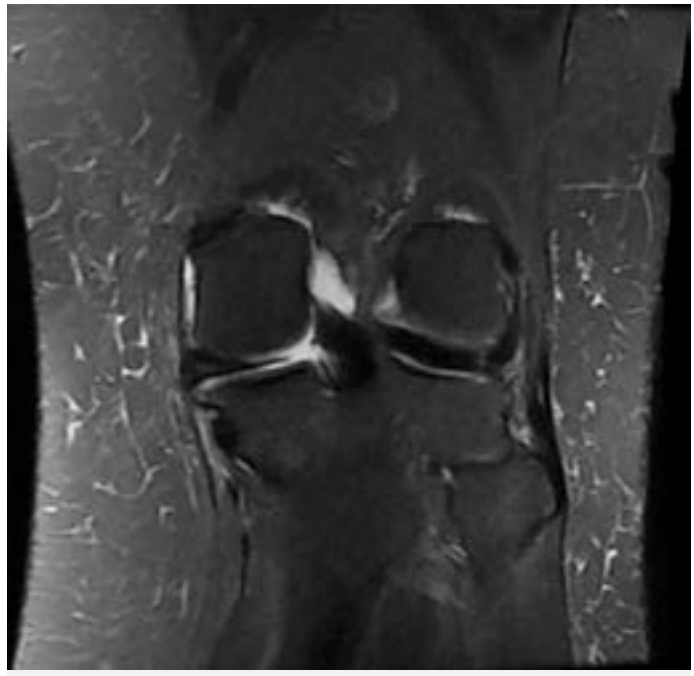

Figure 1. A coronal T2-weighted MRI section of a 50 year old female patient with a degenerative medial menicus posterior root tear (Optima MR450 GE, Matrix 512*512)

(Fig. 2) Although being a significant sign of a MRT, it could also indicate articular cartilage degeneration, severe meniscal degeneration and a complex meniscal tear.[29] That is why, not all cases with meniscal extrusion should be attributed to a MRT.

Although MRI is the most sensitive and specific imaging modality for diagnosing meniscal tears, some MRTs may still be missed during interpretation. Thus, arthroscopic visualization still remains as the gold standart for diagnosis.[17]

Ultrasound (US)

Ultrasound is a non-invasive, dynamic imaging modality that may assist in detecting meniscal extrusion or joint effusion, particularly in follow-up assessments or resource-limited settings. However, moderate to significant heterogeneity exists among studies evaluating the use of ultrasound, likely due to variations in equipment, scanning techniques, and radiologist experience.[30] "Dynamic extrusion" can be assessed by measuring the change in meniscal extrusion from the supine to the standing position; minimal change in this measurement, often referred to as the "dead meniscus sign," is suggestive of an MRT.[31] While ultrasound may be considered a complementary diagnostic tool for meniscal root tears, it currently lacks the resolution to visualize deep intra-articular structures as clearly as MRI.

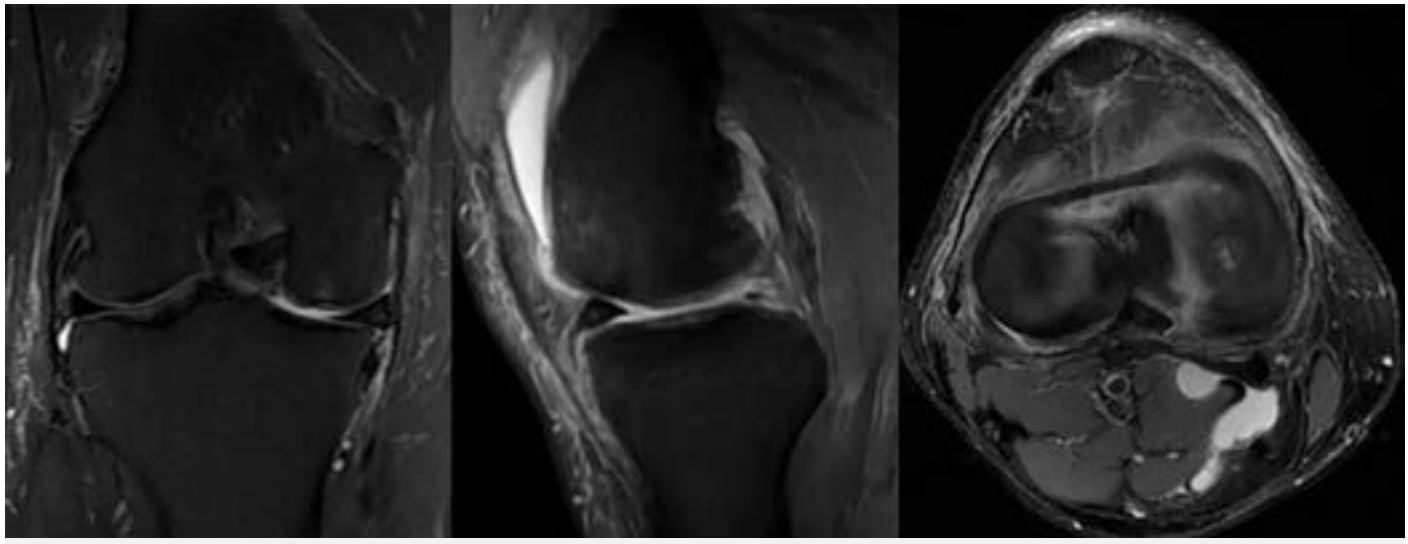

Figure 2. MRI sections of a 55 year old male patient with a degenerative medial menicus posterior root tear (Optima MR450 GE, Matrix 512*512). a) meniscal extrusion at the level of medial collateral ligament in the T2-weighted coronal section, b) 'ghost sign' showing the loss of meniscal structure in the T2-weighted sagital section, c) high signal intensity at the posterior root replacing the dark meniscal tissue in Proton Density (PD)-weighted axial section.

Treatment Algorithm

The management of MRTs depends on patient-specific factors including age, activity level, degree of cartilage degeneration, mechanical alignment, and the chronicity of the tear. While non-operative options may be appropriate in select cases, root repair remains the gold standard for restoring native biomechanics and preventing progression of osteoarthritis in suitable candidates. Two main techniques used to fix the roots are transtibial pullout and suture anchor techniques.[8] Centralization is a newer technique aiming to reduce the extrusion of the meniscus.[32] Combining the repair with high tibial osteotomy is indicated for suitable patients with concomitant varus malalignment. The treatment modalities are detailed in the subsequent section, and a comparative summary of the advantages and disadvantages associated with each surgical technique is presented in Table 1.

Table 1. Comparison of Surgical Techniques for Meniscal Root Tears

Surgical Technique	Advantages	Disadvantages
Transtibial Pullout Repair	• Provides anatomic reduction • Well-established technique • Good long-term outcomes	• Technically demanding • Risk of tunnel widening • Requires implants
Suture Anchor Repair	• No tibial tunnel needed • Reproducible technique • Shorter surgical time	• Posteromedial portal access can be challenging • Higher implant cost
Centralization	• Reduces meniscal extrusion • Restores biomechanics • Promising outcomes	• Technically complex • Steep learning curve • Limited long-term data
Root Repair with HTO	• Corrects varus malalignment • Reduces medial compartment overload	• Two-stage procedure • Prolonged rehabilitation • Higher complication risk
Partial Meniscectomy	• Shorter operative time • Rapid symptom relief	• Accelerates osteoarthritis progression • Loss of meniscal function

Non-Operative Treatment

Non-operative management may be considered in patients with advanced articular cartilage damage and for those who are not medically fit for surgery such as obese and elderly with comorbidites.[1] The management includes activity modification, nonsteroidal anti-inflammatory drugs (NSAIDs), weight loss, physical therapy, and intra-articular injections. However, several longitudinal studies have demonstrated that untreated root tears significantly increase the risk of joint space narrowing and conversion to total knee arthroplasty within 5 years.[33,34]

Operative Treatment

Partial Meniscectomy

Partial meniscectomy no longer remains as the gold standart treatment protocol for MRTs as it is now known that anatomical repair of the meniscus is mandatory to preserve its function to delay osteoarthritis. However, advanced osteoarthritis and chondral damage, severe malalignment and instability are contraindiciations for repairing meniscal roots.[17,33] In these patients who do not benefit from conservative methods, partial meniscectomy could be preferred in order to provide symptom relief. It should be acknowledged that although patients' pain is relieves in short-term, the consequence is development of further osteoarthritis invariably.[17]

Root Repair with Transtibial Pullout Technique

This technique is considered the gold standart treatment for MRTs since it provides a better anatomical reduction, which is shown to be the main indicator for proper functioning of the meniscus and restoration of knee biomechanics.[1,7,8,22] This technique involves drilling a tunnel from anterior proximal tibia to the meniscus root attachment site. Sutures are passed from the meniscal root and pulled through the tunnel and secured on anterior proximal tibia with a suture anchor or a cortical button.[17,32] (Fig. 3)

Root repair with suture anchor

In this technique, sutures are passed through meniscus and secured into the underlying tibia with a suture anchor via posteromedial portal.[32] This method eliminates the need for a guide and tunnel during repair and offers a reproducible technique.[35] Studies showed that both transtibial pullout and suture anchor techniques restore contact pressure and delay further osteoarthritis.[36]

Centralization

This technique has been proposed due to increased attraction towards meniscus extrusion and its role in potential early

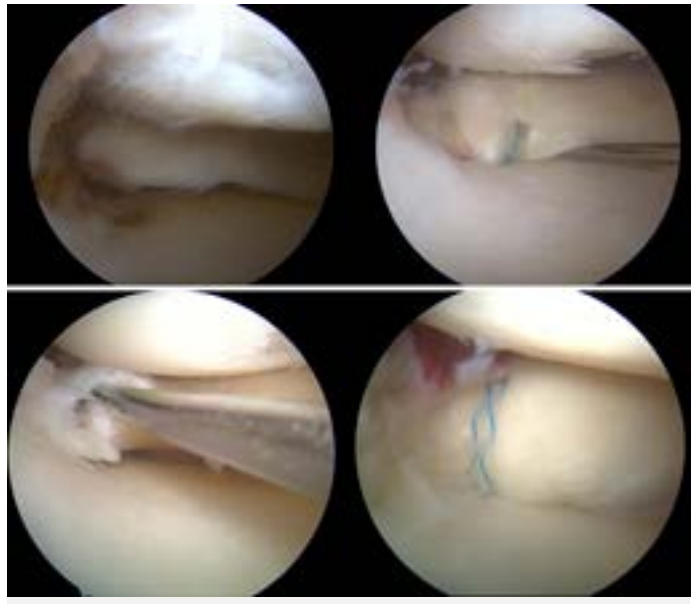

Figure 3. Arthroscopic images of a medial meniscus posterior root tear and repair with transtibial pullout technique.

osteoarthritis.[37] The procedure involves suturing the meniscus-capsule complex to the underlying tibial plateau with the aim of reducing meniscal extrusion.[22] (Fig. 4) Studies showed reduced extrusion in short term postoperative MRIs of these patients.[38] Moreover, it was demonstrated that this technique could restore meniscus biomechanics and reduce further osteoarhritis.[39] However, it still remains as a technically demanding procedure requiring a systemic approach and experience.[40]

Combining root repair with HTO

MRT repair alone could not be sufficient when there is a varus abnormality and a significant deviation of the mechanicl axis. Such tears are associated with medial femorotibial compartment degenerative changes and extrusion >3mm.[41]

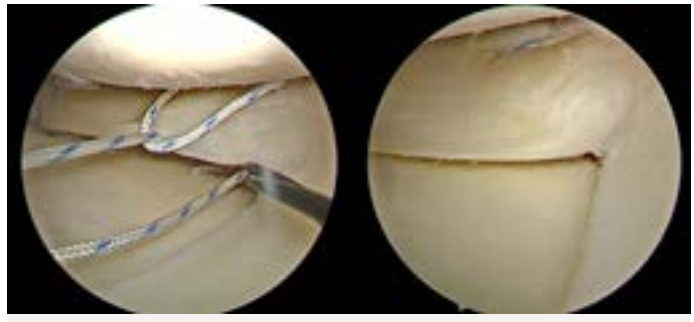

Figure 4. Arthroscopic images of the centralization technique.

HTO can be combined with root repair in such cases in order to reduce the stress distribution on the medial meniscus caused by the deformity thus acellerating the healing process. Patients with varus alignment less than 5° were confirmed to have better results with HTO compared to the ones with higher varus degrees.[42] However, studies have reported varying outcomes regarding whether to perform isolated root repair or to combine it with HTO, and the optimal approach remains a subject of ongoing debate.[43] Several studies have also evaluated the outcomes of isolated HTO versus combined HTO and MRT repair. While short-term results were similar between the two groups, the addition of MRT repair was shown to favor improved meniscal healing and cartilage scores, supporting a combined approach.[44]

Postoperative Rehabilitation

The optimal postoperative rehabilitation protocol following MRT repair remains a subject of ongoing debate among surgeons. Some studies recommend maintaining full knee extension for the first two weeks, followed by a gradual increase in passive flexion, with active flexion permitted starting in the fourth week up to 90°.[1] It is widely accepted that flexion beyond 90° places additional stress on the repaired root.[45] Majority of the protocols doe not recommend full weight bearing until 6 weeks after the surgery.[46]

The International Delphi Consensus published in 2025 emphasized the critical role of postoperative rehabilitation in optimizing outcomes following MRT repair.[47] A structured rehabilitation protocol that began with range of motion exercises and progressive muscle strengthening was deemed essential. In accordance with the current literature, the consensus recommended restricting full weight-bearing during the first 4–6 weeks postoperatively. Furthermore, passive deep knee flexion was advised to be limited during this period, with a gradual increase thereafter.

The postoperative protocol used by the senior author of this study is individualized for each patient, with priority given to restoring range of motion. Full weight bearing is prohibited until the sixth week, in accordance with protocols reported in other studies. However, if the repair demonstrates sufficient stability, active flexion and extension exercises are initiated within a 0–90° range using a knee brace on postoperative day 1. The brace is worn for six weeks. Beginning in the sixth week, range of motion is progressively increased under the guidance of the physiotherapy and rehabilitation department.

CONCLUSION

MRTs have gained particular importance in recent years, as it is now well established that untreated or non-anatomically repaired root tears result in biomechanical consequences equivalent to total meniscectomy.[8]This leads to altered load distribution across the knee joint and accelerates the progression of osteoarthritis. Early diagnosis is critical and relies on a thorough physical examination, careful assessment of patient-specific risk factors, and detailed radiological evaluation, particularly with MRI.

Historically, partial meniscectomy was the preferred treatment method; however, it is now recognized that meniscal preservation offers superior long-term outcomes. Consequently, repair techniques—especially anatomic transtibial pullout or suture anchor methods—are now considered the gold standard for managing meniscal root tears.[22] These techniques aim to restore the native biomechanics of the meniscus and prevent further joint degeneration.

DECLARATIONS

Ethics Committee Approval: This is a review, and therefore ethics committee approval was not required in accordance with institutional policies.

Informed Consent: Informed consent was not deemed necessary for this study.

Conflict of Interest: The authors declared no conflict of interest.

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