Evaluation, Treatment, and Outcomes of Meniscal Root Tears

A Critical Analysis Review

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Abstract

» Meniscal root tears or avulsions compromise the biomechanical function of the menisci to a greater extent than simple meniscal tears do. As such, if left untreated, root injuries render the menisci incapable of properly distributing axial load and resisting rotation and translation.

» The clinical diagnosis of meniscal root abnormalities may be difficult as the signs and symptoms typically associated with meniscal body injuries, such as mechanical locking and catching, may not be present in patients with root injury and there may not be a history of an acute traumatic event. Treating practitioners need to have a high suspicion for meniscal root abnormalities in patients presenting with joint line tenderness and pain with deep flexion activities.

» Magnetic resonance imaging (MRI) signs indicative of meniscal root abnormality include a radial tear of the meniscal root (on axial imaging), a vertical linear defect in the meniscal root (truncation sign on coronal imaging), meniscal extrusion >3 mm outside the peripheral margin of the joint (on coronal imaging), and increased signal within the meniscal root (ghost sign on sagittal sequences).

» Two main approaches for meniscal root repair have evolved. One approach involves the use of a transtibial pullout technique, and the other involves the use of a suture anchor repair. The goal of both approaches is to restore an anatomical attachment of the meniscal root to bone that is capable of converting axial weight-bearing loads into hoop stresses.

» In a recent systematic review of meniscal root repairs, healing (partial and complete) was reported to have occurred in 96% of cases, with all studies demonstrating improvements in terms of subjective and functional scores at a mean of 30.2 months postoperatively.

Understanding of the meniscal root and its importance to normal meniscal function has evolved in the last 5 to 10 years, resulting in an improved ability to adequately identify and address this unique type of meniscal injury. The limitations currently preventing better understanding of meniscal root tears include lack of physician awareness, diagnostic difficulty, evolving indications for and contraindications to surgical repair, technical difficulty, and limited clinical follow-up data. What has been borne out by the existing literature is that healed meniscal root repairs restore meniscal continuity, thereby restoring the ability of the meniscus to generate hoop stresses as a means of resisting axial loads.

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TABLE I Prevalence of Typical Diagnostic Criteria in the Series of Lee et al.[37] and Kim et al.[36]

Diagnostic Criterion	No. of Knees (N = 66)
Joint line tenderness	58 (88%)
Pain in deep knee flexion	55 (83%)
Positive McMurray test	47 (71%)
Effusion	39 (59%)
Locking	28 (42%)
Giving-way	11 (17%)

The present article provides a critical analysis review of the available literature on the evaluation and treatment of meniscal root tears and assesses the indications for surgical intervention, techniques for operative repair, and the outcomes reported following meniscal root repair.

Anatomy and Biomechanical Impact of Root Tears

The integrity of the meniscus of the knee is essential for the preservation of the long-term function of the joint and the prevention of arthrosis[1-11]. The meniscus functions by augmenting tibiofemoral congruity and distributing axial loads[12]. The function of the meniscus is dictated by its structure and composition. The meniscus is composed of water, collagen (primarily Type I), and proteoglycan[13]. Macroscopically, these tissue components form 2 crescent-shaped structures located at the periphery of the medial and lateral tibiofemoral compartments. The superior aspect of each meniscus is concave to accommodate the convexity of the distal part of the femur. The inferior surface of the meniscus is relatively flat to match the flatter tibial plateau[2]. Microscopically, these tissue components are organized in such a way as to provide the menisci with the ability to dissipate axial loads by conversion to hoop stresses, especially when the knee is in full extension and deep flexion[13]. Secure attachment of the menisci to the tibial plateau is essential for the performance of this function, with root abnormalities being associated with meniscal extrusion and the development of degenerative joint disease[14,15]. Biomechanical evidence supports this association as root injury produces increased tibiofemoral contact pressures with applied loads[8,16].

Insertion Site Anatomy

Several authors have recently explored the anatomy of the insertion sites of the anterior and posterior root attachments of the medial and lateral menisci[17-20]. The morphology of the attachment of the anterior root of the medial meniscus is variable. The anterior root may insert onto the flat portion of the intercondylar region of the tibia, onto the slope from the medial spine down toward the intercondylar area, or onto the anterior slope of the plateau, or it may be secured only with a soft-tissue attachment without osseous attachment to the plateau[21]. In the study by LaPrade et al.[18], the anterior root of the medial meniscus covered an average area (and standard deviation) of 56.3 ± 14.9 mm^2. With respect to identifiable arthroscopic landmarks, the anterior root attachment of the medial meniscus is 27.5 ± 3.3 mm anterior to the apex of the medial tibial eminence, 9.2 ± 2.7 mm anterior to the anterior edge of the anterior cruciate ligament (ACL), and 7.6 ± 2.3 mm anterolateral to the medial articular surface[18,22,23]. The smaller anterior root attachment of the lateral meniscus is located adjacent to the tibial insertion of the ACL[23], and, as such, is often used as a reference point for the tibial insertion of the ACL during ACL reconstruction. The anterior root of the lateral meniscus is often confluent with the ACL, with an average of 88.9 mm^2 of overlap shared between the insertion sites[18,23-25]. The anterior root of the lateral meniscus covers 140.7 mm^2 and is 14.2 ± 2.2 mm anteromedial to the apex of the lateral tibial eminence, 5.0 ± 1.8 mm anterolateral to the center of the ACL, and 13.4 ± 2.1 mm anterior to the nearest edge of the posterior lateral meniscal root[18,25].

The posterior root of the medial meniscus inserts 9.6 mm posterior and 0.7 mm lateral to the apex of the medial tibial eminence, in a position 3.5 mm lateral to the inflection point of the medial plateau articular cartilage and 8.2 mm anterior to the posterior cruciate ligament (PCL)[20]. In addition to this direct insertion, supplemental, diagonally oriented fibers have been described on the posterior aspect of the posterior root of the medial meniscus[26]. These fibers are referred to as "shiny white fibers" because of their arthroscopic appearance[20]. The posterior root of the lateral meniscus inserts more anteriorly than its medial counterpart. The insertion of the posterior root of the lateral meniscus lies 4.2 mm medial and 1.5 mm posterior to the apex of the lateral tibial eminence, at a point 4.3 mm medial to the articular margin of the lateral plateau and 12.7 mm anterior to the PCL[20] (Fig. 1).

Magnetic resonance imaging (MRI) studies have supplemented the anatomical data obtained from cadaveric dissections[27,28]. In addition to permitting an in vivo assessment of root morphology and dimensions, characteristic MRI signals have been identified for each root in the uninjured state. The anterior root of the medial meniscus is most often low signal on proton-density-weighted (PDW) MRI scans. The posterior root of the medial meniscus and the anterior root of the lateral meniscus appear either hyperintense or with alternating striations of hyperintensity and hypointensity. The posterior root of the lateral meniscus is either hypointense or striated[27].

Biomechanical Consequences of Meniscal Root Injury

Prior to consideration of the effect of meniscal root pathology on tibiofemoral

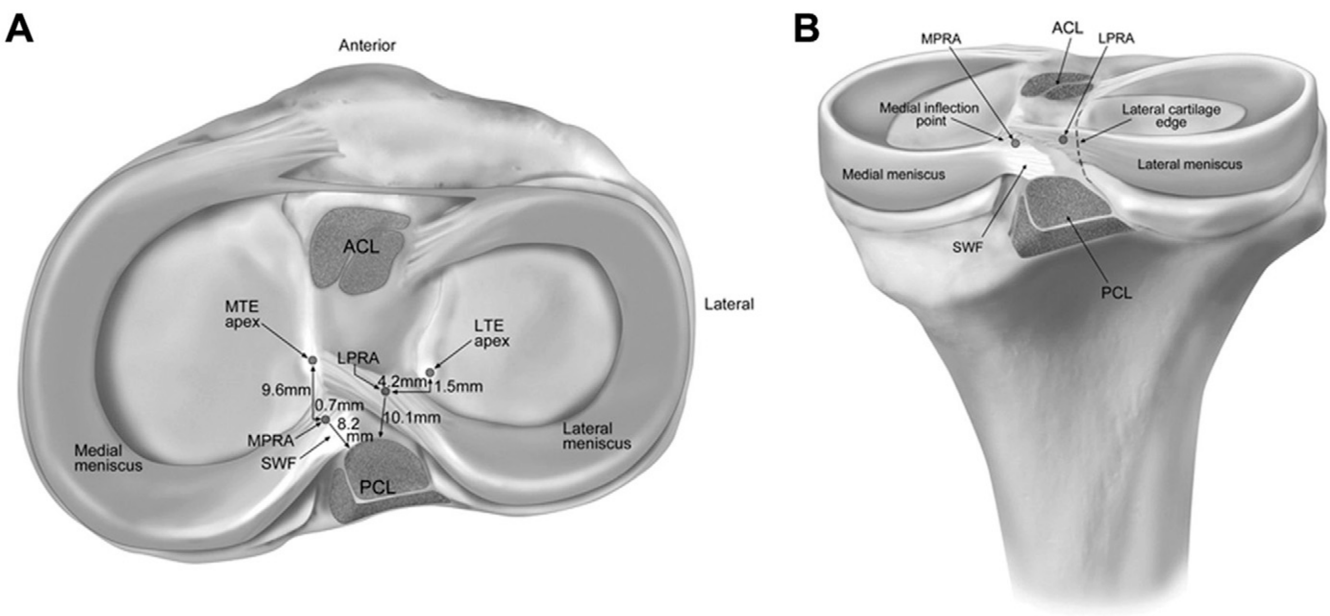

Fig. 1

Figs. 1-A and 1-B Illustrations showing the superior (**Fig. 1-A**) and posterior (**Fig. 1-B**) views of the posterior root attachments of the medial and lateral menisci. ACL = anterior cruciate ligament, LPRA = lateral meniscus posterior root attachment, LTE = lateral tibial eminence, MPRA = medial meniscus posterior root attachment, MTE = medial tibial eminence, PCL = posterior cruciate ligament, and SWF = shiny white fibers. (Reprinted, with permission of Springer, from: Johannsen AM, Civitarese DM, Padalecki JR, Goldsmith MT, Wijdicks CA, LaPrade RF. Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci. Am J Sports Med. 2012 Oct;40[10]:2342-7. Epub 2012 Sep 7.)

biomechanics, it should be noted that meniscal root injury may not occur in isolation and may be the result of a preexisting biomechanical abnormality in a previously asymptomatic knee. Concomitant ligament injury has implications for knee stability; in a cadaveric model, lateral meniscal root injury was found to further reduce the stability of the ACL-deficient knee in rotational loading[29]. Similarly, anterior or posterior root tears of the medial meniscus confer decreased translational and rotational stability of the knee in both ACL-intact and ACL-deficient states[11,30,31]. Lower-extremity alignment abnormalities may predispose patients to root injury; in a retrospective case-control study comparing 27 posterior medial meniscal root tears with 19 posterior medial horn cleavage tears, preoperative standing lower-extremity alignment radiographs demonstrated significantly increased mean tibiofemoral varus alignment in patients with root tears ($p = 0.002$)[32].

Even without concomitant abnormalities, meniscal root tears have a profound effect on the biomechanics of the knee[5,6,8,15,16,33,34]. In a cadaveric study analyzing loading and kinematics in intact knees, knees with a posterior root tear of the medial meniscus, knees with a repaired posterior root, and knees with a total meniscectomy, Allaire et al. found that a root tear resulted in increased tibiofemoral contact pressure equal to that following a total meniscectomy, whereas repair restored contact pressure to that of the uninjured knee[5]. Marzo and Gurske-DePerio confirmed these findings in a cadaveric study of contact pressure in intact, posteromedial root-injured, and root-repaired cadaveric knees[34]. Forkel et al. confirmed the findings of increased contact pressure in association with meniscal root injuries on the medial side but demonstrated that tibiofemoral contact pressure was not significantly increased in association with lateral root injury ($p > 0.05$) unless the meniscofemoral ligament was sectioned, concluding that an isolated lateral root injury without damage to the meniscofemoral ligament might have a better prognosis than its medial counterpart[6]. Although these in vitro findings suggest a prognostic role for the integrity of the meniscofemoral ligament, the lack of corresponding clinical data and the difficulty of visualizing this structure arthroscopically currently limit its use in clinical decision-making. While we are aware of no long-term studies that prove the role of meniscal root tears in subsequent joint degeneration, a recent imaging study demonstrated that tears of the posterior root of the medial meniscus were independent risk factors for the development of cartilage degeneration as seen on T1ρ MRI scans[35].

Diagnosis of Meniscal Root Tears

Clinical Presentation

The clinical diagnosis of meniscal root tears may be difficult as the signs and symptoms typically associated with meniscal body injuries, such as mechanical locking and catching, may not be present in patients with root injury. In addition, there may or may not be a history of an acute traumatic event. In a recent series, 31 (68.9%) of 45 patients undergoing repair of the posterior root

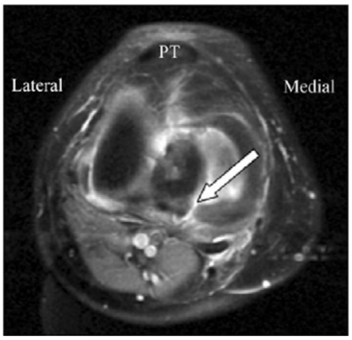

Fig. 2
Fat-suppressed proton-density-weighted MRI scan showing a radial tear (arrow) of the meniscal root of the posterior horn of the medial meniscus in the axial plane. PT = patellar tendon. (Reprinted, with permission of Springer, from: Choi SH, Bae S, Ji SK, Chang MJ. The MRI findings of meniscal root tear of the medial meniscus: emphasis on coronal, sagittal and axial images. Knee Surg Sports Traumatol Arthrosc. 2012 Oct; 20[10]:2098-103. Epub 2011 Nov 24.)

of the medial meniscus reported only minor trauma[36]. The remainder of the patients reported no trauma, and the mean time from symptom onset to repair was >4 months. These findings may indicate a degenerative element in the pathogenesis of meniscal root injury.

The most common signs of meniscal root injury are joint line tenderness and pain on deep knee flexion. One study demonstrated joint line tenderness in 45 (100%) of 45 patients who underwent root repair[36]. Another study demonstrated joint line tenderness in 13 (62%) of 21 patients undergoing repair of a posteromedial root tear[37]. The authors of those studies found pain on deep flexion in 41 (91%) of 45 patients[36] and 14 (67%) of 21 patients[37], respectively. Effusion was present in 36 (80%) of 45 patients in one of those studies[36] and in only 3 (14%) of 21 patients in the other study[37]. McMurray testing was positive in 35 (78%) of 45 patients[36] and 12 (57%) of 21 patients[37], respectively. Locking was present in 25 (56%) of 45 patients[36] and 3 (14%) of 21 patients[37]. Giving-way was noted in 9 (20%) of 45 patients[36] and 2 (10%) of 21 patients[37]. These results are summarized in Table I. However, the sensitivity and specificity of signs and symptoms of meniscal root injury have not been elucidated, with most authors relying on MRI to confirm the diagnosis.

Imaging

Orthogonal weight-bearing radiographs of the affected knee are made to rule out osseous abnormality and to assess for evidence of degenerative joint disease. Full-length, standing bilateral lower-extremity alignment radiographs are made for any patient with clinical examination findings that suggest the presence of malalignment. MRI is the mainstay of diagnostic imaging for meniscal root abnormality[38]. MRI can identify meniscal root abnormality and the extent of extrusion from the tibiofemoral joint[39-41]. The meniscal roots should be specifically reviewed as part of the surgeon's MRI interpretation routine because injuries may otherwise easily be missed, with recent studies demonstrating moderate sensitivity and specificity and low positive predictive value for diagnosing root tears[38,42-44].

MRI signs indicative of meniscal root abnormality include (1) a radial tear of the meniscal root on axial imaging (Fig. 2), (2) a vertical linear defect in the meniscal root on coronal imaging (truncation sign) (Fig. 3-A), (3) increased signal in the meniscal root on sagittal sequences (ghost sign) (Fig. 3-B), and (4) meniscal extrusion >3 mm outside the peripheral margin of the joint on coronal imaging (Fig. 4). Meniscal extrusion of >3 mm is strongly associated with meniscal root abnormality as well as the presence[14] and severity[45] of radiographic signs of degenerative joint disease.

The ability of MRI to detect meniscal root abnormality has varied among reports. Thus, high-quality images and skilled interpretation are essential. In a series of 287 consecutive patients who had a preoperative MRI evaluation followed by arthroscopic surgery, LaPrade et al.[43] found that MRI had an overall sensitivity of 77% and a specificity of 73% for the detection of root tears. For medial tears, the sensitivity and specificity were 82% and 80%, respectively. For lateral tears, the sensitivity and specificity were 60% and 90%, respectively. Other authors have

Fig. 3-A

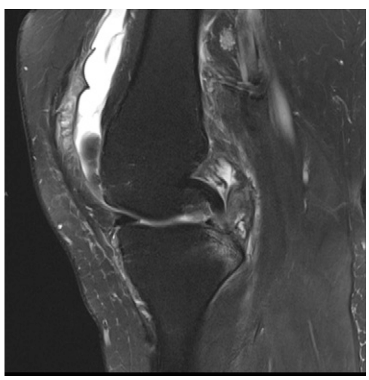

Fig. 3-B

Figs. 3-A and 3-B Coronal (**Fig. 3-A**) and sagittal (**Fig. 3-B**) T2-weighted MRI scans of the knee of a 23-year-old man with an acute medial meniscal root tear. Note truncation of the posterior root of the medial meniscus on the coronal image and the absence of low-intensity T2 signal in the area of the posterior root on the sagittal image (ghost sign).

Fig. 4
Proton-density-weighted MRI scan showing meniscal extrusion (arrow) >3 mm from the medial margin of the proximal part of the tibia in the coronal plane. A vertical line is drawn intersecting the margin of the medial tibial plateau at the site of transition from horizontal to vertical. Extrusion is measured from this line to the outer edge of the meniscus. (Reprinted, with permission of Springer, from: Choi SH, Bae S, Ji SK, Chang MJ. The MRI findings of meniscal root tear of the medial meniscus: emphasis on coronal, sagittal and axial images. Knee Surg Sports Traumatol Arthrosc. 2012 Oct;20[10]:2098-103. Epub 2011 Nov 24.)

reported higher sensitivities and specificities ranging from 89% to 100% for medial[38,41,44] and lateral[42] meniscal root tears.

Indications for Operative Treatment

The treatment of meniscal root tears has evolved in recent years, and current options include nonoperative therapy, partial meniscectomy, and meniscal root repair. Ideally, meniscal root repair restores native joint biomechanics, although not all patients are candidates for surgery and not all root tears are amenable to repair. Patient selection is therefore highly important. Those who are not ideal candidates for meniscal root repair may benefit from nonoperative therapy.

The indications for nonoperative treatment of meniscal root tears include a sedentary lifestyle, extensive medical comorbidities, advanced signs of osteoarthritis (Outerbridge[46] grade 3 or 4), joint-space narrowing, marked varus malalignment (>5°), or chronic, degenerative, irreparable tears[47,48]. An age of >45 or 50 years has been cited as a contraindication to operative treatment as degenerative meniscal tissue is assumed to have poor healing capacity; however, recent studies have demonstrated good short-term clinical results in patients >50 years of age[1,47-49]. Patients meeting the criteria for nonoperative treatment may benefit from a multimodal approach including physical therapy, nonsteroidal anti-inflammatory drugs, intra-articular injections, and off-loader bracing to provide symptomatic relief[50].

Two surgical options—arthroscopic meniscectomy or arthroscopic meniscal root repair—are available for active, healthy individuals with minimal or no degenerative changes (Outerbridge grade 1 or 2), minimal to no joint-space narrowing, normal mechanical alignment, intact cruciate ligaments, and meniscal root tears[1,12,48]. Meniscectomy is potentially a better option for chronic root tears because the healing capacity and tissue quality of the meniscus are poor; however, the definition of chronicity with respect to reparability has yet to be determined[49]. While subjective clinical improvement has been seen following meniscectomy, outcomes may be worse in comparison with meniscal root repair, with postoperative degenerative changes becoming more pronounced[1,4,7]. In addition, there is some evidence to suggest that partial meniscectomy for the treatment of root tears may portend poorer outcomes compared with partial meniscectomy for the treatment of other types of meniscal abnormality, potentially suggesting that chronic root tears should be treated conservatively[5,51,52]. Partial meniscectomy in the setting of a root tear effectively creates a meniscus-deficient state, resulting in progressive chondral degeneration and eventual osteoarthritis[5,51,52]. Conversely, patients with acute tears may benefit from root repair; Kim et al. demonstrated greater improvement and decreased subsequent degenerative changes in patients who underwent root repair 4 years after surgery[4]. However, root repair in patients with excessive varus malalignment (>5°) and radiographic signs of chondral degeneration (Kellgren-Lawrence[53] grade III or IV and Outerbridge grade III or IV) have been shown to have poorer clinical outcomes and may not be indicated for repair unless a realignment procedure is planned or the chondral lesion is focal and can be addressed with a cartilage procedure[47,48]. Acute tears in the setting of an ACL rupture or multiligamentous injury should also be repaired to restore native meniscal anatomy in an effort to prevent future degeneration[12].

As outlined by LaPrade et al., the decision to repair a meniscal root tear can be simplified[54]. Patients who are not candidates for surgery should have nonoperative treatment. Surgical candidates with healthy articular surfaces, as described above, and acute meniscal root tears should undergo arthroscopic meniscal root repair. Patients with chronic meniscal root tears in the setting of little to no articular cartilage wear (Outerbridge grade 1 or 2) are candidates for meniscal root repair, whereas those with symptomatic tears demonstrating advanced degenerative changes (Outerbridge grade 3 or 4) are indicated for arthroscopic meniscectomy. Patients with excessive varus deformity should also be evaluated for possible staged or concomitant high tibial osteotomy (HTO).

Techniques for Arthroscopic Meniscal Root Repair

Two main approaches for meniscal root repair have evolved[36,55]. One approach involves the use of a transtibial pullout technique, and the other involves the use of a suture anchor repair. The goal of both approaches is to restore an anatomical attachment of the meniscal root to bone that is capable of converting axial weight-bearing loads into hoop stresses. With the knee in 90° of flexion, with or without a leg holder, standard anteromedial and anterolateral arthroscopic portals are created. Often, accessory posteromedial or posterolateral

TABLE II Clinical Outcomes of Medial Meniscal Root Repair

Author	Year	Level of Evidence	No. of Patients	Age* (yr)	Duration of Follow-up* (mo)	IKDC Score (Preop./Postop.)*† (points)	Lysholm Score (Preop./Postop.)*† (points)
Lee et al.[37]	2009	IV	21	51	31.8	NR	57.0/93.1‡
Seo et al.[61]	2011	IV	11	55	13	NR	56.1/83.0‡
Kim et al.[36]	2011	III	45	53	26	SA: 57.3/91.8‡; TT: 58.5/93.4‡	SA: 54.3/91.7‡; TT: 55.4/93.2‡
Kim et al.[4]	2011	III	58	55	48.5	42.6/77.2‡	56.8/85.1‡
Moon et al.[48]	2012	IV	51	59	33	NR	48.3/83.2‡
Lee et al.[59]	2014	III	50	56	25	S: 43.5/77.7‡; MA: 44.1/78.4‡	S: 56.1/85.4‡; MA: 57.4/87.6‡
Cho and Song[60]	2014	IV	13	50	7	NR	34.7/75.6‡
Ahn et al.[47]	2015	III	25	56	17	37.3/59.2‡	57.3/73.4‡
Chung et al.[1]	2015	III	37	55	72	40.1/73.7‡	52.3/84.3‡

*The values are given as the mean. †IKDC = International Knee Documentation Committee, NR = not reported, SA = suture anchor repair, TT = transtibial pullout repair, S = single suture, MA = Mason-Allen sutures. ‡Significant difference ($p < 0.05$).

portals are created to facilitate anchor placement or suture passage.

Transtibial Pullout Repair (Authors' Preferred Technique)

Under arthroscopic visualization, the anatomical position of the meniscal root is identified, debrided, and prepared for repair. An ACL tibial drill guide is utilized to drill a guide pin or a retro-cutting reamer into position through a small incision at the anteromedial aspect of the proximal aspect of the tibia. After confirmation of anatomical positioning, a 5 to 6-mm-diameter tunnel is made with use of a reamer or a 1-cm-deep tunnel is made with use of a retro-cutting reamer. The use of a traditional or retro-cutting reamer is subject to surgeon preference. Number-2 nonabsorbable sutures are passed through the substance of the torn meniscal root with a suture-passage device of the surgeon's choosing. Once passed, the suture limbs are shuttled through the transtibial tunnel, tensioned, and fixed with use of whatever fixation construct the surgeon prefers (typically a cortical button or screw and washer) with the knee in 30° of flexion[56]. This degree of knee flexion facilitates fixation of the root while the meniscus is in an anatomical, reduced position (Video 1).

Suture Anchor Repair

Suture anchor repair utilizes the accessory posteromedial or posterolateral portal to facilitate anchor insertion at the anatomical root-attachment site and suture passage through the torn meniscal root. Often, the accessory portal is created more proximally than usual to allow for more vertical insertion of the suture anchor and avoidance of the posterior convexity of the medial femoral condyle[36,54,55]. Under arthroscopic visualization, the anatomical position of the meniscal root is identified, debrided, and prepared for repair. A double-loaded suture anchor is inserted at the meniscal root site and suture passage is performed with use of a suture lasso through the accessory portal or with use of a rotator cuff-type suture-passage device through the anteromedial or anterolateral portal. Once passed, the suture limbs are tied arthroscopically with the knee in 30° of flexion, with the arthroscopic knots being kept posterior, away from the articular surfaces of the affected compartment[36,55].

Suture Configurations for Meniscal Root Repair

Various suture configurations have been reported for use in meniscal root repairs, including 2 simple sutures, horizontal mattress sutures, modified Mason-Allen

TABLE II (continued)

HSS Score (Preop./Postop.)*† *(points)*	Progression	Notes†
61.1/93.8‡	4.8% (1 of 21)	1 retear at 6 mo. postop.
64.1/87.4‡	9% (1 of 11)	Second-look arthroscopy: 5 with lax healing, 4 with scar-tissue healing, and 2 failed healing
SA: 55.3/91.7‡; TT: 54.7/93.8‡	SA: 13.9%; TT: 13.7%	Compared transtibial pullout repair (TT) vs. suture anchor repair (SA)
NR	42.9% (9 of 21)	Significant improvement compared with meniscectomy ($p < 0.05$), with lower percentage of osteoarthritis progression
NR	NR	Visual analog scale and American Knee Society scores significantly better compared with the preoperative baseline ($p < 0.01$ for both comparisons)
NR	S: 48% (12 of 25)‡; MA: 24% (6 of 25)	Compared simple (S) vs. Mason-Allen (MA) sutures
33.5/82.2‡	NR	Second-look arthroscopy: 4 completely healed, 4 with lax healing, 4 with scar-tissue healing, and 1 failed to heal
NR	NR	Outcomes significantly better than conservative management group with respect to IKDC score ($p < 0.001$) and Tegner activity score ($p < 0.017$)
NR	68% (25 of 37)	Significantly better postoperative Lysholm ($p < 0.039$) and IKDC ($p < 0.037$) scores compared to partial meniscectomy group; 35% conversion to total knee arthroplasty following meniscectomy with 0% conversion after repair

sutures, and different loop/cinch stitch approaches. Anz et al. evaluated 4 different suture configurations, including 2 simple sutures, an inverted mattress suture, 1 double-locking loop suture, and 2 double-locking loop sutures, in a cadaveric model[57]. The authors found that the 2 double-locking loop sutures had significantly higher failure loads compared with the other 3 methods tested ($p < 0.01$). In a biomechanical study, Feucht et al. demonstrated that the modified Mason-Allen and 2-simple-suture approaches outperformed horizontal mattress and loop stitch configurations with respect to stiffness, cyclic loading, and load-to-failure testing[58]. Lee et al. compared the clinical and radiographic results for 25 patients who underwent arthroscopic medial meniscal root repair with use of a Mason-Allen stitch configuration with those for 25 patients in whom the repair was performed with simple stitches[59]. Although no significant differences in clinical outcomes were noted at the time of short-term follow-up, patients who had been managed with a Mason-Allen-type repair had less meniscal extrusion and less cartilage degeneration on follow-up MRI scans.

Complications

Potential complications associated with meniscal root repair include the potential for neurovascular injury related to poorly visualized guide-pin placement, iatrogenic injury to the ACL or PCL, failure of the meniscal root to heal, and other general complications of knee arthroscopy, including infection, postoperative stiffness, and deep venous thrombosis[56].

Postoperative Management

There is considerable variability in published postoperative protocols after meniscal root repair. Most protocols involve early immobilization and protected weight-bearing, allowance of gradually increased flexion, and return to sport at 6 months. Isometric quadriceps activation is permitted early. If ACL reconstruction is performed concomitantly, rehabilitation includes a standardized ACL protocol, with modifications to weight-bearing allowance (non-weight-bearing for 6 weeks) and restriction of deep flexion (no flexion past 90° for 4 weeks) to protect the meniscal root repair. We do not recommend staging meniscal root repair and ACL surgery as both can be performed in a single surgical setting.

Immobilization

Many authors recommend 2 weeks of immobilization in full extension with use of either a cylinder cast[36,37,48,60] or a hinged brace locked in extension[61]. At 2 weeks postoperatively, either external immobilization is discarded or the patient is transitioned from a cast to a hinged knee brace[36,37,60]. Other authors have advocated early range of motion[4,59]. Following meniscal root repair, we recommend the use of a hinged knee brace locked in extension

TABLE III Grade of Recommendation for Meniscal Root Repair*

Grade	Description
B	While additional data are necessary to determine the role root repair plays in joint preservation and which repair technique is optimal, on the basis of the currently available literature, a Grade-B recommendation is appropriate for the repair of meniscal root tears

*Grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending intervention. Grade B indicates fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention. Grade C indicates conflicting or poor-quality evidence (Level-IV or V studies) not allowing a recommendation for or against intervention. Grade I indicates that there is insufficient evidence to make a recommendation.

for 2 weeks. The brace is then unlocked to facilitate return of range of motion.

Weight-Bearing

Some restriction of weight-bearing is widely recommended in the first 6 weeks. Protocols include partial weight-bearing for 6 weeks[4], toe-touch weight-bearing for 6 weeks[48,59], non-weight-bearing for 6 weeks[12,60], and non-weight-bearing for 6 weeks followed by partial weight-bearing for an additional 2 weeks[36,37]. Following meniscal root repair, we recommend 6 weeks of non-weight-bearing with use of crutches as assistive devices.

Range of Motion, Deep Flexion, and Return to Sport

Range of motion is gradually increased during the postoperative period. Most authors have reported that they allow active flexion up to 90° starting at 2, 4, or 6 weeks postoperatively[36,37,48,60]. Deep flexion and squatting are generally prohibited for 3 to 6 months, and return to sport is permitted at 6 months[12,36,37,48,59-61]. Following meniscal root repair, we recommend a hinged knee brace locked in extension for 2 weeks. The brace is then unlocked to facilitate return of range of motion and is set from 0° to 90° until 4 weeks postoperatively, at which time it is completely unlocked. The brace is removed at 6 weeks postoperatively. Depending on the return of strength and endurance of the quadriceps and the resolution of pain and swelling at the operative site, return to athletic activity is permitted at 6 months postoperatively.

Outcomes of Surgical Repair

In the last 7 years, a number of clinical studies evaluating the outcomes following meniscal root repair have been published in the orthopaedic surgery literature (Table II)[1,4,36,37,47,48,59-61]. To date, all reported studies have been Level-III and IV evidence, including 5 retrospective comparative studies and 4 case series. Each published study demonstrated improvements in clinical outcome scores compared with the preoperative baseline values. Ahn et al. reported significantly better results compared with conservative management ($p < 0.001$)[47]. Two studies demonstrated significantly ($p < 0.05$) better outcomes following meniscal root repair compared with partial meniscectomy[1,4], with Chung et al. reporting a 35% rate of conversion to total knee arthroplasty in the meniscectomy group compared with 0% in the repair group[1]. Two small case series that included data from second-look arthroscopies demonstrated a variable rate of healing following meniscal root repair[60,61]. Cho and Song, in a series of 13 patients, reported that, at the time of second-look arthroscopy, 4 repairs were completely healed, 4 had healed in a lax position, 4 had healed with scar tissue, and 1 had failed to heal[60]. Seo et al. reported similar variability of root healing in their series of 11 cases, with 5 repairs healing in a lax position, 4 healing with scar tissue, and 2 failing to heal[61]. Most studies in the literature have reported the percentage of patients in whom progression of osteoarthritis is evident on follow-up imaging. While meniscal root repair demonstrates the ability to slow the progression of arthritic changes compared with meniscectomy, the procedure does not completely prevent the development of future degenerative disease.

In the recent systematic review by Feucht et al., the compiled data revealed a predominantly female population (83%) with a mean age of 55.3 years; demonstrated no progression of cartilage degeneration in 84% and 82% of patients who were evaluated with conventional radiographs and MRI, respectively; and demonstrated decreased meniscal extrusion in 56% of patients[62]. Healing, assessed with a combination of MRI and second-look arthroscopy, was reported as complete in 62% of patients, partial in 34%, and failed in 3%. All studies demonstrated improvements in subjective and functional scores at a mean of 30.2 months, with the mean Lysholm score increasing from 52.4 preoperatively to 85.9 postoperatively.

Lee et al. reported a 5% rate of reoperation, most commonly performed because of recurrent symptoms related to a complete or partial retear of the meniscal root[37]. Chung et al., in a study of fifty-seven patients with posterior meniscal root tears, reported that the 5-year survival rate was 100% after meniscal repair, compared 75% after meniscectomy[1].

While long-term data on meniscal root repair are scarce, Kenny, in 2009, reported the case of a patient who was followed for 20 years after transtibial pull-out fixation of a lateral posterior meniscal root avulsion[63]. Second-look arthroscopy revealed improvement of prior chondromalacia and a healed posterior root. Objective and subjective functional outcome was excellent, and radiographic assessment revealed only mild degenerative changes. While the majority of meniscal root tears are medial, the success of the repair of this lateral meniscal root tear suggests a role for the procedure in effectively restoring native meniscal function and biomechanical properties as a joint-preserving procedure.

Recommendations for Care

With an improved understanding of the important role that an intact meniscal root has on proper meniscal function, the recent attention paid to the identification and treatment of meniscal root tears is appropriate and necessary. While the biomechanical data are relatively consistent in demonstrating the negative implications of meniscal root tears on tibiofemoral contact pressures and the ability of root repairs to restore normal meniscal function, the current clinical outcome data are limited in terms of study size and duration of follow-up. The majority of the available outcome studies represent Level-III and IV evidence, with no randomized controlled trials currently available in the literature comparing the outcomes following meniscectomy with those following meniscal root repair or comparing transtibial with suture anchor repair techniques. What is supported by the existing literature is that healed meniscal root repairs restore meniscal continuity, thereby restoring meniscal integrity and the ability of the meniscus to generate hoop stress as a means of resisting axial load, leading to improvements in terms of symptoms and function. While additional data are necessary to determine the role of root repair in joint preservation and which repair technique is optimal, on the basis of the currently available literature, a Grade-B recommendation (one supported by fair evidence [consistent findings in Level-II and III studies]) is appropriate for the repair of meniscal root tears (Table III).

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