JB&JS REVIEWS

Meniscal Extrusion

A Critical Analysis Review

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Abstract

» Pathologic meniscal extrusion can compromise meniscal function, leading to increased contact forces in the tibiofemoral compartment and the acceleration of osteoarthritic changes.

» Extrusion is typically defined as radial displacement of ≥3 mm outside the tibial border and is best diagnosed via magnetic resonance imaging, although ultrasonography has also demonstrated encouraging diagnostic utility.

» Surgical management of meniscal extrusion is based on the underlying etiology, the patient's symptom profile, the preexisting health of the articular surface, and the risk of future chondral injury and osteoarthritis.

Anatomy and Pathophysiology

The menisci are fibrocartilaginous structures that play a vital role in load distribution, shock absorption, and stability of the knee[1-4]. Originally arising from the intermediate layer of mesenchymal tissue of the joint capsule, they achieve their characteristic crescent shape by weeks 8 to 10 of fetal development[5]. They are composed primarily of water, proteoglycans, glycosaminoglycans, and type-I collagen fibers that are oriented in a circumferential pattern with interspersed woven radial fibers[6-8]. The arrangement of these fibers allows the meniscus to resist radial displacement (or hoop stress) when an axial load is applied to the joint, cushioning the tibiofemoral compartment and protecting the articular surfaces during weight-bearing activity[2,7].

The menisci are anchored to the tibial plateau at both the anterior and the posterior horn[5,9]. The anterior horn of the medial meniscus attaches to the tibia at the attachment of the anterior cruciate ligament (ACL), while the posterior horn inserts at the tibial attachment of the posterior cruciate ligament (PCL). The posterior border of the medial meniscus inserts directly into the knee joint capsule, with additional stabilization provided by the meniscotibial (coronary) ligament[3,5,10]. In the lateral compartment, the anterior horn of the lateral meniscus attaches to the lateral intercondylar fossa in close proximity to the insertion of the ACL[5]. The posterior horn of the lateral meniscus is anchored to the tibia between the PCL and the posterior horn of the medial meniscus[5]. It is anchored by 2 meniscofemoral ligaments, the posterior meniscofemoral ligament (the ligament of Wrisberg) and the anterior meniscofemoral ligament (the ligament of Humphrey)[5,9,11]. The lateral meniscus lacks substantial peripheral attachment to the femur, the tibia, and the joint capsule, resulting in increased mobility when compared with the medial meniscus[11] (Fig. 1).

Historically, vascularization of the menisci has been thought to decrease during development, resulting in only the peripheral 10% to 25% receiving substantial blood flow by maturity[5,12]. This peripheral region of relative vascularity is known as the red-red zone, while the completely avascular inner regions of the

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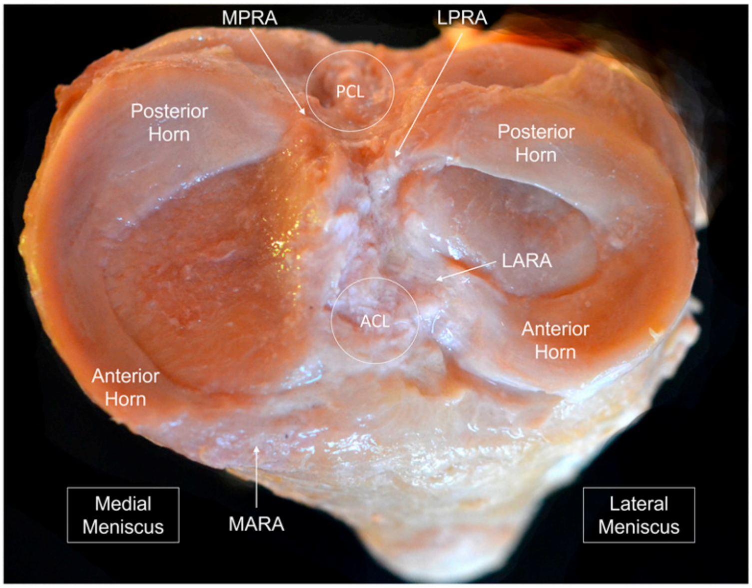

Fig. 1
Superior view of a cadaveric knee showing the meniscal root and the cruciate ligament insertion sites. ACL = anterior cruciate ligament, LARA = lateral anterior root attachment, LPRA = lateral posterior root attachment, MARA = medial anterior root attachment, MPRA = medial posterior root attachment, and PCL = posterior cruciate ligament.

menisci are termed the white-white zone. The middle zone of transition between the 2 zones is called the red-white zone[12]. However, meniscal vascularity is an evolving topic, and recent investigation has demonstrated that the central white-white zone may be more vascularized than previously thought[13].

Given this relative avascularity, the menisci are historically believed to have limited regenerative potential. Injury or disruption of the circumferential fibers of the meniscus results in its decreased ability to withstand hoop stresses, which may manifest as increased meniscal excursion and subluxation of the meniscus outside of the meniscotibial compartment, a condition known as meniscal extrusion[2,4,7,14]. The potential clinical implications of pathologic extrusion are substantial, and its association with degenerative joint disease (DJD) is well documented in the literature[2,15-19]. As a result, there has been increased interest in defining the pathophysiology of meniscal extrusion.

Like other meniscal pathologies, meniscal extrusion impacts weight-bearing distribution in the tibiofemoral compartment, predisposing patients to articular cartilage damage in the knee, subchondral bone cysts, osteophyte formation, and accelerated DJD[2,3,20,21]. A 2-year prospective study of 294 patients without osteoarthritis (OA) revealed that patients with meniscal extrusion had a significantly greater number of cartilage defects ($p < 0.001$) and osteophytes ($p < 0.001$) on magnetic resonance imaging (MRI) of the knee when compared with matched patients without evidence of extrusion. Furthermore, the study revealed that medial meniscal extrusion (MME) was also associated with a 1.4% greater acceleration in cartilage volume loss year-over-year when compared with controls ($p < 0.05$)[21]. This point was further emphasized by Wang et al., who concluded that patients with any degree of meniscal extrusion have higher rates of bone marrow lesions and cysts and reduced tibial cartilage volume when compared with those who do not have meniscal extrusion (all $p < 0.001$)[20]. Thus, early identification and appropriate treatment of meniscal extrusion can theoretically be important in preventing the development and progression of knee DJD.

Classification

Meniscal extrusion is defined as radial displacement of the meniscus outside of the margin of the tibial plateau. Costa et al. were the first to categorize extrusion into 2 subgroups: those with displacement of <3 mm were defined as having minor extrusion, and those with displacement of ≥3 mm were defined as having major extrusion[22]. Given that some degree of meniscal extrusion is the result of normal knee kinematics, minor extrusion is often described or classified as physiologic extrusion, while major extrusion is typically the result of a pathologic process.

Multiple large cohort and case-control studies have sought to validate the degree of physiologic meniscal extrusion categorized by Costa et al. Svensson et al. reviewed MRI results from >700 middle-aged individuals without OA and determined mean meniscal extrusion to be 2.7 mm medially and 1.8 mm laterally[23]. Similarly, a case-control study of 291 patients with and without OA who underwent standard supine MRI identified that the average meniscal extrusion in controls was 2.8 mm medially and 0.2 mm laterally, compared with 5.1 mm medially and 0.8 mm laterally in patients with OA[15].

Given that meniscal extrusion is partially the result of normal knee kinematics, investigations have also defined meniscal extrusion under both dynamic and load-bearing conditions. Achtnich et al. studied MME in 75 healthy patients using ultrasonography under different loading conditions. The findings revealed that MME increased from an average of 1.1 ± 0.5 mm when in the supine position and non-load-bearing to 1.9 ± 0.9 mm when standing and under full weight-bearing ($p < 0.001$)[7]. These results are supported by findings from Patel et al., who compiled MRI results of 143 asymptomatic individuals under both non-loading conditions and loading conditions equivalent to 50% of body weight. MME in the coronal plane increased from an average of 1.0 ± 0.8 mm with no joint-loading to 1.8 ± 1.0 mm at loading equaling 50% of weight ($p < 0.0001$)[24].

Major meniscal extrusion is often a result of a knee injury and resultant tearing at the meniscal root attachment. In a review of nearly 250 medial meniscal tears, Choi et al. found that the mean extrusion for patients with root tears was 3.8 ± 1.4 mm compared with 2.7 ± 1.3 mm in patients with all other forms of meniscal tears ($p < 0.001$)[25]. Furthermore, a retrospective analysis of 100 medial meniscal posterior root tears demonstrated that the mean extrusion was 4.6 ± 3.2 mm and the severity of meniscal extrusion was associated with worsening Kellgren-Lawrence grades ($p = 0.001$)[4].

A uniform classification system of meniscal extrusion has not yet been adopted. Some investigations have utilized grading systems based on the percentage of the meniscal body extruded[2,26]; the degree of joint-space narrowing (JSN)[21,27]; or 2, 3, or 5-mm cutoffs[28]. Other studies argue for the evaluation of the anterior horn, the posterior horn, and the meniscal body using separate criteria because of different physiologic ranges of displacement with various joint movements[29-31]. Meanwhile, a 4-year longitudinal study of 235 patients with meniscal extrusion determined a 2.5-mm threshold for predicting knee pain and cartilage damage, contesting that the traditional 3-mm threshold may be too liberal[32]. While 3 mm remains the value of importance in diagnosing pathologic meniscal extrusion for most in clinical practice, evaluation and treatment may come down to subtle clinical judgment in the context of other relevant or contributing knee pathology, such as meniscal injury, lower-extremity malalignment, meniscocapsular laxity, or OA, as well as key patient demographics such as age, activity level, and body mass index (BMI).

Epidemiology, Etiology, and Natural History

While epidemiological data are not abundant on the topic of meniscal extrusion, there are a handful of cohort studies that provide insight into its prevalence and other associated findings or pathology. In a cohort of 1,630 patients who ranged from 65 to 84 years of age, Kaneko et al. detected the prevalence of ≥3 mm of meniscal extrusion to be 73.5%, and that prevalence increased with age[33]. Meanwhile, in a multicenter study of >1,500 patients with or at risk for OA, 44.2% of patients demonstrated prevalent (>50% of the meniscal body) MME, while 9.4% of patients demonstrated prevalent lateral meniscal extrusion. Concomitant meniscal tears were present in 57.8% and 51.3% of medial and lateral extrusion cases, respectively[2]. The conclusion that meniscal extrusion is far more common in the medial compartment than in the lateral compartment was further validated in a review of MRI results of 100 knees without OA or meniscal pathology, which showed MME of >3 mm in 68.5% of patients compared with 18.8% with lateral excursion[34].

The etiology of isolated meniscal extrusion is not well-established in the literature, although there have been reports that abnormality of the meniscotibial and meniscofemoral ligaments begets isolated meniscal extrusion, given their role in anchoring the meniscus to the tibial plateau[10,11,16,35,36]. Extrusion is more commonly encountered in patients with meniscal root or large radial tears and meniscal degeneration, as well as in patients with obesity (from presumed secondary overload) and those with findings suggestive of DJD, such as articular cartilage loss, osteophyte formation, JSN, or OA[2-4,7,14,15,22,30].

Meniscal root tears and large radial meniscal tears are frequently cited in the literature as the cause of meniscal extrusion[22,37]. Meniscal root tears are a common knee injury, with a reported prevalence of 9.1% according to a large retrospective analysis of patients who underwent arthroscopic knee surgery at a single institution[38]. Medial meniscal posterior root tears are commonly degenerative injuries and often present with medial compartment chondral injuries, while lateral posterior root tears are frequently associated with concomitant ACL rupture and can sometimes be missed during arthroscopic ACL reconstruction[39]. A multicenter review of MRI results of >2,000 knees in patients with or at risk for OA demonstrated that patients with root tears were >10 times as likely to present with MME than those without root tears[2]. Meanwhile, regression analysis of >100 MRI results of patients with evidence of a posterior horn meniscal tear demonstrated that extrusion was most severe in tears with a radial component[40]. Along similar lines, in a review of MRI results of 105 knees with the presence of meniscal extrusion, Costa et al. reported that radial tears were present in 17% of patients, and 87% of large radial tears presented with major extrusion[22]. Recently, it has been suggested that meniscal extrusion may actually be implicated as a cause, rather than the result, of root tears by concentrating forces at the posterior meniscal root[41].

The link between extrusion and the progression of DJD is also well-established in the literature. As such, numerous studies have identified extrusion as an independent predictor of tibiofemoral cartilage loss, JSN, and knee OA[15,17,18,20,42,43]. Along similar lines, associations with meniscal degeneration, age, and BMI have been demonstrated in the literature, further illustrating the role of extrusion in DJD[2,7,44].

Other investigations have identified the presence of meniscal extrusion in knees without evidence of meniscal tears or DJD. Goto et al. reviewed imaging from nearly 200 patients with radiographic evidence of malalignment; they reported that varus malalignment measurements were all significant independent predictors of MME of ≥3 mm and were associated with OA progression[45]. These findings supported those from the multicenter trial by Crema et al., which identified varus malalignment as an independent risk factor for MME[2]. In addition, improvement of extrusion has been observed at 4 years following realignment osteotomy, suggesting that extrusion may be reversible in some cases[46].

Extrusion following meniscal allograft transplantation (MAT) is a topic of recent investigation. A 2018 meta-analysis by Lee of 21 studies investigating extrusion following MAT reported pooled mean proportions of medial and lateral compartment extrusion of >3 mm to be 61% and 39%, respectively[47]. Previous investigations have identified that graft oversizing of >10% of the native meniscus is associated with extrusion and that improper width matching is more likely to result in extrusion than improper length matching[48,49]. Other theories for the higher degree of extrusion following MAT include overtensioning during fixation, loss of fixation at the anterior and posterior horns, poor graft positioning, and failure to repair accessory meniscal stabilizers such as the meniscotibial ligament and the popliteomeniscal fascicles[48-50]. Additionally, allograft suture fixation has been linked to a significantly higher degree of extrusion when compared with osseous fixation or bone plug techniques, although the study failed to demonstrate a significant decline in patient-reported functional Lysholm scores[51].

Diagnosis

Meniscal extrusion is primarily an imaging-driven diagnosis. Extrusion cases that occur in the absence of other knee pathology often go undiagnosed in the general population because isolated extrusion is rarely symptomatic[15]. However, pathologies known to produce meniscal extrusion, such as a meniscal tear or OA, should be met with high suspicion for underlying extrusion during clinical evaluation. Patients who present with OA may note joint-line tenderness, stiffness, and/or crepitus, and can be diagnosed with radiographs showing evidence of JSN, subchondral sclerosis, and/or osteophyte formation[52]. Meanwhile, a meniscal tear may present clinically with pain during deep flexion; mechanical symptoms of clicking, catching, or locking; or a knee effusion[53]. Diagnosis is best made with the use of T2-weighted MRI, with

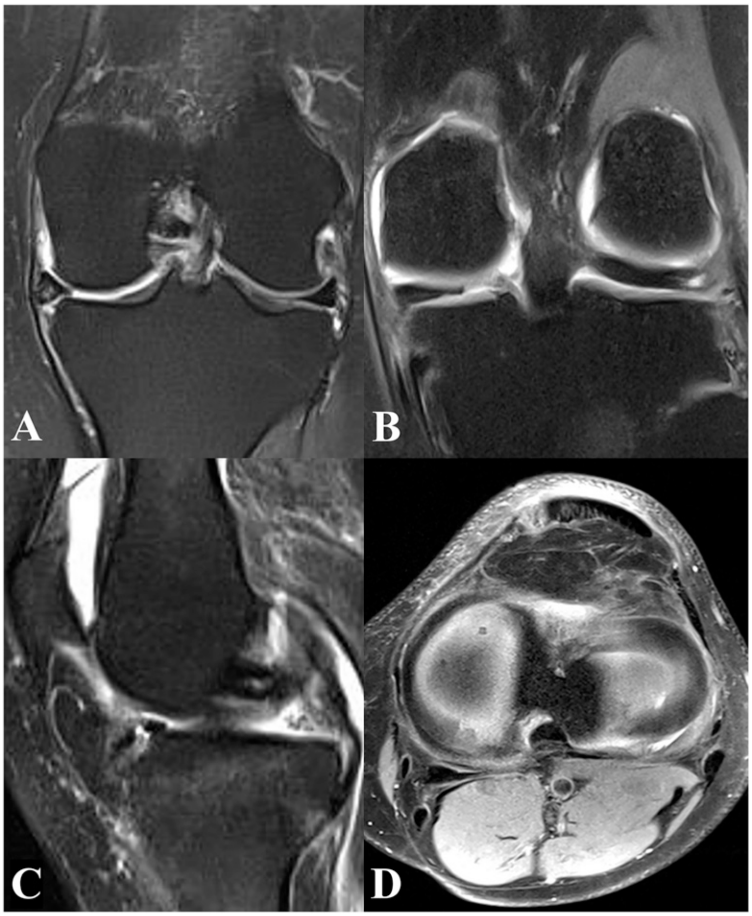

Fig. 2

Figs. 2-A through 2-D T2-weighted MRI of the knee revealing a tear of the posterior root of the medial meniscus. **Fig. 2-A** Meniscal extrusion beyond the border of the medial tibial plateau. **Fig. 2-B** Coronal view showing "truncation sign" discontinuity at the posterior root attachment site. **Fig. 2-C** Sagittal view of the knee demonstrating near-complete signal loss at the site of the injury, the "ghost sign." **Fig. 2-D** Discontinuity of the posterior root of the medial meniscus.

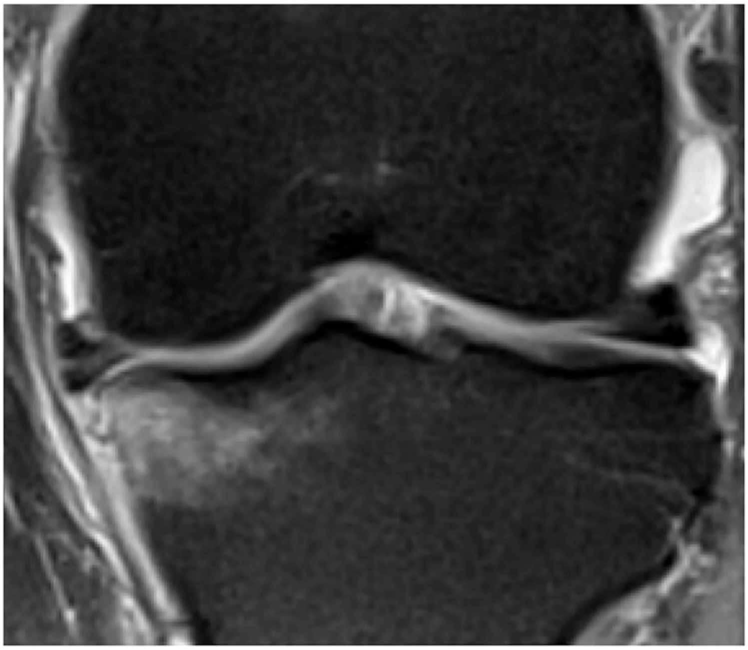

Fig. 3

Measuring meniscal extrusion using the coronal T2- weighted MRI view. Absolute extrusion [A] of the meniscus beyond the tibial plateau is the most common method of measuring meniscal extrusion, although the percentage of absolute extrusion relative to the total width [B] of the meniscus ([A/B] × 100) may also be utilized.

reported ranges of sensitivity and specificity in the literature between 77% and 94% and 73% to 100%, respectively[38,54-56]. In addition to the presence of extrusion, findings that are diagnostic of a root tear include the absence of meniscal signal in the sagittal plane, known as the "ghost sign," and/or the "truncation sign," which is a vertical line defect through the root on a coronal MRI series, indicating a lack of continuity at the root[57,58] (Fig. 2). Discontinuity of the root can also be identified on some axial slices that are in the plane of the meniscus[57,58].

Current diagnostic recommendations endorse both MRI and ultrasonography as feasible and effective in confirming the presence of meniscal extrusion. MRI is sensitive for meniscal pathology and has proven to be the diagnostic gold standard[50]. Both 1.5-T and 3-T MRI can provide quality images, either with or without fat-suppression sequencing[27,29,59]. Coronal plane cuts are most frequently used to quantify extrusion because they provide a view with a clear contrast between the tibial plateau and the meniscal bodies, allowing for consistent and reproducible measurement[29] (Fig. 3). MRI also allows for comprehensive evaluation of the knee for concomitant pathology, making it a valuable resource when attempting to diagnose the underlying cause of extrusion.

While MRI offers many diagnostic advantages, its limitations are the lack of examination of the meniscus under weight-bearing conditions and lack of bedside availability[60]. Ultrasonography is superior in this regard as it is a cost-effective, widely available, quick imaging modality that allows for dynamic multiplanar evaluation of the meniscus under differing load-bearing conditions. Previous studies have validated ultrasonography as a reliable diagnostic tool, with performance comparable with MRI when used by an experienced operator[7,59,61,62]. However, the efficacy of ultrasonography is widely known to be user-dependent[59]. Similarly, it does not allow for complete visualization of the meniscus—in particular, the anterior and posterior horns—or the entire knee joint and, therefore, cannot be used to identify pathology contributing to extrusion[29].

While weight-bearing radiographs can highlight important findings such as JSN and subchondral sclerosis[63], quantification of extrusion is not feasible with radiographs since soft-tissue structures cannot be visualized. Meanwhile, computed tomography (CT) arthrography does allow for visualization of the menisci and thus can detect the presence of extrusion. However, there are no high-level studies in the current body of literature that have validated its functionality as a diagnostic tool, and it is an inferior modality for evaluation of the knee and surrounding soft tissues compared with MRI[63,64]. However, CT arthrography can be considered in patients with other conditions or implants that preclude MRI.

Treatment Considerations

Management of meniscal extrusion is dependent on multiple factors, including the etiology of extrusion and concomitant knee pathology, patient symptoms, and the risk of the development of chondral injury or OA (Table I). There is evidence from both cross-sectional and longitudinal analyses that meniscal extrusion is associated with the development and progression of OA[21,59,65]. In cases where surgical intervention is indicated to treat the underlying pathology, it is important that an attempt to reduce the extrusion should also be made, given the association with

TABLE I Recommendations for Care

Pathology	Treatment Recommendations	Grade*
Meniscal root tear	Meniscal root repair vs. meniscectomy or nonoperative management	B
	Transtibial approach vs. suture anchor method	I
Radial meniscal tear	Radial meniscal tear repair vs. meniscectomy or nonoperative management	B
	All-inside repair vs. inside-out repair vs. transtibial approach	I
Meniscal deficiency	Bone fixation vs. suture fixation of meniscal allograft transplant	B
	Meniscal allograft transplantation with or without concomitant capsulodesis, osteophyte excision, or delayed rehabilitation	I
Isolated meniscal extrusion	Meniscal centralization to manage meniscocapsular laxity	C
	Meniscal stabilization via meniscotibial and meniscofemoral ligament repair	I

*According to Wright[95], grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending intervention; grade B, fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention; grade C, poor-quality evidence (Level-IV or V studies with consistent findings) for or against recommending intervention; and grade I, insufficient or conflicting evidence not allowing a recommendation for or against intervention.

increased risk of cartilage loss and tibial bone expansion. This is especially true in young athletic individuals who have no other risk factors for the development of chondral injury or arthrosis. However, in patients with severe cartilage loss, those who are elderly or obese, or those who are otherwise poor surgical candidates, nonoperative treatment options should be exhausted prior to considering surgical intervention. Nonoperative treatment modalities consist of nonsteroidal anti-inflammatory drugs, weight loss, physical therapy, and activity modification[66,67].

Meniscal Repair

Meniscal injuries—particularly root and radial tears—are a well-documented cause of meniscal extrusion[2,3,22,40]. When possible, meniscal repair is preferred to partial meniscectomy or nonoperative management, as the repair preserves the native anatomy of the tibiofemoral compartment and the ability of the meniscus to withstand hoop stress and radial displacement[6,14,39]. The contrast in outcomes is stark: a meta-analysis and cost-effective analysis of 13 studies by Faucett et al. found that when compared with meniscectomy and nonoperative treatment at 10 years postoperatively, root repair led to a nearly 50% reduction in the development of OA and a 15% to 20% reduction in the rate of total knee arthroplasty[68].

Both suture anchor (direct) and transtibial pullout (indirect) techniques have been popularized for arthroscopic repair of meniscal root tears, the most common cause for extrusion[66]. While the suture anchor repair typically involves an all-inside technique with a suture anchor and additional sutures secured at the root attachment, the transtibial approach involves drilling a tunnel through the tibia to the native root attachment, shuttling sutures that are cinched to the torn meniscus through the tunnel, and then securing the sutures to the anterior aspect of the tibia[66,69,70]. Small case-control and cohort studies have demonstrated favorable clinical outcomes following meniscal repair utilizing either repair method, although the persistence and progression of extrusion remains a risk[66,69,71-75]. The transtibial approach is preferred by the senior author (B.J.C.) and is considered the gold standard by many investigators[66].

There remains a lack of consensus regarding the preferred approach to treating radial meniscal tears. All-inside and inside-out repairs were the first techniques developed; however, novel and modified techniques, including a transtibial method, have since been developed secondary to inconclusive and sometimes less than satisfactory prior outcomes[76-80]. Nonetheless, the overall body of literature affirms that regardless of technique, meniscal repair should be attempted, instead of partial or total meniscectomy, when feasible in order to preserve the meniscus, restore its functionality, limit the progression of arthrosis, and maximize patient outcomes[39,68,81-83].

Meniscal Allograft Transplantation

Investigation into the prevalence of meniscal extrusion following MAT, its role in clinical outcomes, and techniques for prevention are ongoing topics of research. In 2018, a meta-analysis of 8 studies demonstrated that graft extrusion of >3 mm was 5 times more likely to occur following medial MAT compared with lateral MAT when using an arthroscopic-assisted technique, but no difference in extrusion rates occurred following a completely arthroscopic approach[84].

While results following MAT are generally encouraging with respect to clinical outcomes and survivorship, isolating the influence of meniscal extrusion on outcomes has not been studied in great detail and remains a topic requiring further study[85].

Meniscocapsular Disruption

While uncommon, meniscocapsular disruption in the absence of meniscal injury has also been shown to present with evidence of meniscal extrusion. Arthroscopic reconstruction techniques for repair of both the meniscotibial and meniscofemoral ligaments have been described in the literature, although, to our knowledge, the only clinical study of outcomes following direct stabilization of the meniscotibial ligaments was performed by Paletta et al.[86]. Their study of 15 patients found that a novel suture-bridging technique reduced MME from 2.4 ± 0.5 to 1.2 ± 0.6 mm ($p < 0.001$).

Meniscal centralization and capsular advancement techniques are also growing therapeutic options for the treatment of extrusion. Capsular laxity is known to be the result of meniscotibial ligament damage caused by meniscal injury, extensive meniscectomy, or a root tear; even in cases of satisfactory root repair, extrusion can be a persistent postoperative complication[75,87-89]. Additionally, recent investigations have indicated that meniscotibial ligament injury and associated extrusion may be the cause, rather than the result, of root tears[41]. Centralization seeks to reconfigure meniscal shape and position on the tibia and involves releasing the meniscotibial ligament and reattaching the meniscal midbody-capsular complex just central to the peripheral rim of the tibial plateau[90-92]. Initial biomechanical models have demonstrated that root repair techniques that incorporated centralization were successful in normalizing tibiofemoral contact pressures and reducing extrusion[87,88]. In the clinical setting, centralization has been shown to be effective in reducing extrusion and laxity while improving patient outcomes, although the body of evidence is limited[93,94].

Overview

Pathologic meniscal extrusion can cause loss of meniscal function, is associated with increased contact forces in the tibiofemoral compartment, and is a known predictor of the development of OA. Pathologic extrusion is typically defined as radial displacement of ≥3 mm outside the tibial border and is most commonly identified on MRI, which is considered the diagnostic gold standard. Although some degree of extrusion is a physiologic phenomenon of normal joint biomechanics, major extrusion is primarily the result of meniscal root tears, but other identified etiologies include large radial tears, lower-extremity varus malalignment, age, and elevated BMI. The phenomenon can also occur following MAT. Surgical treatment should be tailored to the underlying etiology of extrusion, the patient's symptom profile, the preexisting health of the articular surface, and the risk of development of chondral injury or OA. In the case of root tears, meniscal repair is favored over meniscectomy in order to preserve the meniscal anatomy and restore its ability to withstand weight-bearing hoop stresses. The current body of meniscal extrusion literature is devoid of long-term studies with high methodologic quality. Given the well-reported association between extrusion and DJD, future studies should be dedicated to investigating clinical outcomes following treatment.

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