

A narrative review of lateral meniscus root tears and extrusion: techniques and outcomes

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Objective: In this review, we performed a literature search and described the surgical procedure for a lateral meniscus posterior root tears (LMPRT) repair using a pull-out technique and an arthroscopic centralization for lateral meniscus (LM) extrusion.

Background: The menisci play a pivotal role in the shock-absorbing and load-dispersing functions of the knee joint. They also contribute to its stability. Meniscal root tears substantially affect meniscal hoop function and accelerate cartilage degeneration. Additionally, LMPRT have been shown to affect anterolateral knee laxity and tibiofemoral contact pressure in knees with anterior cruciate ligament (ACL) injury. Therefore, appropriate management of LMPRT is essential for restoring knee function. Meniscus extrusion has attracted attention due to its association with early osteoarthritis (OA). Recently, an arthroscopic centralization technique has been proposed to reduce meniscal extrusion. During this procedure the capsule attached to the meniscus is sutured to the edge of the tibial plateau using suture anchors.

Methods: A narrative review of LMPRT repair and arthroscopic centralization of lateral meniscal extrusion was performed through a PubMed search.

Conclusions: Specific magnetic resonance imaging (MRI) signs were useful for the diagnosis of LMPRT. Pull-out techniques can restore knee stability and load distribution function and result in favorable clinical outcomes. Arthroscopic centralization of the extruded LM caused by meniscectomy and lateral discoid meniscus achieved satisfactory clinical outcomes at the 2-year follow-up. Biomechanical studies demonstrated that this procedure reduced meniscus extrusion and had beneficial effects on load distribution and joint stability. In summary, to restore knee function, LMPRT should be repaired as much as possible. The centralization technique is a promising surgical treatment for extruded lateral menisci due to meniscectomy and discoid meniscus. However, due to the lack of high-level evidence studies such as randomized control trials (RCTs) in this field, it remains necessary to accumulate evidence to confirm the efficacy of LMPRT repair and the centralization technique.

Keywords: Lateral meniscus (LM); arthroscopic centralization; extrusion; posterior root tears (PRTs); meniscus repair

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Introduction

Menisci play a pivotal role in the shock-absorbing and load-dispersing functions of the knee joint. They also contribute to its stability (1,2). The medial meniscus (MM) can act as a secondary stabilizer of anterior tibial translation. The lateral meniscus (LM) provides anterolateral laxity in anterior cruciate ligament (ACL)-deficient knees (3,4). Meniscal extrusion induces dysfunction of load distribution (1,2,5) and is caused by the disruption of the meniscus hoop function. It is often observed after meniscectomy (1,6,7), meniscus root tears (8), discoid LM (6,9) and in aging (10-12). Consequently, meniscal extrusion initiates osteoarthritis (OA) and is accompanied by its progression (13-16).

Posterior root tear (PRT) is an avulsion injury or radial tear within 1 cm of the meniscal attachment site. LM posterior root tears (LMPRT) occur in 10–15% of all ACL injury cases (17,18). However, PRTs on the MM are rare in ACL-injured knees (18). LMPRT should be repaired if at all possible. LMPRT has been shown to affect anterolateral knee laxity and tibiofemoral contact pressure in ACL-injured knees in both clinical (18) and biomechanical studies (19,20). In terms of the effects of LMPRT repair, some biomechanical studies have revealed that LMPRT repair improves knee stability, reduces ACL graft force, and restores load-distribution function (21-23). In this review, we described our surgical technique for LMPRT repair. We also performed a narrative search of the literature.

Previously, there was no surgical solution for a meniscal extrusion for causes seen after meniscectomy and discoid LM. We developed an arthroscopic centralization technique to reduce meniscal extrusion. The capsule attached to the meniscus was sutured to the edge of the tibial plateau using suture anchors (24). The centralization technique could restore the lost function caused by meniscal extrusion (25-27). It could also delay OA progression (28). In addition, arthroscopic centralization of the extruded LM improved clinical outcomes at the 2-year follow-up (29). In this article, a narrative review of the literature for the arthroscopic centralization technique for lateral extruded meniscus was performed. It describes the indications, surgical techniques, clinical outcomes, and biomechanics of this procedure.

We present the following article in accordance with the Narrative Review reporting checklist (available at <https://aoj.amegroups.com/article/view/10.21037/aoj-20-112/rc>).

LMPRT repair

A literature review of LMPRT repair

A narrative review of the literature for LMPRT repair was performed using PubMed. The main criteria for selection were articles focused on the biomechanical role of LMPRT, magnetic resonance imaging (MRI) examination of LMPRT, and the clinical outcomes of LMPRT repair.

Biomechanical role of LMPRT and repair

Meniscal root tears substantially affect meniscal hoop function and accelerate cartilage degeneration. The LM posterior root also plays an important role as a secondary restraint against pivotal shift in ACL-deficient knees. A cadaveric study showed that LMPRT significantly increased the pivotal shift in ACL-deficient knees (19). Clinically, it has also been shown that LMPRT is associated with a larger pivot shift grade in ACL-injured knees (30). Its repair decreases tibial acceleration during the pivot shift test (4). Tang *et al.* (23) reported that LMPRT repair improves anterolateral laxity and reduces ACL graft force in ACL-reconstructed knees in a cadaveric study. Therefore, the importance of LMPRT repair at the time of ACL surgery has been widely recognized. In recent years efforts have been made to develop successful repair techniques (31).

MRI diagnosis of LMPRT

A high percentage of LMPRTs are often missed. It is nearly impossible to diagnose them preoperatively with imaging techniques (32). Consequently, surgeons should prepare the necessary instruments for LMPRT repair in all ACL reconstruction surgeries. Nevertheless, several studies have demonstrated the usefulness of MRI findings. Minami *et al.* (18) calculated the sensitivities and specificities of vertical linear defects in the coronal plane (*Figure 1A*), radial linear defects in the axial plane (*Figure 1B*), ghost sign in the sagittal plane (*Figure 1C*), and meniscus extrusion in the coronal plane (*Figure 1D*). The authors demonstrated that 71.8% of patients showed at least one positive sign. The highest sensitivity was 69.2% for vertical linear defects. Asai *et al.* (33) examined three specific signs: vertical linear defects (cleft sign), ghost signs, and the truncated triangle sign in the sagittal plane. They further demonstrated that vertical linear defects (cleft sign) showed the highest

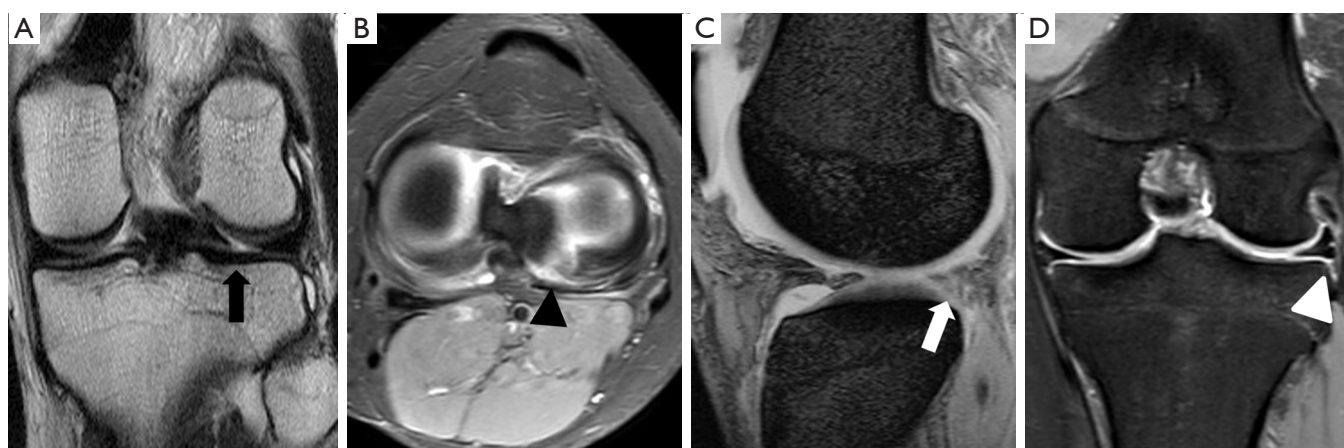


Figure 1 MRI findings in LMPRT. (A) Vertical linear defect in the coronal plane (arrow). (B) Radial linear defect in the axial plane (arrowhead). (C) White meniscus sign in the sagittal plane (arrow). (D) Meniscal extrusion in the coronal plane (arrowhead). MRI, magnetic resonance imaging; LMPRT, lateral meniscus posterior root tears.

sensitivity of 65.6%. They also demonstrated that the combination of these signs improved the approximate sensitivity by up to 80%. With regard to meniscal extrusion, there was a relationship between the meniscal extrusion and the status of LMPRT in ACL injury patients (34). The average meniscus extrusion width was 0.2 ± 0.5 mm in patients with intact LM, 0.4 ± 0.8 mm in patients with partial LMPRT, and 2.0 ± 0.6 mm in patients with complete LMPRT. This suggests that meniscal extrusion is a useful indicator for estimating the status of LMPRT. Therefore, careful preoperative evaluation with MRI would assist in the diagnosis of LMPRT.

Clinical outcomes of LMPRT repair

There were primarily two surgical techniques utilized in LMPRT repairs. Side-to-side suture repair was performed in radial tears if there was a root remnant with adequate tissue quality. A pull-out repair was conducted in root avulsions and radial tears with an inadequate meniscal remnant. Ahn *et al.* (35) demonstrated favorable short-term results of an all-inside side-to-side LMPRT repair in ACLR patients. They reported that over a mean follow-up period of 18 months the mean subjective International Knee Documentation Committee Subjective Knee Form (IKDC) scores and Lysholm scores significantly improved from 67 to 90 and from 62 to 93, respectively. Anderson *et al.* (36) also reported the clinical outcomes of both an all-inside side-to-side repair and a transtibial pull-out repair over a mean follow-up of 58 months in ACLR patients. In patients who

underwent a side-to-side repair, the mean subjective IKDC and Lysholm scores were 82 and 87, respectively; patients who underwent a transtibial pull-out repair had scores of 84 and 86, respectively. However, these studies were case series. They did not show the effects of the LMPRT repair itself. In contrast, Pan *et al.* (37) compared ACLR patients who underwent an LMPRT repair with those who did not. They reported higher functional scores (although not significant) and statistically lower rates of radiological osteoarthritic changes in patients who underwent an LMPRT repair. In terms of meniscal extrusion, a transtibial pull-out repair of LMPRT achieved reduction of meniscal extrusion (38,39). These results indicate that an LMPRT repair successfully recovered the hoop function of the LM. Several studies have reported the healing rates of LMPRT after a repair with second-look arthroscopy. The complete/partial healing rate ranged from 86.7% to 100% (35,36,40,41). This seemed to be better than the 61% healing rate of radial tears in the midbody of LM (42). Overall, LMPRT repair concomitant with an ACLR resulted in favorable outcomes.

Our surgical technique of LMPRT repair and its clinical outcomes

Our indications for LMPRT repair include all types of LMPRT to prevent acceleration of articular cartilage degeneration as well as to control anterolateral instability. First, a standard arthroscopy is performed through anterolateral and anteromedial portals to evaluate the status of the menisci and ACL. If LMPRT is identified

(Figure 2A-2C), it is repaired appropriately. Most type 2a and 2b tears under the LaPrade classification (43) are repaired using a pull-out technique. Fibrous tissues around the torn meniscus edge are removed and adhesions around the torn meniscus edge are released using a motorized shaver. An ACUFEX™ Director ACL Tip Aimer (Smith and Nephew Endoscopy, Andover, MA, USA) is inserted from the anteromedial portal with the tip of the aimer placed over the attachment site of the LM posterior root (Figure 2D). A 2.4 mm guidewire is inserted from the anteromedial aspect of the proximal tibia. A 6-mm-diameter tunnel is then created with a cannulated drill (Figure 2E). The 6-mm-diameter tunnel allows the meniscus and bone to heal by pulling the torn edge of the LM posterior root into the tunnel. Articular cartilage around the bone tunnel is removed with a curette until the subchondral bone is exposed to promote adhesion of the meniscus to the bone (Figure 2F). A vertical mattress suture with a 2-0 FiberWire (Arthrex, Naples, FL, USA) is applied approximately 3 mm away from the torn edge of the meniscus using a Knee Scorpion Suture Passer (Arthrex) (Figure 2G). The tied suture is left uncut so that it can be pulled into the tunnel. Two racking hitch knot sutures with SutureTapes (Arthrex) are placed over the vertical mattress suture as a locking suture to securely hold the torn edge of the meniscus (Figure 2H,I). The sutures are then shuttled through the tunnel to the anteromedial aspect of the proximal tibia (Figure 2J). Using the arthroscopic view from the anterolateral port, the suture ends for the LMPRT are finally tied over a TightRope ABS Button (Arthrex) under adequate tension (Figure 2K). A final arthroscopic evaluation is performed to confirm reattachment of the LM posterior root to the insertion site, adequate tension within the entire meniscus, and reduction of the extruded meniscus (Figure 2L). The tips and pitfalls of this technique are presented in Table 1. Type 2c and type 4 tears are repaired using the all-inside suture technique. ACL reconstruction is performed following LMPRT repair.

The postoperative rehabilitation protocol is the same regardless of the presence of LMPRT repair. Patients can begin to practice range of motion and quadriceps-setting exercises one day after surgery. Weightbearing and walking exercises with crutches and a knee brace are ordered on the third postoperative day. Crutches are removed after four-weeks. Running exercises are initiated at three months. Patients progress to full activity after 6 months.

We compared 22 ACLR patients with simultaneous LMPRT repair with 75 ACLR patients without meniscus

injury. The Knee Injury and Osteoarthritis Outcome Score (KOOS) and IKDC subjective score were used which were validated to evaluate ACL injury patients (44). We found that patients with concomitant LMPRT showed greater pivot shift grade and poorer subjective outcomes (KOOS and IKDC subjective score) than patients with isolated ACL preoperatively. However, the differences were not significant at 2 years postoperatively (unpublished observation). Our short-term results of LMPRT repair in ACLR patients were equivalent to those reported in previous studies (35,36).

Arthroscopic centralization for LM extrusion

A literature review of arthroscopic centralization

No surgical technique for LM extrusion was seen after meniscectomy or in the discoid LM. We developed an arthroscopic centralization technique to reduce meniscal extrusion. Herein, we describe the indications, surgical techniques, rehabilitation protocols, clinical outcomes, and biomechanical effects of this technique based on published articles searched by PubMed.

Indications for arthroscopic centralization

Original indication

The original indications for arthroscopic centralization were a symptomatic knee (pain, swelling, and/or catching) despite sufficient conservative treatment, with OA (Kellgren-Lawrence grades 0 to 2) in the lateral compartment, or after partial meniscectomy of the LM. The extrusion of the midbody of the LM had been confirmed preoperatively on coronal view of an MRI (24). Meniscal extrusion was determined by measuring the distance between the most peripheral aspect of the meniscus and the border of the tibia (excluding osteophytes) on coronal views of the MRI (45). This technique is also applicable in cases of symptomatic torn discoid meniscus (pain, swelling, and/or catching) after conservative treatment. In such cases, centralization is performed concomitantly with saucerization to prevent extrusion. Extrusion of the LM was defined as an extrusion of ≥ 3 mm based on MRI measurements.

Expanded indications

Recently, the indications for this technique have been expanded to include advanced lateral compartment OA through the development of a new meniscoplasty technique.

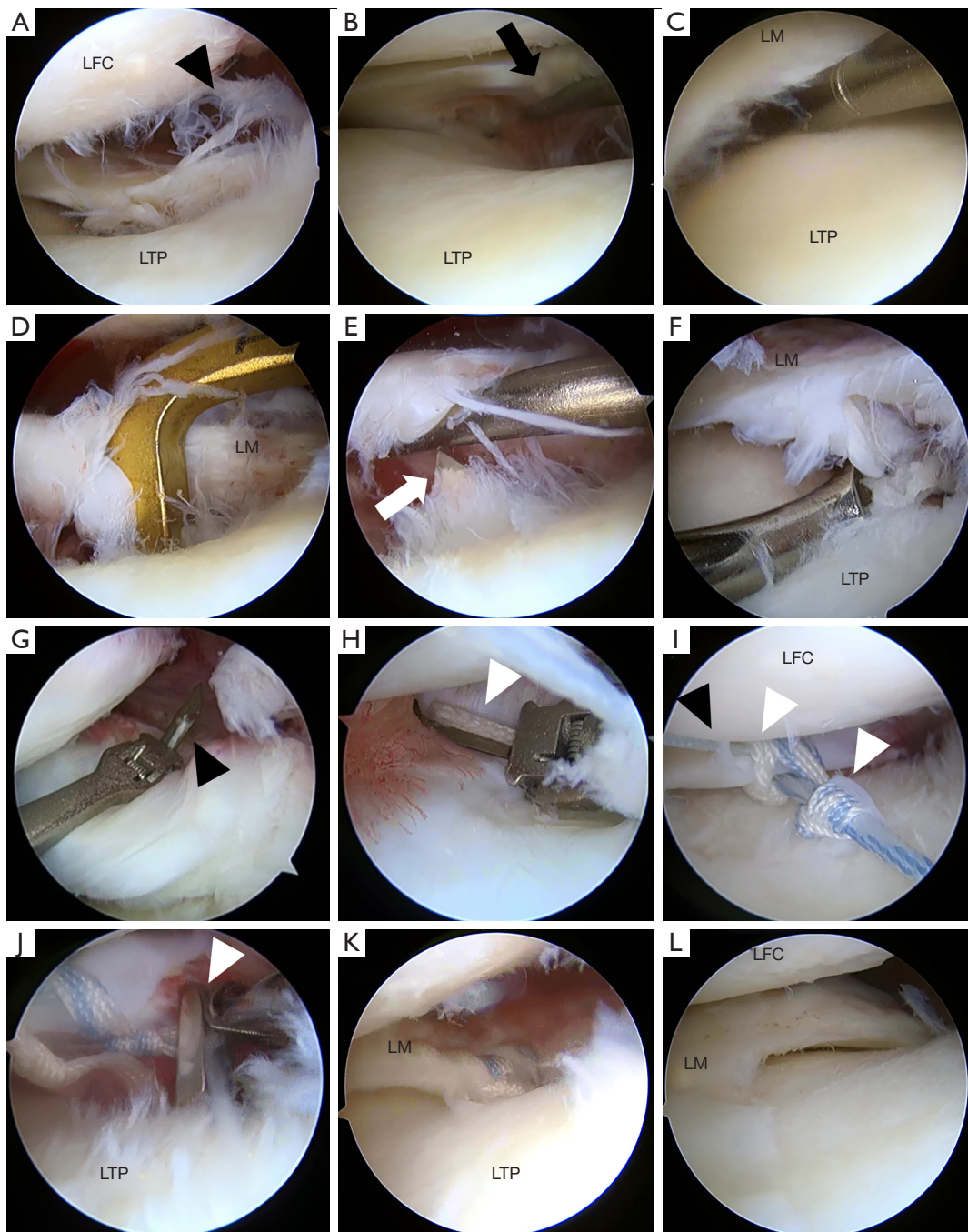


Figure 2 Arthroscopic findings in the LMPRT pull-out repair technique. (A) LMPRT is not easily identified without probing (arrowhead). (B) Positive lift-off sign is observed by probing (arrow). (C) Extrusion of LM is observed. (D) The tibial ACL guide is set at the anatomical attachment site of the LM posterior root. (E) The bone tunnel is created with a cannulated reamer (arrow). (F) Articular cartilage around the bone tunnel is removed with a curette until subchondral bone is exposed. This is to promote adhesion of meniscus. (G) A vertical mattress suture is applied using the Knee Scorpion Suture Passer (arrowhead). (H) A SutureTape for a racking hitch knot suture (arrowhead) is placed using the Knee Scorpion Suture Passer. (I) Two racking hitch knot sutures (white arrowheads) are placed over the vertical mattress suture (black arrowhead) as a locking suture to securely hold the torn edge of the meniscus. (J) The sutures are introduced into the tunnel (arrowhead). (K) After fixation, reattachment of the LM posterior root to the insertion site is confirmed. (L) Reduction of the extruded LM is also confirmed. LMPRT, lateral meniscus posterior root tears; LM, lateral meniscus; LFC, lateral femoral condyle; LTP, lateral tibial plateau.

Table 1 Tips and pitfalls in LMPRT pull-out repair

Tips	Pitfalls
Use a curette to remove articular cartilage around the tunnel to enhance adhesion of the meniscus to bone	LMPRT (especially in chronic phase) is often missed even under arthroscopic observation. Careful probing to check lift-off sign is useful for diagnosis of LMPRT
Position the transtibial tunnel for the pull-out repair at the anatomic footprint of the LM posterior root insertion site	When resecting fibrous tissues around torn site, surgeons should be careful not to resect the meniscomfemoral ligament
As secure a fixation as possible should be performed for the LMPRT repair, and if the fixation is not secure enough or reduction of the meniscus extrusion is not achieved, additional centralization for augmentation should be considered	Avoid overlap of bone tunnels for LMPRT repair and ACL reconstruction

LM, lateral meniscus; LMPRT, lateral meniscus posterior root tear; ACL, anterior cruciate ligament.

This technique is for patients with lateral compartment OA due to LM defects. The released meniscotibial capsule is advanced and centralized onto the rim of the lateral tibial plateau to reform a meniscus-like configuration. Regeneration of meniscus-like tissue is expected (46,47). Indications for meniscoplasty due to capsular advancement include symptomatic knee (pain, swelling, and/or catching) with neutral alignment (mechanical axis <60%) after sufficient conservative treatment with OA (Kellgren-Lawrence grade 3–4) in the lateral compartment due to LM defects. This is regardless of a history of meniscectomy, and in patients who are too young to undergo arthroplasty. This is also for patients who are active and desire to continue sports activity. In patients with valgus knee alignment, distal femoral closed osteotomy is performed concomitantly. In cases of meniscal extrusion due to LMPRT or radial tear, if a repair would be insufficient to restore hoop function because of the chronic and/or degenerative status of the torn site, arthroscopic centralization is considered for augmentation of an anatomical repair. Centralization is also effective for augmentation of MMPRT repairs (48–51) as well as for LM allograft transplantation (52). This includes improvements in load distribution function and reduction of meniscus extrusion.

Surgical technique of arthroscopic centralization

This technique has been described previously (24,29). A standard arthroscopic examination can be performed via routine anteromedial and anterolateral portals. Other ligament and cartilage injuries should be managed according to the injury status. The LM status was evaluated, and extrusion of the meniscus was confirmed

(*Figure 3A*). The size of the osteophytes, both at the lateral femoral condyle and the lateral tibial plateau, were also evaluated. A midlateral portal was made 1 cm proximal to the LM and 1 cm anterior to the popliteal hiatus under an arthroscopic view from the anterolateral portal (*Figure 3B,3C*). If osteophytes were present on both the femoral and tibial sides, they were resected using an osteotome and/or a motorized abradar through the midlateral and anterolateral portals. The resected area on the femoral side was coagulated to prevent regrowth of the osteophytes. The tibial side was left uncoagulated to ensure adhesion of the meniscotibial capsule to the tibia. The meniscotibial capsule was released from the tibia from anterior to posterior using a rasp to mobilize the lateral capsule (*Figure 3D*). The extruded meniscus was confirmed to be easily reduced (or in cases with meniscal defects, the released capsule was easily and sufficiently advanced to form a meniscus-like configuration) by pulling the meniscus centrally using a grasper. Subsequently, the centralization technique was performed. A soft anchor loaded with a No. 1 suture (JuggerKnot Soft Anchor; Zimmer-Biomet, Warsaw, IN, USA, Q-Fix Anchor; Smith & Nephew Endoscopy, or FiberTak Soft Anchor, Arthrex) was inserted into the lateral edge of the lateral tibial plateau, just anterior to the popliteal hiatus (*Figure 3E*). A micro suture lasso small curve with a Nitinol wire loop (Arthrex) was then inserted through the midlateral portal. The tip of the Micro SutureLasso penetrated the capsule from superior to inferior direction (*Figure 3F*). One strand of the suture was passed into the wire loop, and the other limb of the wire loop was pulled to pass the suture from the inferior to the superior direction (*Figure 3G*). The same procedure was repeated for another strand of the suture to create a

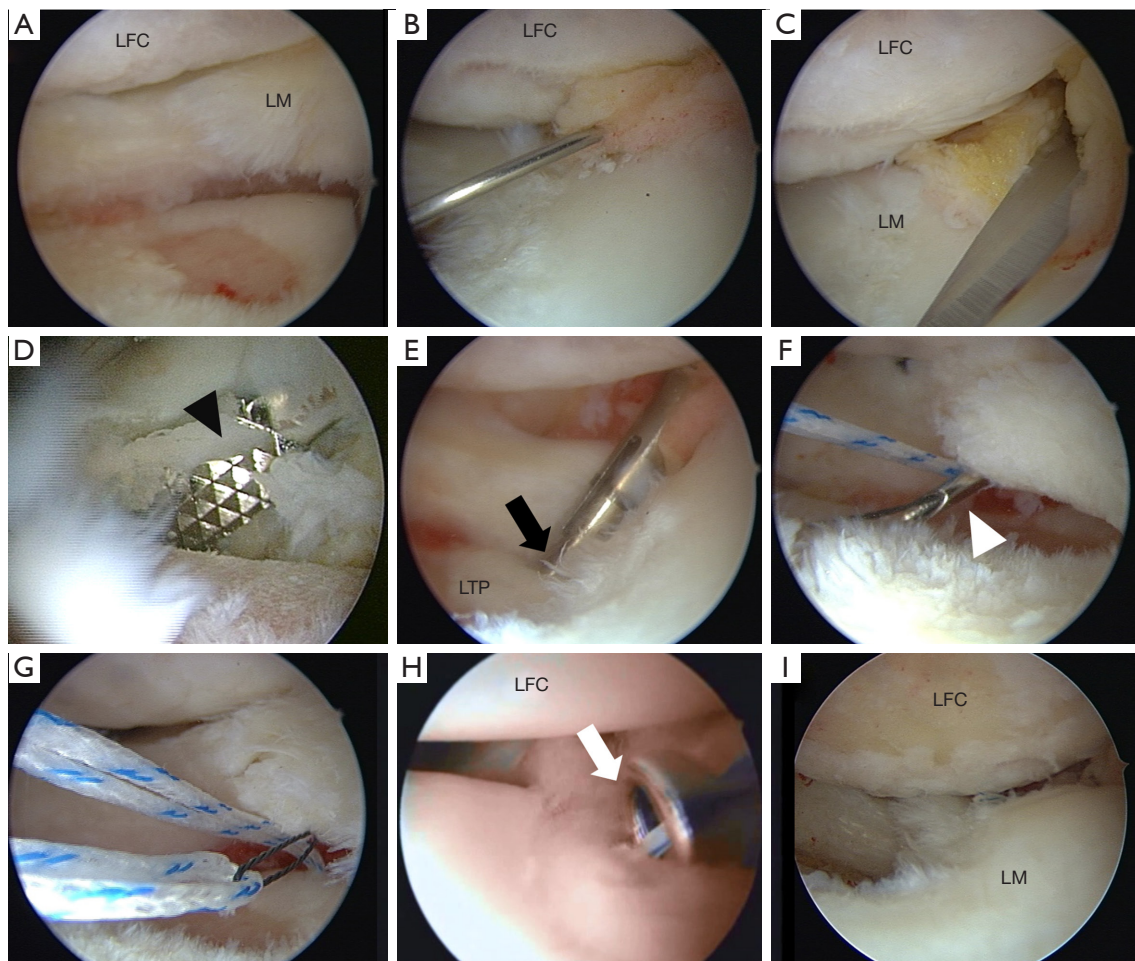


Figure 3 Arthroscopic findings in the arthroscopic centralization technique. (A) Displacement of the LM is confirmed arthroscopically. (B) A spinal needle is used to accurately place the midlateral portal. (C) The midlateral portal is made 1 cm proximal to the LM and 1 cm anterior to the popliteal hiatus. (D) The meniscotibial capsule is released from the tibia from anterior to posterior using a rasp (arrowhead). (E) A soft anchor is inserted on the lateral edge of the lateral tibial plateau (arrow). (F) A Micro SutureLasso Small Curve (arrowhead) with Nitinol Wire Loop is inserted and penetrates the capsule from superior to inferior at the margin between the meniscus and the capsule. (G) One strand of the suture is passed into the wire loop and the other limb of the wire loop is pulled to pass the suture from inferior to superior. (H) The passed sutures are tied through the midlateral portal using a self-locking sliding knot (arrow). (I) Displaced meniscus is centralized after centralization of the midbody of the LM. LM, lateral meniscus; LFC, lateral femoral condyle; LTP, lateral tibial plateau.

mattress suture configuration. An additional soft anchor was inserted on the lateral edge of the lateral tibial plateau 1 cm anterior to the first anchor. The same procedure was then repeated. The sutures were tied through the midlateral portal using a self-locking sliding knot (*Figure 3H*). The extruded meniscus was centralized onto the rim of the lateral tibial plateau (*Figure 3I*). *Figure 4* schematically demonstrates the surgical technique for arthroscopic centralization. The tips and pitfalls of this technique are

listed in *Table 2*. The rehabilitation protocol has been described previously (29). Range-of-motion exercises without restriction are encouraged immediately after surgery. Partial weight-bearing with a knee immobilizer and crutches were allowed for the first 4 weeks. After 4 weeks, partial weight-bearing without the knee immobilizer was permitted with progression to full weight-bearing at 6 weeks. Deep squatting over 90° was permitted after three months. Running was allowed at three months.

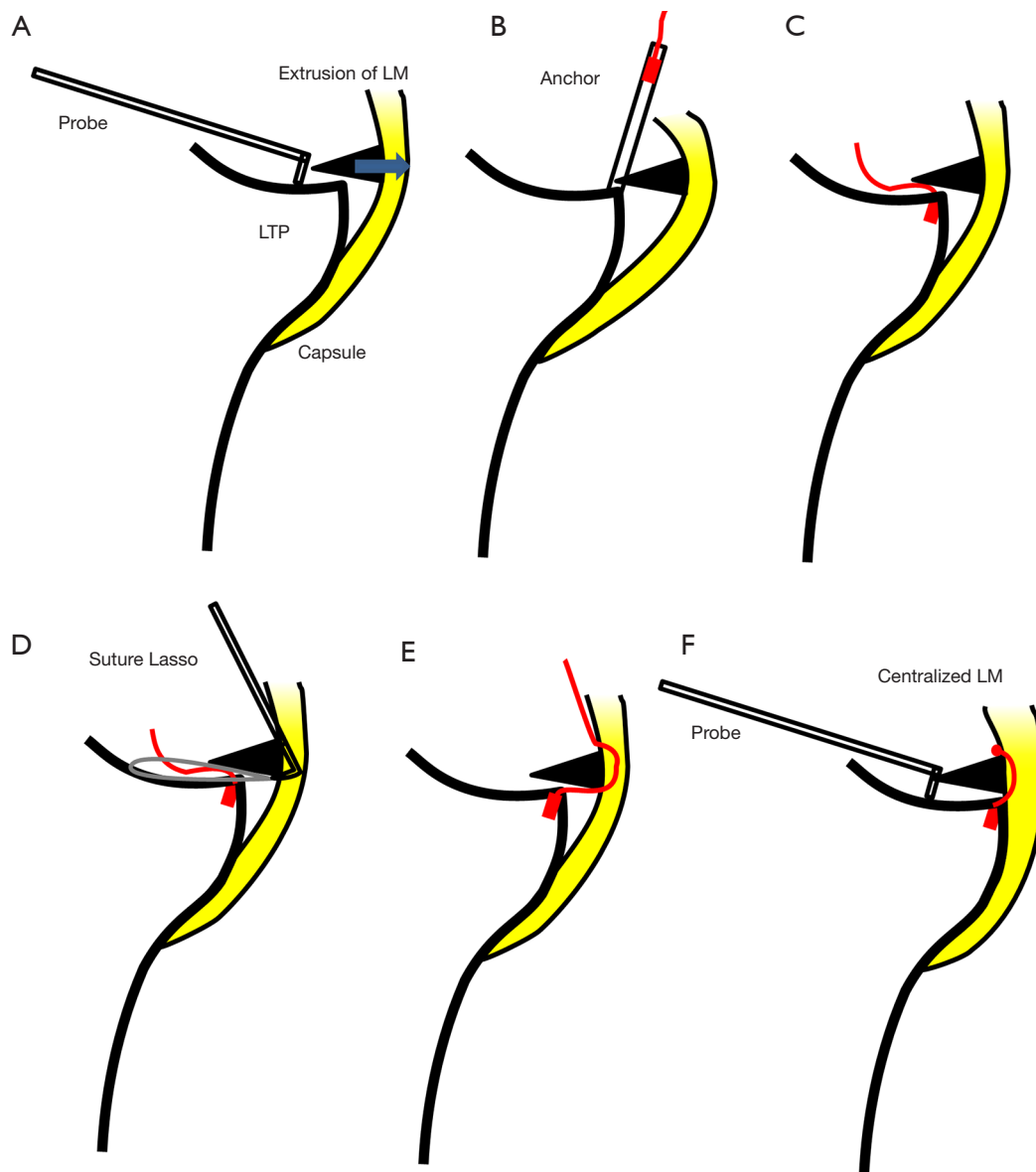


Figure 4 Schematic drawings of the arthroscopic centralization procedures. (A) Confirmation of meniscal extrusion by a probe. (B,C) Insertion of the anchor at the edge of tibial plateau. (D,E) Passing a suture through the capsule using a Micro SutureLasso. (F) After the knot is tied, the extruded LM is centralized. LM, lateral meniscus; LTP, lateral tibial plateau.

Patients progressed to full activity after six months.

Clinical outcomes of arthroscopic centralization

Arthroscopic centralization of the extruded LM obtained satisfactory clinical results as indicated by KOOS or Lysholm scores at the 2-year follow-up. MRI evaluation showed a significant reduction in meniscus extrusion width. The radiographic lateral joint space width in a standing

45-degree flexion posteroanterior view was also significantly increased at 3 months post-surgery and was maintained for 2 years (29).

Three-dimensional reconstructed (3D recon) MRI has been reported to quantitatively evaluate the meniscus in more detail (13,53,54). Wenger *et al.* (12) used 3D recon MRI to analyze the three-dimensional meniscal morphology and position in patients with knee OA. We analyzed the effects of arthroscopic centralization

Table 2 Tips and pitfalls in arthroscopic centralization

Tips	Pitfalls
The appropriate placement of the midlateral portal is essential. Use a spinal needle to check portal placement before creation	Instruments such as the rasp and suture passer should be handled carefully to avoid chondral damage
Use an arthroscopic rasp to release the meniscotibial capsule to mobilize the LM centrally	Anchors on the osteophyte or on weightbearing areas of the tibial plateau must be avoided and should be inserted at the rim of lateral tibial plateau
The resection of osteophytes is very important (especially on the tibial side) to reduce the extruded meniscus	The Micro SutureLasso should penetrate the capsule at the margin between the meniscus and the capsule during the centralization procedure. Penetration of the meniscus body would result in overconstraint of the LM

LM, lateral meniscus.

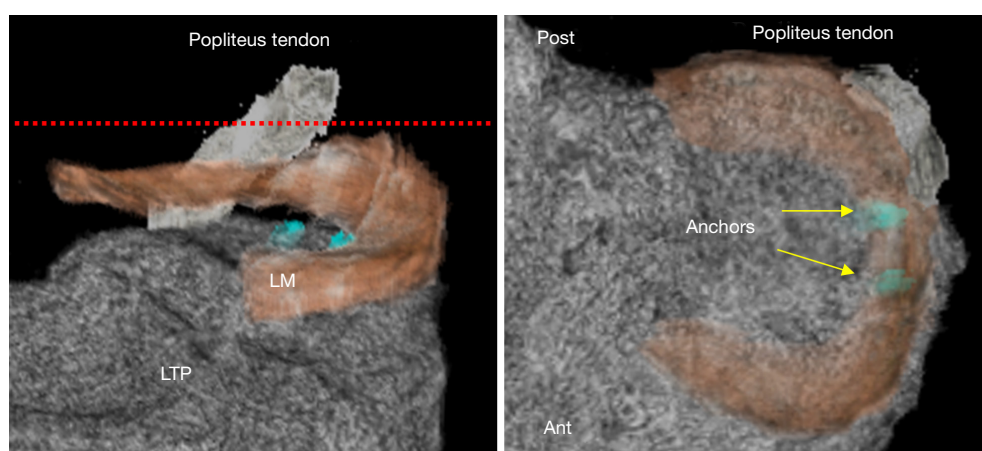


Figure 5 3D reconstructed MR images of a patient who underwent arthroscopic centralization. The posterior anchor was placed just anterior to the popliteus tendon, and the anterior anchor was placed 1 cm anterior to the first anchor. Both anchors were inserted at the edge of the tibial plateau. LM, lateral meniscus; LTP, lateral tibial plateau.

on the degree of LM extrusion using 3D recon MRI (Figures 5,6) in five patients (average age: 32 years, range, 15–47 years) who had an extruded LM from partial meniscectomy or meniscoplasty of the discoid meniscus. Each patient underwent MRI prior to and one year post-surgery. MR images were acquired using a proton density-weighted sequence using a 3.0T scanner (Achieva, Philips Medical System, Andover, MA, USA) and an eight-channel knee coil (Philips Medical System). For 3D recon images, ZioStation2 software (Ziosoft Inc., Tokyo, Japan) was used. Segmentation of the external surface of the LM and tibia was performed in the coronal view (47). The length (mm) and area (mm²) of the portion of the LM extrusion and the meniscus coverage of the tibial plateau (mm²) were quantified. The meniscal extrusion lengths (Figure 6C–6E) and area (Figure 6F–6H) at 1-year postoperatively were

significantly lower than those measured preoperatively. Additionally, meniscus coverage (Figure 6I–6K) at 1-year was significantly higher than that prior to the operation. These data further support the concept that the arthroscopic centralization technique is a promising option for the treatment of extruded LM.

Biomechanics of centralization

The biomechanical analyses of the centralization procedure for extruded LM with posterior root deficiency were performed using a porcine model. Ozeki *et al.* (25) reported that the centralization procedure restored the load distribution to a value closer to that of the normal knee joint at 45° of knee flexion (Figure 7). Additionally, further analysis demonstrated that this effect was also observed

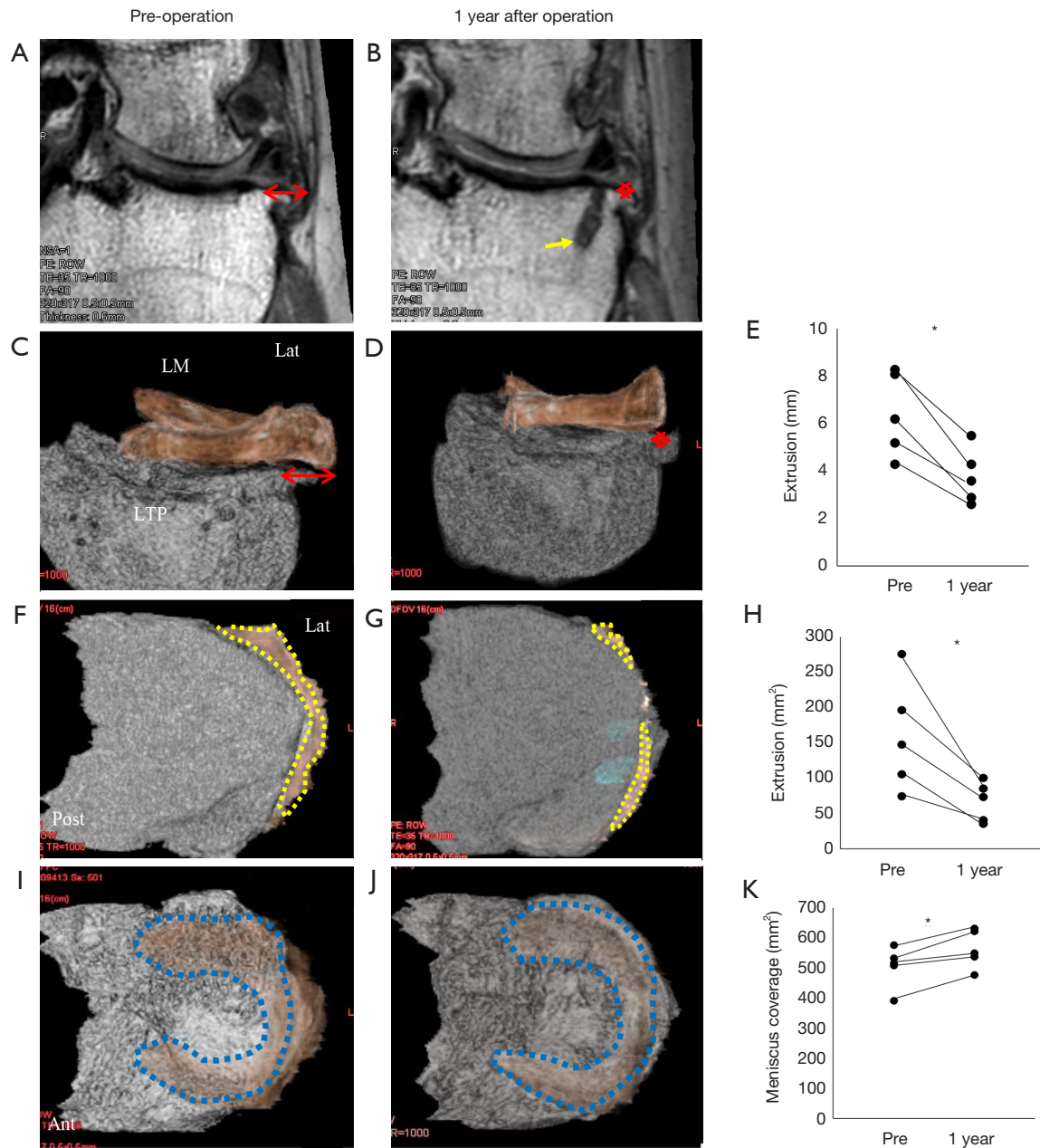


Figure 6 Three-dimensional reconstructed MRI evaluation of arthroscopic centralization technique for extruded LM. (A,B,C,D,F,G,I,J) A representative case. A 20-year-old female who underwent meniscectomy 3 years prior, in whom an arthroscopic centralization was performed. (A,B) Coronal MR images revealed that the midbody of LM was extruded by 5 mm preoperatively. (A) This extrusion was reduced to 1 mm at 1 year (B). Red arrows indicate the extrusion length. The yellow arrow indicates an anchor hole. (C,D) Antero-posterior view of 3D recon MRI revealed that the midbody of LM was extruded by 6 mm preoperatively. (C) This extrusion was reduced to 2 mm at 1 year (D). Red arrows indicate extrusion length. (E) Extrusion length. All data are plotted in the graph. * indicates $P < 0.05$ by the Wilcoxon signed-rank test. (F,G) Upward views demonstrate that the area of extruded LM was 197 mm^2 preoperatively and reduced to 101 mm^2 . The areas surrounded by the yellow dotted lines indicate areas of extruded LM. (H) Extrusion area, * indicates $P < 0.05$ by the Wilcoxon signed-rank test. (I,J) Craniocaudal views of 3D recon MRI show that the meniscus coverage on the tibial plateau was 577 mm^2 preoperatively and increased to 622 mm^2 . Areas surrounded by blue dotted lines indicate the meniscus coverage area. (K) Meniscus coverage, * indicates $P < 0.05$ by the Wilcoxon signed-rank test. LM, lateral meniscus, LTP, lateral tibial plateau.

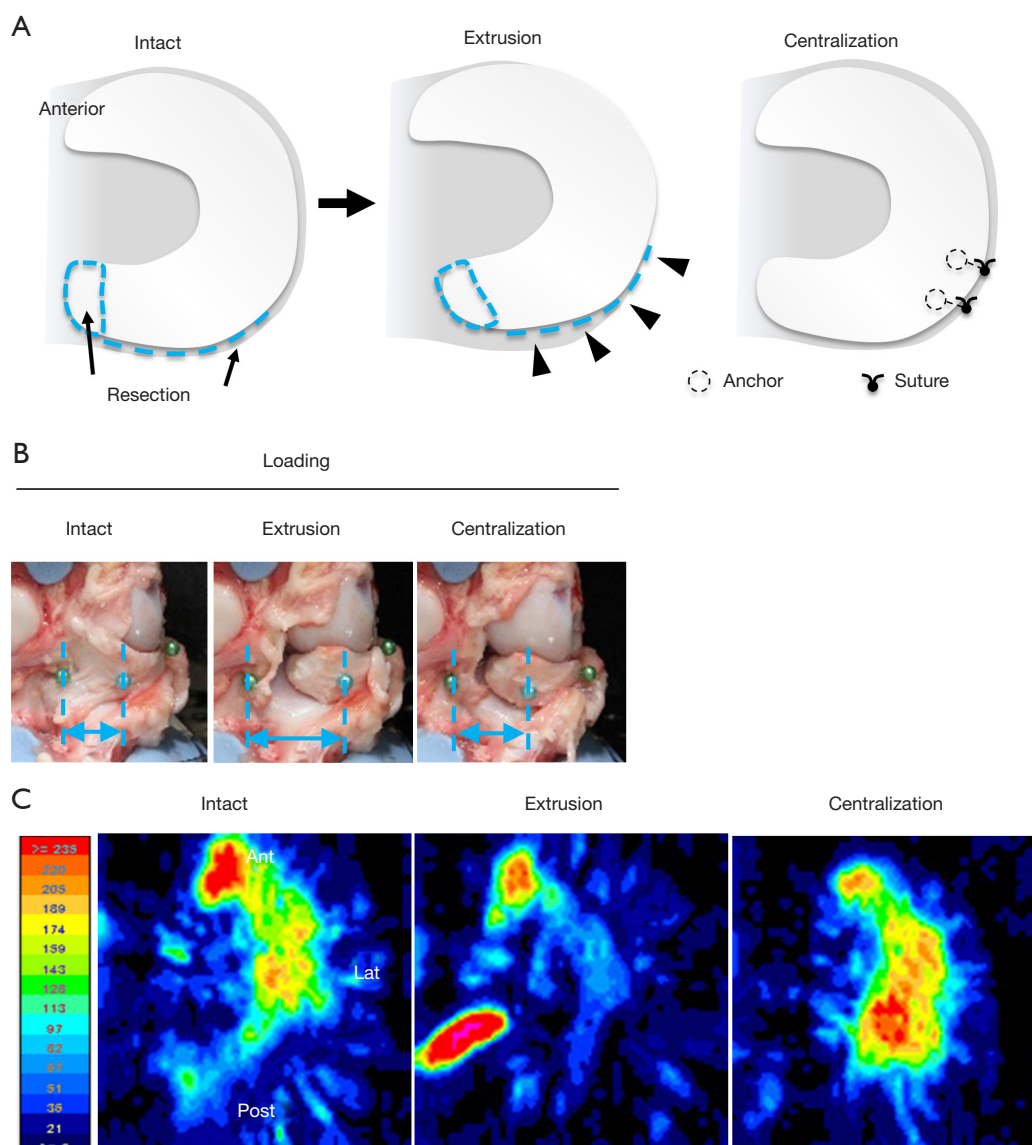


Figure 7 Biomechanical study of centralization using a porcine model. (A) Schematic drawings of the models. The meniscal extrusion condition was induced by resection of a 1 cm wide portion of the LM posterior root from the attachment site (blue dotted line). The centralization condition was created by 2 anchors. Arrowheads indicate meniscus extrusion. (B) Distance between two markers placed on the posterior cruciate ligament and the lateral meniscus was measured in three conditions under loading. The distance in the centralization condition was clearly reduced compared with the extrusion condition. (C) Load distribution of the lateral meniscus was measured using a Tekscan® pressure mapping sensor system. Load distribution of the meniscus under the centralization condition increased compared with the extrusion condition.

at various knee flexion positions at 30°, 60°, and 90° (26). Nakamura *et al.* (27) demonstrated that centralization improved the residual rotational laxity of the ACL-reconstructed knee accompanied by middle segment LM defects in porcine knees, as evaluated by a robotic testing system. These biomechanical studies further strengthened

the rationale for the centralization procedure.

Discussion

The treatment of LMPRT has received increased attention among surgeons who perform ACLR. Several

biomechanical studies have revealed the efficacy of LMPRT repair for decreasing the tibiofemoral contact pressure and restoring the kinematics of the knee joint (20,55). To restore knee function, the LMPRT should be repaired as completely as possible. LMPRT is often accompanied by ACL injury. Therefore, surgeons should prepare the necessary instruments for LMPRT repair for all ACL reconstruction surgeries. Specific MRI signs and careful arthroscopic observation will ensure that the diagnosis of LMPRT is not overlooked. Pull-out techniques can provide adequate fixation strength and will result in favorable clinical outcomes.

The centralization technique has been proven to reduce meniscal extrusion and has beneficial effects on load distribution and joint stability (25-27). In a clinical study, arthroscopic centralization of the extruded LM improved patient-reported outcomes and meniscus extrusion width 2 years post-surgery. This new technique has expanded the surgical indications for addressing secondary OA caused by meniscal defects and achieved satisfactory clinical and radiographic outcomes (46,47).

A limitation of this narrative review is that the literature includes laboratory studies or low-level evidence clinical studies (case series or cohort study). So far, there have been no high-level evidence clinical trials such as randomized control trials (RCTs) regarding LMPRT repair or arthroscopic centralization. Additionally, as these techniques are relatively new, long-term clinical results remain controversial. Further studies with higher evidence levels and long-term follow-up are required to confirm the efficacy of LMPRT repair and arthroscopic centralization.

Conclusions

To restore knee function, LMPRT should be repaired as much as possible during ACLR. The centralization technique is a promising surgical treatment for extruded lateral menisci due to meniscectomy and discoid meniscus.

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