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Original Article

The Early Arthroscopic Pullout Repair of Medial Meniscus Posterior Root Tear Is More Effective for Reducing Medial Meniscus Extrusion

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Clinical studies have demonstrated that transtibial pullout repair led to favorable midterm outcomes in patients with medial meniscus posterior root tears (MMPRTs) although medial meniscal extrusion (MME) continued to be present. It has been unclear whether these residual postoperative MMEs existed after the pullout repair or had progressed at the very short-term evaluation after surgery. We sought to determine which characteristics of patients with MMPRTs influence the incidence of postoperative MME. The cases of 23 patients whose date of injury was known were analyzed. All patients underwent MMPRT pullout fixation. Preoperative and 3-month postoperative magnetic resonance imaging (MRI) examinations were performed. MME was retrospectively assessed on the mid-coronal plane of MRI scans. The preoperative and postoperative MME values were 4.2 ± 1.2 mm and 4.3 ± 1.5 mm, respectively ($p = 0.559$). Pullout repair surgery was performed significantly earlier after the MMPRT-specific injury in patients whose postoperative MME improved compared to the patients whose MME did not improve ($p < 0.001$). Our findings demonstrated that an early transtibial pullout repair of an MMPRT was more effective in reducing MME than a late repair. Surgeons should not miss the optimal timing for the pullout repair of an MMPRT, considering the period from the injury and the preoperative MME.

Key words: medial meniscus, posterior root tear, pullout repair, medial meniscus extrusion, magnetic resonance imaging

Medial meniscus posterior root tears (MMPRTs) lead to medial meniscal extrusion (MME), resulting in accelerated degeneration of the knee joint articular cartilage [1, 2] or spontaneous osteonecrosis of the knee (SONK) [3]. Magnetic resonance imaging (MRI) is a useful tool to diagnose MMPRTs and several characteristic findings on MR images have been reported including the radial tear sign (radial linear defect), the ghost (or white meniscus) sign, and the giraffe neck sign [4-6]. In the detection of MMPRTs by 3 T MRI, the sensitivity was 0.824, the specificity was 0.800, positive predictive value was 0.206, and the negative predictive value was 0.986 [7]. It is important for surgeons to obtain information from the patient regarding any painful popping sensation, which is a highly predictive clinical sign of the posterior root tear of medial meniscus (MM) in middle-aged to older people, particularly in the Asian population [8].

Biomechanical studies have reported that MMPRTs

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are functionally equivalent to a total meniscectomy of the MM [1]. In a human cadaveric study, after the MM posterior root was detached, the peak contact pressure of the medial compartment was increased by 24% and the contact area was decreased by 20% [9]. However, repair of the MMPRT has been shown to reduce the mean tibiofemoral contact pressure by increasing the tibiofemoral contact area [2, 9], and several techniques for repairing an MMPRT have been reported [10-13].

In a previous investigation of MMPRTs, we observed that the mean absolute MME was 3 mm even in the early period (< 1 month) after the sudden onset of MMPRT, and the mean absolute MME then increased progressively [14, 15]. The non-operative treatment of MMPRTs was reported to be associated with poor clinical outcome, worsening arthritis, and a relatively high rate of arthroplasty at the 5-year follow-up [16]. In contrast, Chung *et al.* demonstrated that the use of a transtibial pullout repair led to favorable midterm outcomes in patients with MMPRTs, although the meniscal extrusion was still present [17, 18].

Based on these findings, it has been recommended that when surgeons diagnose a repairable MMPRT, the patients with a symptomatic MMPRT should be treated with an arthroscopic meniscal repair technique as early as possible. However, in the studies cited above, the first follow-up MRI was performed at 1 year postoperatively. There is little information available about whether these residual postoperative MMEs came to exist immediately after the pullout repair or progressed gradually after the surgery. We thus conducted the present study to evaluate the effects of pullout repair on improving meniscal extrusion in the early postoperative period. We also sought to determine the factors that could affect postoperative MME in MMPRT patients (*e.g.*, height, weight, duration from injury to surgery, and lower leg alignment) toward the goal of improving clinical outcomes. We hypothesized that the duration from injury to surgery may influence the degree of improvement in postoperative MME.

Patients and Methods

This retrospective study was approved by our Institutional Review Board (#1857). The pullout repair of the MMPRT was performed in patients with a femorotibial angle (FTA) < 180°, Kellgren-Lawrence (K-L) grade 0-2, and mild cartilage degeneration on preoperative MRI (Outerbridge grade I or II). Patients diagnosed with SONK or a partial MMPRT and patients who had MMPRT without a memory of painful popping were excluded.

We analyzed the cases of 23 patients (19 women and 4 men, mean age 60.8 ± 9.3 years) who underwent a transtibial pullout repair for an MMPRT by a modified Mason-Allen suture technique with the FasT-Fix™ Meniscal Repair System (Smith & Nephew, Andover, MA, USA) between February 2016 and October 2017. Some of the patients had been part of our previous studies [14, 15, 19]. According to a classification system based on tear morphology, we classified the 23 MMPRTs into 5 tear types at surgery: type 1 tears are partial stable meniscal tears within 9 mm of the center of the root attachment; type 2 tears are complete radial tears within 9 mm of the center of the root attachment; type 3 tears are bucket-handle tears with meniscal root detachment; type 4 tears are complex oblique meniscal tears extending into the root attachment; and type 5 tears are avulsion fractures of the meniscal root attachment [20].

Postoperative MRI was performed at a mean of 3 months after the pullout repair surgery to detect the direct effect of the pullout repair of MMPRTs. Patient medical records were reviewed to determine the age, gender, height, body weight, body mass index (BMI), interval from injury to surgery, and MMPRT arthroscopic findings.

Surgical procedure and postoperative rehabilitation. The patient was placed in a supine position on the operating table. A standard arthroscopic examination was performed using a 4-mm-dia., 30° arthroscope (Smith & Nephew) through routine anteromedial (AM) and anterolateral portals. A probe was introduced through the AM portal and the severity of the MMPRT was then evaluated. In cases with a tight medial compartment, we used the outside-in pie-crusting technique of the medial collateral ligament with a standard 18-gauge hollow needle (TERUMO, Tokyo) [21]. The posterior meniscal peripheral attachment of the MM was detached by a rasp to gain meniscal mobility. In the modified Mason-Allen suture technique with the FasT-Fix system, a Knee Scorpion™ Suture passer (Arthrex, Naples, FL, USA) was used to pass a No. 2 Ultrabraid suture vertically through the meniscal tissue.

Subsequently, the FasT-Fix 360™ meniscal repair system was inserted from the AM portal into the MM posterior horn and root across the Ultrabraid suture in a modified Mason-Allen configuration [12,13]. The MMPRT guide (Smith & Nephew) — which can create the tibial tunnel at favorable position because of the narrow twisting/curving shape in transtibial pullout repair for MMPRT — was placed at the center of the attachment area [19]. A 2.4-mm guide pin was inserted, using the MMPRT guide, at a 55° angle to the articular surface, and a 4.5-mm cannulated drill was used to over-drill. The free ends of the sutures were pulled out through the tibial tunnel with the use of a suture manipulator. Gentle tension was applied to the sutures until the posterior horn reached its tibial attachment area. The pulled sutures were rigidly tied to a double-spike plate (Meira, Nagoya, Japan) 10 mm from the extra-articular aperture of the tibial tunnel. Tibial fixation was performed using the double-spike plate and screw with the knee flexed at 45° using an initial 20-N tension [12,13].

The postoperative rehabilitation protocol was similar for all 23 patients. All patients were initially kept in a non-weight-bearing status in a knee immobilizer for 2 weeks after the pullout repair surgery. Knee-flexion exercise was limited to 90° for the first 4 weeks. The patients were allowed full weight-bearing and 120° knee flexion after 6 weeks. Deep knee flexion was permitted 3 months postoperatively [12].

Radiographic evaluations and MRI measurements. The coronal radiological FTA was measured to assess the degree of preoperative knee deformity. The FTA is defined as the external angle between the femoral and tibial shaft axes measured on a coronal radiograph of the whole lower limbs in the standing position. The Rosenberg 45° posteroanterior standing view was used to assess the K-L arthritis grade preoperatively. The K-L grades were defined as follows: 0, no degenerative change; 1, questionable osteophytes and no joint space narrowing; 2, definite osteophytes with possible joint space narrowing; 3, definite joint space narrowing with moderate multiple osteophytes and some sclerosis; and 4, severe joint space narrowing with cysts, osteophytes, and sclerosis [22]. Radiographic images were examined independently by two orthopaedic surgeons (SMa and YuO) blinded to the procedures using the digital calliper function of a picture archiving and communication system (PACS).

MRI was performed using an Achieva 1.5 T system (Philips, Amsterdam, The Netherlands) and an Oasis 1.2 T system (Hitachi Medical, Chiba, Japan) with a coil under the 10° knee-flexed position in a non-weight-bearing condition. Standard sequences of the Achieva included sagittal (repetition time [TR]/echo time [TE], 601/14), coronal (TR/TE, 553/14) T2-weighted multi-echo sequence and with a 30° flip angle, and axial (TR/TE, 4330/104) T2 BLADE fat saturation with a 150° flip angle. The slice thickness was 3 mm with a 0.6-mm gap. The field of view was 16 cm with an acquisition matrix size of 205 × 256.

Standard sequences of the Oasis included a sagittal proton density weighted sequence (TR/TE, 1718/12) using a driven equilibrium pulse with a 10° flip angle and a coronal T2-weighted multi-echo sequence (TR/TE, 4600/84) with a 10° flip angle. The slice thickness was 4 mm with a 0-mm gap. The field of view was 16 cm with an acquisition matrix size of 320416 [23].

The MME was measured as the distance from the medial edge of the tibial plateau cartilage to the medial border of MM (Fig. 1). The medial meniscal height (MMH) was the distance from the bottom to the top of the MM middle segment (Fig. 1). The distance from the inner edge to the medial border of the MM was the medial meniscal body width (MMBW) (Fig. 1). MME

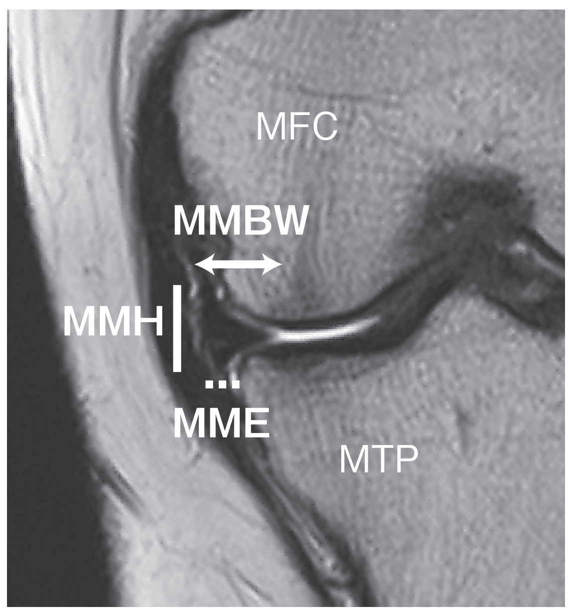

Fig. 1 MRI-based measurements in the mid-coronal plane of a left knee flexed at 10°. *Dotted line*: Medial meniscal extrusion (MME). *Solid line*: Medial meniscal height (MMH). *Double-headed arrow*: Medial meniscal body width (MMBW). MFC, medial femoral condyle; MTP, medial tibial plateau.

measurements were obtained in the T2-weighted mid-coronal plane by linking the coronal and sagittal image series. The MME was evaluated independently by 2 reviewers (TH and YoO) using the PACS. The mean value of each observer's measurement was obtained [24]. Both intra- and inter-observer reliabilities were excellent (intra-class correlation coefficient [ICC] >0.87) for each measurement.

Statistical analyses. Values are expressed as the mean ± standard deviation unless otherwise indicated. Statistical significance was set at $p<0.05$. The Wilcoxon signed-rank test was used to compare the preoperative results with the postoperative results. We evaluated the correlations between the postoperative increase in MME (ΔMME) and the duration from the injury to the surgery or the preoperative MME by performing a Spearman's rank correlation analysis. The differences in the patient demographics and MRI measurements between the improved MME (*i.e.*, $\Delta\text{MME} \leq 0$) and progressive MME groups ($\Delta\text{MME} > 0$) were evaluated. The Mann-Whitney *U*-test was used to compare the 2 groups. The χ^2-test was used for the comparisons of the groups' gender distribution, MMPRT types and K-L grades. Statistical calculations were performed using EZR-WIN software. The MRI measurements were completed by the two independent orthopaedic surgeons to determine the inter-observer reliability using the ICC. Each observer repeated the measurements with a 4-week interval to determine intra-observer reliability.

Results

In the radiographic evaluations, the mean preoperative FTA was 177.3° ± 1.7° (range 173°-179°). Seven of the patients were shown to have no radiographic osteoarthritis (OA), and the other patients had mild radiographic OA, including eight patients diagnosed with K-L grade 1 and eight patients with K-L grade 2. The patient demographics are summarized in Table 1.

In the MRI evaluations, the preoperative and 3-month postoperative MME values were 4.2 ± 1.2 mm and 4.3 ± 1.5 mm, respectively (Table 2). The ICC for the MRI measurements ranged between 0.879 and 0.970 for intra-observer reliability, and between 0.975 and 0.989 for inter-observer reliability. Significant progression was not observed between the preoperative and postoperative MME, MMH, or relative MME (100 × MME/MMBW) ($p>0.05$). However, the postoperative MMBWs were significantly decreased compared to the preoperative MMBWs ($p=0.004$).

Table 2 Postoperative changes in MRI measurements

	Preoperative	Postoperative	*p* value
MME (mm)	4.2 ± 1.2	4.3 ± 1.5	*0.559*
MMBW (mm)	9.4 ± 1.3	9.0 ± 1.4	*0.004**
Relative MME (%)	45.6 ± 10.8	47.9 ± 14.3	*0.144*
MMH (mm)	7.3 ± 1.0	7.5 ± 1.0	*0.503*

MRI, Magnetic resonance imaging; MME, Medial meniscal extrusion; MMBW, Medial meniscal body width; MMH, Medial meniscal height; Data are displayed as a mean ± standard deviation.
*Statistically significant.

Table 1 Patient demographics

		Range
Cases (knees)	23	
Gender (men : women)	4 : 19	
Age (years)	60.8 ± 9.3	35–74
Height (m)	1.56 ± 0.07	1.44–1.72
Weight (kg)	65.6 ± 9.7	51–88
Body mass index (kg/m^2)	26.9 ± 3.4	23.0–36.6
Duration (days)		
from injury to preoperative MRI	91 ± 79	8–251
from injury to operation	107 ± 83	20–276
from injury to postoperative MRI	193 ± 80	100–365
from operation to postoperative MRI	85.5 ± 20.3	65–135
MMPRT type (1/2/3/4/5)	0/21/0/2/0	
Kellgren-Lawrence grade (0/1/2/3/4)	7/8/8/0/0	
Femorotibial angle (°)	177.3 ± 1.7	173–179

MRI, Magnetic resonance imaging; MMPRT, Medial meniscus posterior root tear; Data are presented as a mean ± standard deviation.

Our comparison of the improvement group (ΔMME ≤ 0, $n=15$) with the progressive group (ΔMME >0, $n=8$) revealed that the improvement-group patients had been diagnosed as having an MMPRT based on MRI findings and had undergone a pullout repair surgery after their injuries significantly earlier compared to the progressive-group patients (Table 3). There were also significant between-group differences in preoperative MME, preoperative relative MME, and ΔMME (Table 4). There was a strong correlation between ΔMME and the duration from injury to surgery ($y=0.0047x-0.525$, $rs=0.729$; $p<0.001$, Fig. 2). In our sample, 11 of the 15 patients (86.7%) who underwent a pullout repair of their MMPRT at ≤ 112 days after their injuries had improved MME, whereas only one of the eight patients (12.5%) who underwent a pullout repair of their MMPRT at >112 days after injury had an improved MME.

The results of our analyses demonstrated a significant correlation between ΔMME and preoperative MME ($y=0.1916x-0.8256$, $rs=0.456$; $p=0.032$, Fig. 3). Eleven of the 14 patients (78.6%) whose preoperative MMEs were ≤ 4.3 mm had an improved MME, whereas only two of the nine patients (22.2%) whose preoperative MMEs were >4.3 mm had an improved MME.

Discussion

The most important finding of our study was that early arthroscopic surgery after the injury was more effective in preventing an increase in the MME compared to delayed surgery, even though the 3-month postoperative MRI revealed the presence of residual postoperative MMEs. Our results suggest that once surgeons diagnose a patient as having an MMPRT, they should repair it as soon as possible unless the patient has progressive or severe OA of the knee.

MME is one of the indicators of an MMPRT on MRI.

Table 3 Between-group comparisons of patient demographics

	ΔMME ≤ 0 mm	ΔMME >0 mm	p value
Cases (knees)	15	8	
Male : Female	3 : 12	1 : 7	*0.651*
Age (years)	62.3 ± 8.2	57.9 ± 11.1	*0.349*
Height (m)	1.56 ± 0.08	1.56 ± 0.06	*0.699*
Weight (kg)	65.3 ± 9.5	66.0 ± 10.6	*0.872*
Body mass index (kg/m^2)	26.8 ± 3.2	27.1 ± 4.1	*0.846*
Duration (days)			
from injury to preoperative MRI	41 ± 26	184 ± 55	*<0.001**
from injury to operation	55 ± 32	206 ± 55	*<0.001**
from injury to postoperative MRI	147 ± 33	281 ± 66	*<0.001**
from operation to postoperative MRI	92 ± 17	75 ± 21	*0.076*
MMPRT type (2/4)	14/1	7/1	*0.636*
Kellgren-Lawrence grade (0/1/2)	0/6/3	1/2/5	*0.114*
Femorotibial angle (°)	177.3 ± 1.5	177.4 ± 2.1	*0.628*

MRI, Magnetic resonance imaging; MMPRT, Medial meniscus posterior root tear; ΔMME, Postoperative increase of medial meniscal extrusion; Data are displayed as a mean ± standard deviation. *Statistically significant.

Table 4 Measurements of magnetic resonance images

	ΔMME ≤ 0 mm	ΔMME >0 mm	p value
Preoperative MME (mm)	3.8 ± 1.1	5.0 ± 1.1	*0.045**
Preoperative MMBW (mm)	9.2 ± 1.3	9.8 ± 1.2	*0.272*
Preoperative Relative MME (%)	41.6 ± 10.9	50.9 ± 9.2	*0.045**
Preoperative MMH (mm)	7.2 ± 0.8	7.4 ± 1.4	*0.439*
ΔMME (mm)	−0.3 ± 0.2	0.5 ± 0.4	*<0.001**

MME, Medial meniscal extrusion; MMBW, Medial meniscal body width; MMH, Medial meniscal height; Data are displayed as a mean ± standard deviation. *Statistically significant.

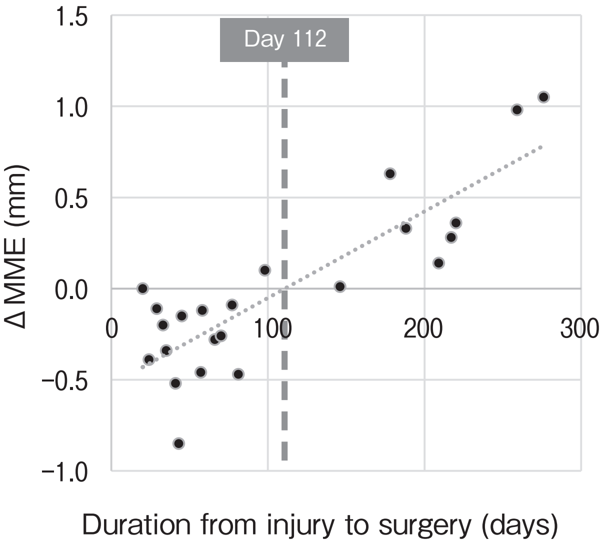

Fig. 2 *Dots* denote the ΔMMEs of each knee. There was a strong correlation between the postoperative increase of medial meniscal extrusion (ΔMME) and the duration from injury to surgery ($y = 0.0047x - 0.525$, rs = 0.729; $p < 0.001$). The cutoff point of 112 days was calculated using this formula by substituting 0 for y.

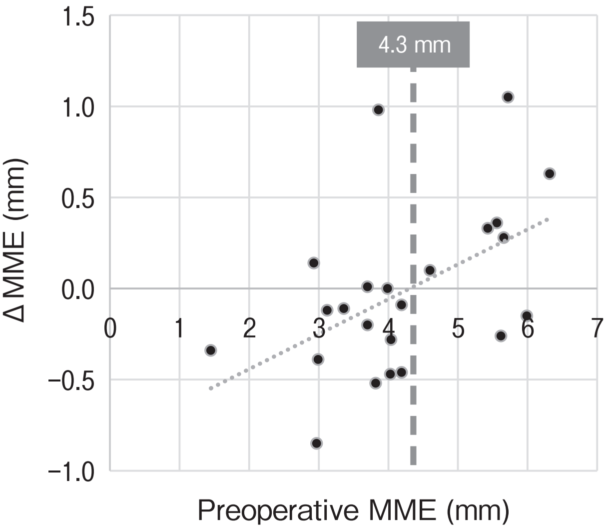

Fig. 3 *Dots* denote the ΔMMEs of each knee. There was a significant correlation between the ΔMME and preoperative MME ($y = 0.1916x - 0.8256$, rs = 0.456; $p = 0.032$). The cutoff point of 4.3 mm was calculated using this formula by substituting 0 for y.

Our previous investigation demonstrated that after the onset of symptomatic MMPRT, the absolute MME increases progressively within a short duration [15]. It has been reported that with greater meniscal extrusion, further progression of arthritic changes is observed in osteoarthritic knees [25]. A clinical study also showed that patients with decreased extrusion had significantly less risk of arthritis progression compared to patients with increased extrusion [18]. Therefore, preventing the progression of MME and reducing it as much as possible are essential for protecting the articular cartilage.

In the present study, we observed that the pullout repair of MMPRTs prevented MME from progressing. A meta-analysis reported that MMPRT repair resulted in significant improvements in the postoperative clinical subjective scores compared to the preoperative status, although meniscal extrusion was not completely reduced [26]. Chung *et al.* similarly reported that the pullout repair of MMPRT lead to favorable midterm outcomes regardless of residual MME at the 1-year follow-up, and patients with decreased MME at postoperative 1-year had more favorable clinical scores and radiographic findings at midterm follow-up compared to the patients with increased extrusion at 1 year [17].

One of the underlying reasons for this might be that the pullout repair of an MMPRT would improve not only the MME but also posterior extrusion of the MM [27]. The loading condition would also have an effect on MME. In fact, Patel *et al.* demonstrated that there was significantly more MME with loading than with unloading in patients with and without MM tears [28]. These studies imply that MME during loading and/or knee flexion might be exacerbated if a patient with an MMPRT has non-operative therapy. However, it is unclear how much MME should be reduced in a pullout repair of an MMPRT. Further studies are required to address this issue.

We do not have any information on the timing after the appearance of painful popping among the patient, which is the point at which patients with MMPRTs should undergo a pullout repair. Our analyzes demonstrated significant correlations between the ΔMME and both the duration from injury to surgery and the preoperative MME. Our results also suggest that an MMPRT pullout repair should be performed within 3-4 months after injury or before the preoperative MME is > 4.3 mm, in order to reduce or at least maintain the preoperative MME. A clinical study demonstrated that patients treated with the transtibial pullout repair technique using two locking cinch sutures had increased extrusion on follow-up MRI; their mean extrusion increased from 4.7 ± 1.7 mm pre-operatively to 6.0 ± 2.8 mm postoperatively even though the repair improved the patients' clinical outcomes [29]. However, those patients underwent the pullout repair at a mean interval of 4.2 ± 4.2 months (0.6-13.6) after injury. Therefore, some of those patients would have missed the optimal timing for pullout repair.

One of the reasons that late surgery does not tend to improve MME is that a radially displaced MM would undergo degenerative changes resulting in a bulged or swollen meniscus [30], thereby preventing the improvement of the MME. In the present study, we did not detect any significant difference in preoperative MMH between the improvement group (ΔMME ≤ 0) and the progressive group (ΔMME > 0), implying that there was no significant difference in the volume of extruded MM between the 2 groups. However, we consider that the less-loaded status of the MM might have an effect on the degenerative change in the extruded MM, and this degeneration might have prevented a further reduction of the MME.

We propose that an earlier pullout repair of an MMPRT would prevent not only the progression of MME, but also degenerative change in the meniscus and articular cartilage, which would result in preserving the tibiofemoral joint. Based on our present findings, we recommend that surgeons should not miss the optimal timing for the pullout repair of an MMPRT; patients with an MMPRT should undergo pullout repair within 4 months from the onset of painful popping or before the preoperative MME is >4 mm or at most 4.5 mm, unless they have progressive or severe OA of the knees.

There were several limitations to this study. The study's design was a retrospective, and the sample size was relatively small ($n = 23$). The follow-up period after the surgery was very short: we opted to evaluate postoperative MRI findings at a mean of 3 months following the pullout repair of the MMPRTs to determine the direct effects of the repair on the patients' MME. In addition, we did not evaluate the patients' clinical outcomes. Further long-term follow-up studies are required to evaluate the transitional impact of MRI measurements on clinical outcomes.

In conclusion, the result of our analyses demonstrated that the early transtibial pullout repair of an MMPRT was more effective in preventing an MME increase than a late repair. Our results suggest that surgeons should not miss the optimal timing for the pullout repair of an MMPRT, considering the period from the patient's injury and the presence of preoperative MME.

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