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Original article

Medial meniscus posterior root tear induces pathological posterior extrusion of the meniscus in the knee-flexed position: An open magnetic resonance imaging analysis

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A B S T R A C T

Background: A medial meniscus posterior root tear (MMPRT) is defined as an injury to the posterior meniscal insertion on the tibia. In MMPRT, the medial meniscus (MM) hoop function is damaged, and the MM undergoes a medial extrusion into the interior from the superior articular surface of the tibia. However, the details of MM position and movement during knee joint movement are unclear in MMPRT cases. The present study aims to evaluate MM position and movement via magnetic resonance imaging (MRI) examination of the MM posterior extrusion (MMPE) at knee flexion angles of 10° and 90°. We hypothesized that, during knee flexion, the MM will shift to the posterior and the posterior extrusion will increase compared to that when the knee is extended.

Materials and methods: Twenty-four patients were diagnosed with symptomatic MMPRT on open MRI examination. Preoperative MMPE, anteroposterior interval (API) of the MM, and MM medial extrusion (MMME) at knee flexion angles of 10° and 90° were measured.

Results: For patients with MMPRT, the MMPE increased from -4.77 ± 1.43 mm to 3.79 ± 1.17 mm ($p < 0.001$) when the knee flexion angle increased from 10° to 90°. Further, flexing the knee from 10° to 90° decreased the API of the MM from 20.19 ± 4.22 mm to 16.41 ± 5.14 mm ($p < 0.001$). MMME showed no significant change between knee flexion angles of 10° and 90°.

Discussion: This study demonstrated that, in cases of MMPRT, the MMPE clearly increases when the knee is flexed to 90°, while MMME does not change. Our results suggest that open MRI examination can be used to evaluate the dynamic position of the posterior MM by scanning the knee as it flexes to 90°.

Level of evidence: IV: retrospective cohort study.

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1. Introduction

A medial meniscus posterior root tear (MMPRT) is an injury to the posterior meniscal insertion on the tibia. An MMPRT leads to abnormal knee joint kinematics [1] and can compromise the circumferential knee integrity. Therefore, axial loads cannot be transferred to hoop stress [2]. Medial meniscus (MM) undergoes radial displacement, which is defined as MM extrusion. MM extrusion has been described as an important risk factor in the progression of knee osteoarthritis, as it is involved in the thinning of articular cartilage, joint space narrowing, and spontaneous osteonecrosis of the knee [3,4]. Further, the success rate of conservative medical treatments or partial meniscectomies in MMPRT is not favorable; presently, meniscal repair procedures using the pull-out method or the suture anchor method are recommended [5–8]. However, these procedures are controversial and require further validation. In cases of medial extrusion, meniscus repair does not lead to complete resolution.

Magnetic resonance imaging (MRI) is effective for diagnosing MMPRT [9–11]. Until now, the characteristic indications of MMPRT have been reported to include radial tear signs, ghost signs, cleft signs, and giraffe neck signs [12]. Further, MRI examination can show medial meniscus medial extrusion (MMME), though this is not a finding specific to MMPRT [12,13]. When substantial meniscal extrusion is identified, it is highly likely that one of these lesions is present, resulting in the disruption of meniscal stability [14];

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however, some acute root tears can occur without any extrusion. Sung et al. compared the incidence of spontaneous osteonecrosis between patients with MMPRTs and those with MM posterior horizontal tears; the incidence of osteonecrosis and the extent of meniscal extrusion were significantly greater in the knees with MMPRTs [15]. Meniscal extrusion after an MMPRT often leads to clinical signs such as early joint space narrowing, swift progression of arthritis, and various deformities of the knee [16].

Even in a normal knee, the MM is known to move to the posterior as the knee flexes [13]. During knee flexion, the posterior horn of the medial meniscus will increase peak contact pressure and decrease contact area in the medial compartment of the knee [17]. However, there has been no dynamic evaluation of the MM in cases of MMPRT. This means that, in cases of MMPRT, the position and movement of the MM during knee movement are unclear, including the position of the MM when the knee flexes to 90°, or how exactly the MM moves as the knee flexes. In MMPRT, the posterior root connecting the MM posterior horn to the tibia is torn. Based on this, we hypothesized that, during knee flexion, the MM will shift to the posterior and the posterior extrusion will increase compared to that when the knee is extended. The aim of the present study was to evaluate MM posterior extrusion (MMPE) of a knee afflicted with MMPRT during knee flexion angles of 10° and 90° using open MRI examination.

2. Materials and methods

2.1. Patients

Twenty-four patients (19 women and 5 men; mean age, 60.3 years) who underwent surgical treatments for MMPRT between March 2016 and January 2018 were included (Table 1). All patients were diagnosed with MMPRT on MRI and surgical findings. We excluded patients with other MM injuries and anterior cruciate ligament injuries. Patients had Kellgren–Lawrence grade 0, 1, or 2. MMPRTs included both acute (< 3 months) ($n = 11$) and chronic ($\geqq$ 3 months) ($n = 13$) tears after painful popping events [18]. Types of MMPRT were determined by arthroscopic examinations according to the meniscal root tear classification. Arthroscopic pullout repair was performed in all patients.

2.2. Assessments of MR images

Open MRI was performed using the Oasis 1.2 T (Hitachi Medical, Chiba, Japan) with a coil under the 10° and 90° knee-flexed positions in a non-weight-bearing condition and lateral position (affected knee down on the table). Standard sequences of the Oasis included a sagittal proton density-weighted sequence (repetition time [TR]/echo time [TE]: 1718/12) using a driven equilibrium pulse with a 90° flip angle and coronal T2-weighted multi-echo sequence (TR/TE: 4600/84) with a 90° 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 320 (phase) × 416 (frequency) [19]. Measurements of the MM were performed using a simple MRI-based meniscal sizing technique on the sagittal and coronal views at knee flexion angles of 10° and 90° (Fig. 1). First, knee flexion was set with the femoral and tibial axial angles at 10° and 90°; then, scout views were taken. Axial imaging visualized the cross-section where both menisci – the MM and lateral meniscus – were visualized in the same slice. The axial imaging of the distal part of the femur was used to set the posterior condylar axis (PCA), and a reference line was drawn perpendicular to it. The reference line defined the sagittal cross-section that passed through the center of the MM's transverse diameter as the measured cross-section for the MMPE. The MMPE was measured using a line passing orthogonally through the medial tibial plateau, the distance from the posterior edge of the tibia (excluding osteophytes) to the posterior edge of the MM. Using the posterior edge of the tibia as the standard, extrusions toward the posterior from the tibial edge was noted as positive value, and absence of extrusion as negative value (Fig. 2). Additionally, we set the distance between the anterior and posterior MM free edge (inner edge) when the knee was flexed at 10° and 90° as the anteroposterior interval (API) of the MM and measured each. The absolute MMME was measured from the osteophyte-excluded outer margin of the medial tibial plateau to the outer edge of the MM [20].

Table 1
Demographics and clinical characteristics.

Number of patients	24
Gender, men/women	5/19
Root tear classification Type 1/2/3/4/5	1/20/0/3/0
Kellgren-Lawrence grade Grade 0/I/II/III/IV	3/14/7/0/0
Age (years)	60.3 ± 9.7
Height (m)	1.56 ± 0.07
Body weight (kg)	65.9 ± 13.3

Data of age, height, and body weight are displayed as mean ± standard deviation.

2.3. Statistical analysis

Data were presented as means ± standard deviation. Differences between groups were compared using the Mann-Whitney U test. Power and statistical analyses were performed using EZR-WIN software. Statistical significance was set to $p < 0.05$. The sample size was estimated for a minimal statistical power of 80% ($\alpha = 0.05$). All sample size and power calculations were completed using the EZR-WIN software.

3. Results

There was no MMPE in 10° knee flexion (−4.77 ± 1.43 mm). At 90° knee flexion, the MMPE significantly increased to 3.79 ± 1.17 mm (Table 2; $p < 0.001$) The global AP mobility was 8.56 ± 2 mm.

At 10°, the API was 20.19 ± 4.22 mm, while, at 90°, it significantly decreased to 16.41 ± 5.14 mm (Table 2; $p < 0.001$).

In MMPRT, MMME was 2.80 ± 0.66 mm at 10° knee flexion and 2.55 ± 0.56 mm at 90° (Table 2; $p = 0.052$).

4. Discussion

The most important finding of the present study is that, in cases of MMPRT, the MMPE becomes greater when the angle of knee flexion increases to 90°. In contrast, the MMME remains unaffected by the angle of knee flexion. Our hypothesis is confirmed.

When MMPRT occurs, the posterior edge of the MM was found to move to the posterior a mean 8.56 ± 2.00 mm. This distance of MM movement to the posterior in cases of MMPRT is clearly greater than the distance the MM posterior edge of normal knees moved during flexion.

In a normal meniscus, MM posterior movement in the non-weight-bearing knee is reported to reach 3.8 mm at the posterior horn with 3.3 mm of radial displacement. Conversely, MM posterior movement in the weight-bearing knee is 3.9 mm and radial movement is 3.6 mm [21]. In a cadaveric study, during knee flexion, the posterior movement of the MM was 5.1 mm [22]. Compared with that in previous research, the MM posterior movement was much greater in cases of MMPRT: 8.56 ± 2 mm. Because MMPE increases as the knee flexes from 10° to 90°, the posterior movement of the MM is thought to increase as well. Those experiencing MMPRT have

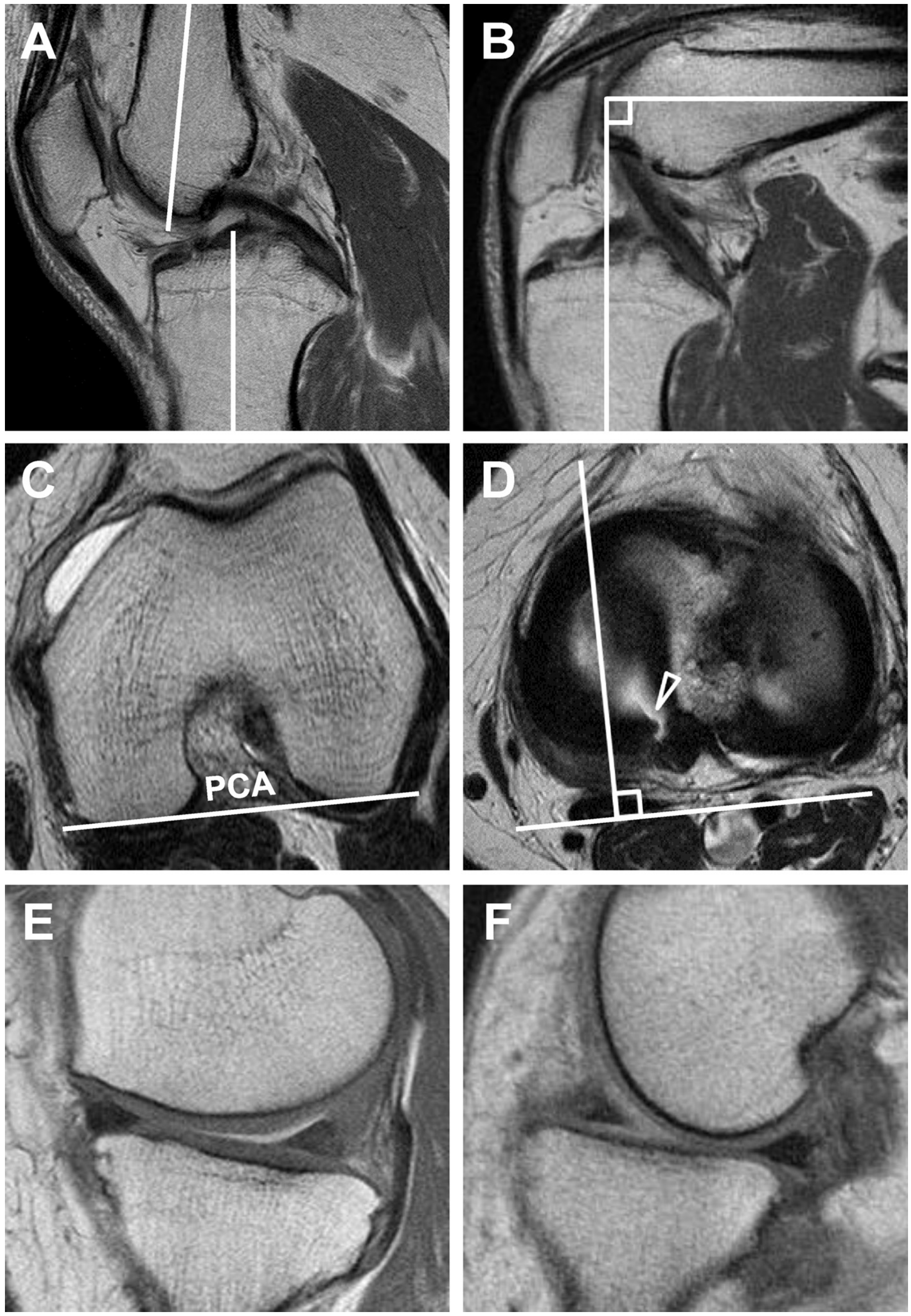

Fig. 1. MRI-based measurements. Knee flexion was set with the femoral and tibial axial angle at 10° (A) and 90° (B), respectively. We set the posterior condylar axis (PCA, C), and a reference line was drawn perpendicular to it (D). The reference line defined the sagittal cross-section that passed through the center of the MM's transverse diameter. (D) Radial tear sign (arrowhead). (E) and (F) indicate the measurement of MMPE with the knee flexed 10° and 90°, respectively.

injured the posterior root connecting the MM posterior horn to the tibia. Therefore, when knee flexion increases to 90°, the MM moves posteriorly and extrudes beyond the posterior tibial edge, resulting in MMPE. Further, in a previous study, the distance between the anterior and posterior horn of the MM is 25.88 ± 3.33 mm in cadaveric knees [23]. In cases of MMPRT, the API decreases as the angle of knee flexion increases to 90°. Due to this, the contact pressure on the tibiofemoral contact area increases when the knee is flexed at 90° in individuals with MMPRT. Based on these findings, we surmise that the contact pressure from the knee joint cartilage at a knee flexion angle of 90° must be much greater in individuals with MMPRT.

Static evaluation of the MM has been possible via MRI examination. However, MRI examination of the MM during dynamic activity, such as knee flexion, is difficult. There have been occasional studies on MRI examination of the knee during flexion, but almost all of them examined cadaver knees; only a few studies have evaluated the knees performing dynamic movements in living participants [4,20,22]. Computed tomography scanning has been used not only to evaluate bone, but also dynamic knee flexion. However, it is not relevant for soft tissue structures such as the MM. The present study used open MRI examination to dynamically evaluate the MM and MMPE.

Previous research has linked MMME to osteoarthritis progression in the knee [24]. MMME is not only observed in cases of MMPRT, but also at high rates in other forms of MM tearing.

There are several limitations of this study. First, the number of cases studied is small. Second, the MMPE of normal knees was

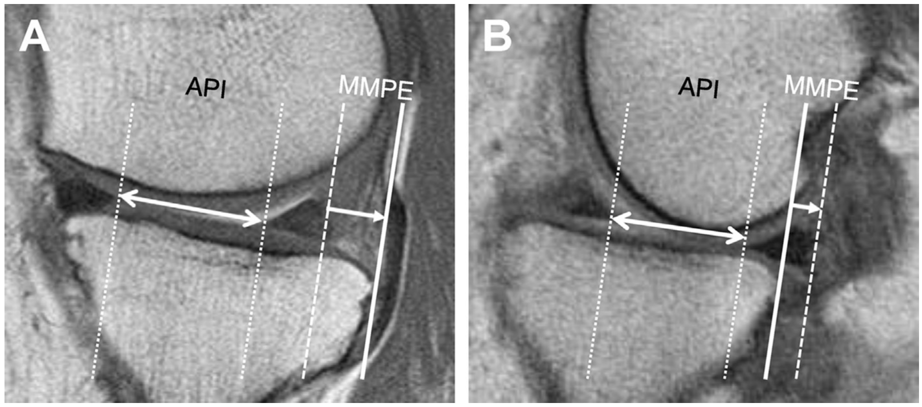

Fig. 2. MRI-based measurements. Sagittal images of the knee flexed at 10° (A) and 90° (B). Anteroposterior interval, API (double-headed arrows, dotted lines). Medial meniscus posterior extrusion, MMPE (arrows). Posterior margins of the medial tibial plateau (solid lines) and MM (dashed lines).

Table 2
Measurement of magnetic resonance imaging.

	10° of knee flexion	90° of knee flexion	*p*-value
MMPE (mm)	−4.77 ± 1.43	3.79 ± 1.17	< 0.001
API (mm)	20.19 ± 4.22	16.41 ± 5.14	< 0.001
MMME (mm)	2.80 ± 0.66	2.55 ± 0.56	0.052

MMPE: medial meniscus posterior extrusion; API: anteroposterior interval; MMME: medial meniscus medial extrusion. Data are displayed as mean ± standard deviation.

under-evaluated using open MRI examination. The knee joints of middle-aged and older patients commonly show injury to the MM to some degree, and normal MM cases are few [25–27]. So, it is difficult to obtain perfect normal control. Another reason for this limitation was the limited number of facilities where open MRI examination was possible. Third, MRI examinations of knees at 10° and 90° of flexion are not evaluations of dynamic MM movement using perfectly matched sagittal sections. Normally, the tibia undergoes internal rotation as the knee flexes [28]. In cases of MMPRT, the MMposterior root is torn, which means that the MM's function as a secondary stabilizer is also reduced, leading to the increased possibility that the tibia will rotate externally during knee flexion [29]. Fourth, we only evaluated the non-weight-bearing meniscus by open MRI. The meniscus in the weight-bearing condition was not assessed.

5. Conclusions

When a knee presenting an MMPRT is flexed to 90°, MMME does not change, but the posterior MM moves excessively to the posterior, causing a notable MMPE. Our results suggest that using open MRI examination to observe the condition and position of the MM when knee flexion is at 90° can assist in evaluating the effects of therapies addressing this condition.

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Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.otsr.2018.02.012.

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