Time-Dependent Increase in Medial Meniscus Extrusion after Medial Meniscus Posterior Root Tear Analyzed by Using Magnetic Resonance Imaging

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Purpose: Medial meniscus posterior root tear (MMPRT) causes progression of medial meniscus extrusion (MME). This study aims to calculate the progression rate of MME based on findings in two preoperative magnetic resonance imaging (MRI) scans and determine the associated factors.

Materials and Methods: We retrospectively reviewed 33 patients (27 females and 6 males; mean age, 60 years) who underwent MRI twice, at a mean interval of 48 days. We measured the medial meniscus body width, medial joint space width (MJSW), and MME. The MME progression rate was derived from regression analysis of the increase in MME (ΔMME) between the two MRI scans. In addition, the correlations of the MME increase rate with age, body mass index, femorotibial angle, and MJSW were evaluated.

Results: The mean MME increased from 3.4 mm to 4.5 mm (p<0.001). A good correlation was observed between ΔMME and the interval of MRI scans ($R^2=0.621$), and the MME progression rate was 0.020 mm per day. A moderate correlation was observed between the MME increase rate and the MJSW ($R^2=0.432$).

Conclusions: The MME progression rate was rapid in MMPRT and narrowing of the MJSW was associated with the progression of MME.

Level of Evidence: V, Cross-sectional study

Keywords: Medial meniscus, Root tear, Extrusion, Magnetic resonance imaging, Risk factors
progressively within 12 months after the onset of symptomatic MMPRT. They also reported that the extent of MME was correlated with the duration of a symptomatic MMPRT after a painful popping event and a good correlation was observed between the MME measurement and the duration from injury to MRI examination\(^\text{13}\). However, these studies were not longitudinal studies based on serial MRI examinations of the same patients. Therefore, the understanding of the time-dependent increase of MME in the same patient remains unclear.

To the best of our knowledge, this is the first study to analyze the MME increase in MMPRT patients who underwent MRI twice before surgery. We aimed to investigate the correlation between the MME increase and the time interval of MRI examinations to identify the progression speed of MME, and determine the factors associated with rapid progression of MME among the four factors including age, body mass index (BMI), femorotibial angle (FTA), and medial joint space narrowing. Our hypotheses were as follows: (1) the MME increase would positively correlate with the interval between the first and second MRI examinations and (2) the four abovementioned factors would be associated with rapid progression of MME.

**Materials and Methods**

**1. Study Subjects**

From December 2014 to March 2018, 71 patients at Okayama University Hospital were found to possibly have MMPRT according to characteristic MRI findings (ghost/cleft/radial tear signs of the MM posterior root within 9 mm from the attachment, and the giraffe neck sign\(^\text{14}\)). Of those, we excluded patients with Kellgren–Lawrence grade 3 or higher OA or Outerbridge grade 3 or higher cartilage degeneration. Thus, 40 patients were initially enrolled in the study. We conducted second MRI in them to examine cartilage lesions and bone edema just before surgery. The Institutional Review Board of Okayama University (no. 1857) approved this study, and written informed consent was obtained from all patients before the second MRI. Later, we excluded patients without a memory of painful popping event, because MMPRTs without the event were associated with more severe degenerative changes in the articular cartilage than those with the event\(^\text{4}\). Patients with a history of previous meniscal surgery were also excluded. Ultimately, 33 patients were included in this study (Fig. 1). Medical records and preoperative standing radiographs were reviewed retrospectively to examine age, sex, height, body weight, BMI, and FTA. Patient demographics are shown in Table 1.

**2. MRI-based Measurements**

MRI was performed using Achieva 1.5 T (Philips, Amsterdam, The Netherlands) with a knee coil. Standard sequences included sagittal (repetition time [TR]/echo time [TE]: 742/18), coronal (TR/TE: 637/18), and axial (TR/TE: 499/18) T2-weighted fast-field echo with a 20° flip angle. Slice thickness was 3 mm with a 0.6-mm gap. Field of view was 16 or 17 cm with an acquisition matrix size of 205×256 (or 200×368)\(^\text{15}\). The MM body width (MMBW), medial joint space width (MJSW), and MME were assessed on the coronal plane showing maximal meniscal extrusion (Fig. 2). MMBW was measured from the inner margin to the outer margin of the MM. MME was defined as the distance between the medial edge of the tibial plateau and the outer margin of the MM posterior root within 9 mm from the attachment, and the giraffe neck sign\(^\text{14}\). Of those, we excluded patients with Kellgren–Lawrence grade 3 or higher OA or Outerbridge grade 3 or higher cartilage degeneration. Thus, 40 patients were initially enrolled in the study. We conducted second MRI in them to examine cartilage lesions and bone edema just before surgery. The Institutional Review Board of Okayama University (no. 1857) approved this study, and written informed consent was obtained from all patients before the second MRI. Later, we excluded patients without a memory of painful popping event, because MMPRTs without the event were associated with more severe degenerative changes in the articular cartilage than those with the event\(^\text{4}\). Patients with a history of previous meniscal surgery were also excluded. Ultimately, 33 patients were included in this study (Fig. 1). Medical records and preoperative standing radiographs were reviewed retrospectively to examine age, sex, height, body weight, BMI, and FTA. Patient demographics are shown in Table 1.

**Table 1. Demographic and Clinical Characteristics**

| Characteristic            | Value                        |
|---------------------------|------------------------------|
| No. of patients/knees     | 33/33                        |
| Sex, male/female          | 6/27                         |
| Age (yr)                  | 59.8±9.7 (35–74)              |
| Height (m)                | 1.58±0.07 (1.46–1.75)        |
| Body weight (kg)          | 69.9±15.6 (51–112)           |
| Body mass index (kg/m\(^2\)) | 27.9±5.1 (23.0–44.3)     |
| Femorotibial angle (°)    | 177.8±1.9 (174–181)         |
| Duration from injury to first MRI (day) | 45.4±59.3 (1–197)          |
| Interval between first and second MRIs (day) | 47.8±40.1 (2–155)        |

Values are presented as number only or mean±standard deviation (range). MRI: magnetic resonance imaging.
of the MM\textsuperscript{16}. Osteophytes were excluded in the determination of the tibial margin. The MJSW was measured as the minimum distance between the femoral and tibial margins. To validate the MRI measurements, we assessed inter-observer and intra-observer reliabilities using the intraclass correlation coefficient (ICC). Four orthopedic surgeons (Yo.O., T.U., Y.K., and Yu.O.) retrospectively examined the MRI scans in a blinded manner. The ICC was calculated for each MRI parameter using two-way, random, single measures with absolute agreement.

In addition, we calculated the increase of MME (ΔMME) between the first and second MRI examinations and performed linear regression analysis to assess the correlation of ΔMME with the interval of MRI examinations. We defined the best-fit regression coefficient as the MME progression speed. The MME increase rate was also calculated as ΔMME divided by the interval of MRI examinations. The correlations of MME increase rate with age, BMI, FTA, and MJSW were also evaluated.

3. Statistical Analysis

The changes in MRI measurements between the first and second MRI scans were evaluated using the Wilcoxon signed-rank test. Data are presented as mean±standard deviation. Significance was set at \( p<0.05 \). Power and statistical analyses were performed using EZR (Saitama Medical Center, Saitama, Japan), which is a graphical user interface for R (R Foundation for Statistical Computing, Vienna, Austria). Sample size was estimated for a minimal statistical power of 80% (\( \alpha=0.05 \)). Linear regression analysis was used to evaluate Pearson's correlation coefficient. A good correlation was represented by \( R^2\geq 0.60 \); moderate correlation, by \( R^2\geq 0.40 \); and poor correlation, by \( R^2<0.40 \).

Results

On MRI-based measurements, MMBW and MJSW showed no significant differences between the first and second MRI examinations (\( p=0.066 \) and 0.260, respectively; Table 2). The mean MME significantly increased from 3.4±1.1 mm to 4.5±1.1 mm between the two MRI examinations. The values of inter-observer and intra-observer reliabilities were excellent (ICC\( \geq 0.91 \)) for all MRI measurements. A good correlation was observed between ΔMME and the time interval of MRI (\( R^2=0.621 \)). The regression analysis was calculated as follows: \( \Delta \text{MME} (\text{mm})=0.020 (\text{mm/day}) \times \text{MRI interval (day)} \).

Table 2. Mean Differences between the First and Second MRI Examinations

| Variable     | First MRI | Second MRI | p-value |
|--------------|-----------|------------|---------|
| MMBW (mm)   | 8.7±1.2   | 9.2±1.4    | 0.066   |
| MJSW (mm)   | 3.8±0.4   | 3.7±0.5    | 0.260   |
| MME (mm)    | 3.4±1.1   | 4.5±1.1    | <0.001* |

Values are presented as mean±standard deviation.

MRI: magnetic resonance imaging, MMBW: medial meniscus body width, MJSW: medial joint space width, MME: medial meniscus extrusion.

*Significance was determined with use of Wilcoxon signed-rank test (\( p<0.05 \)).

![Fig. 2. Magnetic resonance imaging (MRI)-based measurements of the medial meniscus body width (MMBW), medial joint space width (MJSW), and medial meniscus extrusion (MME) (left knee). The measurement was performed on the coronal plane image showing maximal MME. The vertical lines show the inner and outer borders of the medial meniscus. A vertical dashed line denotes the tibial medial margin. The MJSW was measured as the minimum distance between the femoral and tibial margins (the horizontal dashed lines).](image)

![Fig. 3. Correlation between the increase in medial meniscus extrusion (ΔMME) and the time interval of magnetic resonance imaging (MRI) scans, with a Pearson's correlation coefficient (\( R^2=0.621 \)). The regression equation was linear: ΔMME (mm)=0.020 (mm/day)×MRI interval (day).](image)
Fig. 4 presents the results of linear regression analysis for correlations of the MME increase rate with age, BMI, FTA, and MJSW. Little correlation was seen between the MME increase rate and age, BMI, and FTA ($R^2=0.019$, $0.001$, and $0.031$, respectively; Fig. 4A–C). On the other hand, a moderate inverse correlation was observed between the MME increase rate and MJSW ($R^2=0.432$; Fig. 4D).

**Discussion**

The important findings of this study were that the MME increase correlated with the time interval of MRI and that the narrowing of MJSW was associated with the MME increase rate. In addition, the time-dependent MME increase rate was estimated to be 0.020 mm per day, which is much faster than that in OA knees (0.040 mm per year) on the basis of a cohort study data from the Osteoarthritis Initiative\(^{17}\). Several studies have reported that MME is associated with the progression of symptomatic OA and spontaneous osteonecrosis of the knee (SONK)\(^{8,18,19}\). In this regard, the rapid MME increase may explain why MMPRT leads to advanced OA and SONK during short-term symptomatic periods\(^1,3,5\).

Previous studies showed that the extent of MME highly correlated with the degree of joint space narrowing\(^7\), but no studies have analyzed the correlation between the MME increase rate and MJSW. The 1-year change in MJSW had been explored by using slight flexion radiographs of OA knees with only medial joint space narrowing: the narrowing of the MJSW in OA knees was as rapid as that of non-OA knees, with an annual rate of <0.2 mm\(^{20}\). Similarly, in this study, there was no significant change in the MJSW between the first and second MRI examinations in MMPRT knees, and the mean reduction of MJSW was only 0.1 mm. On the other hand, the novel finding of this study was the
The presence of direct correlation between narrowing of the MJSW and the MME increase rate. Narrowing of MJSW is considered as one of the indicators of MME progression in the natural course after the onset of an MMPRT. We infer from the results of this study that an MJSW of <3.5 mm may be a risk factor for rapid progression of MME due to femorotibial cartilage loss and advanced structural OA: all knees with an MJSN of <3.5 mm were found to have an MME increase rate of >0.05 mm per day (Fig. 4D).

The clinical results of conservative treatment for MMPRT have been described to be satisfactory with early diagnosis and appropriate protocols. However, Kwak et al. reported that the high meniscal extrusion rate was the main poor prognostic factor of conservative treatment for MMPRT. It is conceivable that early surgical repair could be recommended for MMPRT patients with large meniscal extrusion. A meta-analysis reported that MMPRT repair resulted in significant improvements of the postoperative clinical subjective scores compared with the preoperative ones, although meniscal extrusion was not completely reduced. In contrast, Chung et al. demonstrated that, decreased meniscal extrusion was associated with more favorable clinical and radiological mid-term outcomes after pullout repair of MMPRTs. Therefore, we think surgeons should perform early treatment for MMPRT to prevent a deleterious effect on the outcomes, considering that the extent of MME can increase by 1 mm in 50 days in the presence of an MMPRT.

There were several limitations to this study. First, the MRI examinations were performed at different intervals (from the onset of MMPRT to the first MRI and from the first MRI to the second MRI). Second, we calculated the MME increase rate using only linear regression analysis. In actuality, MME is more likely to show a curvilinear increase to some extent because the MME progression might reach the plateau in the chronic period from the onset of an MMPRT. However, to avoid including patients with chronic MMPRT, we excluded patients who did not have a painful popping event and degenerative changes in the cartilage and meniscus. Third, we evaluated the MRI-based MME under non-weight bearing conditions, hence the increase in MME might have been underestimated. MRI multiplanar reconstruction using thin slices under loading condition would provide a large amount of data on the MME progression and meniscal movement. Finally, our study had a retrospective design and a small sample size. Further studies with large sample sizes will be required to evaluate the effect of MME progression on the symptomatic course of MMPRT.

The clinical significance of this study is the evaluation of the MME increase rate; this information may help surgeons to select between conservative and operative treatment for MMPRTs. In addition, the MRI-based measurement of MJSW may be useful to determine the timing of surgery to address the concerns of further progression of MME and cartilage damage.

Conclusions

This study demonstrated that the MME increase in MMPRT knees correlated with the time interval of MRI scans after the onset of MMPRT, and the MME increase rate was estimated to be 0.020 mm per day. The narrowing of MJSW was an associated factor in the rapid increase of MME, indicating that the measurement of MJSW may be useful to predict further progression of MME.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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