Original Article

Knee Surg Relat Res 2017;29(4):295-301
https://doi.org/10.5792/ksrr.17.027
pISSN 2234-0726 · eISSN 2234-2451

KSRR
Knee Surgery & Related Research

Meniscal Extrusion Progresses Shortly after the Medial Meniscus Posterior Root Tear

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Purpose: Medial meniscus posterior root tears (MMPRT) induce medial meniscus extrusion (MME). However, the time-dependent extent of MME in patients suffering from the MMPRT remains unclear. This study evaluated the extent of MME after painful popping events that occurred at the onset of the MMPRT.

Materials and Methods: Thirty-five patients who had an episode of posteromedial painful popping were investigated. All the patients were diagnosed as having an MMPRT by magnetic resonance imaging (MRI) within 12 months after painful popping. Medial meniscus body width (MMBW), absolute MME, and relative MME (100×absolute MME/MMBW) were assessed among three groups divided according to the time after painful popping events: early period (<1 month), subacute period (1–3 months), and chronic period (4–12 months).

Results: In the early period, absolute and relative MMEs were 3.0 mm and 32.7%, respectively. Absolute MME increased up to 4.2 mm and 5.8 mm during the subacute and chronic periods, respectively. Relative MME also progressed to 49.2% and 60.3% in the subacute and chronic periods, respectively.

Conclusions: This study demonstrated that absolute and relative MMEs increased progressively within the short period after the onset of symptomatic MMPRT. Our results suggest that early diagnosis of an MMPRT may be important to prevent progression of MME following the MMPRT.

Keywords: Meniscus, Tear, Root, Extrusion

Introduction

The posterior root of the medial meniscus (MM) can serve as an anchor to regulate the meniscal shift during the knee motion and load bearing. Injuries to the MM posterior root, including complete radial and/or oblique tears adjacent to the ligamentous insertion and posterior horn, lead to accelerated degeneration of the knee joint articular cartilage by disrupting meniscal functions[1]. In addition, the medial meniscus posterior root tear (MMPRT) leads to abnormal biomechanics of the tibiofemoral joint and the inability to convert axial loads into hoop stresses by inducing radial displacement of the MM, also called medial meniscus extrusion (MME)[2,3]. Extrusion (subluxation, bulging, and radial/extra-articular displacement) of the MM is associated with a loss of medial compartment cartilage volume[4], medial joint space narrowing[5], severity of osteoarthritis as reflected by radiographic Kellgren-Lawrence grade[6,7], degenerative knee abnormalities[8], and knee joint pain[9] in patients with osteoarthritic knees. In addition, meniscal extrusion predicts an increase in subchondral bone lesions and tibial plateau expansion in osteoarthritic knees[10]. MME is also a characteristic finding on magnetic resonance imaging (MRI) of patients having the MMPRT[11]. However, the time-dependent extent of MME in patients suffering from the MMPRT remains unclear. Moreover, the relationship among the MME severity, treatment choice, and optimal timing for surgical intervention has not been elucidated.

Received May 4, 2017; Revised June 6, 2017;
Accepted July 3, 2017
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The MMPRT can occur especially in middle-aged or older patients who have a single event of posteromedial painful popping sensation during light activities such as using stairs and squatting[12,13]. The positive predictive value of painful popping in identifying the MMPRT is 96.5% and the specificity is 99.5%[13]. In the treatment of the MMPRT, early diagnosis and appropriate surgical intervention are important to obtain a successful clinical outcome and prevent rapid progression of degenerative knee diseases[1,14]. MRI-based characteristic findings such as a radial tear, cleft/truncation, ghost, and giraffe neck signs provide high diagnostic accuracy and specificity[11,15]. However, we cannot obtain information about the exact onset of the MMPRT from these MRI findings. Although the sensitivity of a painful popping for the detection of an MMPRT is low (35%)[13], the memory of hearing a painful popping sound seems to be necessary to determine the timing of the MMPRT onset and MRI examination and treatment strategy for the symptomatic MMPRT.

Repair of the MMPRT can reduce the mean tibiofemoral contact pressure by increasing the tibiofemoral contact area as demonstrated in a human cadaveric knee study[16]. Several repair techniques such as transtibial pullout repair, suture anchor-dependent repair, direct all-inside repair, and posterior reattachment of the MM posterior root have been developed for arthroscopic treatment of the MMPRT[1,14]. MMPRT repairs produce more favorable clinical outcomes compared with conservative treatments[17]. Despite the favorable clinical results of transtibial pullout repair of the MMPRT, several meta-analyses have demonstrated that many patients show no significant reduction in MME following the MMPRT repair[18,19]. On the other hand, there are few reports that demonstrate the MMPRT repair can reduce MME. For example, MMPRT pullout repairs decreased MME from 3.13 mm to 2.94 mm[20]. Patients with decreased MME following the MMPRT pullout repair had more favorable clinical scores than those with increased MME at 1 year postoperatively[21]. Based on these findings, a timely surgical intervention before causing a severe MME may be a critical factor for the treatment of the MMPRT and preventing progression of degenerative knee joint diseases. In this study, we evaluated the time-dependent changes in the extent of MME after painful popping events involved in the MMPRT onset.

Materials and Methods

1. Study Materials

This study received the approval of our Institutional Review Board, and written informed consent was obtained from all patients. Thirty-five patients (32 females and 3 males) who had an episode of posteromedial painful popping between September 2013 and August 2016 were included (Table 1). All the patients were diagnosed as having the MMPRT with MRI examinations. The presence of an MMPRT was defined according to characteristic MRI findings (cleft/giraffe neck/radial tear signs of the MM posterior root within 9 mm from the attachment, ghost sign, and MM extrusion[11,15]). Patients who had an MMPRT without a memory of painful popping (n=3) and an MMPRT with previous meniscal injury and/or knee surgery (n=2) were excluded. The mean age of the patients was 63.5 years. Types of the MMPRT were determined by careful arthroscopic examinations (24 knees) or arthroplasty-associated direct observations (5 knees) according to the meniscal root tear classification (Table 1)[22]. Transtibial pullout repairs (16 knees) were performed in patients who met operative indications for the pullout repair[23-25]. All-inside meniscal repairs (6 knees) were performed in the other patients. There was no patient who underwent meniscectomy alone. Patients were examined by MRI scans prior to surgical treatments and within 12 months after painful popping events. Six patients were treated conservatively because of their low activities and hesitation about surgical treatments. Conservative treatments involved partial weight bearing and a stick, crutch, knee brace, and medical guidance were used appropriately.

2. MRI-Based Measurements

MRI evaluation was performed using an Achieva 1.5 T (Philips, Amsterdam, The Netherlands) with a knee coil. Standard

Table 1. Demographics and Clinical Characteristics

Characteristic	Value
No. of patients	35
Sex (male:female)	3:32
Root tear classification (29 knees)	
Type 1	5
Type 2	22
Type 3	1
Type 4	1
Type 5	0
Age (yr)	63.5±10.3
Height (m)	1.55±0.06
Body weight (kg)	64.9±14.4
Body mass index (kg/m^2)	26.9±5.3
Femorotibial angle (°)	177.5±1.6

Values are presented as mean±standard deviation or number.

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. The slice thickness was 3 mm with a 0.6-mm gap. The field of view was 16 (or 17) cm with an acquisition matrix size of 205×256 (or 200×368)[26-29]. The MRI-based medial meniscus body width (MMBW), absolute MME, and medial meniscus height (MMH) were assessed. The MMBW was measured from the inner border to the outer border of the MM on the coronal image that crossed the midpoint of the anteroposterior length of the MM. The absolute MME was measured from the medial margin of the tibial plateau to the outer border of the MM. The MMH was measured from the inferior margin to the superior margin of the MM on the same coronal image. The relative MME was calculated using the following formula: 100×absolute MME/MMBW (%).

3. Statistical Analysis

Data were presented as means±standard deviations. Differences among groups were compared using the one-way analysis of variance (ANOVA) with Tukey post hoc tests. Power and statistical analyses were performed using EZR (Saitama Medical Center, Saitama, Japan), which is a graphical user interface for R (the R Foundation for statistical computing). Significance was set to $p<0.05$. Two orthopedic surgeons (TH and YK) independently measured MRI-based values of the MM in a blinded manner. Each observer performed each measurement twice, at least 2 weeks apart. The reliability of the measurements was assessed by examining the inter-observer and intra-observer reliabilities with the intraclass correlation coefficient (ICC). An ICC values of >0.80 was considered to represent a reliable measurement. Linear regression analysis was used to assess the correlation between the absolute MME and the other factors (age, height, body mass index, and femorotibial angle). A good correlation was defined as $R^2 \geq 0.60$, fair correlation as $R^2 \geq 0.50$, and poor correlation as $R^2<0.50$.

Results

On the MRI-based measurements of the MM, the MMBW showed no significant change among three groups divided according to the time after painful popping events into the early period (<1 month), subacute period (1–3 months), and chronic period (4–12 months) (Table 2 and Fig. 1A). In the early period, the absolute and relative MMEs were 3.0±1.2 mm and 32.7%±12.2%, respectively (Table 2, Fig. 1B and C). However, the absolute MME significantly increased up to 4.2±1.2 mm and 5.8±1.6 mm in the subacute and chronic periods, respectively. The relative MME also progressed to 49.2%±11.9% and 60.3%±14.9% in the subacute and chronic periods, respectively. Significant difference in the MMH was observed between the early and chronic durations ($p=0.014$) (Table 2 and Fig. 1D). The inter-observer and

Table 2. Changes in the MMBW, MME, and MMH after Painful Popping Events

Variable	Early (n=15) <1 month	Subacute (n=17) 1–3 months	Chronic (n=17) 4–12 months
MMBW (mm)	9.1±1.2	8.5±1.1	9.6±1.3
Absolute MME (mm)[a]	3.0±1.2	4.2±1.2	5.8±1.6
Relative MME (%)[a]	32.7±12.2	49.2±11.9	60.3±14.9
MMH (mm)[a]	6.8±1.7	7.1±1.4	8.4±1.6

Values are presented as mean±standard deviation.
MMBW: medial meniscus body width, MME: medial meniscus extrusion, MMH: medial meniscus height.
[a]Significant differences were observed among groups.

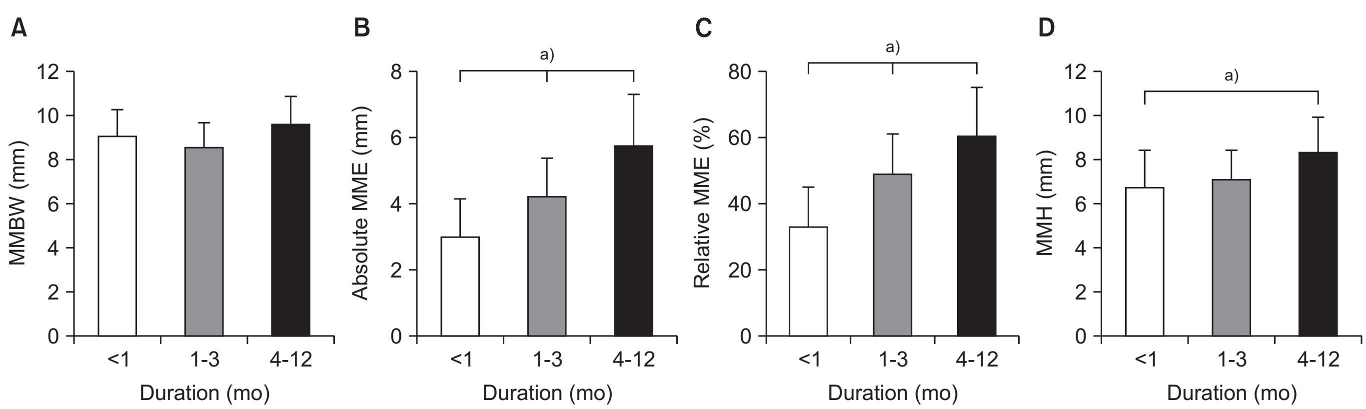

Fig. 1. Magnetic resonance imaging-based measurements of the medial meniscus after the onset of medial meniscus posterior root tears. (A) Medial meniscus body width (MMBW). (B) Absolute medial meniscus extrusion (MME). (C) Relative MME (100×absolute MME/MMBW). (D) Medial meniscus height (MMH). [a]$p<0.05$.

intra-observer reliabilities for the measurements were considered satisfactory (mean ICC values >0.94).

A poor correlation was observed between the absolute MME and age (R^2=0.125). The absolute MME and the other factors (height, body mass index, and tibiofemoral angle) also showed poor correlations (R^2=0.009, 0.011, and 0.001, respectively).

Representative sequential MRI scans showed a post-traumatic progression of MME after a painful popping event of the knee (Fig. 2). A 65-year-old female had a single event of painful popping of her right knee in the full squatting position. Minor MME (1.3 mm) and specific MRI findings of the MMPRT were observed at 1 week after the painful popping event (Fig. 2A). The MME increased to 5.0 mm at 10 weeks after the MMPRT (Fig. 2B). The MME progressed to 5.7 mm at 18 weeks post-MMPRT (Fig. 2C). Bone edematous change in the medial femoral condyle was detected on MRI at 10 and 18 weeks after the MMPRT onset (Fig. 2B and C). Radiographic findings associated with spontaneous osteonecrosis of the knee progressed to the Koshino classification stage 3 (collapsed stage) at 18 weeks (Fig. 3A)[30]. She underwent arthroscopic assessment and unicompartmental knee arthroplasty of her right knee at 20 weeks after the painful popping because of severe knee pain (Fig. 3B and C).

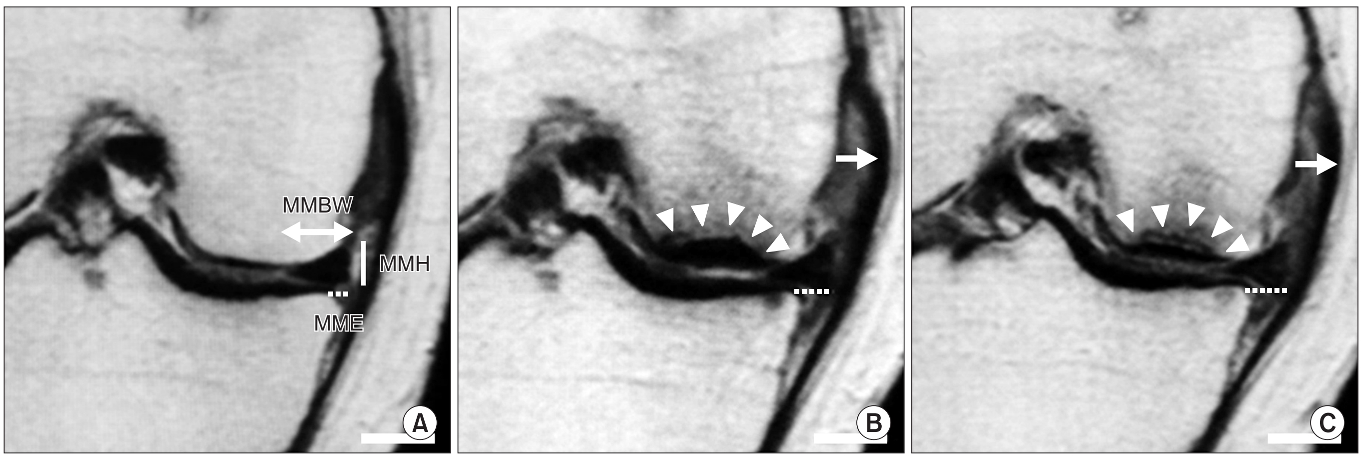

Fig. 2. Medial meniscus extrusion (MME) increased after the medial meniscus posterior root tear (MMPRT) onset in a 65-year-old female (the right knee). (A) The coronal view showed minor MME 1week after a painful popping event indicating the MMPRT onset. Double-headed arrow: medial meniscus body width (MMBW). Dotted line: absolute MME. Solid line: medial meniscus height (MMH). (B) The MME increased 10 weeks after the MMPRT. Note the bone edema of the medial femoral condyle (arrowheads) and medial shift of the medial collateral ligament (arrow). (C) The MME progressed 18 weeks after the MMPRT. Bars: 1 cm.

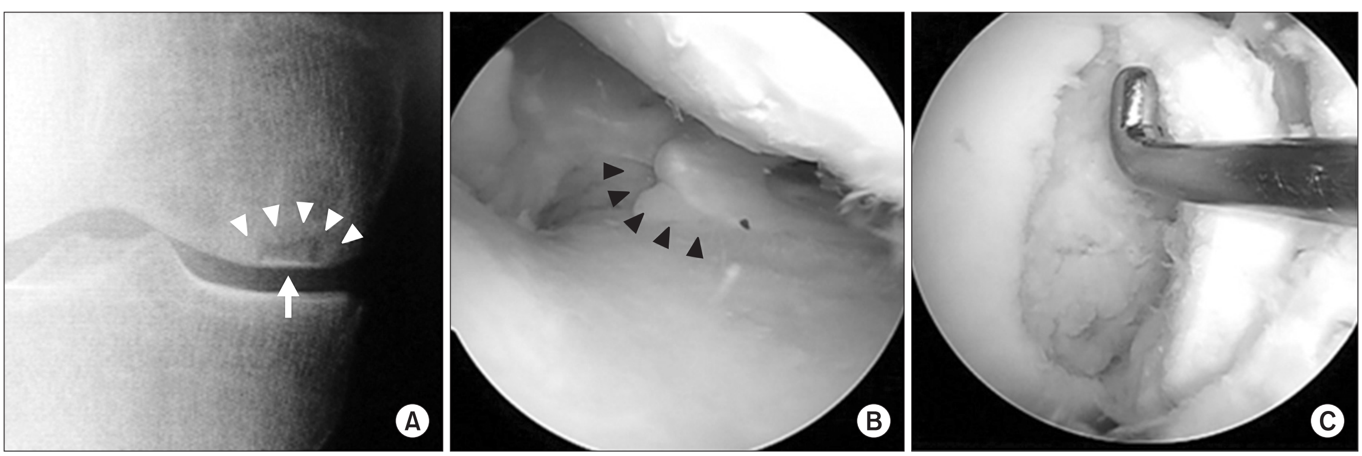

Fig. 3. Spontaneous osteonecrosis of the knee following the medial meniscus posterior root tear (MMPRT) in the 65-year-old female shown in Fig. 2 (the right knee). (A) Sclerotic halo (arrowheads) and calcified plate (arrow) were observed in a radiograph at 18 weeks after a painful popping event. Koshino classification: stage 3. (B) Arthroscopic findings at 20 weeks post-MMPRT. Arrowheads: type 2 MMPRT. (C) An unstable osteochondral flap.

Discussion

The most important finding in this study was that the absolute MME increased progressively within 12 months after the onset of symptomatic MMPRT (Table 2 and Fig. 1B). The relative MME also increased during non-operative treatment period following the posteromedial painful popping event (Table 2 and Fig. 1C). These results may provide us with an important evaluation criterion for the MMPRT to determine the timing of surgical treatments. MME of ≥3 mm is more frequent in painful osteoarthritic knees than in contralateral painless knees, and more frequent in osteoarthritic knees that have a higher radiographic grade (Kellgren-Lawrence grade III)[9]. A radially displaced MM forms a bulged (or swelled) meniscal shape on the coronal MRI during the progression of osteoarthritic knees[31]. In addition, the status of MME can affect postoperative clinical outcome of the MMPRT transtibial pullout repair[21]. Patients with decreased MME (3.5±1.4 mm) at 1 year post-MMPRT pullout repairs have more favorable clinical outcomes and radiographic findings at 5-year follow-up than those with increased MME (5.1±1.4 mm) at 1 year postoperatively[21]. We consider that pullout repair-dependent positional restoration of the MM may be disturbed by a bulged/swelled MM and knee joint space narrowing concomitant with sequential MME increase after the MMPRT onset. Our study demonstrated that the mean absolute MME was 3.0±1.2 mm even in the early period less than 1 month after the MMPRT onset. Based on these findings, it seems that the symptomatic MMPRT should be treated with arthroscopic meniscal repair techniques as soon as possible following the diagnosis of the MMPRT if the patients meet surgical indications for the MMPRT repair.

Non-operative treatment of the MMPRT was associated with poor clinical outcome, worsening osteoarthritis of the knee, and a relatively high rate (16/52 knees, 31%) of total knee arthroplasty at a mean of 30 months after diagnosis of the MMPRT[29]. The overall failure rate based on clinical and radiographic criteria was 87% in this literature. In addition, female gender was related to a higher rate of arthroplasty[32]. In biomechanical studies, the MMPRT led to excessive contact pressure on the articular surface of the knee by reducing the contact area of the knee joint cartilage[2,3]. We consider that the MMPRT can suddenly deteriorate the status of articular cartilage and subchondral bone by altering the knee joint kinematics and homeostasis immediately. Therefore, the MMPRT-related osteonecrotic lesions and spontaneous osteonecrosis of the knee may be associated with female gender having osteoporotic subchondral bone quality.

Many studies have reported that MME is associated with progression of symptomatic knee osteoarthritis[4,6,9]. Meniscus-to-femoral condyle congruity is essential for the development of circumferential hoop stresses and meniscal function. Abnormalities in the position of the MM and its coverage, such as the MMPRT, MME, and meniscectomy-related meniscal defects, can alter knee joint congruity and are associated with the progression of tibiofemoral osteoarthritis and cartilage degradation[4]. Sung et al.[33] reported that the mean absolute MME and relative MME were 4.1±0.7 mm and 46.1%±9.0% in 36 knees showing the MMPRT at a mean of 5.3-months symptom duration, respectively. In addition, MRI-based osteonecrotic lesions were observed in 12/36 knees (33%) of the MMPRT patients[33]. In our study, the absolute MME significantly increased from 3.0±1.2 mm to 5.8±1.6 mm post-MMPRT (Table 2 and Fig. 1). In the subacute period (1–3 months after the painful popping), the absolute and relative MME progressed to 4.2±1.2 mm and 49.2%±11.9%, respectively (Table 2). Based on these findings, the MMPRT should be treated within the subacute period after the MMPRT onset for preventing a substantial MME of more than 4 mm. We consider that surgical intervention at an adequate timing may be important to prevent degenerative knee joint disease following the MMPRT if the patient meets operative indications. Further investigations will be required to determine the precise timing of operative treatment for the MMPRT.

There are several limitations in this study. MRI examinations were performed differently in terms of the number of examinations and duration from the onset of MMPRT to MRI assessment. Follow-up MRI scans were not performed in all the patients after the primary MRI-based diagnosis of the MMPRT. Repeated MRI examinations in the same patients will be needed to precisely assess the time-dependent MME progression following the MMPRT. In this study, we evaluated the MRI-based MME in a single knee flexion angle (10°) under non-weight bearing condition. Open MRI assessments of meniscal movement using thin slices in several knee flexion angles under loading condition will be required to enhance the diagnostic value of MME in the MMPRT treatment. In addition, three-dimensional reconstruction of the MM using dynamic MRI may be useful to understand the MME increase after the MMPRT onset. Our study was a retrospective comparative study with a small sample size. Additional follow-up MRI studies involving in a larger sample size will be required to evaluate the real effect of MME on the progression of post-MMPRT symptoms.

Conclusions

This study demonstrated that the absolute and relative MME increased progressively within the short period after the onset of symptomatic MMPRT. Our results suggest that the accurate diagnosis of the MMPRT in the early period after the onset may be important to prevent the increase of MME following the MMPRT.

Conflict of Interest

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

Acknowledgements

We thank Drs. Shinichi Miyazawa, Takaaki Tanaka, and Hiroto Inoue for their clinical supports.

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