Original article

Injury patterns of medial meniscus posterior root tears

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Abstract

Introduction Medial meniscus posterior root tear (MMPRT) can occur in middle-aged patients who have a posteromedial painful popping during light activities. MMPRTs are more common in patients with increased age, female gender, sedentary lifestyle, obesity, and varus knee alignment. However, injury mechanisms of minor traumatic MMPRTs are still unclear. We hypothesized that high flexion activities are the major cause of MMPRTs. The aim of this study was to clarify injury patterns of MMPRTs.

Materials and methods One hundred patients were diagnosed having MMPRTs after posteromedial painful popping episodes. Details of posteromedial painful popping episode, situation of injury, and position of injured leg were obtained from the patients by careful interviews. Injury patterns were divided into 8 groups: descending knee motion, walking, squatting, standing up action, falling down, twisting, light exercise, and minor automobile accident.

Results A descending knee motion was the most common cause of MMPRTs (38%) followed by a walking injury pattern (18%) and a squatting action related to high flexion activities of the knee (13%). The other injury patterns were less than 10%.

Discussion Descending knee motions associated with descending stairs, step, and downhill slope are the most common injury pattern of MMPRTs. High flexion activities of the knee are not the greatest cause of MMPRTs. Our results suggest that the descending action with a low knee flexion angle may trigger minor traumatic MMPRTs.

Level of evidence: IV retrospective cohort study

Keywords: Medial meniscus, posterior root tear, injury pattern, descending knee motion, squatting

1. Introduction

Medial meniscus posterior root tear (MMPRT) can occur especially in middle-aged patients who have a posteromedial painful popping during light activities such as using stairs and walking [1, 2]. MMPRT is more common in patients with the following risk factors: increased age, female gender, sedentary lifestyle, obesity, and overall varus knee alignment [3]. MMPRT can often be missed in these patients as there is usually not a history of trauma and often with a subacute pain history [4, 5]. The prevalence of MMPRT seems to be higher in Asia than in Western countries [6]. In Asia and the Middle-East, people often flex the knees deeply to perform activities of daily living such as cross-legged or seiza sitting on the floor and repetitive squatting knee motion. High flexion of the knee has been considered to induce repetitive impingement of the medial meniscus (MM) posterior root, resulting in subsequent degenerative changes and MMPRT. In multi-ligament knee injuries involved in single cruciate ligament rupture at least, varus injury pattern and medial compartmental fracture are associated with MM root tears [7]. However, an injury mechanism of commonly-observed low-energy MMPRT is still unclear. An in vivo three-dimensional kinematics of normal knees (a mean age of 42 years) during squatting demonstrates medial pivoting pattern from 0˚ to 40˚ of knee flexion and bicondylar rollback from 40˚ to 150˚ [8]. During cross-legged sitting, the femur displays internal rotation from 10˚ to 100˚ of knee flexion. From 100˚ to high flexion angle, femoral external rotation is observed [8]. The aim of this study was to clarify injury patterns of commonly-observed MMPRTs in middle-aged patients. We hypothesized that high flexion activity of the knee and/or squatting motion are the major cause of MMPRT onset in a specific group with history of painful popping.

2. Materials and Methods

This study received the approval of our Institutional Review Board. Informed consent was obtained from all patients. One hundred patients (100 knees) were diagnosed as having the true MMPRT (MMPRT having have a popping episode and requiring a surgical procedure) with magnetic resonance imaging (MRI) examinations and/or intraoperative findings between June 2013 and May 2018. A diagnosis of MMPRT was made by characteristic MRI findings (giraffe neck sign, cleft sign, ghost sign, and/or radial tear sign) within 12 months after posteromedial painful popping sensations of injured knees [9-12]. All MMPRTs were confirmed by intra-operative findings involved in transtibial MM pullout repairs (n=78) [13-15] or knee arthroplasties (n=22). In addition, each MMPRT was classified according to a morphological classification system of meniscal root tears [16]. Posterior horn tear and posterior segment tear of the MM were excluded. All the patients (84 women and 16 men) who had an episode of the posteromedial painful popping involved in a minor traumatic injury pattern during daily activities were included. Patients who had no painful popping memory, previous history of meniscal injury, or knee surgery were excluded. A mean age of the patients was 64.7 years at the diagnosis of the MMPRT with a sudden onset. Complete radial and/or oblique tears adjacent to the MM posterior insertion and posterior horn were observed in 93 patients who had a sudden posteromedial painful popping of the injured knee. Partial tears of MM posterior root were detected in 7 patients. Patient demographics are shown in Table 1. No patient was lost during the follow-up.

MRI and radiograph assessments

MRI examinations were performed using an Achieva 1.5 T (Philips, Amsterdam, The Netherlands). Standard sequences included sagittal, coronal, and axial 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 cm with an acquisition matrix size of 205 × 256 as described [17-19]. Three orthopaedic surgeons (T.F., S.M., and Y.O.) independently diagnosed the MMPRT by MR images. Degenerative changes of the knee were assessed by Kellgren-Lawrence (KL) grade using anteroposterior radiographs under loaded conditions at the timing of medical interviews.

Injury patterns of MMPRTs

Details of posteromedial painful popping episode, situation of injury, and position of injured leg were obtained from the MMPRT patients by careful interviews. A mean duration from painful popping events to medical interviews was 55 days (range, 1-269 days). Orthopaedic surgeons performed medical interviews prior to MRI examinations for hearing a painful popping episode using the following questions: “Did you feel a sudden knee joint pain?” “Did you feel the pain at the posteromedial side of your knee?” “Do you remember the situation at the time of acute knee joint pain?” “Could you tell me the detailed situation that you felt the knee pain?", and/or "Did the pain occur during stair descending, flat walking, squatting, or stair ascending?" Injury patterns were divided into 8 groups (Table 2): descending knee motion, walking, squatting, standing up action, falling down, twisting knee motion, light exercise, and minor automobile accident. Injury histories involved in descending stairs, step, bus platform, mountain, and slope and falling into a ditch/gutter were classified as descending actions of the lead leg. Walking or trotting on a flat ground and taking a dog for a walk were considered as a level walking injury pattern. High flexion activities of the injured knee such as squatting, weeding, cross-legged sitting, and seiza sitting were classified as squatting actions. Standing up from chair, bed, and car seat and ascending stairs were determined as standing up knee motions. Injury patterns for falling down, twisting knee motion (turning around and looking back), light exercise (tennis, golf, and calisthenics), and thrusting a foot on the brake pedal or floor at minor automobile accidents were prepared.

Statistical analysis

Data were presented as means ± standard deviations. Values of each group were compared by a one-way analysis of variance. Differences in KL grade and root tear classification between groups were compared using Fisher's exact test. 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).

3. Results

A descending knee motion was the most common cause of acute MMPRT onset (38%) followed by a walking injury pattern (18%) and a squatting action related to high flexion activities of the knee (13%). The other injury patterns such as standing up, falling down, twisting, light exercise, and minor automobile accident were less than 10% (Table 2 and Fig. 1). No significant differences among the three major causes of injury patterns were observed in age, height, body weight, body mass index, KL grade, and meniscal root tear classification (Table 3). Number of the knees associated with injury patterns, KL grade, and meniscal root tear classification is shown in Tables 4 and 5. Injury patterns were similar between each KL grade (Table 4) and each type of MMPRTs (Table 5).

Eleven patients underwent total knee arthroplasties and 11 patients required unicompartmental knee arthroplasties in this study. The KL grade observed in arthroplasty group (n = 22) was significantly higher than that in pullout repair group (n = 78, a median KL grade of 3 vs. 2, $P < 0.001$). However, no differences between arthroplasty and meniscal repair groups were detected in injury patterns of MMPRTs ($P = 0.753$).

4. Discussion

The most important finding of this study was that high flexion activities of the knee was not the greatest cause of acute onset of the MMPRT's requiring surgery. These results dismissed our hypotheses that high flexion activity and/or squatting knee motion may be the major cause of MMPRT. In this study, descending actions associated with stairs, step, and downhill slope were the most serious injury pattern of MMPRTs.

Descending stairs by a traditional step-over-step pattern that place both feet on the same step before descending has a peak knee flexion angle of 83.3° at stairs with each step being 15 cm high and 26 cm deep [20]. A higher knee flexion angle (< 90°) is observed around the timing of toe-off during stair descent [20, 21]. An initial knee flexion angle at the beginning of the stance phase is 15.6°−29.2° during a forward descending stairs [21]. In our study, the posteromedial painful popping was mainly occurred at a moment of stepping by the lead/injured leg during the knee motion involved in descending (38%), walking (18%), twisting (6%), and thrusting foot (2%) actions. In addition, falling down episodes (8%) seemed to be associated with an MMPRT of the supporting leg. These findings suggest that acute MMPRTs may be triggered mostly by the descending or stepping action with a low knee flexion angle (< 30°). In previous studies, high flexion activities of the knee are considered to lead to repetitive impingement of the MM posterior root and generate excessive tensile forces in the MM posterior root, resulting in subsequent meniscal degeneration and MMPRT [1, 12, 22]. However, an injury pattern dependent on the "high flexion theory" was not the greatest cause of posteromedial painful popping associated with acute MMPRTs in our study (Table 2 and Fig. 1). Further investigations involved in motion analyses during descending actions will be required to understand the precise injury mechanism of MMPRT in middle-aged or older female patients.

In our study, a walking injury pattern was the second major cause of MMPRT (18%). The axial tibiofemoral joint force has two major peaks during the stance phase of level walking [23]. The first peak occurs in early stance, reaching a magnitude of 2.8 × body weight. The second peak in late stance reaches a magnitude of 2.0 × body weight [23]. Under 2000 N compression similar to level walking, a principal tensile strain at the inner region adjacent to the MM posterior root/horn reaches more than 7% strain in a finite element model of human knee joint [24]. On the other hand, a maximum knee joint force increases by 6.31−8.89 times of body weight during stair descending [25]. In a human cadaveric study, femoral internal rotation increases a tensile force at the MM posterior root under 100 and 500 N of tibiofemoral compressive load, while femoral external rotation decreases the resultant tension [22]. In neutral and femoral internal rotation, a trend toward 90° of knee flexion causing more tension is observed. The highest mean tension of 60 N is generated with femoral internal rotation, a 500-N load, and 90° of knee flexion [22]. Based on these findings, we consider that descending knee motion concomitant with femoral internal rotation (or tibial external rotation) may have a higher risk of inducing MMPRT compared with the other injury patterns such as walking and twisting knee motion.

Posteromedial painful popping sensation is a reliable medical sign in identifying MMPRTs [1]. In our previous study, 87.3% of the MMPRT patients had an acute posteromedial painful popping episode [2]. Hearing of the painful popping memory is required to expect the presence of MMPRT. Recognizing injury patterns of acute MMPRTs may be useful to obtain valuable information for expecting the MMPRT from the patients who have the knee joint pain during medical history interview and examination. Painful popping events were often observed in conservatively-treated patients who were diagnosed as having MMPRTs by MRI examinations alone. Eleven patients had painful popping episodes of injured knees in a non-operative treatment group. Injury patterns of these patients were the followings: descend (3 knees), walk (3 knees), squat (1 knee), stand up (2 knees), fall down (1 knee), and twist (1 knee). However, we could not confirm whether these patients had true MMPRTs or not. Thus, injury patterns shown in this study may not completely represent a real incidence of each injury pattern in patients with MMPRTs.

Patients who had osteoarthritic knees with KL grade 3 or more often showed symptomatic knee pains during standing up and squatting activities. On the other hand, patients with KL grade 2 or less were usually asymptomatic prior to painful popping events. Thus, the activity of daily living may be higher in patients with KL grade 2 or less compared with those with KL grade 3 or more. However, injury patterns of MMPRTs were similar between each KL grade in our study (Table 4). These findings suggest that osteoarthritic knee status may not predominantly affect injury mechanisms of MMPRTs. Lee et al. demonstrate that medial compartmental degeneration of the knee precedes the painful popping event [26]. Our study also showed that no knees of KL grade 0 were observed in patients with MMPRTs. We consider that mild degenerative changes of knee components in asymptomatic active patients may be a relative risk of developing MMPRTs. Serious degenerative changes of the MM posterior segment/horn would decrease the incidence of MMPRTs in severe osteoarthritic knees (KL grade $\geq$ 3) because of an insufficient meniscal function as a compressive load-to-hoop tension converter. Further investigations involved in the status of meniscal root, meniscal body, and articular cartilage will be required to understand detailed injury mechanisms of MMPRTs.

There are several limitations in this study. Our study was a retrospective study. Durations between painful popping sensation and medical interview were not the same. In addition, a specific group of MMPRTs with popping episodes may not represent the whole MMPRT cases.

5. Conclusions

Descending knee motions associated with descending stairs, step, and downhill slope are the most common injury pattern of MMPRTs. High flexion activities of the knee are not the greatest cause of sudden onset of the MMPRT. Our results suggest that the descending or stepping action with a low knee flexion angle may trigger a minor traumatic injury of the MM posterior root.

Conflict of interest

The authors have no conflict of interest.

Funding information

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Authors' contribution

TF designed this study and prepared manuscript, Tables, and Figure. TF, SM, and YO diagnosed MMPRTs by MRI examinations. TF and SM performed surgical treatments. TF, YO, TH, YK, and SM had medical interviews with patients. EN, JH, TK, and TO evaluated clinical records and radiographs.

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Table 1. Demographics and clinical characteristics

Number of patients	100
Gender, men/women	16/84
Injured side, right/left	44/56
Root tear classification, Type 1/2/3/4/5	7/80/1/12/0
Age (years)	64.7 ± 9.7
Height (m)	1.56 ± 0.08
Body weight (kg)	64.3 ± 15.3
Body mass index (kg/m^2)	26.2 ± 4.6

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

Table 2. Injury patterns of medial meniscus posterior root tears

	Patients (n = 100)
Descend (stairs, step, ditch/gutter, bus platform, mountain path, slope)	38
Walk (flat ground, trot, take a dog for a walk)	18
Squat (high flexion, weeding, seiza sitting)	13
Stand up (chair, bed, car seat, ascend stairs)	9
Fall down	8
Twist (turn around, look back)	6
Light exercise (tennis, golf, calisthenics)	6
Automobile accident (thrust a foot)	2

Table 3. Details of three major injury patterns

	Age (years)	Height (m)	Body weight (kg)	BMI (kg/m^2)	KL grade: 0/1/2/3/4 (knees)	Root tear: 1/2/3/4/5 (knees)
Descend	64.6 ± 7.7	1.56 ± 0.09	63.1 ± 14.1	25.8 ± 3.9	0/13/17/7/1	0/31/1/6/0
Walk	66.2 ± 8.2	1.56 ± 0.08	66.9 ± 20.4	27.3 ± 6.2	0/7/10/1/0	3/14/0/1/0
Squat	61.8 ± 15.7	1.55 ± 0.08	64.5 ± 16.4	26.5 ± 5.5	0/4/7/2/0	0/12/0/1/0
P value	0.486	0.919	0.741	0.600	0.874	0.129

BMI, body mass index. KL, Kellgren-Lawrence. Data of age, height, body weight, and BMI are displayed as a mean ± standard deviation.

Table 4. Injury patterns and Kellgren-Lawrence grade of the knees

Grade	Descend (knees)	Walk (knees)	Squat (knees)	Stand up (knees)	Fall down (knees)	Twist (knees)	Exercise (knees)	Accident (knees)	Total (knees)
0	0	0	0	0	0	0	0	0	0
1	13	7	4	1	2	1	2	1	31
2	17	10	7	6	4	3	3	0	50
3	7	1	2	2	2	0	1	1	16
4	1	0	0	0	0	2	0	0	3

Table 5. Injury patterns and meniscal root tear classification

Type	Descend (knees)	Walk (knees)	Squat (knees)	Stand up (knees)	Fall down (knees)	Twist (knees)	Exercise (knees)	Accident (knees)	Total (knees)
1	0	3	0	1	1	0	1	1	7
2	31	14	12	7	5	6	4	1	80
3	1	0	0	0	0	0	0	0	1
4	6	1	1	1	2	0	1	0	12
5	0	0	0	0	0	0	0	0	0

Figure legends

Figure 1. Injury patterns of 100 MMPRTs. Schematic illustrations of each injury pattern and percentages are shown in a pie chart.