Medial meniscus posterior root repair decreases posteromedial extrusion of the medial meniscus during knee flexion

Yuki Okazaki[a], Takayuki Furumatsu[a], Yoshiki Okazaki[a], Shin Masuda[a], Takaaki Hiranaka[a], Yuya Kodama[b], Yusuke Kamatsuki[c], Shinichi Miyazawa[a], Tomonori Tetsunaga[a], Toshifumi Ozaki[a]

[a]Department of Orthopaedic Surgery, Okayama University Hospital, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan

[b]Department of Orthopaedic Surgery, National Hospital Organization Iwakuni Clinical Center, 1-1-1 Atagomachi, iwakuni, Yamaguchi, 740-8510, Japan

[c]Department of Orthopaedic Surgery, Kochi Health Science Center, 2125-1 Ike, Kochi 781-8555, Japan

Corresponding author:

Takayuki Furumatsu

Department of Orthopaedic Surgery, Okayama University Hospital

2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan

E-mail address: matino@md.okayama-u.ac.jp

MM, medial meniscus; MMPRT, medial meniscus posterior root tear; MTP, medial tibial plateau; PR, posterior root

1. Introduction

The medial meniscus (MM) shows only minimal posteromedial shift during knee flexion in normal knees because the MM posterior root (PR) serves as an anchor to limit meniscal shift during knee movement and load bearing [1,2]. A MM posterior root tear (MMPRT) often occurs in middle-aged women [3] and leads to abnormal tibiofemoral joint biomechanics and the inability to convert axial loads into hoop stresses [4,5]. Furthermore, the function of the MM as a joint stabilizer is lost, which leads to severe medial and posterior extrusion beyond the medial tibial plateau (MTP) [6]. MMPRT repair restores physiological rotation during knee flexion [7] and reduces mean tibiofemoral contact pressure by increasing tibiofemoral contact area [8]. Favorable clinical outcomes were reported for MMPRT pullout repair [9], provided that patients with Outerbridge grade III or IV cartilage lesions were excluded [10]. However, MM medial extrusion in the coronal plane does not always improve even after repair [11], and patients with increased extrusion after repair have low clinical scores [12].

Although some surgical techniques to reduce MM extrusion after pullout repair exist, such as anatomic bone tunnel creation [13,14] and combination with centralization [15,16], few studies evaluated three-dimensional (3D) meniscal movement to understand the underlying mechanisms of MM extrusion. We therefore used 3D magnetic resonance imaging (MRI) to investigate changes in the position of the extruded MM before and after repair to determine how the MM position changes during knee flexion before and after MMPRT pullout repair. We hypothesized that posteromedial extrusion of the MM during knee flexion following MMPRT would be reduced by pullout repair.

2. Material and methods

2.1 Patients

This retrospective cohort study was approved by our Institutional Review Board and has been performed according to the Declaration of Helsinki. All patients provided informed consent. Sixty-six patients who underwent MMPRT pullout repair between August 1, 2017, and October 31, 2018 at our institution were included. Pullout repair was performed in patients with a femorotibial angle <180˚, mild cartilage lesions (Outerbridge grade I or II), and Kellgren–Lawrence grade 0–II, which are confirmed by preoperative radiographs and magnetic resonance images. Furthermore, high tibial osteotomy or total/unicompartmental knee arthroplasty was performed in patients other than those who met the above requirements. All MMPRTs were treated with either a FasT-Fix® (Smith & Nephew, Andover, MA, USA)-dependent modified Mason-Allen suture or two simple stitches after creating the tibial bone tunnel with an MMPRT guide, as previously described [17-19]. In brief, after No. 2 Ultrarbraid (Smith & Nephew, Andover, MA, USA) was passed vertically using the Knee Scorpion suture passer (Arthrex, Naples, FL, USA), FasT-Fix 360 (Smith & Nephew) was passed horizontally across the Ultrabraid in a modified Mason-Allen configuration (Fig 1A, B), or two No. 2 TigerStick (Arthrex) was simply applied vertically using the same passer (Fig 1C, D). Fifty-two patients were excluded because their pre- or postoperative 3D-MRI data were unavailable or they had concomitant injuries such as ACL rupture and MMPRT and a history of previous surgery at the index knee, resulting in a final sample size of 14 patients.

Table 1 reports the patients' demographic and clinical characteristics. The mean age at the time of surgery was 63.4 (range, 50–78) years, and the mean duration between injury and surgery was 15.5 (range, 1–42) weeks.

2.2 Methods

Open MRI scanning was used to analyze changes in MM position preoperatively and ≥3 months postoperatively using a 1.2-T device (Hitachi Medical, Chiba, Japan) with the coil at 90º knee flexion under a non-weight-bearing condition. Multiplanar images were acquired using proton density-weighted isotropic resolution fast spin-echo (iso FSE, Hitachi Medical) sequence with continuous 1-mm slice thicknesses. The 3D FSE images were acquired in the sagittal and coronal planes with the following parameters: repetition time/echo time, 600/96; matrix, 224 × 224; field of view, 18 cm; echo-train length, 24; bandwidth, ± 98.1 kHz; and scanning time, 4.8 min. Data on the femur and tibia were extracted semi-automatically with the voxel density threshold for the surface definition using a 3D image analysis workstation (SYNAPSE VINCENT®; Fujifilm Medical System, Tokyo, Japan); meniscal segmentations were performed manually using the texture-tracing technique [20]. The 3D-MRI of the tibial surface with the meniscus was evaluated using a rectangular measurement grid, as described by Tsukada et al. [21] because the tibial plateau size differs among patients. The image was rotated to visualize the superior aspect of the proximal tibia, with the internal/external rotation adjusted until the most posterior articular margins of both the medial and lateral tibial plateau were horizontal.

2.3 Methods of assessment

The location of each point was determined by two coordinates—one on the anteroposterior axis and one on the mediolateral axis. The expected MMPR attachment point (point A) was determined as the center of a virtual circle that was circumscribed by the sides of the triangular PR footprint—the anterior border of the posterior cruciate ligament-tibial attachment, lateral margin of the MTP, and the retro-eminence ridge [22] (Fig. 2A).

Point E was defined as the part of the MM farthest away from point A. Point I, located at the intersection of a line through the posteromedial corner of the MTP and a line connecting point A and E was investigated preoperatively (Fig. 2B) and postoperatively (Fig. 2C). Subsequently, the distances from points A to E (AE distance) and from points I to E (IE distance) were calculated using the Pythagorean theorem, as previously described [2]: $(\text{the distance})^2 = (\text{the anteroposterior distance of each point})^2 + (\text{the mediolateral distance of each point})^2$. The mean values were then reported and compared.

Two orthopedic surgeons independently measured the location of points A, E, and I. Each surgeon performed each measurement twice with an interval of at least two weeks between measurements.

2.4 Statistical analysis

Statistical analysis, sample size, and power calculation were performed using EZR software (Saitama Medical Center, Jichi Medical University, Tochigi, Japan). The final sample size ($n = 14$) demonstrated adequate power (> 0.80) to detect a significant difference between the pre- and postoperative distance.

Data are presented as means ± standard deviations. The Wilcoxon’s signed rank test was used to compare preoperative and postoperative values. Statistical significance was set at $P < 0.05$. The inter-observer and intra-observer reliabilities were assessed using the intra-class correlation coefficient (ICC).

3. Results

3.1 Location of critical points and distances on serial 3D-MRI

On average, point A was located 77.7% posteriorly and 39.5% laterally (Fig. 3A). Preoperatively, point E was located 88.5% posteriorly and -4.0% laterally (Fig. 3B), whereas postoperatively, it was located 87.3% posteriorly and -1.1% laterally (Fig. 3C). Preoperatively, point I was located 85.3% posteriorly and 8.6% laterally (Fig. 3D), whereas postoperatively, it was located 85.1% posteriorly and 8.3% laterally (Fig. 3E). Point E was displaced medially by the pullout repair procedure, whereas point I showed no significant change in position after repair in comparison to its position before repair.

The postoperative IE distance (6.7 mm) was significantly shorter than the preoperative one (9.1 mm, $P < 0.01$). Moreover, the postoperative AE distance (29.3 mm) was significantly shorter than the preoperative one (31.5 mm, $P < 0.01$, Table 2). Posteromedial extrusion of the MM decreased after MMPRT pullout repair.

Inter-observer and intra-observer reliabilities for the point measurements were satisfactory with mean ICC values of 0.91 and 0.93, respectively.

4. Discussion

This study compared MM extrusion before and after MMPRT pullout repair. The results confirmed the initial hypothesis and demonstrated that the AE and IE distance significantly decreased after MMPRT pullout repair.

Recently, several studies have investigated the meniscal root properties, kinematics, and biomechanics [23-26]. MMPRT leads to significant changes in the in-vivo knee kinematics [27] and the loading profile of the medial joint compartment, resulting in loss of hoop resistance, meniscus extrusion [6], and early degenerative changes [28]. Other reports found no difference between the peak contact pressure after total medial meniscectomy and that associated with a root tear and established that root repair was successful in restoring joint biomechanics and knee rotation to normal conditions [5,7].

The normal MM shows only a minimal posteromedial shift in association with knee flexion, because the MM PR serves as an anchor to control the meniscal shift during knee motion and load bearing [29,30]. In MMPRT, the extent of posterior MM movement during flexion is greater than that in a normal knee [6]. MM extrusion progressed rapidly after MMPRT, and medial joint space narrowing was found associated with this progression [31-33]. Furthermore, increased extrusion and a higher International Cartilage Repair Society grade at the 2-year follow-up following transtibial MMPRT repair was reported [11]. At midterm follow-up in another study, patients with decreased extrusion after one year had more favorable clinical scores and radiographic findings than those with increased extrusion after one year [12]. Consequently, at our institution, we aimed to reduce meniscus extrusion after MMPRT pullout repair as much as possible.

A non-anatomic position of the horn attachment affects the conversion of femorotibial loads into circumferential tension [14] as it does not restore the contact area and mean contact pressure to that of an intact knee. Anatomic repair can produce a similar contact area and result in only minimal increases in mean and peak contact pressures compared with the intact knee [8]. Although many surgical techniques have been reported to reduce MM extrusion when combined with pullout repair, such as anatomic bone tunnel creation [34], fixation technique [35], and combination with centralization [15,16], the best approach is still controversial.

Because point I showed no remarkable changes in our analysis, we consider that an additional suture in point I combined with pullout repair of MMPRT might decrease MM extrusion during knee flexion. If the extruded MM is reduced close to its original position, long-term MM and femorotibial cartilage survivorship and more favorable clinical outcomes might be expected.

This study had several limitations. First, the sample size was small; however, the statistical power was sufficient. Second, the relationship between tibial tunnel position and clinical outcome was not evaluated postoperatively. Third, two different suture techniques using different initial fixation tension were employed [17,19]. Finally, the exact tibial tunnel position was not considered; however, nearly anatomically normal tibial tunnel position was confirmed previously [2]. Further evaluation with larger sample sizes is required to expand on our findings and clarify these points.

5. Conclusions

This study demonstrated that the AE and IE distances significantly decreased after MM posterior-root repair. Our study suggests that transtibial pullout repair may be a useful surgical treatment to reduce pathological posteromedial extrusion of the MM during knee flexion in patients with MMPRTs.

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Tables

Table 1. Demographic and clinical characteristics of patients (n = 14) prior to medical meniscus posterior root tear repair

Number of patients	14
Sex (male/female)	2/12
Age (years)	63.4 ± 8.5
Height (m)	1.57 ± 0.08
Weight (kg)	62.4 ± 15.5
Body mass index (kg/m^2)	25.1 ± 3.8
Root tear classification type 1/2/3/4/5 (n)	1/12/0/1/0
Kellgren-Lawrence grade I/II (n)	5/9

Age, height, and body mass index are presented as mean ± standard deviation

Table 2. Location of critical points on the 3D tibial surface in patients (n = 14) with medial meniscus posterior root tear

	Preoperative	Postoperative	P value
Point A			
Posterior (%)	77.7 ± 1.4	N/A	
Lateral (%)	39.5 ± 1.6	N/A	
Point E			
Posterior (%)	88.5 ± 4.8	87.3 ± 4.8	> 0.05
Lateral (%)	-4.0 ± 3.1	-1.1 ± 3.7	< 0.01*
Point I			
Posterior (%)	85.3 ± 3.6	85.1 ± 4.1	> 0.05
Lateral (%)	8.6 ± 2.1	8.3 ± 2.4	> 0.05
AE distance (mm)	31.5 ± 2.6	29.3 ± 3.2	< 0.01*
IE distance (mm)	9.1 ± 2.3	6.7 ± 2.2	< 0.01*

Data are presented as mean ± standard deviation.

* P values < 0.05

Point A: expected PR attachment; Point E: the farthest part of the MM from point A; Point I: the intersection of a line through the posteromedial corner of the medial tibial plateau and a line connecting point A and E; AE distance: the distance from point A to E; IE distance: the distance from point I to E; N/A: not applicable

Figure legends

Figure 1. Intraoperative arthroscopic findings, which show FasT-Fix-dependent modified Mason-Allen suture (Fig A. B) and two simple stitches (Fig C. D)

PR; posterior root. MFC; Medial femoral condyle. MTP; Medial tibial plateau. PCL; posterior cruciate ligament.

A. The second implant of FasT-Fix is inserted into the posterior root of the MM across the Ultrabraid, whereas the passed Ultrabraid is tensioned.

B. Final appearance after FasT-Fix-dependent modified Mason-Allen suture was applied.

C. The second stitch is applied using Knee Scorpion suture passer, whereas the passed TigerStick is tensioned.

D. Final appearance after two simple stitches was applied.

Figure 2. Measurement of critical points on the 3D tibial surface of one patient

Point A (yellow circle): expected PR attachment; point E (red triangle): the farthest MM point from point A; point I (orange square): the intersection of a line through the posteromedial corner of the medial tibial plateau and a line connecting points A and E.

Grey: proximal tibia; blue: meniscus on the tibial surface; violet: extruded medial meniscus.

A. Point A, E, and I. Point A was determined as the center of a virtual circle that contacted three sides of PR triangular footprint (Dotted line: anterior border of the tibial attachment of the posterior crucial ligament, lateral margin of the medial tibial plateau, and retro-eminence ridge [22]).

B. In this example, point A is located at a 77% posterior and 38% lateral position, point E is located at an 88% posterior and -5% lateral position, point I is located at an 85% posterior and 6% lateral position, preoperatively.

C. Postoperatively, point E is located at a 91% posterior and 0% lateral position, point I is located at an 88% posterior and 6% lateral position. Note that the torn end of the MM is repositioned near a native MMPR attachment.

Figure 3. Respective locations of critical points on 3D tibial surface in patients with posterior root tear of the medical meniscus (n = 14)

A. Locations of point A (expected PR attachment) in all patients (black circles). Yellow circle: mean point A location, 77.7% posterior and 39.5% lateral.

B. Preoperative location of point E (the farthest MM point from point A) in all patients (black squares). Orange square: mean point E location, 88.5% posterior and -4.0% lateral.

C. Postoperative location of point E in all patients (black squares). Orange square: mean point E location, 87.3% posterior and -1.1% lateral.

D. Preoperative location of point I (point at the intersection of MTP posteromedial corner and a line connecting point A and E) in all patients (black triangles). Red triangle: mean point I location, 85.3% posterior and 8.6% lateral.

E. Postoperative location of point I in all patients (black triangles). Red triangle: mean point I location, 85.1% posterior and 8.3% lateral.