Placement of an anatomic tibial tunnel significantly improves the medial meniscus posterior extrusion at 90° of knee flexion following medial meniscus posterior root pullout repair

Abstract

Purpose: The purpose of this study was to evaluate the influence of tibial tunnel position in pullout repair for a medial meniscus (MM) posterior root tear (MMPRT) on postoperative MM extrusion.

Methods: Thirty patients (median age: 63 years, range: 35–72 years) who underwent transtibial pullout repairs for MMPRTs were included. Three-dimensional computed tomography (3D-CT) images of the tibial surface were evaluated using a rectangular measurement grid for assessment of tibial tunnel position and MM posterior root attachment. Preoperative and postoperative MM medial extrusion (MMME) and posterior extrusion (MMPE) at 10° and 90° knee flexion were measured using open magnetic resonance imaging.

Results: Tibial tunnel centers were located more anteriorly and more medially than the anatomic center (median distance: 5.8 mm, range: 0 to 9.3 mm). The postoperative MMPE at 90° knee flexion was significantly reduced after pullout repair, although there was no significant reduction in MMME or MMPE at 10° knee flexion after surgery. In the correlation analysis of the displacement between the anatomic center to the tibial tunnel center and improvements in MMME, and MMPE at 10° and 90° knee flexion, there was a significant positive correlation between percentage distance and improvement of MMPE at 90° knee flexion.

Conclusion: This study demonstrated that the nearer the tibial tunnel position to the anatomic attachment of the MM posterior root, the more effective the reduction in MMPE at 90° knee flexion. Our results emphasize that an anatomic tibial tunnel should be created in the MM posterior root to improve the postoperative MMPE and protect the articular cartilage in a knee flexion position. Placement of an anatomic tibial tunnel significantly improves the medial meniscus posterior extrusion at 90˚ of knee flexion after medial meniscus posterior root pullout repair.

Level of Evidence: Level IV

Keywords: medial meniscus, posterior root tear, pullout repair, tibial tunnel, meniscus extrusion, three-dimensional CT

Introduction

A medial meniscus (MM) posterior root tear (MMPRT) is a critical injury to the medial compartment of the knee [1, 28, 29]. It leads rapidly to osteoarthritic or osteonecrotic changes [26, 29] and is treated with arthroscopic repair in order to protect the knee joint [6, 17, 24]. Arthroscopic pullout repair has been performed and evaluated using clinical scores and magnetic resonance imaging (MRI) measurements in previous studies [14, 18, 22]. In these studies, pullout repair has not completely reduced MM extrusions. Nevertheless, Chung et al. demonstrated that transtibial pullout repair leads to favorable midterm outcomes in patients with MMPRTs, despite the presence of residual meniscal extrusion [3, 4]. One of the reasons for this may be pathological MM posterior extrusion (MMPE) as MMPRTs result in not only in MM medial extrusion (MMME), but also posterior extrusion at 90° knee flexion [23, 27]. However, pullout repair of MMPRTs reduces the MMPE at 90° knee flexion [18, 22] and restores the hoop structure of the MM by stabilizing the MM posterior root [2, 21]. Biomechanical studies revealed that anatomic pullout repair of MMPRTs restores the loading profiles of the medial compartment and non-anatomic repair does not restore the contact area or mean contact pressure to that of the intact knee or the anatomic repair knee [5, 20]. In a study of meniscal allograft transplantation, tibial tunnel position changes affected meniscus subluxation, indicating that transplanting the MM close to its native position could reduce MM extrusion after MM allograft transplantation [16].

Previous studies have showed the anatomic attachment of the MM posterior root [9, 12]. A cadaveric study reported that the MM posterior insertion was located 9.6 mm posteriorly and 0.7 mm laterally from the medial tibial eminence (MTE) apex and 8.2 mm directly from the nearest tibial attachment margin of the posterior cruciate ligament (PCL) [12]. One histological study also demonstrated that the distance from the MM posterior insertion center is located 7.7 mm posterior to the MTE apex [9].

Based on these findings, we considered that tibial tunnel position in MMPRT pullout repair might affect not only hoop stress, but also MM extrusion. Therefore, the purpose of this study was to evaluate how tibial tunnel position in MMPRT pullout repair affects postoperative MM extrusion. It was hypothesized that it is difficult to reduce the MM extrusion when a tibial tunnel is created far from the anatomic attachment of the MM posterior root.

Materials and Methods

This study was approved by the Institutional Review Board of Okayama University Graduate School (ID number: 1857) and patients provided informed consent prior to participation. The flow chart of the study protocol is shown in Fig. 1. Pullout repair of the MMPRT was performed in patients with a femorotibial angle (FTA) < 180°, Kellgren–Lawrence (K-L) grade 0–2, and mild cartilage lesion (Outerbridge grade I or II), which was confirmed by preoperative radiographs and MRI. We excluded: 1) patients diagnosed with a partial MMPRT, 2) patients diagnosed with spontaneous osteonecrosis of the knee, 3) patients with a concomitant ligament injury, 4) patients without a memory of painful popping, and 5) patients with insufficient postoperative computed tomography (CT)/MRI data. Thirty patients (25 women and 5 men, mean age 61 years) who underwent transtibial pullout repairs for MMPRT using the FasT-Fix (Smith & Nephew, Andover, MA, USA) modified Mason-Allen (F-MMA) suture technique between April 2016 and July 2018 were included. We reviewed the patients' medical records to determine age, sex, height, body weight, body mass index (BMI), interval from injury to preoperative MRI and to surgery, and arthroscopic findings of MMPRT. The patient demographics are summarized in Table 1.

Surgical procedure

The patients were placed in a supine position on the operating table. A standard arthroscopic examination was performed using a 4-mm-diameter 30° arthroscope (Smith & Nephew, Andover, MA, USA) through routine anteromedial (AM) and anterolateral (AL) portals. A probe was introduced through the AM portal and the severity of MMPRT was evaluated. In cases with a tight medial compartment, we used the outside-in pie-crusting technique on the medial collateral ligament with a standard 18-gauge hollow needle (TERUMO, Tokyo, Japan) [30]. The posterior meniscal peripheral attachment of the MM was detached by a rasp to achieve meniscal mobility. For the F-MMA technique, the Knee Scorpion suture passer (Arthrex, Naples, FL, USA) was used to pass a no. 2 Ultrabraid (Smith & Nephew) vertically through the meniscal tissue. Subsequently, the FasT-Fix 360 meniscal repair system was inserted from the AM portal into the MM posterior horn and root across the Ultrabraid in a modified Mason-Allen configuration [6, 17].

The MMPRT guide (Smith & Nephew), which can create the tibial tunnel at a favorable position because of a narrow twisting/curving shape during transtibial pullout repair for MMPRT, was placed at the center of the attachment area [8]. A 2.4-mm guide pin was inserted using the MMPRT guide at a 45° angle to the articular surface, and a 4.5-mm cannulated drill was used to over-drill. The free-ends of the sutures were pulled out through the tibial tunnel using a suture manipulator. Gentle tension was applied to the sutures until the posterior horn reached its tibial attachment area. The pulled sutures were tied rigidly to the double-spike plate (Meira, Aichi, Japan) 10 mm from the extra-articular aperture of the tibial tunnel. Tibial fixation was performed using the double-spike plate and screw with the knee flexed at 45° using an initial 20-N tension [6, 17].

Postoperative rehabilitation

The postoperative rehabilitation protocol was similar for all patients. All patients wore a knee immobilizer for 2 weeks after surgery to avoid weight-bearing. Knee flexion was limited to 90° for the first 4 weeks. The patients were allowed full weight-bearing and 120° knee flexion after 6 weeks. Deep knee flexion was permitted 3 months postoperatively [6].

Radiographic evaluations

The coronal radiological FTA was measured to assess the degree of preoperative knee deformity. FTA is defined as the external angle between the femoral and tibial shaft axes on coronal radiograph of the entire lower limbs in the standing position. The Rosenberg 45° posteroanterior standing view was used to assess the K-L arthritis grade preoperatively. The K-L grades were defined as follows: 0, no degenerative change; 1, questionable osteophytes and no joint space narrowing; 2, definite osteophytes with possible joint space narrowing; 3, definite joint space narrowing with moderate multiple osteophytes and some sclerosis; and 4, severe joint space narrowing with cysts, osteophytes, and sclerosis [15]. Radiographic images were examined independently by two orthopedic surgeons blinded to the procedures using the digital caliper function of a picture archiving and communication system (PACS). FTA can be measured up to the unit digit. Two observers independently measured each radiological outcome, and the averages of these measurements were used in analysis.

Three-dimensional (3D) CT-based measurements

All patients underwent CT examination 1 week postoperatively. CT images were obtained with an Asteion 4 Multislice CT System (Toshiba Medical Systems, Tochigi, Japan) using 120 kVp and 150 mA, and 1-mm slice thickness. CT reconstruction of the tibial condyles in the axial plane [23] was completed using a three-dimensional volume-rendering technique (AZE Virtual Place software; AZE Ltd., Tokyo, Japan). 3D-CT images of the tibial surface were evaluated using a rectangular measurement grid as described by Tsukada et al. [31]. 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 plateaus were placed on the horizontal level (Fig.

2). The location on the tibial surface was assessed using a percentage-dependent method [31] and the location of a critical point was determined by two coordinates (one on an anteroposterior [AP] axis and the other one on an ML axis). The anatomic center of the MM posterior root attachment and tibial tunnel center were determined according to a previous study [8]. The anatomic center of the MM posterior root attachment was the center of a virtual circle that joined the three sides (anterior border of the PCL tibial attachment, lateral margin of the medial tibial plateau, and retro-eminence ridge [33]) of the triangular footprint of the MM posterior root, and the tibial tunnel center was the central point of the circular or oval tunnel aperture. The percentage distance between the anatomic center and tunnel center was calculated using the Pythagorean theorem: $(\text{percentage distance})^2 = (\text{difference between the AP percentage of each center; } \Delta\text{Posterior})^2 + (\text{difference between the ML percentage of each center; } \Delta\text{Lateral})^2$ [8] (Fig. 2). We also calculated the absolute distance as the minimum distance between the anatomic center and tunnel center. 3D-CT measurements that allowed one decimal value were documented two times at six-week intervals to assess intra-observer reliability. The averages of these measurements were used in analysis.

MRI measurements

MRI was performed preoperatively and 3 months postoperatively using an Achieva 1.5 T (Philips, Amsterdam, The Netherlands) and an Oasis 1.2 T (Hitachi Medical, Chiba, Japan) with a coil under a non-weight-bearing 10° knee flexion position. Standard sequences of the Achieva included sagittal (repetition time [TR]/echo time [TE], 601/14), coronal (TR/TE, 553/14) T2-weighted multi-echo with a 30° flip angle, and axial (TR/TE, 4330/104) T2 BLADE fat saturation with a 150° flip angle. The slice thickness was 3 mm with a 0.6-mm gap. The field of view was 16 cm with an acquisition matrix size of 205 × 256. 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 10° flip angle and coronal T2-weighted multi-echo sequence (TR/TE, 4600/84) with a 10° 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 × 416 [7, 11]. The MM medial extrusion (MMME) was measured as the distance from the medial edge of the tibial plateau cartilage to the medial border of the MM (Fig. 3a). The MM posterior extrusion at 10° (MMPE [10°]) and 90° (MMPE [90°]) knee flexion 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 were noted as a positive value, and absence of extrusion as a negative value (Fig. 3b, 3c). MMME or MMPE measurements were obtained in the mid-coronal plane or in the mid-sagittal plane by linking the sagittal or coronal image series, respectively. The MMME and MMPE were evaluated independently by two reviewers using the PACS. The mean value of each observer's measurement was obtained [13].

ΔMMME was calculated as follows; ΔMMME = (preoperative MMME) – (postoperative MMME). A negative value of ΔMMME indicated improvement of MMME after pullout repair and a positive value of ΔMMME indicated that postoperative MMME had worsened compared to the preoperative result [14]. ΔMMPE (10°) and ΔMMPE (90°) was calculated in the same way.

Clinical outcome evaluations

Clinical outcomes were assessed preoperatively and at 1-year follow-up after the surgery, using the Knee Injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee (IKDC) subjective knee evaluation form, Lysholm knee score, Tegner activity level scale, and visual analogue scale (VAS) as pain score. Preoperative results were compared with the 1-year follow-up results. The KOOS consists of five subscales: pain, symptoms, activities of daily living (ADL), sport and recreation function (sport/rec), and knee-related quality of life (QOL).

Statistical analysis

Values are expressed as mean ± standard deviation (SD) unless otherwise indicated. Statistical significance was set at $p < 0.05$. The Wilcoxon signed-rank test was used to compare the preoperative and the postoperative results. The Chi-square test was used for sex, MMPRT type and K-L grade comparison, and the Mann-Whitney U-test was used for the other items to compare between two groups. Correlation analyses were performed using a Spearman's rank correlation analysis. Statistical calculations were performed using EZR-WIN software (Saitama Medical Center, Saitama, Japan). The inter-observer and intra-observer reliabilities were assessed with the intra-class correlation coefficient (ICC). All measurements were completed by two independent orthopedic surgeons to determine inter-observer reliability using the ICC. Each observer repeated the measurements with a 6-week interval to determine intra-observer reliability. An ICC >0.80 was considered to represent a reliable measurement. The sample size was estimated for a minimal statistical power of 80% ($\alpha = 0.05$). In the Spearman's rank correlation analysis, a sample of 29 patients was sufficient to detect an effect size of $d = 0.5$ with 80% statistical power.

Results

From 2016 to 2018, a total of 64 MMPRTs were identified in 64 patients (17 men, 47 women) with a median age of 63 years (range, 35–72 years) at our institution. Of the 64 MMPRTs, 34 patients were excluded according to the exclusion criteria (Fig. 1). Therefore, 30 MMPRTs in 30 patients were included in the final analysis. As for MMPE (90°), eight patients were excluded because they did not have MR images in 90° knee flexion.

Twenty-seven out of 30 patients had a radial tear (type 2) and three patients had an oblique tear (type 4). In radiographic evaluations, the mean preoperative FTA was 176.8 ± 1.8° (range, 173–179°). We found six patients with no radiographic osteoarthritis (OA) and 24 patients with mild radiographic OA in the medial compartment, including 16 patients diagnosed with K-L grade 1 and eight patients with K-L grade 2. The mean ICC values for inter-observer and intra-observer reliabilities were 0.88 and 0.91, respectively. Patient demographics are reported in Table 1.

The anatomic center of the MM posterior root footprint was located at a mean position of 78.1% ± 2.9% posteriorly and 39.6% ± 2.6% laterally (Table 3). The tibial tunnel center of the MM posterior root was located at a mean position of 70.0% ± 4.9% posteriorly and 38.3% ± 2.7% laterally. The tibial tunnel centers were thus located more anteriorly and medially compared to the anatomic center (Fig. 4). The mean absolute distance between the tibial tunnel center and the MM posterior root anatomic center is 5.1 ± 2.3 mm. The inter-observer and intra-observer reliabilities were considered high, with mean ICC values of 0.88 and 0.90, respectively.

In MRI evaluations, the postoperative MMPE (90°) was significantly reduced after pullout repair, although there was no significant difference in the preoperative and postoperative MMME, or preoperative and postoperative MMPE (10°) (Table 2). Regarding MRI measurements, the mean ICC values for inter-observer and intra-observer reliabilities were 0.86 and 0.89, respectively.

In the correlation analysis between the displacement from the anatomic center to the tibial tunnel center and improvement in MMME, MMPE (10°), and MMPE (90°), there was a significant positive correlation only between the percentage distance and ΔMMPE (90°) ($r_s = 0.46$; $p = 0.03$, Fig. 5). The same was true of the absolute distance and ΔMMPE (90°) ($r_s = 0.47$; $p = 0.03$, Table 3). However, there were little correlations between preoperative FTA or BMI and improvement in MMME, MMPE (10°), and MMPE (90°) (Table 3).

Patients were divided into two groups according to the previous study [20]: anatomic group, which represented patients whose distances between the tibial tunnel center and the MM posterior root anatomic center were ≤ 5.0 mm, and non-anatomic group, which represented patients whose distances between the two points were > 5.0 mm. Patients of the anatomic group were significantly smaller than those of the non-anatomic group (p = 0.02). The improvement of MMPE at 90° flexion of the anatomic group was significantly better than that of the non-anatomic group (p = 0.02) (Table 4). In the evaluation of clinical outcomes, the 1-year postoperative scores showed significant improvement when compared with the preoperative scores in all the items assessed in both groups. However, there was no significant difference in any of the clinical scores between the anatomic group and the non-anatomic group preoperatively, and at 1-year follow-up after the surgery, excluding the preoperative Lysholm knee score ($p = 0.03$) (Fig. 6).

Discussion

The most important finding of our study was that transtibial pullout repair of MMPRTs reduces MM posterior extrusion at 90° knee flexion, and the nearer the tibial tunnel position to the anatomic attachment of the MM posterior root, the more effective the reduction of postoperative MM posterior extrusion at 90° knee flexion. Furthermore, the mean reduced distance of postoperative MM posterior extrusion at 90° knee flexion in anatomic group was twice better than that in non-anatomic group. Our results emphasize that surgeons should create an anatomic tibial tunnel of the MM posterior root to improve postoperative MMPE.

There are several possible reasons why cases with larger percentage and absolute distances did not show the same postoperative MMPE reduction at 90° knee flexion as those with smaller percentage and absolute distances. We considered that in the knee extension position, tension on the MM posterior segment and pullout suture might not be as tight, even when a non-anatomic tibial tunnel is created. On the other hand, when the knee is flexed to 90°, the MM extrudes in a posteromedial direction [27], and excessive load on the posterior part of the MM [32] creates tension that is too tight to endure and this might result in suture loosening or tearing (Fig. 7). A cadaveric study demonstrated that non-anatomic repair, which was placed 5 mm posteromedially from the MM posterior root attachments, did not restore the contact area or mean contact pressure to that of the intact knee or the anatomic repair knee [20]. In this study, mean reduction of the MMPE at 90° knee flexion in the anatomic group was twice better than that in the non-anatomic group (1.8 mm vs. 0.9 mm). Although the displacement direction of the tibial tunnel from the MM anatomic attachment is different between the above cadaveric study and this clinical study, the displacement itself would result in preventing the repaired MM from regaining the original hoop structure. From these findings, surgeons should recognize the necessity to create an anatomic tibial tunnel of the MM posterior root, at least within 5 mm from the anatomic attachment. However, it is unclear how much displacement can be accepted. Further research is required to confirm this point.

In this study, tibial tunnel positions were located more anteriorly and medially than the MM posterior root attachments. This result was similar to a previous study [8]. One of the reasons for the discrepancy may be that it is difficult for surgeons to view the MM posterior root attachment through an arthroscope because it is located posterior to the apex of the medial tibial eminence. Another reason may be the relationship between the insertion angle of the guide pin and the posterior slope of the MM posterior attachment, which would lead to creation of a tibial tunnel anterior to the position where the surgeon wants to create a tunnel. Surgeons should have a complete understanding of the surgical technique so that an exact anatomic tibial tunnel can be created during pullout repair of MMPRTs so as to improve MM stability.

A negative finding of this study was that postoperative MMME and MMPE at 10° knee flexion were not significantly reduced using the F-MMA technique, although postoperative 1-year clinical outcomes were significantly improved in comparison with preoperative ones. A morphological analysis using 3D-MRI suggested that pullout repair may have an effect of reducing not medial extrusion but pathological posteromedial extrusion of the knee flexion in patients with MMPRTs [25]. Another study demonstrated that suppression of cartilage degeneration was observed at medial and posterior parts of medial femoral condyle (MFC) at 12 months after pullout repair, although progression of cartilage degeneration was observed especially at anteromedial part of MFC [18]. On the other hand, it was reported that two simple stitches technique, additional surgical augmentation like centralization technique or an early pullout repair surgery after injury can be effective in reducing MMME [10, 14, 19]. Therefore, we should improve a surgical strategy for reducing MMME in order to get better MM function and prevent articular cartilage from degeneration.

There were several limitations to this study. First, we did not address the direction of the percentage distance. However, 96.7% of patients (29/30) were located at a more anterior position compared to the anatomic attachment and the improvement of postoperative MMPE at 90° knee flexion exhibited a significant positive correlation with percentage distance. Second, we evaluated MM extrusions using short-term follow-up MRI after pullout repair. In this study, the patients underwent postoperative MRI at a mean of 3 months after pullout repair. Therefore, postoperative MRI may directly detect the effect of the pullout repair of MMPRTs. Third, we did not evaluate long-term clinical outcomes. Further studies are required to evaluate the transitional impact of MRI measurements to clinical outcomes. Nevertheless, this study is clinically relevant as it discusses the importance of creating an anatomic tibial tunnel to improve the medial meniscus posterior extrusion at 90˚ knee flexion.

Conclusions

This study demonstrated that transtibial pullout repair of MMPRTs reduced MM posterior extrusion at 90° knee flexion. The nearer the tibial tunnel position to the anatomic attachment of the MM posterior root, the more effective the reduction of the postoperative MM posterior extrusion at 90° knee flexion. Our results emphasize that an anatomic tibial tunnel should be created in the MM posterior root to improve the postoperative MM posterior extrusion and protect the articular cartilage during knee flexion.

Compliance with Ethical Standards

Conflict of interest

The authors have no conflicts of interests to declare.

Funding

No funding was received for this research.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Figure legends

Fig. 1 Flow chart detailing the study protocol

MMPRT, medial meniscus posterior root tear; MMME, medial meniscus medial extrusion. MMPE, medial meniscus posterior extrusion

Fig. 2 Measurements of anatomic center (Ac) and tibial tunnel center (Tc)

The location on the three-dimensional CT-based tibial surface is expressed as a posterolateral percentage using Tsukada's method [21]. White dashed circle: expected anatomic attachment of the medial meniscus (MM) posterior root. White triangle: MM posterior root attachment anatomic center (Ac). White dot: tibial tunnel center (Tc). White double line: percentage distance between the anatomic center and tunnel center. ΔPosterior: difference between the anteroposterior percentage of each center. ΔLateral: difference between the mediolateral percentage of each center.

Fig. 3 MRI-based measurements in the mid-coronal plane of the right knee flexed at 10° and in the mid-sagittal plane of the right knee flexed at 10° and 90°

(a) Medial meniscus medial extrusion at 10° knee flexion. (b) Medial meniscus posterior extrusion at 10° knee flexion. (c) Medial meniscus posterior extrusion at 90° knee flexion. Dotted line: medial or posterior edge of medial tibial plateau. Solid line: medial or posterior border of the medial meniscus. White arrow: distance from medial or posterior edge of medial tibial plateau to medial or posterior border of the medial meniscus.

MFC, medial femoral condyle; MTP, medial tibial plateau

Fig. 4 Respective locations of (a) anatomic centers and (b) tibial tunnel centers

(a) The mean of the MM posterior root anatomic center is 78.1% posterior and 39.6% lateral (black dot) on a three-dimensional CT image of the tibial surface. White dots indicate the location in each case. (b) The mean of the tibial tunnel center is 70.0% posterior and 38.3% lateral (black triangle). White triangles indicate the location in each case. The mean distance between the MM posterior root anatomic center and the tibial tunnel center is 5.1 ± 2.3 mm.

Fig. 5 Correlation analysis of the three tibial tunnel position parameters and postoperative increase in medial meniscus or posterior extrusions

ΔPosterior and (a) ΔMMME (r_s = -0.17, *n.s.*), (b) ΔMMPE (10°) (r_s = -0.09, *n.s.*), and (c) ΔMMPE (90°) (r_s = -0.28, *n.s.*). ΔLateral and (d) ΔMMME (r_s = 0.02, *n.s.*), (e) ΔMMPE (10°) (r_s = -0.13, *n.s.*), and (f) ΔMMPE (90°) (r_s = -0.29, *n.s.*). Percentage distance and (g) ΔMMME (r_s = 0.27, *n.s.*), (h) ΔMMPE (10°) (r_s = 0.23, *n.s.*), and (i) ΔMMPE (90°) (r_s = 0.46, p = *0.03*). Black dots, triangles, and squares denote each case. The grey, light blue, and red dots lines show little, weak and moderate correlation, respectively, between two items. There is a significant positive correlation between percentage distance and ΔMMPE (90°).

Fig. 6 Between-group comparisons of clinical outcomes

Data were collected preoperatively and at 1-year follow-up. All scores were significantly improved at the 1-year follow-up after surgery ($p < 0.05$). However, there was no significant difference between the anatomic and non-anatomic groups, excluding the preoperative Lysholm knee score ($p = 0.03$). KOOS, Knee Injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sport/Rec, sport and recreation function; QOL, quality of life. IKDC, International Knee Documentation Committee subjective knee evaluation form; VAS, visual analogue scale.

Fig. 7 Theory of how malposition of tibial tunnel affects the reduction of MM posterior extrusion at 90° knee flexion

(a) MRI of a volunteer's normal knee. (b) During knee extension, the tension between the medial meniscus posterior segment and pullout suture might not be tight even if a nonanatomic tibial tunnel is created. (c)(d) When the knee is flexed to 90°, the tension may be too tight to endure and result in loosening or tearing of the sutures.

References

1. Allaire R, Muriuki M, Gilbertson L, Harner CD (2008) Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. J Bone Joint Surg Am 90:1922-1931
2. Chahla J, LaPrade RF (2019) Meniscal Root Tears. Arthroscopy 35:1304-1305
3. Chung KS, Ha JK, Ra HJ, Lee HS, Lee DW, Park JH, et al. (2019) Pullout fixation for medial meniscus posterior root tears: clinical results were not age-dependent, but osteoarthritis progressed. Knee Surg Sports Traumatol Arthrosc 27:189-196
4. Chung KS, Ha JK, Ra HJ, Nam GW, Kim JG (2017) Pullout Fixation of Posterior Medial Meniscus Root Tears: Correlation Between Meniscus Extrusion and Midterm Clinical Results. Am J Sports Med 45:42-49
5. Daney BT, Aman ZS, Krob JJ, Storaci HW, Brady AW, Nakama G, et al. (2019) Utilization of Transtibial Centralization Suture Best Minimizes Extrusion and Restores Tibiofemoral Contact Mechanics for Anatomic Medial Meniscal Root Repairs in a Cadaveric Model. Am J Sports Med 47:1591-1600
6. Fujii M, Furumatsu T, Kodama Y, Miyazawa S, Hino T, Kamatsuki Y, et al. (2017) A novel suture technique using the FasT-Fix combined with Ultrabraid for pullout repair of the medial meniscus posterior root tear. Eur J Orthop

Surg Traumatol 27:559-562

7. Fujii M, Furumatsu T, Miyazawa S, Okada Y, Tanaka T, Ozaki T, et al. (2015) Intercondylar notch size influences cyclops formation after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 23:1092-1099
8. Furumatsu T, Kodama Y, Fujii M, Tanaka T, Hino T, Kamatsuki Y, et al. (2017) A new aiming guide can create the tibial tunnel at favorable position in transtibial pullout repair for the medial meniscus posterior root tear. Orthop Traumatol Surg Res 103:367-371
9. Hino T, Furumatsu T, Miyazawa S, Fujii M, Kodama Y, Kamatsuki Y, et al. (2019) A histological study of the medial meniscus posterior root tibial insertion. Connect Tissue Res. doi: 10.1080/03008207.2019.1631298. Online ahead of print.
10. Hiranaka T, Furumatsu T, Masuda S, Okazaki Y, Okazaki Y, Kodama Y, et al. (2020) A repair technique using two simple stitches reduces the short-term postoperative medial meniscus extrusion after pullout repair for medial meniscus posterior root tear. Eur J Orthop Surg Traumatol. doi: 10.1007/s00590-020-02647-w. Online ahead of print.
11. Inoue H, Furumatsu T, Miyazawa S, Fujii M, Kodama Y, Ozaki T (2018) Improvement in the medial meniscus posterior shift following anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 26:434-441
12. Johannsen AM, Civitarese DM, Padalecki JR, Goldsmith MT, Wijdicks CA, LaPrade RF (2012) Qualitative and quantitative anatomic analysis of the posterior root attachments of the medial and lateral menisci. Am J Sports Med 40:2342-2347
13. Kamatsuki Y, Furumatsu T, Fujii M, Kodama Y, Miyazawa S, Hino T, et al. (2018) Complete tear of the lateral meniscus posterior root is associated with meniscal extrusion in anterior cruciate ligament deficient knees. J Orthop Res
14. Kamatsuki Y, Furumatsu T, Miyazawa S, Kodama Y, Hino T, Okazaki Y, et al. (2019) The Early Arthroscopic Pullout Repair of Medial Meniscus Posterior Root Tear Is More Effective for Reducing Medial Meniscus Extrusion. Acta Med Okayama 73:503-510
15. Kellgren JH, Lawrence JS (1957) Radiological assessment of osteo-arthrosis. Ann Rheum Dis 16:494-502
16. Kim NK, Bin SI, Kim JM, Lee BS, Lee CR (2019) Meniscal extrusion is positively correlated with the anatomical position changes of the meniscal anterior and posterior horns, following medial meniscal allograft transplantation. Knee Surg Sports Traumatol Arthrosc 27:2389-2399
17. Kodama Y, Furumatsu T, Fujii M, Tanaka T, Miyazawa S, Ozaki T (2016) Pullout repair of a medial meniscus posterior root tear using a FasT-Fix((R)) all-inside suture technique. Orthop Traumatol Surg Res 102:951-954
18. Kodama Y, Furumatsu T, Masuda S, Okazaki Y, Kamatsuki Y, Okazaki Y, et al. (2019) Transtibial fixation for medial meniscus posterior root tear reduces posterior extrusion and physiological translation of the medial meniscus in middle-aged and elderly patients. Knee Surg Sports Traumatol Arthrosc. doi: 10.1007/s00167-019-05810-x. Online ahead of print.
19. Koga H, Watanabe T, Horie M, Katagiri H, Otabe K, Ohara T, et al. (2017) Augmentation of the Pullout Repair of a Medial Meniscus Posterior Root Tear by Arthroscopic Centralization. Arthrosc Tech 6:e1335-e1339

20. LaPrade CM, Foad A, Smith SD, Turnbull TL, Dornan GJ, Engebretsen L, et al. (2015) Biomechanical consequences of a nonanatomic posterior medial meniscal root repair. Am J Sports Med 43:912-920
21. Marzo JM, Gurske-DePerio J (2009) Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. Am J Sports Med 37:124-129
22. Masuda S, Furumatsu T, Okazaki Y, Kamatsuki Y, Okazaki Y, Kodama Y, et al. (2019) Transtibial Pullout Repair Reduces Posterior Extrusion of the Medial Meniscus. Acta Med Okayama 73:495-501
23. Masuda S, Furumatsu T, Okazaki Y, Kodama Y, Hino T, Kamatsuki Y, et al. (2018) Medial meniscus posterior root tear induces pathological posterior extrusion of the meniscus in the knee-flexed position: An open magnetic resonance imaging analysis. Orthop Traumatol Surg Res 104:485-489
24. Okazaki Y, Furumatsu T, Kodama Y, Kamatsuki Y, Masuda S, Ozaki T (2019) Description of a surgical technique of medial meniscus root repair: a fixation technique with two simple stiches under an expected initial tension. Eur J Orthop Surg Traumatol 29:705-709
25. Okazaki Y, Furumatsu T, Okazaki Y, Masuda S, Hiranaka T, Kodama Y, et al. (2020) Medial meniscus posterior root repair decreases posteromedial extrusion of the medial meniscus during knee flexion. Knee 27:132-139
26. Okazaki Y, Furumatsu T, Shimamura Y, Saiga K, Ohashi H, Uchino T, et al. (2019) Time-Dependent Increase in Medial Meniscus Extrusion after Medial Meniscus Posterior Root Tear Analyzed by Using Magnetic Resonance Imaging. Knee Surg Relat Res 31:120-125
27. Okazaki Y, Furumatsu T, Yamaguchi T, Kodama Y, Kamatsuki Y, Masuda S, et al. (2019) Medial meniscus posterior root tear causes swelling of the medial meniscus and expansion of the extruded meniscus: a comparative analysis between 2D and 3D MRI. Knee Surg Sports Traumatol Arthrosc. doi: 10.1007/s00167-019-05580-6. Online ahead of print.
28. Padalecki JR, Jansson KS, Smith SD, Dornan GJ, Pierce CM, Wijdicks CA, et al. (2014) Biomechanical consequences of a complete radial tear adjacent to the medial meniscus posterior root attachment site: in situ pull-out repair restores derangement of joint mechanics. Am J Sports Med 42:699-707
29. Park JY, Kim BH, Ro DH, Lee MC, Han HS (2019) Characteristic location and rapid progression of medial femoral condylar chondral lesions accompanying medial meniscus posterior root tear. Knee 26:673-678
30. Todor A, Caterev S, Nistor DV (2016) Outside-In Deep Medial Collateral Ligament Release During Arthroscopic Medial Meniscus Surgery. Arthrosc Tech 5:e781-e785
31. Tsukada H, Ishibashi Y, Tsuda E, Fukuda A, Toh S (2008) Anatomical analysis of the anterior cruciate ligament femoral and tibial footprints. J Orthop Sci 13:122-129
32. Walker PS, Arno S, Bell C, Salvadore G, Borukhov I, Oh C (2015) Function of the medial meniscus in force transmission and stability. J Biomech 48:1383-1388
33. Ziegler CG, Pietrini SD, Westerhaus BD, Anderson CJ, Wijdicks CA, Johansen S, et al. (2011) Arthroscopically pertinent landmarks for tunnel positioning in single-bundle and double-bundle anterior cruciate ligament reconstructions. Am J Sports Med 39:743-752