Transtibial fixation for medial meniscus posterior root tear reduces posterior extrusion and physiological translation of the medial meniscus in middle-aged and elderly patients

Abstract

Purpose: To investigate changes in meniscal extrusion during knee flexion before and after pullout fixation for medial meniscus posterior root tears (MMPRTs) and determine whether these changes correlate with articular cartilage degeneration and short-term clinical outcomes.

Methods: Twenty-two patients (mean age, 58.4±8.2 years) diagnosed with type II MMPRT underwent open MRI preoperatively, 3-months after transtibial fixation, and at 12-months after surgery, when second-look arthroscopy was also performed. The medial meniscus (MM) medial and posterior extrusion (MMME and MMPE) were measured at knee 10° and 90° flexion; at which MM posterior translation was also calculated. Articular cartilage degeneration was assessed using ICRS grade at primary surgery and second-look arthroscopy. Clinical evaluations included Knee Injury and Osteoarthritis Outcome Score, International Knee Documentation Committee subjective knee evaluation form, Lysholm score, Tegner activity level scale, and visual analog scale.

Results: MMME at 10˚ knee flexion was higher 12 months postoperatively than preoperatively (4.77±1.48 vs. 3.53±1.17, $p=0.012$). MMPE at 90˚ knee flexion and MM posterior translation were smaller 12 months postoperatively than preoperatively (3.49±1.05 vs. 4.60±1.27, 7.23±1.74 vs. 8.89±1.98, $p<0.001$). Articular cartilage degeneration of medial femoral condyle correlated with

MMME in knee extension (r=0.48, p=0.04). All clinical scores significantly improved 12 months postoperatively; however, correlations of all clinical scores against decreased MMPE and increased MMME were not detected.

Conclusions: MMPRT transtibial fixation suppressed the progression of MMPE and cartilage degeneration and progressed MMME minimally in knee flexion position at one-year. However, in the knee extension position, MMME progressed and correlated with MFC cartilage degeneration.

Level of Evidence: IV

Keywords: Medial meniscus; Posterior root tear; transtibial fixation; Meniscus extrusion; Open magnetic resonance imaging.

Introduction

Many studies have shown that medial meniscus (MM) posterior root tears (PRT) are associated with osteoarthritis; 31% of patients with MMPRT undergo subsequent TKA at a mean duration of 30 months after conservative treatment [19]. The medial meniscus is rigidly attached to the tibia and is therefore less mobile, making it more vulnerable to traumatic injuries and degenerative changes than the lateral meniscus [13, 21]. Therefore, loss of hoop strain caused by MMPRT leads to a physiological state equivalent to total meniscectomy and can accelerate the process of degenerative arthritis with meniscal extrusion [1, 4, 7]. Due to repair of hoop tension, several meniscus repair techniques such as transtibial fixation, suture anchor-dependent repair, direct all-inside repair, and posterior reattachment of the MM posterior root have been developed for arthroscopic treatment of MMPRT [4, 6, 16, 21]. LaPrade et al. described that MM posterior root repair is indicated in active patients following acute or chronic MMPRTs with no significant knee osteoarthritis, joint space narrowing, and malalignment [21]. Chung et al. described that midterm clinical outcomes after transtibial fixation are not age-dependent [5]. They preferred transtibial fixation because of its lower technical challenges and ability to restore anatomic attachment of the MM posterior root [8, 21]. Although there is currently a lack of consensus regarding the superior technique, transtibial fixation is increasingly being used in clinical practice. A meta-analysis on the outcomes of MMPRT fixation in transtibial fixation [4] demonstrated good midterm results after surgery but revealed that MM medial extrusion does not necessarily affect clinical outcomes such as the Lysholm knee score and International Knee Documentation Committee

(IKDC) evaluation. However, these knee scores are not suitable for evaluating middle-aged or older patients who develop MMPRTs during light activities such as using stairs and squatting [2]. MMPRT with a degenerating meniscus is reported in middle-aged or older people due to their lifestyle and behaviors, including frequent squatting and sitting on the floor with folded legs [2]. These behaviors may lead to an increased risk of posterior meniscal segment impingement, and injury due to degenerated MMPRs may occur at low knee flexion angles when performing activities, such as descending stairs, stepping, and walking downhill [3, 11]. Additionally, most meniscal tears, including radial tears occurring within 9 mm from the root attachment, are classified as Type II in middle-aged and older individuals [17, 21]. However, few studies have reported MM conditions, including the extrusion and translation of the meniscus during knee flexion pre- and postoperative MMPRT.

An open MRI analysis found that MMPRT caused pathological posterior extrusion of the MM medial and posterior segment at 90° knee flexion [23, 24]. Therefore, analysis of MM medial/posterior extrusion (MMME/MMPE) in older patients after transtibial fixation of MMPRT using open MRI is clinically useful in assessing MM conditions, especially at 90° knee flexion.

Performing MMPRT fixation in elderly patients remains potentially controversial; surgeons may hesitate to perform surgical fixation in such patients due to their lower ability to heal. The purpose of this study was to investigate pre- and postoperative changes in meniscal extrusion of the medial and posterior segments in MMPRT patients using open MRI in knee extension and flexion positions and to determine whether these extrusions correlated with cartilage damage and short-term clinical outcomes, including the Knee Injury and Osteoarthritis Outcome Score (KOOS). We hypothesized that transtibial fixation in MMPRT patients does not suppress the progression of MMME and cartilage degeneration during knee extension but is useful for suppressing the progression of MMPE and cartilage degeneration in knee flexion position.

Even in elderly patients with low healing ability, transtibial fixation of MMPRT can be clinically relevant if improvements in meniscal extrusion and suppression of cartilage degeneration are observed in the knee flexion position; this would hold true even if the remaining meniscal medial extrusion was in the knee extension position. In addition, it is clinically meaningful to further improve surgical techniques by examining in detail the relationship between cartilage damage and meniscal extrusion during knee extension and flexion positions.

Methods

Patients

This study was retrospective in nature. All medical records were reviewed retrospectively to obtain patients' demographic and clinical characteristics from a database at our institution. The medical records for 51 consecutive patients receiving transtibial fixation between March 1, 2016 and October 31, 2017 were reviewed. All patients had an episode of sudden posteromedial painful popping, continuous knee pain, and prolonged pooling of joint fluid [3]. MMPRTs were classified according to the description by LaPrade [20] into 5 tear types at surgery: type I tears were partially stable meniscal tears within 9 mm of the center of the root attachment (n=1), type II tears were complete radial tears within 9 mm of the center of the root attachment (n=46), type III tears were bucket-handle tears with meniscal root detachment (n=0), type IV tears were complex oblique meniscal tears extending into the root attachment (n=4), and type V tears were avulsion fractures of the meniscal root attachment (n=0) [20]. The exclusion criteria were: (a) more than 70 years old and a body mass index (BMI) greater than 30 kg/m^2, included varus alignment > 5º, severe cartilage lesion (International Cartilage Research Society grade III or IV), and Kellgren-Lawrence grade > III in radiographs. (b) Other than type II MMPRT. Among these 51 patients, 46 were diagnosed with type II MMPRT under arthroscopic findings. Among the remaining 5 patients, one was diagnosed with type I MMPRT and four were diagnosed with Type IV MMPRT. These 5 patients were excluded. Among the included 46 patients, 22 underwent open MRI preoperatively, as well as 3 and 12 months after surgery. Second-look arthroscopic evaluation was performed in all cases. This retrospective study analyzed the changes in MMME and MMPE after transtibial fixation using open MRI and assessed cartilage degeneration using arthroscopic images and video recordings. Patients were treated with a modified transtibial suture technique combined with FasT-Fix® (Smith & Nephew, Andover, MA, USA) after creating the tibial bone tunnel with a PRT guide, as previously described [7, 10, 18, 31]. We reviewed the patients' medical records to determine age, sex, height, body weight, BMI, as well as preoperative, and 3-month and 12-month postoperative clinical outcomes. The patient demographics are summarized in Table 1.

Arthroscopic evaluation (Cartilage status, Anterior Cruciate ligament status)

Arthroscopic assessment of the cartilage lesions and anterior cruciate ligament (ACL) were performed using arthroscopic images and video recordings. Evaluation of the cartilage and its documentation were carried out using the same ICRS articular cartilage lesion classification system at primary surgery and second-look arthroscopy. Articular surfaces on the medial/lateral femoral condyle (MFC/LFC) were divided into 9 segments (MF 1-9, LF 1-9). The medial/lateral tibia plateau (MTP/LTP) was divided into 5 segments (MT 1-5, LT 1-5). The trochlea was divided into 3 segments (T 1-3) and the patella was divided into 9 segments (P 1-9) (Figure 3). The ACL was evaluated using synovial coverage grade at primary surgery and at second-look arthroscopy.

Surgical procedure

Surgical indications of MMPRT repair in patients under 70 years old and a BMI less than 30 kg/m^2 included varus alignment < 5º, mild cartilage lesion (International Cartilage Research Society low grade I or II), and Kellgren–Lawrence grade 0–II in radiographs. 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) 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 of the medial collateral ligament with a standard 18-gauge hollow needle (TERUMO, Tokyo, Japan) [28]. The posterior meniscal peripheral attachment of the MM was detached using a rasp to gain meniscal mobility. In the modified transtibial suture combined with FasT-Fix technique, a Knee Scorpion suture was passed (Arthrex, Naples, FL, USA) was used to pass a No. 2 Ultrabraid (Smith & Nephew) vertically through the meniscal tissue (figure 4a). 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 [7, 8, 10] (figure 4b, c). The PRT guide (Smith & Nephew), which can create the tibial tunnel at a favorable position because of a narrow twisting/curving shape during transtibial fixation for MMPRT, was placed at the center of the attachment area [9] A 2.4-mm guide pin was inserted, using the PRT guide, at a 55° angle to the articular surface, and a 4.5-mm cannulated drill was used to over-drill [18]. The free ends of the sutures were pulled out through the tibial tunnel using a suture manipulator (figure 4d, e). Gentle tension was applied to the sutures until the posterior horn reached its tibial attachment area. The pulled sutures were rigidly tied 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 [7, 8, 18].

Postoperative Rehabilitation

The postoperative rehabilitation protocol was similar for all patients. All patients were initially kept non-weight bearing in the knee immobilizer for 2 weeks after surgery. Knee flexion exercises were 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 [7].

MRI measurements

Open MRI scanning was performed in the supine position preoperatively, and at 3 months and 12 months postoperatively using an Oasis 1.2 T (Hitachi Medical, Chiba, Japan) with a coil in the 10° (Figure 1a) and 90° (Figure 1b) knee-flexed positions under non-weight-bearing conditions. 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 90° flip angle and coronal T2-weighted multi-echo sequence (TR/TE, 4600/84) with a 90° 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 (phase) × 416 (frequency) [23]. MM measurements were performed using a simple MRI-based meniscal sizing technique on the sagittal and coronal views at knee flexion angles of 10° and 90°.

The MM medial extrusion was measured as the distance from the medial edge of the tibial plateau cartilage to the medial border of the MM. MM extrusion measurements were obtained in the mid-coronal plane by linking the coronal and sagittal image series (Figure 1c, 1d) [14].

The details of the MM posterior extrusion measurements were determined from a previously described method [19]. MM posterior extrusion was measured using a line passing orthogonally through the medial tibial plateau, which is the distance from the posterior edge of the tibia (excluding osteophytes) to the posterior edge of the MM (Figure 1e, 1f). Using the posterior edge of the tibia as the standard, extrusions toward the posterior from the tibial edge represented a positive value, whereas a negative value was defined as the absence of such extrusions. The MMME and MMPE were measured from the osteophyte-excluded outer and posterior margin of the medial tibial plateau to the outer and posterior edge of the MM, respectively.

Clinical outcome evaluations

Clinical outcomes were assessed preoperatively and at the 3-month, 6-month, and 12-month follow-ups after the surgery using the Knee Injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee (IKDC) subjective knee evaluation form, Lysholm score, Tegner activity level scale, and visual analog scale (VAS) as indicators of pain score. Preoperative results were compared with the 3-month, 6-month and 12-month 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) outcomes.

Statistical analyses

Statistical analyses were performed using EZR software (Saitama Medical Center Jichi Medical

University, Tochigi, Japan). Data are expressed as mean ± standard deviation (SD), unless otherwise indicated. Statistical significance was set at $p < 0.05$. The repeated measures analysis of variance (ANOVA) was used to compare the preoperative and postoperative clinical scores. One-way ANOVA with Dunnett's multiple comparison post-hoc test was used to compare the preoperative and postoperative MRI data. The averages of these measurements were used in analysis. Differences in cartilage degeneration between primary and second-look arthroscopy were determined by using the Wilcoxon signed-rank test. The Spearman rank correlation was calculated to assess the correlation between MM medial extrusion and MM posterior translation and the area with significant change in cartilage degeneration. MRI measurements were completed by two independent orthopedic surgeons to determine inter-observer reliability using the intraclass correlation coefficient (ICC). Each observer repeated the measurements at a 4-week interval to determine intra-observer reliability. Linear regression analysis was used to assess the correlation of all clinical scores at 12 months with MMPE (knee flexion angles of 10° and 90°) and MMME (knee flexion angles of 10° and 90°).

Results

Table 1 shows clinical characteristics of type II MMPRT patients. These patients met surgical indications for MMPRT. Comparing clinical scores before and after transtibial fixation, all scores were significantly greater at the 12-month follow-up after surgery ($p < 0.05$, Figure 2).

The extent of MMME at 10˚ knee flexion was greater at 12 months postoperatively compared to the preoperative measurement (4.77±1.48 vs 3.53±1.17, $p = 0.012$). On the other hand, the extent of MMME at 90˚ knee flexion was greater at 12 months postoperatively, but the difference was not statistically significant (3.28±0.84 vs 2.46±0.58, $p = 0.095$). The extent of MMPE at 90˚ knee flexion was smaller at 3 months and 12 months postoperatively when compared with the preoperative measurement (3.21±1.03, 3.49±1.05 vs 4.60±1.27, $p<0.001$). MM posterior translation during knee flexion between 10˚ and 90˚ was smaller at 3 months and 12 months postoperatively compared with preoperative MM translation (7.07±1.87, 7.23±1.74 vs 8.89±1.98, $p<0.001$) (Table 2). Significant differences in the area of cartilage degeneration were observed between primary surgery and second-look arthroscopy at the medial femoral condyle (MF1-4), medial tibial plateau (T2), patella (P5), and trochlea (T2) (Table 3-5). The cartilage degeneration changes of MF 4 correlated with MMME in knee extension position ($r = 0.48$, $p = 0.04$) (Table 6). At the primary surgery, the ACL synovial coverage grade was A in all cases. However, at the second-look arthroscopy, ACL degeneration (synovial coverage grade B) were observed in one patient. Regarding measurements of MMME, the ICCs for intra-observer repeatability and inter-observer repeatability ranged between 0.823 and 0.876 and 0.873 and 0.902, respectively. For MMPE measurements, the ICCs for intra-observer repeatability and inter-observer repeatability ranged between 0.892 and 0.921 and 0.922 and 0.945, respectively. Correlations of all clinical scores with decreased MMPE and increased MMME were not detected.

Discussion

There were 3 main findings from the present study. First, in type II MMPRT patients, MMPE at 90° knee flexion and MM posterior translation during knee flexion decreased after performing the modified transtibial suture technique combined with FasT-Fix fixation. In addition, suppression of cartilage degeneration was observed in the area of MFC from the middle to the posterior end of the site. Second, MMME at 90° knee flexion did not progress greatly, but did progress at the knee extension position. In addition, progression of partial cartilage degeneration was observed especially at the anteromedial site of MFC and this cartilage degeneration correlated with MMME in the knee extension position. Third, meniscus extrusion did not affect all clinical scores at the 12-month postoperative follow-up.

A biomechanical study that mimicked MMPRT type II (complete radial tear within 9 mm from root attachment) reported a significant reduction in the medial compartment contact area except for the extension knee position. At a knee flexion of 90°, the contact area of the medial compartment decreased by about 40%, while the contact pressure increased by about 70% [25]. Similar results were reported in another biomechanical study; the pathologically decreased contact area and increased contact pressure with a flexed knee were restored by transtibial fixation to the same extent as the intact knee [1]. The results of these biomechanical studies aligned with the results of our study, which indicated that improved MMPE and suppression of cartilage degeneration in the area of MFC from the middle to the posterior end of the site (MF5-9) led to restoration of meniscal hoop tension with the knee in a flexed position. In contrast to the good results reported in biomechanical studies, some reports have demonstrated cartilage degeneration and MMME progression on postoperative magnetic resonance imaging and second-look examinations, regardless of good clinical outcomes [8, 22]. Similar to these results, our study demonstrated that despite MMME progression in the knee extension position and partial cartilage degeneration (especially anteromedial site of MFC cartilage), all clinical outcomes were improved. In addition, MMME in knee extension position and cartilage degeneration of area MF4 showed a moderate correlation. Hasegawa et al. reported that the strongest correlation between ACL and cartilage degeneration was found at the MFC [12]. In this study, we checked the ACL condition using arthroscopic images and video recordings; we could not detect obvious degenerative changes at the primary surgery, but at the second-look arthroscopy, ACL degeneration was observed in one patient. Thus, worsening MFC cartilage degeneration in this study may influence the ACL degeneration. Therefore, additional surgical procedures that can improve MMME in the knee extension position may prevent MFC and ACL degeneration.

In normal knees, the convex femoral condyle slides and rolls on the tibial plateau with knee flexion, and inevitably pushes the meniscus to move backward. During flexion, the meniscus moves backward, and the anteroposterior diameter gradually decreases. The tibiofemoral contact area gradually decreases during flexion because of the large curvature radius at the femoral condyle top and the reduced rearward radius [15]. In the present study, MMME was smaller in the knee flexion position (3.3 mm) than in the knee extension position (4.8 mm). This result may be influenced by the change of curvature radius at the femoral condyle during knee flexion.

If the anterior and posterior cruciate ligaments (ACL/PCL) are normal at 90° knee flexion, anterior translation of the tibia is counteracted by the buttress effect of the medial meniscus [3]. This highlights the role of MM as a secondary stabilizer in knee flexion. In MRI analysis for MMPRT, the posterior translation of MM is 8.6 mm at 90° knee flexion [23]. In addition, the preoperative amount of posterior translation of the MM in MMPRT was very similar (8.9 mm). The amount of posterior translation of the MM after MMPRT repair improved to 7.2 mm, but the amount of posterior translation was about 2 to 3 mm more than that of a normal meniscus (4 to 5 mm) [27, 29]. It was unclear how this difference affected the kinematics (pathological MM translation and rotation of the tibia) in the knee joint. However, MMPRT in elderly patients, which has been considered difficult to repair due to degenerating meniscal tissue and poor healing ability, showed improved MMPE and amount of posterior translation induced by transtibial fixation.

This study did not evaluate MM extrusion (MMME/MMPE) under body weight. The degree of MM extrusion (MMME) is significantly different between loaded and unloaded MRI in those with no osteoarthritis or minimal osteoarthritis [26]. On the other hand, the posterior segment of MM is strongly connected to the posterior joint capsule and the semi-membranous muscle [6]. Since the tension of these structures is increased in the loaded knee extension position, the influence on the MM posterior translation may be small. However, the posterior translation of MM in the loaded knee flexion position is unclear. Thus, further research using ultrasonography that can be applied clinically is required in future studies.

There were several limitations in this study. First, patient records were retrospectively assessed, the sample size was small, and the follow-up period was one year. Second, this study focused on type II MMPRTs; therefore, other tear patterns could not be evaluated. Third, this study did not evaluate MM extrusion (MMME/MMPE) under body weight. Fourth, there was no video recording or image for evaluating PCL, and there was no description of the posterior drawer test in the medical record, so detailed evaluation was not possible. Fifth, since MRI was two-dimensional and did not include axial images, movement of the three-dimensional meniscus was not reflected in the analysis. Morphological analysis of the meniscus should be attempted using three-dimensional MRIs during knee flexion. Future studies should also include more patients with other types of tears and a longer follow-up period.

Conclusions

MMPRT transtibial fixation suppressed the progression of MMPE and cartilage degeneration, and progressed MMME minimally in knee flexion position in a short-term one-year unloaded MRI and arthroscopic evaluation. However, in the knee extension position, MMME progressed and correlated with the MFC cartilage degeneration. The results of this study indicate that transtibial fixation can restore the meniscal morphology at 90° knee flexion, even in elderly patients with poor healing ability. However, the postoperative MM conditions did not affect all good clinical scores by the one-year follow-up.

Compliance with ethical standards

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional review board.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Figure legends

Fig. 1 Magnetic resonance imaging-based measurements: 10° and 90° knee-flexed position in a non-weight-bearing condition (a, b). Coronal and sagittal images of the knee flexed at 10° (c, e) and 90° (d, f). Medial and posterior margins of the medial tibial plateau (solid lines) and medial meniscus (dashed lines).

MMME: medial meniscus medial extrusion, *MMPE:* medial meniscus posterior extrusion

Fig. 2 Time-dependent clinical outcomes. Data were collected preoperatively and at 3-, 6-, and 12-month follow-ups

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 analog scale, *$p < 0.05$.

Fig. 3 Schematic illustrations of the femoral condyle and tibial plateau. (a) The patella was divided into 9 segments. (b) The medial and lateral femoral condyles were divided into 9 segments. (c) The medial and lateral tibial plateaus were divided into 5 segments.

Fig. 4 Modified transtibial suture technique combined with FasT-Fix fixation. (a) No. 2 Ultrabraid was passed through the posterior horn of the MM with the Knee Scorpion suture passer. (b) The first implant of FasT-Fix was inserted into the posterior horn of the MM, whereas the passed Ultrabraid was tensioned throughout the AL portal. (c) The second implant of FasT-Fix was inserted into the posterior root of the MM across the Ultrabraid. (d) Modified transtibial suture technique combined with FasT-Fix fixation. (e) Schematic drawing of the modified transtibial suture technique combined with FasT-Fix fixation. The uncut free ends of the FasT-Fix suture and/or Ultrabraid were retrieved from the tibial tunnel at an anatomic attachment of the medial meniscal posterior root. Note that the FasT-Fix needle penetrated the meniscal horn and posterior joint capsule.