



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

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Abstract

Purpose To investigate changes in meniscal extrusion during knee flexion before and after pullout fixation for medial meniscus posterior root tear (MMPRT) 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 magnetic resonance imaging preoperatively, 3 months after transtibial fixation and at 12 months after surgery, when second-look arthroscopy was also performed. The medial meniscus medial extrusion (MMME) and the medial meniscus posterior extrusion (MMPE) were measured at knee 10° and 90° flexion at which medial meniscus (MM) posterior translation was also calculated. Articular cartilage degeneration was assessed using International Cartilage Research Society 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 pain visual analogue scale.

Results MMPE at 10° knee flexion was higher 12 months postoperatively than preoperatively (4.8 ± 1.5 vs. 3.5 ± 1.2 , $p=0.01$). MMPE at 90° knee flexion and MM posterior translation were smaller 12 months postoperatively than preoperatively (3.5 ± 1.1 vs. 4.6 ± 1.3 , 7.2 ± 1.7 vs. 8.9 ± 2.0 , $p<0.01$). Articular cartilage degeneration of medial femoral condyle correlated with MMME in knee extension ($r=0.5$, $p=0.04$). 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 1 year. However, in the knee extension position, MMME progressed and correlated with cartilage degeneration of medial femoral condyle. MMPRT transtibial fixation contributes to the dynamic stability of the MM in the knee flexion position.

Level of evidence IV.

Keywords Medial meniscus · Posterior root tear · Transtibial fixation · Meniscus extrusion · Open magnetic resonance imaging

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Abbreviations

ACL	Anterior cruciate ligament
ADL	Activities of daily living
BMI	Body mass index
ICC	Intra-class correlation coefficient
ICRS	International Cartilage Research Society
IKDC	International Knee Documentation Committee
K–L	Kellgren–Lawrence
KOOS	Knee Injury and Osteoarthritis Outcome Score
LFC	Lateral femoral condyle
LTP	Lateral tibia plateau

MFC	Medial femoral condyle
MM	Medial meniscus
MMPRT	Medial meniscus posterior root tear
MMME	Medial meniscus medial extrusion
MMPE	Medial meniscus posterior extrusion
MRI	Magnetic resonance imaging
MTP	Medial tibia plateau
QOL	Quality of life
VAS	Visual analogue scale

Introduction

Many studies have shown that medial meniscus posterior root tears (MMPRTs) are associated with osteoarthritis; 31% of patients with MMPRT undergo subsequent total knee arthroplasty at a mean duration of 30 months after conservative treatment [19]. The medial meniscus (MM) 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]. To reproduce the 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]. Although there is currently a lack of consensus regarding the superior technique, transtibial fixation is increasingly being used in clinical practice because of its lower technical challenges and ability to restore anatomic attachment of the MM posterior root [8, 21]. A meta-analysis on the outcomes of MM posterior root repair in transtibial fixation [4] demonstrated good midterm results after surgery but revealed that MM medial extrusion (MMME) persisted after surgery. Therefore, there is still concern in terms of progression of osteoarthritis or prevention of osteoarthritis following root repair for MMPRT. Therefore, performing MMPRT fixation in elderly patients remains potentially controversial. LaPrade et al. described that MM posterior root repair is indicated in active patients following acute or chronic MMPRT 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]. Despite the progression of MMME, the reason for good clinical results after surgery remains unclear. Therefore, it is necessary to further elucidate the pathological condition, including surgical indications for MM posterior root repair.

MMPRT with a degenerating meniscus is reported in middle-aged or older people due to their lifestyle and behaviours, including frequent squatting and sitting on the

floor with folded legs [2]. These behaviours may lead to an increased risk of posterior meniscal segment impingement and injury due to MM posterior root degeneration 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]. Magnetic resonance imaging (MRI) analysis found that MMPRT caused pathological posterior extrusion of the MM at 90° knee flexion [23, 24]. Therefore, the purpose of this study was to investigate pre- and post-operative changes of MMME and MM posterior extrusion (MMPE) 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. We hypothesised 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. In addition, it might be clinically useful to estimate clinical consequences and treatment strategies for MMPRT for elderly patients.

Materials and methods

This retrospective study was approved by the Institutional Review Board at Okayama University (ID number of the approval: 1857) and informed consent was provided by all patients. All medical records were reviewed retrospectively to obtain patients' demographic and clinical characteristics from a database at our institution. The medical records of 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 five tear types at surgery: type I tears were partially stable meniscal tears within 9 mm from the centre of the root attachment ($n=1$), type II tears were complete radial tears within 9 mm from the centre 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 body mass index

(BMI) greater than 30 kg/m², included varus alignment > 5°, severe cartilage lesion [International Cartilage Research Society (ICRS) grade III or IV], and Kellgren–Lawrence (K–L) grade > II 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 five patients, one was diagnosed with type I MMPRT and four were diagnosed with type IV MMPRT. These five 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 analysed the changes in MMME and MMPE after transtibial fixation using open MRI and assessed cartilage degeneration using arthroscopic images and video recordings. 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 summarised in Table 1.

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 femoral condyle (MFC) and lateral femoral condyle (LFC) were divided into nine segments

(MF 1–9, LF 1–9). The medial tibial plateau (MTP) and lateral tibial plateau (LTP) were both divided into five segments (MT 1–5, LT 1–5). The trochlea was divided into three segments (T 1–3) and the patella was divided into nine segments (P 1–9) (Fig. 1). The ACL was evaluated using synovial coverage grade at primary surgery and at second-look arthroscopy.

Surgical indications of MMPRT repair in patients under 70 years and a BMI less than 30 kg/m² included varus alignment < 5°, mild cartilage lesion (ICRS low grade I or II) and K–L grade 0–II in radiographs. 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 an MMPRT guide, as previously described [7, 10, 18]. No. 2 Ultrabraid (or Ultratape) and FasT-Fix 360 reverse curve (Smith & Nephew) were used to stabilize the MM posterior horn in the modified Mason–Allen suture configuration (Fig. 2a–c) [7, 8, 10]. 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]. An MMPRT aiming guide (Smith & Nephew) was placed at the anatomic insertion of the MM posterior root [9]. A 2.4-mm guide pin was inserted at a 55° angle to the articular surface and a tibial tunnel was created with a 4.5-mm cannulated drill [18]. The Ultrabraid and/or uncut free end of the FasT-Fix sutures were retrieved through the tibial tunnel (Fig. 2d, e). Tibial fixation of the sutures was performed using double-spike plate and screw (Meira, Aichi, Japan) at 45° of knee flexion with an initial tension of 20 N [7, 8, 18].

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].

Open MRI scanning was performed in the supine and recumbent positions preoperatively and at 3 months and 12 months postoperatively using an Oasis 1.2 T (Hitachi

Table 1 Patient demographics and clinical characteristics

Number of patients	22
Sex, male/female	4/18
Kellgren–Lawrence grade Grade 0/II/III/IV	8/14/0/0/0
Femorotibial angle, ° (range)	177 ± 2.2 (173–180)
Age, years (range)	58.4 ± 8.2 (51–65)
Height, m (range)	1.57 ± 0.1 (1.48–1.70)
Body weight, kg (range)	65.8 ± 9.2 (50.8–80.1)
Body mass index, kg/m ² (range)	26.5 ± 3.5 (22.8–28.1)

Data for age, height, body weight, body mass index, and femorotibial angle are displayed as mean ± standard deviation

Fig. 1 Schematic illustrations of the femoral condyle and tibial plateau. **a** The patella was divided into nine segments. **b** The medial and lateral femoral condyles were divided into nine segments. **c** The medial and lateral tibial plateaus were divided into five segments

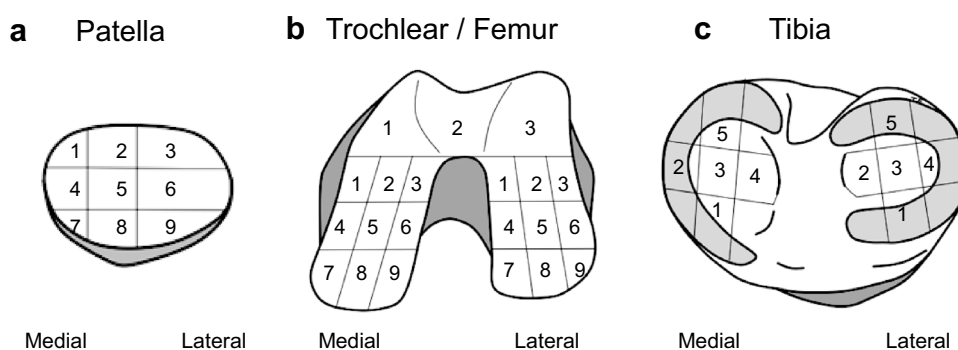
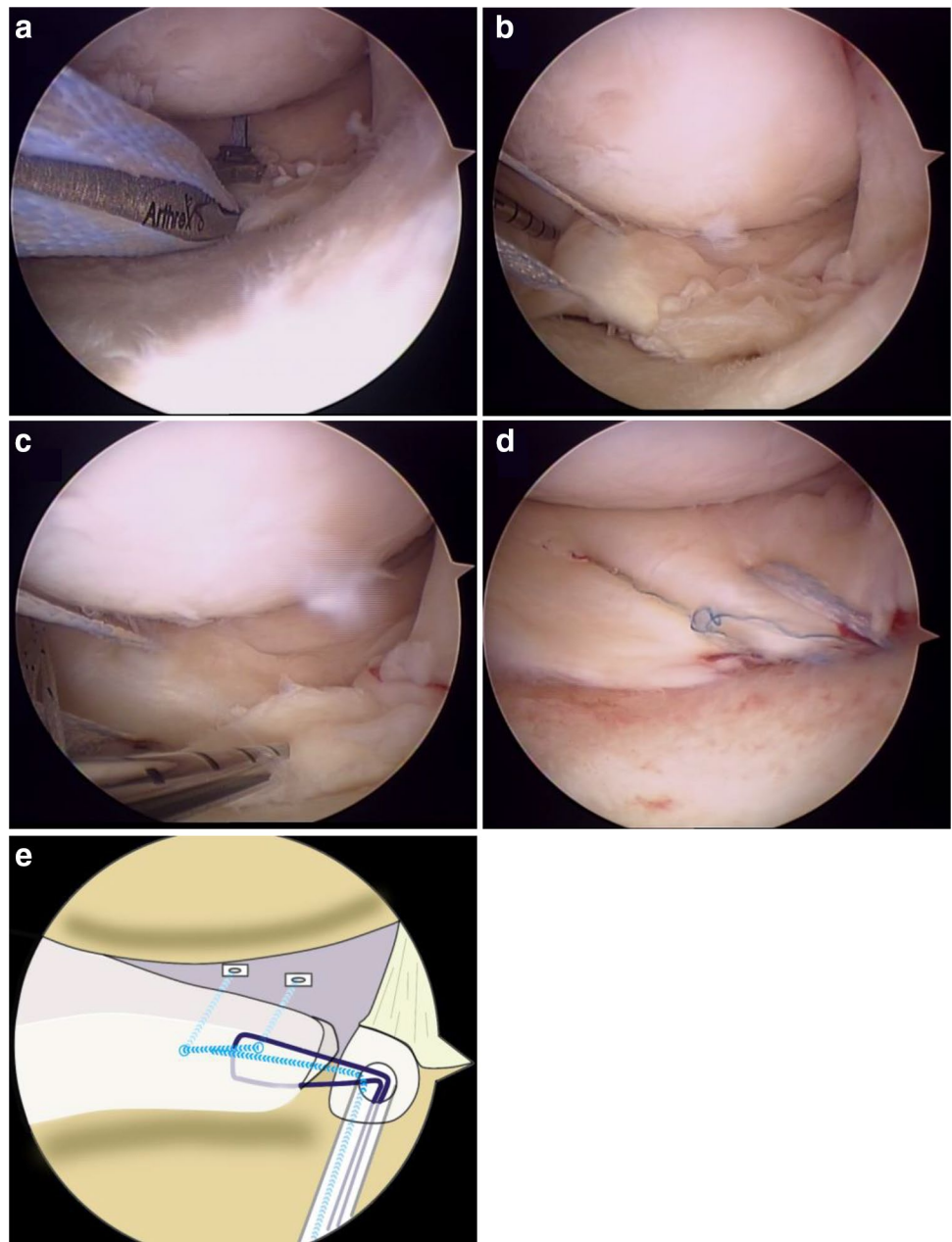


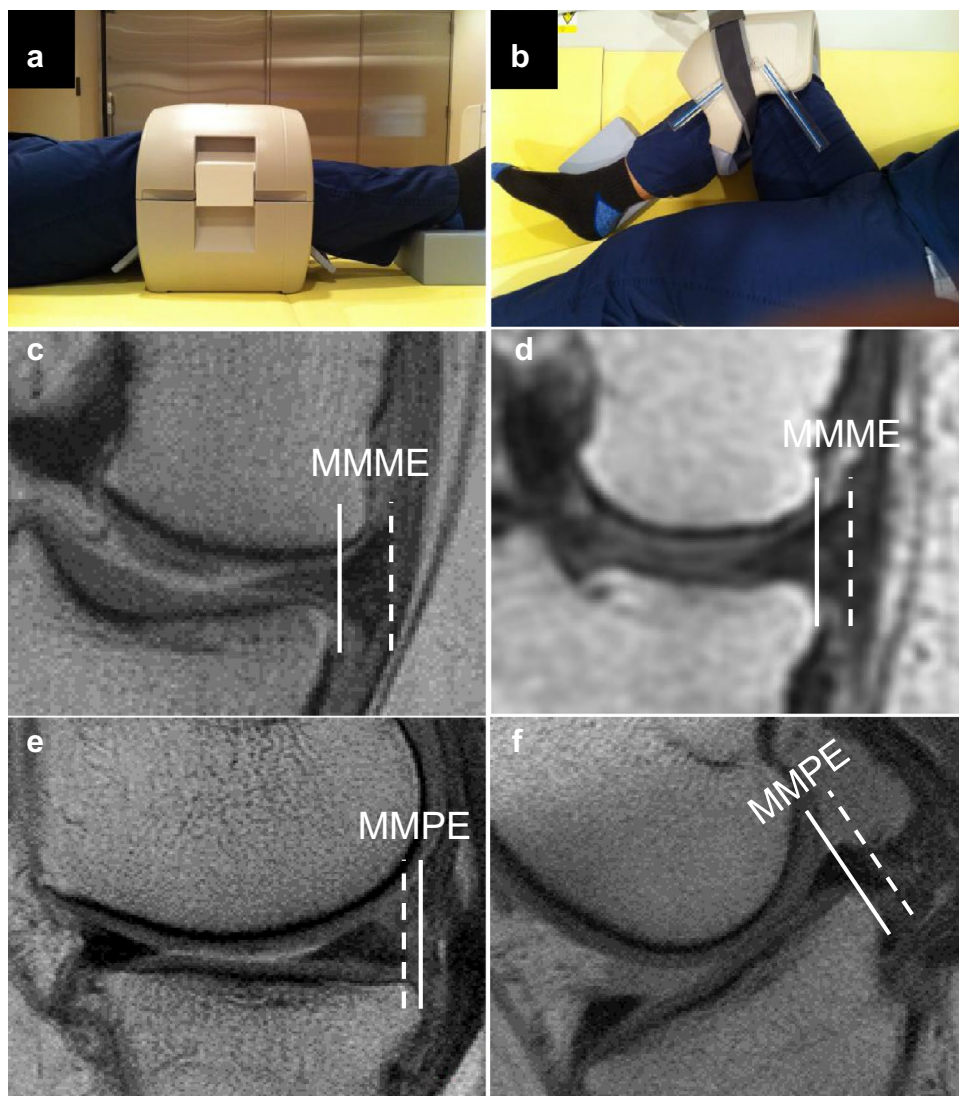
Fig. 2 Modified transtibial suture technique combined with FasT-Fix fixation. **a** Ultratape was passed through the posterior horn of the MM with the Knee Scorpion suture passer. **b** The first implant of FasT-Fix was inserted into the posterior horn of the MM, whereas the passed Ultratape was tensioned throughout the anterolateral portal. **c** The second implant of FasT-Fix was inserted into the posterior root of the MM across the Ultratape. **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 Ultratape were retrieved from the tibial tunnel at an anatomic attachment of the MM posterior root. Note that the FasT-Fix needle penetrated the meniscal horn and posterior joint capsule



Medical, Chiba, Japan) with a coil in the 10° (Fig. 3a) and 90° (Fig. 3b) 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 MMME was measured from the medial margin of the tibial plateau (excluding osteophytes) to the outer border of the MM on the coronal MR image that crossed the midpoint of the anteroposterior length of the MM (Fig. 3c, d) [14]. The details of the MMPE measurements were determined from a previously described method. MMPE was measured using a line passing orthogonally through the MTP, which is the distance from the posterior edge of the tibia (excluding osteophytes) to the posterior edge of the MM (Fig. 3e, f). 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. Two orthopaedic surgeons

Fig. 3 MRI-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). The MMME was measured as the distance from the medial edge of the tibial plateau cartilage to the medial border of the MM. The MMPE was measured as the distance from the posterior edge of the tibia to the posterior edge of the MM. MMME measurements were obtained in the mid-coronal plane by linking the coronal and sagittal image series and MMPE measurements were obtained passing orthogonally through the medial plateau. Medial and posterior margins of the MTP (solid lines) and MM (dashed lines). *MMME* medial meniscus medial extrusion, *MMPE* medial meniscus posterior extrusion



(S.M. and Yu.O.) independently measured the MM extrusion in a blinded manner. MRI measurements were completed by two independent orthopaedic surgeons to determine inter-observer reliability using the intra-class correlation coefficient (ICC). Each observer repeated the measurements at a 4-week interval to determine intra-observer reliability.

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 analogue 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 were performed using EZR software (Saitama Medical Center, Jichi Medical University, Tochigi, Japan). Data are expressed as mean \pm standard deviation (SD), unless otherwise indicated. Statistical significance was set at $p < 0.05$. The repeated measure 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 using the Wilcoxon signed-rank test. The Spearman's rank correlation was calculated to assess the correlation between MMME and MM posterior translation and the area with significant change in cartilage degeneration. 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°). The sample size was estimated for a minimal statistical power of 80% ($\alpha=0.05$). Assuming a one-tailed testing, an alpha of 0.05 and an independent sample *t* test, a sample of 21 patients was sufficient to detect an effect size of $d=0.5$ with 80% statistical power.

Results

Table 1 shows the clinical characteristics of type II MMPRT patients. All clinical scores significantly improved at 12 months postoperatively ($p < 0.05$, Fig. 4). MMME at 10° knee flexion was higher 12 months postoperatively than preoperatively (4.8 ± 1.5 vs. 3.5 ± 1.2 , $p = 0.01$). On

the other hand, MMPE at 90° knee flexion and MM posterior translation were smaller 12 months postoperatively than preoperatively (3.5 ± 1.1 vs. 4.6 ± 1.3 , 7.2 ± 1.7 vs. 8.9 ± 2.0 , $p < 0.01$) (Table 2). Significant differences in the area of cartilage degeneration were observed between primary surgery and second-look arthroscopy at the MFC (MF1–4), MTP (MT2), patella (P5), and trochlear (T2) (Tables 3, 4, 5). Articular cartilage degeneration of MFC correlated with MMME in knee extension ($r=0.5$, $p=0.04$) (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) was observed in one patient. Regarding measurements of MMME, the ICCs for intra-observer repeatability and

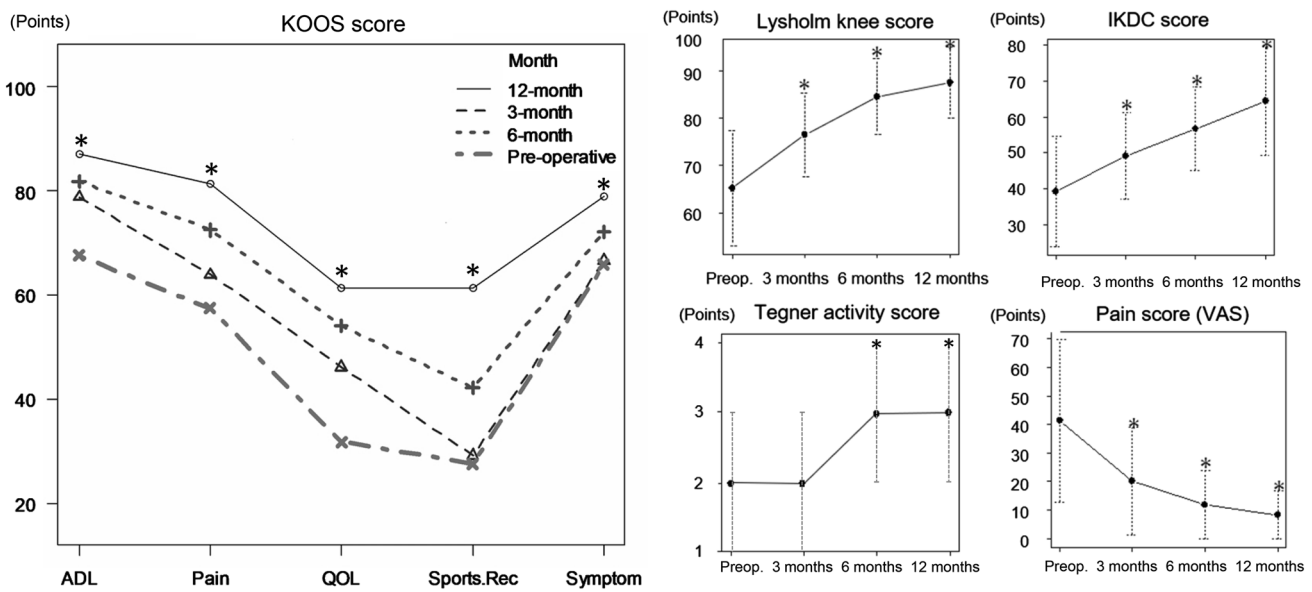


Fig. 4 Time-dependent clinical outcomes. Data were collected preoperatively and at 3-, 6-, and 12-month follow-ups. All scores were significantly improved at the 12-month follow-up after surgery. *KOOS* Knee Injury and Osteoarthritis Outcome Score, *ADL* activities of

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. * $p < 0.05$

Table 2 Measurements of magnetic resonance images

	Preoperative	Postoperative 3 months	Postoperative 12 months	<i>p</i> value
MMME (10°), mm	3.53 ± 1.17	3.69 ± 1.47	4.77 ± 1.48*	0.012
MMME (90°), mm	2.46 ± 0.58	2.61 ± 1.01	3.28 ± 0.84	n.s
MMPE (10°), mm	-4.29 ± 1.38	-3.86 ± 1.65	-3.74 ± 0.57	n.s
MMPE (90°), mm	4.60 ± 1.27	3.21 ± 1.03*	3.49 ± 1.05*	<0.001
MM posterior translation during knee flexion	8.89 ± 1.98	7.07 ± 1.87*	7.23 ± 1.74*	<0.001

Data are displayed as mean ± standard deviation. Dunnett’s multiple comparison post hoc test was used to compare the preoperative and postoperative measurements

MMME medical meniscus medial extrusion, *MMPE* medial meniscus posterior extrusion, *MM* medial meniscus

* $p < 0.05$ compared with preoperative values

Table 3 Differences in patella and trochlear cartilage status (ICRS grade) between primary and second-look arthroscopy

Area	Patella				Trochlear			
	Primary	Second look	Δ	p value	Primary	Second look	Δ	p value
1	0.8±0.8	0.9±0.9	0.1±0.7	n.s	1.5±1.3	1.6±0.9	0.1±1.0	n.s
2	1.0±1.0	1.2±0.9	0.2±0.7	n.s	1.5±1.2	2.3±1.0	0.8±0.9	0.002*
3	0.6±0.8	0.7±0.8	0.1±0.3	n.s	0.5±0.8	0.5±0.8	0±1.1	n.s
4	1.2±0.8	1.4±0.8	0.2±0.7	n.s				
5	1.5±0.9	2.3±0.9	0.8±0.5	0.003*				
6	0.9±0.8	1.0±0.7	0.1±0.7	n.s				
7	0.9±0.9	1.1±0.9	0.1±0.5	n.s				
8	0.9±0.9	1.0±0.9	0.1±0.5	n.s				
9	0.7±0.9	0.8±0.9	0.1±0.3	n.s				

Data are displayed as a mean±standard deviation. Significance was determined with use of Wilcoxon signed-rank test

ICRS International Cartilage Research Society, Δ difference of cartilage status (second look–primary surgery)

*p<0.05

Table 4 Differences in femoral cartilage status (ICRS grade) between primary and second-look arthroscopy

Area	Medial femoral condyle				Lateral femoral condyle			
	Primary	Second look	Δ	p value	Primary	Second look	Δ	p value
1	0.6±0.9	1.3±0.7	0.7±1.1	0.02*	0.4±0.9	0.7±0.6	0.3±1.0	n.s
2	0.6±0.9	1.2±0.7	0.5±0.8	0.01*	0.2±0.4	0.2±0.4	0±0.5	n.s
3	0.7±0.8	1.1±0.8	0.5±0.8	0.02*	0.1±0.3	0.0±0.2	-0.1±0.3	n.s
4	0.8±0.8	1.6±1.0	0.8±1.0	0.003*	0.5±0.7	0.5±0.7	0±1.0	n.s
5	1.5±1.0	2.0±1.0	0.5±1.0	n.s	0.4±0.6	0.4±0.5	0±0.7	n.s
6	1.8±0.8	1.7±0.8	-0.1±0.9	n.s	0.1±0.3	0.2±0.4	0.2±0.4	n.s
7	1.2±1.0	1.4±0.8	0.2±0.8	n.s	0.4±0.6	0.7±0.6	0.3±0.8	n.s
8	1.1±1.0	1.4±0.8	0.2±1.0	n.s	0.3±0.4	0.4±0.7	0.1±0.8	n.s
9	1.0±0.9	0.8±0.8	-0.1±0.8	n.s	0.1±0.2	0.1±0.5	0.1±0.5	n.s

Data are displayed as a mean±standard deviation. Significance was determined with use of Wilcoxon signed-rank test

ICRS International Cartilage Research Society, Δ difference of cartilage status (second look–primary surgery)

*p<0.05

inter-observer repeatability ranged between 0.82 and 0.87, and 0.87 and 0.90, respectively. For MMPE measurements, the ICCs for intra-observer repeatability and inter-observer repeatability ranged between 0.89 and 0.92, and 0.92 and 0.95, respectively. Correlations of all clinical scores with decreased MMPE and increased MMME were not detected.

Discussion

There were three 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

Table 5 Differences in tibial cartilage status (ICRS grade) between primary and second-look arthroscopy

Area	Medial tibial plateau				Lateral tibial plateau			
	Primary	Second look	Δ	<i>p</i> value	Primary	Second look	Δ	<i>p</i> value
1	1.6 ± 0.7	1.5 ± 0.5	-0.1 ± 0.7	n.s	0.3 ± 0.4	0.4 ± 0.7	0.1 ± 0.8	n.s
2	0.9 ± 0.7	1.3 ± 0.6	0.6 ± 0.8	0.02*	1.5 ± 0.8	1.2 ± 0.7	-0.3 ± 0.9	n.s
3	1.7 ± 0.6	2.0 ± 0.7	0.2 ± 0.7	n.s	1.3 ± 0.7	1.3 ± 0.8	0 ± 0.9	n.s
4	1.1 ± 1.0	1.4 ± 0.8	0.2 ± 1.0	n.s	0.5 ± 0.7	0.5 ± 0.6	0 ± 0.9	n.s
5	1.3 ± 1.0	1.6 ± 0.8	0.3 ± 0.8	n.s	1.0 ± 0.8	1.0 ± 0.9	0 ± 0.9	n.s

Data are displayed as a mean ± standard deviation. Significance was determined with the use of Wilcoxon signed-rank test

ICRS International Cartilage Research Society, Δ difference of cartilage status (second look – primary surgery)

**p* < 0.05

Table 6 Correlation between MM medial extrusion (10°) and MM posterior translation and the area with significant change in cartilage degeneration (ICRS grade)

Area	MM medial extrusion (10°)		MM posterior translation	
	<i>r</i>	<i>p</i> value	<i>R</i>	<i>p</i> value
MF 1	0.10	n.s	0.31	n.s
MF 2	0.25	n.s	0.28	n.s
MF 3	0.25	n.s	0.03	n.s
MF 4	0.48	0.04*	0.14	n.s
MT 2	0.32	n.s	0.34	n.s
P 5	0.21	n.s	0.02	n.s
T 2	0.11	n.s	0.32	n.s

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

MM medial meniscus, MF medial femoral condyle, MT medial tibial plateau, P patella, T trochlear

**p* < 0.05

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 MRI 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 ACL and posterior cruciate ligament are normal at 90° knee flexion, anterior translation of the tibia is counteracted by the buttress effect of the MM [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 2–3 mm more than that of a normal meniscus (4–5 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 weight-bearing condition. 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 to this study. First, patient records were retrospectively assessed, the sample size was small, and the follow-up period was 1 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 weight-bearing condition. Fourth, there was no video recording or image for evaluating posterior cruciate ligament, 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.

With regard to clinical relevance, MMPRT transtibial fixation will likely contribute to the dynamic stability of the MM in the knee flexion position. In daily clinical work, MMPRT transtibial fixation should be considered as an effective treatment for MMPRT even in middle-aged and elderly patients.

Conclusions

MMPRT transtibial fixation suppressed the progression of MMPE and cartilage degeneration in the knee flexion position in a short-term 1-year unloaded MRI and arthroscopic evaluation. However, in the knee extension position, MMME progressed and correlated with the MFC cartilage degeneration. 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 1-year follow-up.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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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