



Title	Two simple stitches for medial meniscus posterior root repair prevents the progression of meniscal extrusion and reduces intrameniscal signal intensity better than modified Mason-Allen sutures
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- 1 Two Simple Stitches for Medial Meniscus Posterior Root Repair Prevents the Progression of Meniscal
- 2 Extrusion and Reduces Intrameniscal Signal Intensity better than Modified Mason-Allen Sutures

Abstract

Purpose: Medial meniscus posterior root tears (MMPRTs) can cause severe medial extrusion of the medial meniscus (MMME) and the progression of knee degenerative changes, inducing a high signal intensity of the meniscus on magnetic resonance imaging (MRI). Although MMME and intra-meniscal signal intensity (IMSI) reportedly decreased within 3 months after MMPRT repair, no previous studies have reported these changes after a 1-year follow-up. This study aimed to investigate the 1-year postoperative changes in MMME and IMSI on MRI after using different suture techniques.

Methods: Overall, 33 patients with MMPRT were evaluated, 22 underwent FasT-Fix-dependent modified Mason–Allen suture (F-MMA) repair, and 11 underwent two simple stitches (TSS) repair. MRI examinations were performed preoperatively and 1 year postoperatively. MMME and IMSI were determined using MRI.

Results: A significant decrease in postoperative MMME was observed in the TSS group (4.1 ± 1.0) relative to that in the F-MMA group (5.1 ± 1.4 , $P=0.03$). A significant decrease in postoperative IMSI (0.75 ± 0.14) was observed relative to preoperative IMSI in the TSS group ($P<0.01$), whereas postoperative IMSI (0.94 ± 0.25) was similar to preoperative IMSI in the F-MMA group ($P=0.06$). Furthermore, a significant decrease in postoperative IMSI was observed in the TSS group relative to that in the F-MMA group ($P<0.01$).

Conclusions: The most important finding of this study is that TSS repair yielded a greater decrease in MMME and IMSI than F-MMA repair in patients with MMPRT. These results suggest that TSS repair is more useful for restoring loading stress to the posterior horn of the medial meniscus.

Keywords: Arthroscopic pullout repair, Magnetic resonance imaging, Medial meniscus, Posterior root tear, Signal intensity

1. Introduction

Medial meniscus (MM) posterior root tears (PRTs) decrease the contact area and increase the contact pressure between the medial femoral condyle and tibial plateau. This leads to a disrupted hoop stress distribution, severe MM medial extrusion (MMME), and degenerative changes, which show up as high signal intensity of the MM posterior segment on magnetic resonance imaging (MRI) [1-4]. MM posterior root repair is recommended to prevent subsequent cartilage degeneration or MMME, as well as to restore the contact area, contact pressure, and hoop tension that results in good clinical outcomes [5,6]. The signal intensity of a degenerative meniscus is known to be higher than usual [3]. Furthermore, a short-term study reported that the postoperative intra-meniscal signal intensity (IMSI) of the MM posterior segment decreased at 3 months after pullout repair [2]. This finding may be supported by other research where the extracellular matrix of the posterior horn cells was shown to be activated by physiological stress [7], as the pullout repair of the MMPRT prevents the progression of MMME and restores hoop stress to the meniscal footprint [8].

Although some studies suggest that MRI has low accuracy for evaluating the shape or intensity of a meniscal tear after surgery [9], this modality has been used successfully to diagnose MMPRT based on specific findings such as the giraffe neck sign or the cleft/truncation sign [10]. This evaluation is performed to confirm a reduction of the MM posterior root to the original footprint of the tibial surface, as indicated by the disappearance of the above-mentioned signs or by the appearance of the suspension bridge sign after pullout repair [11]. Further, MRI has been used to confirm MMME and IMSI changes after a transtibial pullout repair using the FasT-Fix-dependent modified Mason-Allen suture (F-MMA), although the associated study was characterized by a short-term follow-up [2,4].

Multiple studies have reported the signal intensity of the meniscus on MRI, and the usefulness of this modality for the diagnosis and treatment of conditions such as MMPRT. However, no previous studies have reported changes in the IMSI of the MM posterior segment after pullout repair, using different suture techniques during a 1-year follow-up. Therefore, it remains unclear which repair technique can achieve the greatest reduction in IMSI. This study aimed to investigate the 1-year postoperative changes in the MMME and the signal intensity of the MM posterior segment after

F-MMA or two simple stitches (TSS) repair with or without additional sutures at the most extruded point (posteromedial portion of the MM) had been applied [12-15]. We hypothesized that when compared with F-MMA repair, TSS repair would better reduce postoperative MMME and IMSI.

2. Patients and methods

2.1. Patients

The study was approved by the Institutional Review Board, and all patients provided informed consent. This retrospective study was designed to analyze changes in MMME and IMSI preoperatively and 1 year after MMPRT pullout repair. The study included 39 patients who had undergone MMPRT pullout repair between October 2016 and May 2019. Until March 2018, patients were treated using the F-MMA technique and then, using the TSS technique from April 2018 onwards. Out of these, 4 patients were excluded because MRI was unavailable, and 2 were excluded because they had a type 4 MMPRT. The final sample size (n=33) provided adequate power to detect significant differences in MMME and IMSI between the F-MMA and TSS groups. The Kellgren–Lawrence grade, MMME, and MMPRT type were determined using plain radiographs, MRI, and careful arthroscopic examinations, respectively [10]. The knee injury and osteoarthritis outcome score (KOOS), Lysholm score, and International Knee Documentation Committee (IKDC) score were obtained preoperatively and 1 year postoperatively. MRI examinations were performed preoperatively and 1 year postoperatively (Figs. 1 and 2).

2.2. Methods

Transtibial pullout repair was performed arthroscopically. A standard anterolateral portal (longitudinal incision) was used for arthroscopic visualization with a 30° arthroscope (Smith & Nephew, Andover, MA, USA). An anteromedial portal (transverse incision) was used for MMPRT guide (Smith & Nephew) [16]. After creating a tibial bone tunnel with the MMPRT guide, patients in the F-MMA group were treated with a FasT-Fix® (Smith & Nephew)-dependent modified Mason–

Allen suture via the all-inside technique; the MM posterior root was grasped to pass one suture using a Knee Scorpion suture passer (Arthrex, Naples, FL, USA), and FasT-Fix® was inserted into the capsule through the MM posterior root across the first suture. The uncut free-end of the FasT-Fix® suture and simple stitch were pulled out through the tibial tunnel [12,17-19]. Patients in the TSS group were treated with two simple stitches, with or without an additional all-inside suture, at the most extruded posteromedial portions of the MM; the MM posterior root was grasped to pass two sutures using the Knee Scorpion suture passer [13-15]. In the F-MMA group, tibial fixation was performed using a double-spike plate and a screw (Meira, Aichi, Japan) with the knee flexed at 45° and 20 N of initial tension [12] (Fig. 3). In the TSS group, this procedure was performed using a bioabsorbable screw (Smith & Nephew) with the knee flexed at 20–30° and 20–30 N of initial tension [13,14] (Fig. 4). Patients in both groups were allowed 45° of flexion and one-third weight-bearing at 2 weeks postoperatively, 90° flexion and full weight-bearing at 4 weeks postoperatively, and a full range of motion at 12 weeks postoperatively, as previously described [12-14].

All patients underwent second-look arthroscopy. The healing status (second-look score; width, stability, and synovial coverage) was evaluated in accordance with the previously described arthroscopic scoring system [20] (Figs. 3c, d and 4c, d).

2.3. Assessment methods

The patients underwent open MRI evaluations using the Oasis 1.2 T MRI system (Hitachi Medical, Chiba, Japan) with a dedicated knee coil in the 10° flexed position under a non-weight-bearing condition. A proton density-weighted image was obtained in the coronal plane. The sequence parameters were as follows: repetition time [TR]=1718 ms, echo time [TE]=12 ms, flip angle=90°, field of view [FOV]=16 cm, slice=4 mm, and matrix=320×416.

MMME was measured from the medial margin of the tibial plateau to the outer border of the MM (Figs. 1, 2). If osteophytes were present in the medial tibial plateau, they were excluded in the determination of the tibial margin as previously described [4].

After assessing all coronal slices of each knee, measurements were taken from the ‘most posterior’

and ‘second-most posterior’ slices to obtain a high positive predictive value [2,21]. The signal intensity of the MM posterior segment was compared to that of the 2 middle segment slices of the intact lateral meniscus (LM) on the ipsilateral side. The IMSI of the MM posterior segment was measured using a free-line region-of-interest (ROI) tool in a picture archiving and communication system (FUJIFILM Holdings Corporation, Tokyo, Japan). The ROI was marked by drawing a freehand line along the edge of the MM posterior segment. Because the IMSI can vary between examinations due to an inconsistent degree of screen contrast, the IMSI value was expressed as a ratio of the signal intensity of the MM posterior segment to that of the intact LM middle segments, as a control to standardize the signal intensity [22]. Preoperative IMSI values in each group defined the baseline as 1.

2.4. Statistical analysis

Data are presented as means±standard deviations. The statistical analysis was performed using EZR software (Saitama Medical Center, Jichi Medical University, Tochigi, Japan) [23]. The Wilcoxon signed-rank test was performed to compare the preoperative and postoperative values in each group. The Mann–Whitney U test was performed to compare the values in the F-MMA and TSS groups. The statistical significance level was set at a P value <0.05. For consistency, 2 orthopedic surgeons independently measured the signal intensity of the MM posterior segment and the ipsilateral control (the intact LM middle segment). Each observer performed each measurement twice at an interval of at least 2 weeks. The inter-observer and intra-observer reliabilities were assessed using the intra-class correlation coefficient (ICC).

3. Results

The patients’ demographic and clinical characteristics are shown in Tables 1 and 2. No significant differences were observed between the demographic factors of patients in both groups. A significant decrease in postoperative MMME/ Δ MMME (postoperative MMME–preoperative MMME) was observed in the TSS group ($4.1\pm1.0/0.5\pm0.5$) relative to that in the F-MMA group ($5.1\pm1.4/1.6\pm1.4$,

P=0.03/P<0.01). However, no significant differences were observed in the duration from injury to preoperative MRI, femorotibial angle, preoperative MMME, and second-look scores. The clinical outcomes are shown in Table 3. A significant difference was observed between the preoperative and postoperative clinical scores in each group, whereas no significant difference was observed in the postoperative clinical scores between both groups.

A significant decrease in postoperative IMSI (0.75 ± 0.14) was observed compared to that in the preoperative IMSI in the TSS group ($P<0.01$, power=0.96), whereas the postoperative IMSI (0.94 ± 0.25) was similar to the preoperative IMSI in the F-MMA group ($P=0.06$). Furthermore, a significant decrease in postoperative IMSI was observed in the TSS group compared to that in the F-MMA group ($P<0.01$, power=0.84; Fig. 5). The interobserver and intraobserver reliabilities for the IMSI measurements were satisfactory, with mean ICC values of 0.86 and 0.91, respectively.

4. Discussion

The most important finding of this study was that TSS repair resulted in a greater decrease in MMME and IMSI than F-MMA repair in patients with MMPRT. Both pullout techniques significantly improved the clinical scores relative to the preoperative clinical scores.

In contrast to non-operative treatments or meniscectomies, studies of transtibial pullout repairs for MMPRT have reported favorable clinical outcomes and meniscal healing based on MRI and arthroscopic evidence [5,24,25]. Although short-term follow-up studies of F-MMA have used MRI to examine MMME [4] and IMSI [2] changes after pullout repair, no previous studies have compared their changes at 1 year after repair between the procedures, involving different pullout techniques. Although some studies have reported the healing status of MMPRT based on MRI findings and assessed the change in MMME and IMSI after MMPRT repair, our study is the first to compare changes in IMSI following the use of different pullout repair techniques [6]. Our results were consistent with those of a previous study. Especially, the postoperative IMSI in the F-MMA group in our study (1 year) was similar to that of a previous study, which used the F-MMA technique (3 months) [2].

A canine meniscus radial tear model study reported a correlation between the histological and MRI findings of the meniscus [26]. A healing meniscus with normal fibrovascular repair tissue can emit persistently increased signals on MRI (repetition time/echo time of 1,000 milliseconds/20 milliseconds) [26]. Similarly, grade 3 signal intensity on MR images of a peripheral meniscal tear after conservative treatment or arthroscopic repair may persist long after the tear becomes asymptomatic and has presumably healed [27]. Pullout repair is essential for MMPRT because the end-to-end suture technique is not suitable, and the process of MMPRT healing may differ from that of a radial tear as shown in previous works [26,27]. Minimal tears, degeneration of the meniscus, and even jogging can cause a high signal intensity in the meniscal body on MRI (T1- and T2-weighted imaging), and severe posteromedial extrusion of the MM in patients with MMPRT may lead to a high signal intensity [28-30].

The results of this study are partially attributable to significant improvements in postoperative MMME and Δ MMME with TSS repair relative to F-MMA repair, which are similar to those of a previous short-term study [4], which may have enabled good coverage of the medial tibial plateau and a decrease in contact pressure, although the clinical outcomes were similar in both groups. These results suggest that TSS repair can better restore loading stress to the MM posterior horn from a reduced MMME [4]. We postulated that this stress distribution may be advantageous during standing or walking because the knee is extended. Therefore, TSS repair may be advantageous in terms of suppressing meniscal and cartilage degeneration. Meniscal tissue remodeling after TSS repair may lead to a compositional change in the MM posterior segment by restoring the hoop tension mechanism 1 year postoperatively.

This study had several limitations, including the retrospective design, the relatively small number of patients, and the short-term follow-up; therefore, the validity of our findings is limited. However, the sample size yielded an acceptable statistical power for evaluating the endpoint. Additionally, the suture technique was limited even though there is a superior stitch construct, such as the cinch suture [31,32]. Furthermore, the meniscal status was not evaluated using T2-weighted imaging. We used the LM to standardize the IMSI, even though this structure may also undergo changes in a year. Another

188 limitation was the absence of immediate postoperative MRI, as a baseline for IMSI. We cannot rule
189 out the possibility that a meniscal reduction would alter the IMSI. Further MRI investigations
190 involving long-term follow-ups and larger sample sizes should be incorporated in subsequent studies.

192 **5. Conclusions**

193 Compared with F-MMA repair, TSS repair better restored loading stress to the posterior horn of the
194 MM and may help suppress meniscal and cartilage degeneration. Both pullout techniques significantly
195 improved the clinical scores postoperatively.

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313

314 **Tables**

315 Table 1. Demographic data

	F-MMA group	TSS group	P value
Number of patients	22	11	
Male/female	5/17	3/8	
Height (m)	1.6±0.3	1.6±0.1	0.93
Weight (kg)	66.7±19.8	62.4±13.0	0.45
Body mass index (kg/m ²)	26.8±7.0	24.5±2.9	0.24
Age (years)	61.2±14.9	63.7±11.2	0.42

316 Data are presented as means±standard deviations.

317 F-MMA, Fast-Fix dependent modified Mason–Allen suture; TSS, two simple stitches

318 Table 2. Clinical characteristics

	F-MMA group	TSS group	P value
Duration (weeks)	11.0±10.9	13.8±12.4	0.63
Kellgren–Lawrence grade, 1/2	8/14	6/5	
Femorotibial angle (°)	177.2±1.8	176.3±1.1	0.09
Preoperative MMME (mm)	3.5±1.0	3.6±0.9	0.76
Postoperative MMME (mm)	5.1±1.4	4.1±1.0	*0.03
△MMME (mm)	1.6±1.4	0.5±0.5	*<0.01
PRT classification type 1/2/3/4/5	1/19/0/2/0	0/10/0/1/0	
Second-look score	6.5±1.7	7.1±1.6	0.58

319 Age, duration from injury to surgery, and MMME are presented as means ± standard deviations.

320 *A statistically significant difference was observed between both groups using the Mann–Whitney U
321 test.

322 F-MMA, FasT-Fix dependent modified Mason–Allen suture; Duration, duration from injury to the
323 time of preoperative magnetic resonance imaging; MMME, medial extrusion of the medial meniscus;
324 PRT, posterior root tear; TSS, two simple stitches

325 Table 3. Clinical outcomes

		Preoperative	Postoperative	P value
F-MMA group	KOOS pain	56.9±26.7	83.8±12.9	*<0.01
	KOOS symptom	67.1±20.4	79.2±15.6	*0.02
	KOOS ADL	68.3±22.6	88.0±9.9	*<0.01
	KOOS sports	27.0±23.5	50.0±29.6	*<0.01
	KOOS QOL	34.3±18.1	59.6±22.5	*<0.01
	Lysholm score	65.3±10.7	85.9±8.5	*<0.01
	IKDC score	38.7±15.7	63.5±16.4	*<0.01
TSS group	KOOS pain	61.0±20.0	85.3±14.5	*<0.01
	KOOS symptom	62.3±20.7	80.9±15.7	*<0.01
	KOOS ADL	70.0±18.1	84.0±18.6	*0.03
	KOOS sports	20.9±23.3	57.3±28.4	*<0.01
	KOOS QOL	23.5±19.3	65.4±23.4	*<0.01
	Lysholm score	53.5±17.8	86.3±14.4	*<0.01
	IKDC score	39.0±12.9	64.1±19.3	*<0.01

326 Data are presented as means±standard deviations.

327 *A statistically significant difference was observed between both groups using the Wilcoxon
 328 signed-rank test.

329 ADL, Activity of Daily Living; F-MMA, FasT-Fix dependent modified Mason-Allen suture; IKDC,

international knee documentation committee; KOOS, Knee injury and osteoarthritis outcome score;
QOL, Quality of Life; TSS, two simple stitches

Figure Captions

Fig. 1 MRI examinations of a left knee in the F-MMA group

(a) Preoperative image of the MM middle segment showing mild MM medial extrusion (white line, 2.7 mm) and bone bruising (white arrow).

(b) Preoperative image of the MM posterior segment (defined as baseline IMSI) showing the giraffe neck sign (dotted line area).

(c) Postoperative image of the MM middle segment showing progression of the MM medial extrusion (white line, 4.8 mm) without bone bruising.

(d) Postoperative image of the MM posterior segment (similar to preoperative IMSI [1.04]) showing continuity between the posterior root and tibial footprint (white arrowhead) without a suspension bridge sign.

F-MMA; FasT-Fix dependent modified Mason-Allen suture; IMSI; intra-meniscal signal intensity; MM, medial meniscus; MRI, magnetic resonance imaging

Fig. 2 MRI examinations of a left knee in the TSS group

(a) Preoperative image of the MM middle segment showing moderate MM medial extrusion (white line, 3.5 mm) and bone bruising (white arrow).

(b) Preoperative image of the MM posterior segment (defined as baseline IMSI) showing the giraffe neck sign (dotted line area).

(c) Postoperative image of the MM middle segment showing unremarkable changes to the MM medial extrusion (white line, 4.0 mm) without bone bruising.

(d) Postoperative image of the MM posterior segment (decreased IMSI [0.56]) showing continuity between the posterior root and tibial footprint (white arrowhead) with the suspension bridge sign (dashed line area).

357 IMSI; intra-meniscal signal intensity; MM, medial meniscus; MRI, magnetic resonance imaging;
358 TSS; two simple stitches
359

360 **Fig. 3** Arthroscopic findings of a left knee in the F-MMA group

361 (a) Intraoperative image of the MMPRT.

362 (b) Intraoperative image of the repaired MM posterior root.

363 (c) MM posterior root showed a complete healing at second-look arthroscopy. Total second-look score
364 was 9; width (4, >5 mm), stability (3, Lifting on probing at 20° of flexion, but no lifting at 60° of
365 flexion), and synovial coverage (2, almost covered).

366 (d) Postoperative image of the healed MM posterior root showing loosening at 20° of flexion.

367 F-MMA; FasT-Fix dependent modified Mason-Allen suture; MFC, medial femoral condyle; MTP,
368 medial tibial plateau; MMPRT, medial meniscus posterior root tear; MM, medial meniscus
369

370 **Fig. 4** Arthroscopic findings of a left knee in the TSS group

371 (a) Intraoperative image of the MMPRT.

372 (b) Intraoperative image of the repaired MM posterior root.

373 (c) MM posterior root showed a complete healing at second-look arthroscopy. Total second-look score
374 was 9; width (4, >5 mm), stability (3, Lifting on probing at 20° of flexion, but no lifting at 60° of
375 flexion), and synovial coverage (2, almost covered).

376 (d) Postoperative image of the healed MM posterior root showing stability at 60° of flexion.

377 MMPRT, medial meniscus posterior root tear; MM, medial meniscus; MFC, medial femoral condyle;
378 MTP, medial tibial plateau; TSS, two simple stitches
379

380 **Fig. 5** MRI-based postoperative IMSI values

381 A statistically significant difference was observed between F-MMA and TSS groups.

382 *P<0.01.

383 F-MMA; FasT-Fix dependent modified Mason-Allen suture; IMSI; intra-meniscal signal intensity;

384 MRI, magnetic resonance imaging; TSS; two simple stitches