A clinical study

Medial meniscus posterior root repairs: A comparison among three surgical techniques in short-term clinical outcomes and arthroscopic meniscal healing scores

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Abstract

Background: Medial meniscus (MM) posterior root repairs lead to favorable clinical outcomes in patients with MM posterior root tears (MMPRTs). However, there are few comparative studies in evaluating the superiority among several pullout repair techniques such as modified Mason-Allen suture, simple stitch, and concomitant posteromedial pullout repair. We hypothesized that an additional pullout suture at the MM posteromedial part would have clinical advantages in transtibial pullout repairs of the MMPRTs. The aim of this study was to compare the clinical usefulness among several types of pullout repair techniques in patients with MMPRTs.

Methods: Eighty-three patients who underwent arthroscopic pullout repairs of the MMPRTs were investigated. Patients were divided into three groups using different pullout repair techniques: a modified Mason-Allen suture using FasT-Fix all-inside meniscal repair device (F-MMA, n = 28), two simple stitches (TSS, n = 30), and TSS concomitant with posteromedial pullout repair using all-inside meniscal repair device (TSS-PM, n = 25). Postoperative clinical outcomes and semi-quantitative arthroscopic meniscal healing scores (0−10 points) were evaluated at second-look arthroscopies.

Results: No significant differences among the three groups were observed in patient demographics and preoperative clinical scores, except for preoperative Lysholm scores. At second-look arthroscopies, there were no significant differences among the three techniques in postoperative clinical outcomes and meniscal healing scores.

Conclusions: This study demonstrated that the TSS-PM pullout repair technique did not show better scores in postoperative clinical outcomes and meniscal healings compared with the F-MMA and TSS techniques. Our results suggest that the concomitant posteromedial pullout suture may have no clinical advantage in the conventional pullout repairs for the patients with MMPRTs.

Introduction

Medial meniscus posterior root tears (MMPRTs) induce a pathological extrusion of the medial meniscus (MM) and lead to rapid progression of knee osteoarthritis and/or unexpected occurrence of subchondral insufficiency fracture of the knee [1-5]. Therefore, accurate diagnosis and appropriate surgical intervention at an early stage are considered to be important in obtaining a successful clinical outcome and preventing rapid progression of degenerative knee joint diseases in patients with MMPRTs [1]. Previous studies demonstrate that arthroscopic MM posterior root repairs can achieve favorable clinical outcomes in the treatment of MMPRTs [6-9]. Several repair techniques such as transtibial pullout repair, suture anchor repair, and side-to-side all-inside repair of the MM posterior root have been developed for arthroscopic treatments of MMPRTs [1]. In transtibial pullout repairs for the MMPRTs, several suturing techniques such as modified Mason-Allen suture, two or three simple stitches, and simple stitches with an additional posteromedial pullout repair have been introduced [8-12]. However, there are few clinical studies for comparing the superiority among several MM posterior root repair techniques [9, 13-16].

A slight difference in clinical usefulness between surgical techniques is not detected by standard clinical outcome measurements of the knee. Lee et al. report that no differences between modified Mason-Allen suture and two or three simple stitches are observed in postoperative clinical outcomes following MM posterior root repairs [14]. In second-look arthroscopic evaluations after MM posterior root repairs, the healing status of repaired MM posterior root is often divided into four classifications composed of complete healing, lax healing, scar tissue healing, and failed healing [17, 18]. Furumatsu et al. proposed a semi-quantitative arthroscopic scoring system of meniscal healing following transtibial pullout repairs in patients with MMPRTs [19]. The Furumatsu meniscal healing scores correlate with some postoperative clinical evaluations, such as quality of life (QOL) subscale, visual analogue scale (VAS)-based pain score, and magnetic resonance imaging (MRI) finding [19, 20]. Image analyses using open MRI devices reveal that posteromedial extrusion of the MM during knee flexion is a serious pathological change in patients with MMPRTs [5, 21, 22]. Several authors demonstrate that conventional pullout repair techniques can reduce the MM posterior and/or posteromedial extrusion, regardless of the slight progression of MM medial extrusion [21-23]. Based on these findings, reducing an excessive posteromedial subluxation of the MM using some additional surgical techniques is considered to be important for obtaining better clinical outcomes and superior meniscal healings in patients with MMPRTs [12]. We hypothesized that the additional posteromedial pullout repair technique concomitant with conventional two simple stitches (TSS) can achieve better clinical outcome scores by inducing superior meniscal healings, rather than the other two pullout repair techniques (modified Mason-Allen suture or TSS alone). The aim of this study was to compare clinical outcomes including the arthroscopic meniscal healing score among several types of MM posterior root repair techniques.

Materials and Methods

This study received the approval of our Institutional Review Board, and written informed consent was obtained from all patients. In total, 136 consecutive patients who were diagnosed with MMPRTs in MR images between May 2017 and May 2019 were initially enrolled in the study. Indications for transtibial pullout repair of the MMPRT were patients with continuous knee pain, the femorotibial angle ≤ 180°, and Kellgren–Lawrence grade 0–2 in the absence of subchondral insufficiency fracture and severe cartilage degeneration. Consequently, 95 patients underwent MM posterior root repair during the study period, and constituted the initial study population (Fig. 1). Of these patients, patients who had concomitant anterior cruciate ligament reconstruction, concomitant surgery for the lateral meniscus tear, previous history of knee surgery, and no painful popping episode were excluded. Eighty-three MMPRT patients who had the posteromedial painful popping episode [24], isolated MM posterior root repair, and second-look arthroscopy were included (Fig. 1 and Table 1). All the included patients were diagnosed having the isolated MMPRT with MRI examinations [25] and met operative indications for MM posterior root repairs [26, 27]. Clinical data of the patients who underwent MM posterior root repairs using modified Mason-Allen suture or two simple stitches techniques were partially shared with our previous studies [9, 15, 19].

Surgical procedure and postoperative care

An arthroscopic examination was performed through standard anteromedial and anterolateral portals. Types of the MMPRT were determined by careful arthroscopic examinations according to the meniscal root tear classification [28]. Patients were divided into three groups according to the difference in suture configuration and the time of surgery. A modified Mason-Allen suture pullout technique using

Ultrabraid and FasT-Fix all-inside meniscal repair device (Smith & Nephew, Andover, MA, USA) was performed in patients who underwent MM posterior root repair between May 2017 and January 2018 (F-MMA group, Fig. 2A) [10, 29]. A two simple stitches (TSS) pullout technique using No. 2 polyethylene sutures such as Ultrabraid (n = 24) and FiberWire (n = 6, Arthrex, Naples, FL, USA) was performed patients who underwent MM posterior root repair between February 2018 and November 2018 (TSS group, Fig. 2B) [11, 30]. A TSS (Ultrabraid, 14; FiberWire, 11) concomitant with an additional posteromedial pullout repair using all-inside meniscal repair device, such as FasT-Fix (n = 15) and AIR (n = 10, Stryker, Kalamazoo, MI, USA), was performed in patients who underwent MM posterior root repair between November 2018 and April 2019 (TSS-PM group, Fig. 2C, D) [12]. Two experienced surgeons (TF and YuK) performed MM posterior root repairs. Surgical procedures of 76 cases were performed by the most experienced surgeon (TF). Seven patients were treated by YuK under the technical support with TF during operation. A 4.0- or 4.5-mm tibial tunnel was created by aiming an accurate placement of the tunnel aperture at a native attachment of the MM posterior root using an MMPRT aiming guide (Smith & Nephew) or Unicorn Meniscal Root guide (Arthrex) [27, 31]. Tibial fixation of the pullout sutures was performed using double-spike plate (Meira, Aichi, Japan) or interference screw at 20˚−45˚of knee flexion with an initial tension of 20−30 N. After the pullout repair, patients were initially kept non-weight bearing in the knee immobilizer for 2 weeks. Between 2 and 4 weeks, knee flexion exercise is gradually increased up to 90˚ under partial weight bearing condition. At 6 weeks postoperatively, patients were allowed full weight bearing and 120˚ of knee flexion. Daily activities accompanied by a high knee flexion and sports were not allowed for 3 months postoperatively.

MRI evaluation for meniscal extrusion

MRI evaluation was performed using an Achieva 1.5 T (Philips, Amsterdam, The Netherlands) with a knee coil. Standard sequences included sagittal [repetition time (TR)/echo time (TE) 742/18], coronal (TR/TE 637/18), and axial (TR/TE 499/18) T2-weighted fast-field echo with a 20° flip angle (FA). Slice thickness was 3 mm with a 0.6-mm gap. Field of view (FOV) was 16 (or 17) cm with an acquisition matrix size of 205 × 256 (or 200 × 368) [2, 3, 25]. Medial extrusion of the MM was measured on the coronal image that crossed the midpoint of the anteroposterior length of the MM. MM extrusion was determined as the distance from the medial margin of the tibial plateau to the outer border of the MM. Two orthopaedic surgeons independently measured the MM extrusion in a blinded manner. Each observer performed each measurement twice, at least 2 weeks apart. The reliability of the measurements was assessed by examining the inter-observer and intra-observer reliabilities with the intra-class correlation coefficient (ICC). An ICC > 0.80 was considered to represent a reliable measurement.

Clinical outcome evaluation

Preoperative and postoperative clinical evaluations were performed at the time of pullout repair (preoperative score, Table 2) and second-look arthroscopy (postoperative score, Table 3). We assessed clinical outcomes using the Lysholm knee score, Tegner activity score, VAS-based pain score, International Knee Documentation Committee (IKDC) subjective knee evaluation form, and Japanese Knee Injury and Osteoarthritis Outcome Score (KOOS). The KOOS consists of five subscales: pain, symptoms, activities of daily living (ADL), sport and recreation function (Sport/Rec), and knee-related QOL. Pain intensity of the knee was assessed with a 100-mm VAS, ranging from 0 mm (no pain) to 100 mm (worst possible pain).

Second-look arthroscopic scoring system

Second-look arthroscopic evaluation and fixation device removal were performed in all patients at a mean of 13.7 months postoperatively. We explained the necessity of metal implant removal (double-spike plate and/or screw) and second-look arthroscopy to the patients at primary informed consent for pullout repairs. All the patients accepted the importance of evaluating the meniscal healing by second-look arthroscopy and expected to remove the metal implant simultaneously. Meniscal healing status was assessed according to the Furumatsu scoring system (Table 4) [19]. This semi-quantitative arthroscopic scoring system is composed of 3 evaluation criteria: anteroposterior width, stability, and synovial coverage of the repaired MM posterior root (perfect score, 10 points). In the anteroposterior meniscal width, 4, 2, and 0 points were assigned to broad (> 5 mm), narrow (2-5 mm), and filamentous (< 2 mm) bridging tissues, respectively. We measured the width of repaired meniscal tissue at an expected junction between the MM posterior horn and posterior root (approximately 10 mm from the native posterior root attachment). In the posterior root stability, 4, 3, 2, 1, and 0 points were set according to the status of lifting and/or anterior drawing of the meniscal root on probing. In the synovial coverage, good (2 points), fair (1 point), and poor (0 point) suture coverages were determined by arthroscopic findings [19]. Separate and/or repeated evaluations of the meniscal healing by multiple surgeons were not performed in a blinded manner although the meniscal healing status was assessed by at least two orthopaedic surgeons. The most experienced surgeon in an operation team decided the healing score finally with a spot consultation.

Statistical analysis

Data were presented as a mean ± standard deviation. Differences between the F-MMA, TSS, TSS-PM groups were investigated using one-way analysis of variance with Tukey's post-hoc test. Differences in gender ratio and root tear classification were evaluated using the Fisher's exact test. Differences between the preoperative and postoperative clinical outcome scores were compared using the Wilcoxon signed-rank tests. Statistical analyses were performed using EZR (Saitama Medical Center, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing). Significance was set to $P < 0.05$.

Results

Ninety-five patients (out of 136 patients) underwent arthroscopic pullout repairs (Fig. 1). Of these 95 patients, 12 patients were excluded. No patients were lost during the follow-up period. Eighty-three patients were included in this study. There were no patients who lacked postoperative follow-up and second-look arthroscopy. No revision surgery was required during the follow-up period (Fig. 1). A mean age of the patients was 63.7 years (range, 42–78 years) at the pullout repair. A mean of preoperative MM extrusion was 3.9, 3.3, and 3.2 mm in the F-MMA, TSS, and TSS-PM repair groups, respectively. The inter-observer and intra-observer reliabilities for the measurements of MM extrusion were considered satisfactory (each ICC value > 0.91). No significant differences among the three pullout repair groups were observed in patient demographics, preoperative MM extrusion, and preoperative clinical scores, except for preoperative Lysholm knee scores (Table 1, 2). The Lysholm score in the F-MMA group was slightly higher than that in the TSS group at preoperatively.

Postoperative follow-up period was a mean of 16.6 months (range, 12–30 months). All the three pullout repair techniques significantly improved postoperative clinical outcome scores in patients with

MMPRTs (Table 2, 3, Fig. 3, $P < 0.01$). However, there were no significant differences among the three techniques in postoperative clinical outcomes (Table 3). Duration from pullout repair to second-look arthroscopy was a mean of 13.7 months (range, 12−18 months). At second-look arthroscopies, there were no significant differences among the three techniques in meniscal healing scores (Table 3). There were no patients who showed 0−2 points of meniscal healing scores at second-look arthroscopies (Fig. 4).

Discussion

The most important finding in this study was that the TSS-PM pullout repair technique did not show better scores in postoperative clinical outcomes and meniscal healings compared with the F-MMA and TSS techniques. However, postoperative clinical outcomes and arthroscopic meniscal healings were equally improved by the three pullout repair techniques in patients with MMPRTs. Our results suggest that the concomitant posteromedial pullout suture with the TSS may have no clinical advantage compared with the conventional pullout repairs for the patients with MMPRTs.

Arthroscopic pullout repairs of the MMPRTs can reduce a mean tibiofemoral contact pressure by increasing a tibiofemoral contact area in a human cadaveric knee study [32]. Previous studies demonstrate that MM posterior root repairs lead to favorable clinical outcomes in patients with MMPRTs [7-9, 15]. However, the healing status of the MM at second-look arthroscopy is not associated with improved clinical scores following surgical treatment of the MMPRT [17, 18]. We consider that the reason why the improvement of clinical outcome scores showed no association with arthroscopic meniscal healing status may be caused by qualitative evaluations of second-look arthroscopic findings. Furumatsu et al. report that the semi-quantitative scoring system of meniscal healing, ranging from 0 to 10, shows good correlation with the KOOS QOL score and moderate correlation with VAS-based pain score following MM posterior root repairs [19]. In addition, they demonstrate that the F-MMA technique obtains better Furumatsu meniscal healing scores and superior clinical outcomes compared with single FasT-Fix pullout repairs in patients with MMPRTs [9]. On the other hand, Hiranaka et al. have reported that no significant difference was seen in the meniscal healing score between the F-MMA and TSS groups at second-look arthroscopy [15]. In the present study, there were no significant differences among the three techniques in the Furumatsu meniscal healing scores (Table 3). Meniscal healing scores of the TSS group were similar to those of the F-MMA or TSS-PM group. Based on these findings, we consider that the Furumatsu meniscal healing score may be possibly useful to evaluate the clinical superiority between two relatively different surgical procedures, instead of among three or more groups. Further investigations based on a large sample size will be required to precisely assess the usefulness of arthroscopic meniscal healing score.

In biomechanical studies using meniscal tissues, modified Mason-Allen sutures exhibit greater failure loads than the TSS techniques [29, 33, 34]. The modified Mason-Allen suture showed the highest maximum load to failure (a mean of 335 N) compared with the TSS (236 N), two modified loop/cinch stitches (250 N), and horizontal mattress suture (280 N) [33]. However, maximum failure loads of the native MM posterior root attachments are extremely greater than those of several suturing techniques (3.8−10.6 times higher than those of the TSS) [35, 36]. LaPrade et al. describe that all suturing techniques would have ultimate failure loads above the currently accepted rehabilitation force threshold [34]. We consider that a suture pullout/cutout may occur if an excessive mechanical stress acts on the suturing site of the MM [33-35]. Non-anatomic repairs of the MM posterior root cannot restore the contact pressures to that of the intact knee or anatomic repair [32]. The distance between the MM posterior root attachment and tibial tunnel center for pullout repair seems to be correlated with postoperative meniscal healing status [37, 38]. Clinical outcomes and meniscal healings following MM posterior root repairs may be also affected by the tibial tunnel position.

Clinical outcomes of MM posterior root repairs are superior to those of partial meniscectomy and non-operative management in patients with MMPRTs [6]. Pullout repairs of the MM posterior root significantly improve the clinical scores involved in the Lysholm knee, KOOS, and IKDC scores [7-9, 15]. In this study, improvements of postoperative clinical scores in the TSS-PM group were equivalent to those in the other surgical technique groups. The status of the MM extrusion can affect postoperative clinical outcome of the MM posterior root repair [3]. Patients with decreased MM extrusion following MM posterior root repairs have more favorable clinical outcomes and radiographic findings at 5-year follow-up than those with increased MM extrusion at 1 year postoperatively [7]. Several authors report that the F-MMA, TSS, and TSS-PM pullout repairs decrease medial and/or posteromedial extrusion of the MM in patients with MMPRTs [21, 22]. In addition, no significant progression of cartilage damage is observed at second-look arthroscopy in the F-MMA and TSS pullout repair groups [15]. Based on these findings, the three transtibial pullout repair techniques would be useful to obtain favorable clinical outcomes and preserve the knee cartilage status during the mid-to-long-term follow-up periods. On the other hand, Ulku et al. describe that the difference between TSS technique and two modified loop stitches in the reduction of MM extrusion does not create any differences in clinical outcomes at a mean of 44.6-months follow-up periods [16]. In our study, the TSS-PM pullout repair technique did not induce better clinical outcomes and superior meniscal healings compared with the F-MMA and TSS techniques. We consider that the additional pullout suture using all-inside meniscal repair device at the posteromedial corner of the MM might be limitedly effective in the prevention of the MM posteromedial extrusion during knee flexion. Further studies will be needed to estimate the effect of several pullout repair techniques on the prevention of cartilage degradation. Our results suggest that the additional posteromedial pullout suture using all-inside meniscal repair device may have no clinical disadvantage in arthroscopic pullout repairs for the patients with MMPRTs. Surgeons can choose one of these suture configurations in accordance with the status of the MM posterior horn.

There are several limitations in this study. This study was a retrospective comparative study with the short-term follow-up period. A randomized prospective study would be useful to distinguish a real clinical advantage among the three surgical techniques. Meniscal healing scores were determined by the surgeon himself who performed most of repair surgeries. The localization of tunnel apertures on the tibial surface was not assessed in this study. Tunnel positions seem to affect the meniscal healing status following MM posterior root repair [37]. There was a possibility that the improvement of surgical skills and instruments may affect postoperative clinical outcomes in each group. In addition, minor transitions of treatment strategy may induce unexpected effects on clinical outcomes. Posteromedial extrusion of the MM was not investigated using open MRI examinations in the knee-flexed position. In addition, progression of knee osteoarthritis was not evaluated among the three surgical techniques in radiographic and arthroscopic findings. Further investigations will be required to understand the relationships between each surgical technique and postoperative progression of knee osteoarthritis in patients who underwent MM posterior root repairs.

Conclusions

This study demonstrated that the TSS-PM pullout repair technique did not show better scores in postoperative clinical outcomes and meniscal healings compared with the conventional F-MMA and TSS techniques. Our results suggest that the additional posteromedial pullout suture using all-inside meniscal repair device may have no clinical advantage in arthroscopic pullout repairs for the patients with MMPRTs in short-term follow-up.

Conflicts of interest

The authors have no conflict of interest.

References

1. Bhatia S, LaPrade CM, Ellman MB, LaPrade RF. Meniscal root tears: significance, diagnosis, and treatment. Am J Sports Med 2014 Dec;42(12):3016-30.
2. Furumatsu T, Kodama Y, Kamatsuki Y, Hino T, Okazaki Y, Ozaki T. Meniscal extrusion progresses shortly after the medial meniscus posterior root tear. Knee Surg Relat Res 2017 Dec;29(4):295-301.
3. Furumatsu T, Kamatsuki Y, Fujii M, Kodama Y, Okazaki Y, Masuda S, Ozaki T. Medial meniscus extrusion correlates with disease duration of the sudden symptomatic medial meniscus posterior root tear. Orthop Traumatol Surg Res 2017 Dec;103(8):1179-82.
4. Masuda S, Furumatsu T, Okazaki Y, Kodama Y, Hino T, Kamatsuki Y, Miyazawa S, Ozaki T. 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 2018 Jun;104(4):485-9.
5. Okazaki Y, Furumatsu T, Yamaguchi T, Kodama Y, Kamatsuki Y, Masuda S, Okazaki Y, Hiranaka T, Zhang X, Ozaki T. 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 2019 Jun;doi: 10.1007/s00167-019-05580-6.
6. Krych AJ, Johnson NR, Mohan R, Dahm DL, Levy BA, Stuart MJ. Partial meniscectomy provides no benefit for symptomatic degenerative medial meniscus posterior root tears. Knee Surg Sports Traumatol Arthrosc 2018 Apr;26(4):1117-22.
7. Chung KS, Ha JK, Ra HJ, Kim JG. A meta-analysis of clinical and radiographic outcomes of posterior

horn medial meniscus root repairs. Knee Surg Sports Traumatol Arthrosc 2016 May;24(5):1455-68.

8. Chung KS, Noh JM, Ha JK, Ra HJ, Park SB, Kim HK, Kim JG. Survivorship analysis and clinical outcomes of transtibial pullout repair for medial meniscus posterior root tears: a 5- to 10-year follow-up study. Arthroscopy 2018 Feb;34(2):530-5.

9. Furumatsu T, Okazaki Y, Kodama Y, Okazaki Y, Masuda S, Kamatsuki Y, Takihira S, Hiranaka T, Yamawaki T, Ozaki T. Pullout repair using modified Mason-Allen suture induces better meniscal healing and superior clinical outcomes: A comparison between two surgical methods. Knee 2019 Jun;26(3):653-9.

10. Fujii M, Furumatsu T, Kodama Y, Miyazawa S, Hino T, Kamatsuki Y, Yamada K, Ozaki T. 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 2017 May;27(4):559-62.

11. Okazaki Y, Furumatsu T, Kodama Y, Kamatsuki Y, Masuda S, Ozaki T. Description of a surgical technique of medial meniscus root repair: a fixation technique with two simple stitches under an expected initial tension. Eur J Orthop Surg Traumatol 2019 Apr;29(3):705-9.

12. Okazaki Y, Furumatsu T, Miyazawa S, Masuda S, Okazaki Y, Hiranaka T, Ozaki T. A novel suture technique to reduce the meniscus extrusion in the pullout repair for medial meniscus posterior root tears. Eur J Orthop Surg Traumatol 2019 Dec;29(8):1805-9.

13. Kim JH, Chung JH, Lee DH, Lee YS, Kim JR, Ryu KJ. Arthroscopic suture anchor repair versus pullout suture repair in posterior root tear of the medial meniscus: a prospective comparison study. Arthroscopy 2011 Dec;27(12):1644-53.

14. Lee DW, Kim MK, Jang HS, Ha JK, Kim JG. Clinical and radiologic evaluation of arthroscopic medial meniscus root tear refixation: comparison of the modified Mason-Allen stitch and simple stitches. Arthroscopy 2014 Nov;30(11):1439-46.

15. Hiranaka T, Furumatsu T, Miyazawa S, Okazaki Y, Okazaki Y, Takihira S, Kodama Y, Kamatsuki Y, Masuda S, Saito T, Ozaki T. Comparison of the clinical outcomes of transtibial pull-out repair for medial meniscus posterior root tear: Two simple stitches versus modified Mason-Allen suture. Knee 2020 Jun;27(3): 701-8.

16. Ulku TK, Kaya A, Kocaoglu B. Suture configuration techniques have no effect on mid-term clinical outcomes of arthroscopic meniscus root repairs. Knee 2020 Jun;27(3):676-82.
17. Seo HS, Lee SC, Jung KA. Second-look arthroscopic findings after repairs of posterior root tears of the medial meniscus. Am J Sports Med 2011 Jan;39(1):99-107.
18. Cho JH, Song JG. Second-look arthroscopic assessment and clinical results of modified pull-out suture for posterior root tear of the medial meniscus. Knee Surg Relat Res 2014 Jun;26(2):106-13.
19. Furumatsu T, Miyazawa S, Fujii M, Tanaka T, Kodama Y, Ozaki T. Arthroscopic scoring system of meniscal healing following medial meniscus posterior root repair. Int Orthop 2019 May;43(5):1239-45.
20. Furumatsu T, Okazaki Y, Hiranaka T, Kodama Y, Kamatsuki Y, Okazaki Y, Zhang X, Ozaki T. An MRI-based suspension bridge sign can predict an arthroscopically favorable meniscal healing following the medial meniscus posterior root repair. J Orthop Sci 2020 Apr;doi: 10.1016/j.jos.2020.03.012.
21. Okazaki Y, Furumatsu T, Okazaki Y, Masuda S, Hiranaka T, Kodama Y, Kamatsuki Y, Miyazawa S, Tetsunaga T, Ozaki T. Medial meniscus posterior root repair decreases posteromedial extrusion of the medial meniscus during knee flexion. Knee 2020 Jan;27(1):132-9.
22. Okazaki Y, Furumatsu T, Yamauchi T, Okazaki Y, Kamatsuki Y, Hiranaka T, Kajiki Y, Zhang X, Ozaki T. Medial meniscus posterior root repair restores the intra-articular volume of the medial meniscus by decreasing posteromedial extrusion at knee flexion. Knee Surg Sports Traumatol Arthrosc 2020 Apr;doi: 10.1007/s00167-020-05953-2
23. Kodama Y, Furumatsu T, Masuda S, Okazaki Y, Kamatsuki Y, Okazaki Y, Hiranaka T, Miyazawa S, Yasumitsu M, Ozaki T. 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 2019 Nov; doi: 10.1007/s00167-019-05810-x.
24. Furumatsu T, Okazaki Y, Okazaki Y, Hino T, Kamatsuki Y, Masuda S, Miyazawa S, Nakata E, Hasei J, Kunisada T, Ozaki T. Injury patterns of medial meniscus posterior root tears. Orthop Traumatol Surg Res 2019 Feb;105(1):107-11.
25. Furumatsu T, Fujii M, Kodama Y, Ozaki T. A giraffe neck sign of the medial meniscus: A characteristic finding of the medial meniscus posterior root tear on magnetic resonance imaging. J Orthop Sci 2017 Jul;22(4):731-6.

26. Kodama Y, Furumatsu T, Fujii M, Tanaka T, Miyazawa S, Ozaki T. Pullout repair of a medial meniscus posterior root tear using a FasT-Fix all-inside suture technique. Orthop Traumatol Surg Res 2016 Nov;102(7):951-4.
27. Furumatsu T, Kodama Y, Fujii M, Tanaka T, Hino T, Kamatsuki Y, Yamada K, Miyazawa S, Ozaki T. 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 2017 May;103(3):367-71.
28. LaPrade CM, James EW, Cram TR, Feagin JA, Engebretsen L, LaPrade RF. Meniscal root tears: a classification system based on tear morphology. Am J Sports Med 2015 Feb;43(2):363-9.
29. Fujii M, Furumatsu T, Xue H, Miyazawa S, Kodama Y, Hino T, Kamatsuki Y, Ozaki T. Tensile strength of the pullout repair technique for the medial meniscus posterior root tear: a porcine study. Int Orthop 2017 Oct;41(10):2113-8.
30. Hiranaka T, Furumatsu T, Masuda S, Okazaki Y, Okazaki Y, Kodama Y, Kamatsuki Y, Kajiki Y, Zhang X, Ozaki T. 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 2020 Mar;doi: 10.1007/s00590-020-02647-w.
31. Furumatsu T, Okazaki Y, Kodama Y, Okazaki Y, Kamatsuki Y, Masuda S, Hiranaka T, Ozaki T. The accuracy of a newly developed guide system in medial meniscus posterior root repair: a comparison between two aiming guides. Knee Surg Relat Res 2019 Aug;31:7.
32. LaPrade CM, Foad A, Smith SD, Turnbull TL, Dornan GJ, Engebretsen L, Wijdicks CA, LaPrade RF. Biomechanical consequences of a nonanatomic posterior medial meniscal root repair. Am J Sports Med 2015 Apr;43(4):912-20.
33. Feucht MJ, Grande E, Brunhuber J, Burgkart R, Imhoff AB, Braun S. Biomechanical evaluation of different suture techniques for arthroscopic transtibial pull-out repair of posterior medial meniscus root tears. Am J Sports Med 2013 Dec;41(12):2784-90.
34. LaPrade RF, LaPrade CM, Ellman MB, Turnbull TL, Cerminara AJ, Wijdicks CA. Cyclic displacement after meniscal root repair fixation: a human biomechanical evaluation. Am J Sports Med 2015 Apr;43(4):892-8.

35. Kopf S, Colvin AC, Muriuki M, Zhang X, Harner CD. Meniscal root suturing techniques: implications for root fixation. Am J Sports Med 2011 Oct;39(10):2141-6.

36. Mitchell R, Pitts R, Kim YM, Matava MJ. Medial Meniscal Root Avulsion: A Biomechanical Comparison of 4 Different Repair Constructs. Arthroscopy 2016 Jan;32(1):111-9.

37. Hiranaka T, Furumatsu T, Kamatsuki Y, Miyazawa S, Okazaki Y, Masuda S, Okazaki Y, Kodama Y, Ozaki T. The distance between the tibial tunnel aperture and meniscal root attachment is correlated with meniscal healing status following transtibial pullout repair for medial meniscus posterior root tear. Knee 2020 Apr;doi: 10.1016/j.knee.2020.02.025.

38. Kamatsuki Y, Furumatsu T, Hiranaka T, Okazaki Y, Okazaki Y, Kodama Y, Hino T, Masuda S, Miyazawa S, Ozaki T. 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. Knee Surg Sports Traumatol Arthrosc 2020 May;doi: 10.1007/s00167-020-06070-w.

Figure legends

Fig. 1. Flow diagram of patients included in this study.

Fig. 2. Pullout repair techniques. (A) A modified Mason-Allen suture pullout using #2 polyethylene and FasT-Fix (F-MMA). (B) Two simple stitches using #2 polyethylene (TSS). (C) TSS and the posteromedial (PM) pullout suture using an all-inside meniscal repair device (TSS-PM). Arrows indicate MMPRTs of the right knees. Note that the free-end suture of all-inside meniscal repair device was preserved and used for pullout repair. (D) A schematic illustration of the TSS-PM pullout repair technique (right knee). Green and orange lines denote #2 polyethylene sutures in the TSS configuration. Blue line, PM pullout suture using FasT-Fix. PCL, posterior cruciate ligament.

Fig. 3. Comparison between preoperative and postoperative clinical scores. Clinical scores in the F-MMA (A), TSS (B), and TSS-PM (C) groups. Light gray bars, preoperative scores. Dark gray bars, postoperative scores. * $P < 0.01$.

Fig. 4. Arthroscopic meniscal healing scores (the Furumatsu scores) in each group. (A) F-MMA pullout repair. (B) TSS pullout repair. (C) TSS-PM pullout repair.

Medial meniscus posterior root repairs: A comparison among three surgical techniques in short-term clinical outcomes and arthroscopic meniscal healing scores

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Table 1. Patient demographics

	F-MMA	TSS	TSS-PM	P value
Number of patients	28	30	25	
Gender, men/women	6/22	5/25	10/15	0.138[a]
Age, years	63.9 ± 9.4	65.0 ± 7.0	61.7 ± 10.3	0.414
Height, m	1.58 ± 0.08	1.56 ± 0.08	1.60 ± 0.10	0.349
Body weight, kg	64.1 ± 10.4	60.4 ± 11.0	69.3 ± 19.8	0.080
Body mass index, kg/m^2	25.7 ± 3.3	24.6 ± 2.9	26.6 ± 4.9	0.133
Duration from injury to surgery, days	87.6 ± 55.8	84.0 ± 67.2	71.3 ± 53.9	0.642
Medial meniscus extrusion, mm	3.9 ± 0.7	3.3 ± 1.3	3.2 ± 0.9	0.108
Root tear classification				
Type 1/2/3/4/5	1/24/0/3/0	3/23/0/4/0	2/21/0/2/0	0.891[a]

Data of age, height, body weight, body mass index, and duration are displayed as a mean ± standard deviation. Statistical differences in age, height, body weight, body mass index, and duration between three groups were analyzed using one-way analysis of variance. [a] Fisher's exact test. F-MMA, modified Mason-Allen suture using FasT-Fix. TSS, two simple stitches. TSS-PM, TSS concomitant with posteromedial pullout repair.

Table 2. Preoperative clinical scores

	F-MMA (n = 28)	TSS (n = 30)	TSS-PM (n = 25)	P value
Lysholm knee score	61.7±11.0	54.6±9.1	58.3±7.1	**0.044**[b]
Tegner activity score	1.8±1.1	1.1±1.0	1.6±0.8	0.073
Pain score (VAS)	42.1±27.8	44.8±22.4	35.0±26.5	0.420
IKDC score	41.3±18.6	33.2±13.9	34.4±14.5	0.178
KOOS				
Pain	50.0±25.6	56.1±17.3	57.8±12.5	0.380
Symptoms	64.6±21.8	61.9±19.3	58.8±18.1	0.628
ADL	66.7±21.9	62.1±19.2	67.5±16.3	0.600
Sport/Rec	27.8±26.3	20.8±22.3	22.4±22.7	0.578
QOL	34.5±22.5	23.6±16.0	24.1±16.8	0.093

VAS, visual analogue scale. IKDC, International Knee Documentation Committee. KOOS, Knee Injury and Osteoarthritis Outcome Score. ADL, activities of daily living. Sport/Rec, sport and recreation function. QOL, knee-related quality of life. Data are displayed as a mean ± standard deviation. [b] Significant differences between F-MMA and TSS groups were detected using Turkey test. F-MMA, modified Mason-Allen suture using FasT-Fix. TSS, two simple stitches. TSS-PM, TSS concomitant with posteromedial pullout repair.

Table 3. Postoperative clinical scores

	F-MMA (n = 28)	TSS (n = 30)	TSS-PM (n = 25)	P value
Lysholm knee score	85.2±10.9	86.0±7.5	88.1±6.7	0.549
Tegner activity score	2.7±1.0	3.0±0.9	3.3±0.7	0.138
Pain score (VAS)	11.3±14.4	11.4±11.3	10.9±11.5	0.993
IKDC score	64.5±15.3	65.2±10.6	64.4±11.1	0.973
KOOS				
Pain	83.2±14.9	81.2±13.7	86.3±11.0	0.463
Symptoms	78.4±15.5	79.1±14.4	74.4±13.8	0.541
ADL	86.4±11.3	85.0±14.6	86.9±8.0	0.855
Sport/Rec	53.3±25.4	49.8±26.8	43.6±29.0	0.505
QOL	56.4±22.7	61.5±22.4	64.3±15.0	0.443
Meniscal healing score (0−10 points)	6.1±1.6	6.7±1.9	7.0±1.2	0.142

VAS, visual analogue scale. IKDC, International Knee Documentation Committee. KOOS, Knee Injury and Osteoarthritis Outcome Score. ADL, activities of daily living. Sport/Rec, sport and recreation function. QOL, knee-related quality of life. Data are displayed as a mean ± standard deviation. F-MMA, modified Mason-Allen suture using FasT-Fix. TSS, two simple stitches. TSS-PM, TSS concomitant with posteromedial pullout repair.

Table 4. Arthroscopic scoring system of meniscal healing (Furumatsu score)

Anteroposterior width of bridging tissue	Stability of the medial meniscus posterior root		Synovial coverage
4 Broad (> 5 mm)	**4** Good	No lifting on probing (20˚ of flexion)	**2** Good Almost covered
	3 Fair	Lifting on probing (20˚ of flexion) No lifting on probing (60˚ of flexion)	
2 Narrow (2−5 mm)	**2** Loose	Lifting on probing (60˚ of flexion) No anterior drawing (20˚ of flexion)	**1** Fair Partially covered
	1 Useless	Anterior drawing (20˚ of flexion)	
0 Filamentous (< 2 mm)	**0** Detached	Totally unstable	**0** Poor Exposed or ruptured

Numbers in bold denote each score. Width, 0/2/4 points. Stability, 0/1/2/3/4 points. Coverage, 0/1/2 points. Perfect score, 10 points.

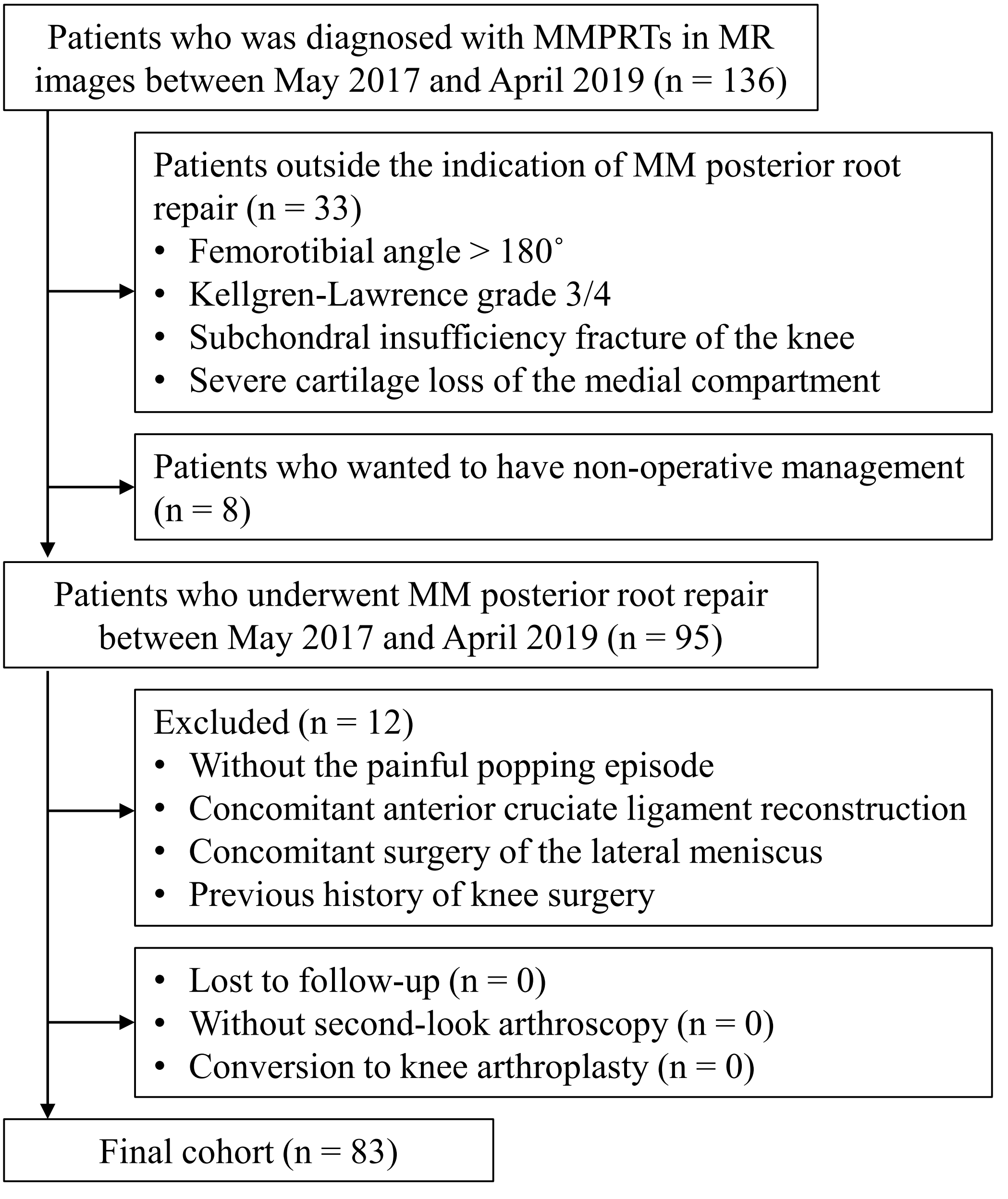

Patients who was diagnosed with MMPRTs in MR images between May 2017 and April 2019 (n = 136)
Patients outside the indication of MM posterior root repair (n = 33)
• Femorotibial angle > 180˚
• Kellgren-Lawrence grade 3/4
• Subchondral insufficiency fracture of the knee
• Severe cartilage loss of the medial compartment
Patients who wanted to have non-operative management (n = 8)
Patients who underwent MM posterior root repair between May 2017 and April 2019 (n = 95)
Excluded (n = 12)
• Without the painful popping episode
• Concomitant anterior cruciate ligament reconstruction
• Concomitant surgery of the lateral meniscus
• Previous history of knee surgery
• Lost to follow-up (n = 0)
• Without second-look arthroscopy (n = 0)
• Conversion to knee arthroplasty (n = 0)
Final cohort (n = 83)

Figure 1

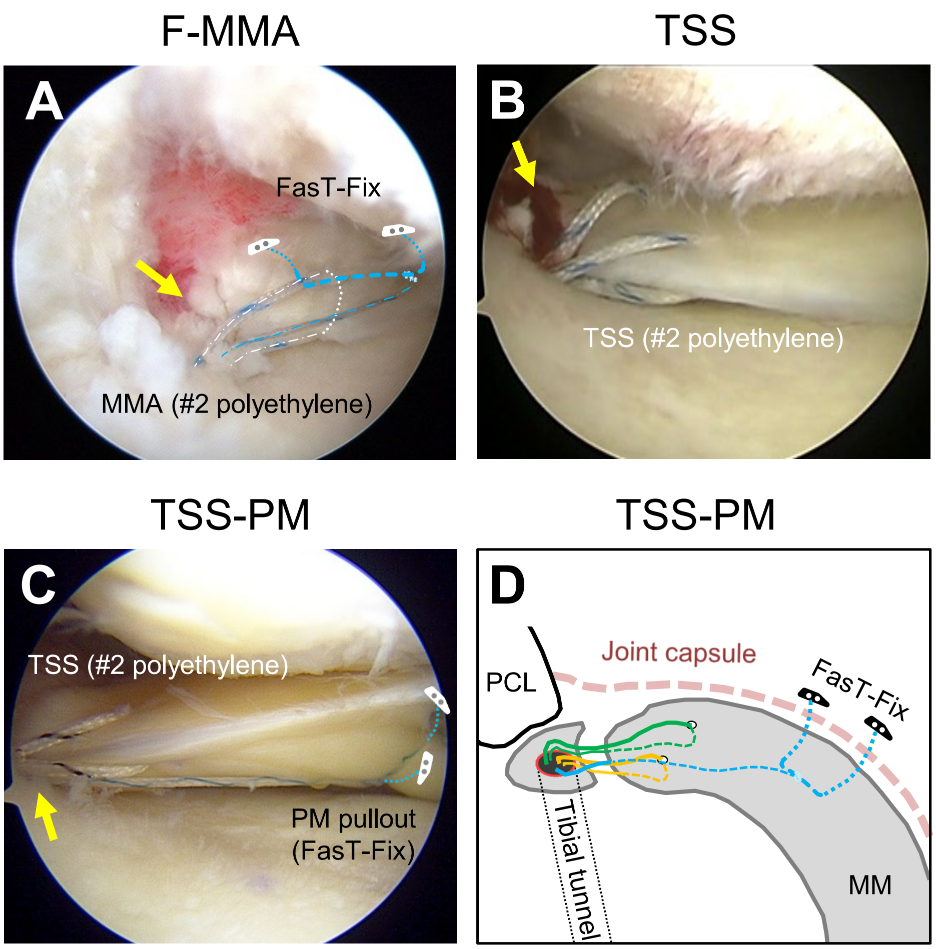

F-MMA
TSS
A
FasT-Fix
MMA (#2 polyethylene)
B
TSS (#2 polyethylene)
TSS-PM
TSS-PM
C
TSS (#2 polyethylene)
PM pullout
(FasT-Fix)
D
Joint capsule
PCL
FasT-Fix
Tibial tunnel
MM

Figure 2

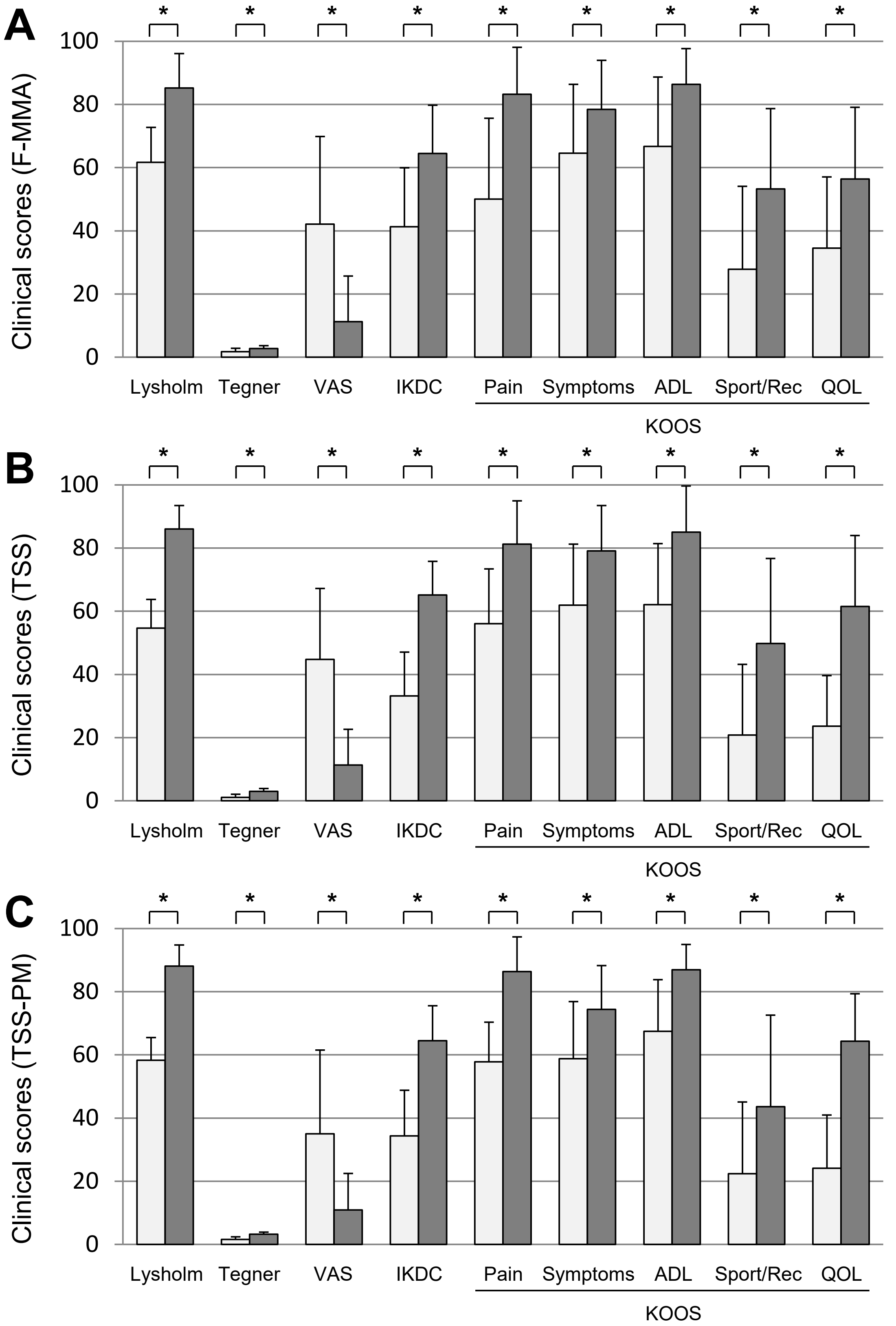
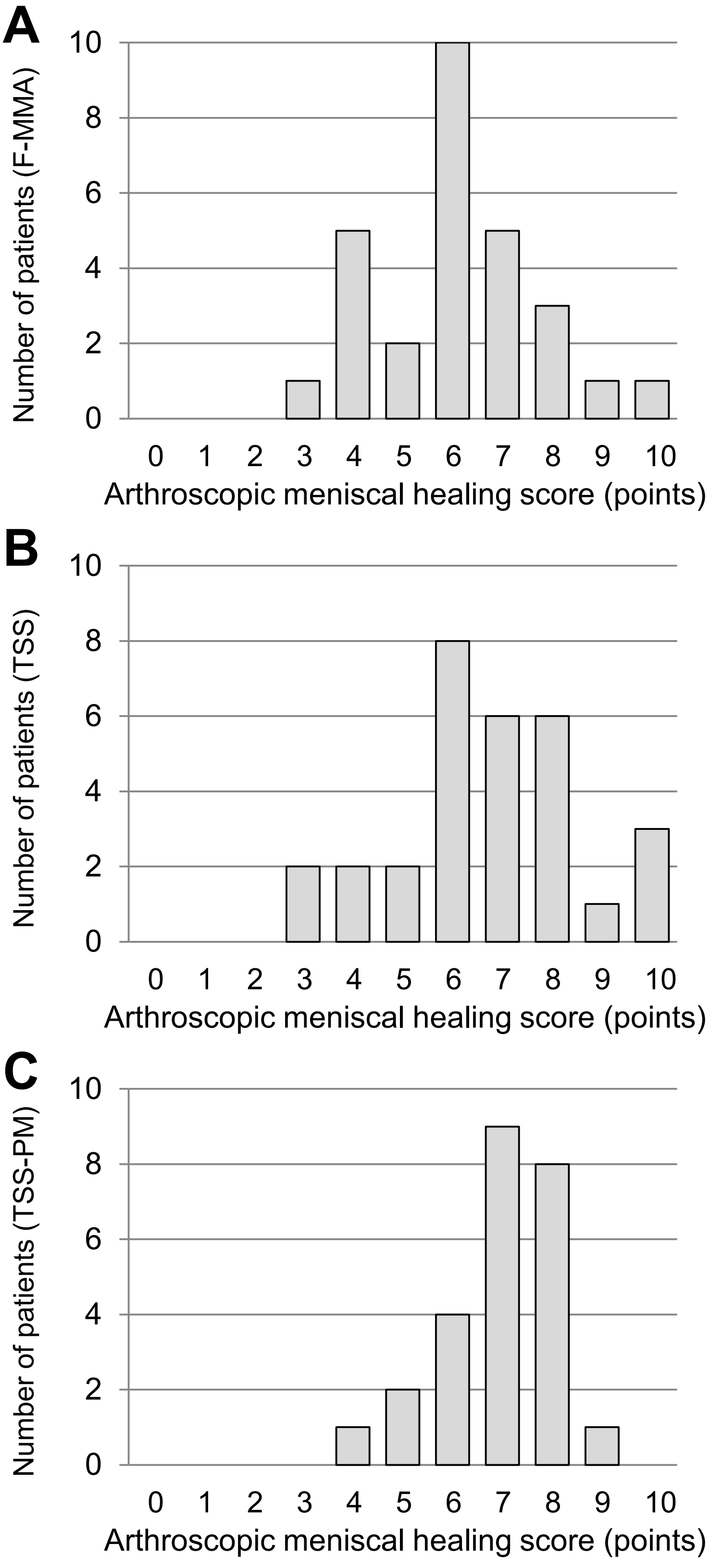

A
B
C
Clinical scores (F-MMA)
Clinical scores (TSS)
Clinical scores (TSS-PM)
100
80
60
40
20
0
*
Lysholm
Tegner
VAS
IKDC
Pain
Symptoms
ADL
Sport/Rec
QOL
KOOS

Figure 3



A
10
8
6
4
2
0
Number of patients (F-MMA)
0 1 2 3 4 5 6 7 8 9 10
Arthroscopic meniscal healing score (points)
B
10
8
6
4
2
0
Number of patients (TSS)
0 1 2 3 4 5 6 7 8 9 10
Arthroscopic meniscal healing score (points)
C
10
8
6
4
2
0
Number of patients (TSS-PM)
0 1 2 3 4 5 6 7 8 9 10
Arthroscopic meniscal healing score (points)

Figure 4