Original paper

Clinical outcomes of medial meniscus posterior root repair: a midterm follow-up study

Takayuki Furumatsu*, Shinichi Miyazawa, Yuya Kodama, Yusuke Kamatsuki, Yoshiki Okazaki, Takaaki Hiranaka, Yuki Okazaki, Keisuke Kintaka, Toshifumi Ozaki

Department of Orthopaedic Surgery, Okayama University Hospital, 2-5-1 Shikata-cho, Kita-ku, Okayama 700-8558, Japan

* Correspondence to: Dr. Takayuki Furumatsu, Department of Orthopaedic Surgery, Okayama University Hospital, 2-5-1 Shikata-cho, Kita-ku, Okayama 700-8558, Japan

Abstract

Background: Transtibial pullout repair of medial meniscus posterior root tears (MMPRTs) cannot prevent the progression of knee osteoarthritis. Conversions of knee arthroplasties are occasionally required following MMPRT repair. However, other knee-related surgical treatments following MMPRT repair are unclear. This study was aimed at investigating the midterm clinical outcomes and knee-related surgical events following MMPRT repair.

Methods: Patients with MMPRT underwent pullout repair using FasT-Fix modified Mason-Allen (F-MMA) suturing with an all-inside meniscal repair device. Thirty-two patients with follow-up duration ≥ 2 years were enrolled. We assessed the clinical outcomes and postoperative surgical treatment of both knees.

Results: F-MMA pullout repair improved all clinical evaluation scores in patients with MMPRT at a mean follow-up of 36.1 months. Postoperative arthroscopic debridement was required for one patient. An additional MMPRT repair was performed in one patient on second-look arthroscopy. None of the patients required ipsilateral knee arthroplasty. In the contralateral knees, one pullout repair of a newly developed MMPRT and two knee arthroplasties were performed.

Conclusions: This study demonstrated that F-MMA pullout repair yielded satisfactory clinical outcomes. However, subsequent knee-related surgeries were observed in 6.3% of the pullout-repaired knees and 9.4% of the contralateral knees. Our results suggest that surgeons should be aware of the worsening and/or occurrence of contralateral knee joint disease, even when the postoperative clinical outcomes are satisfactory following MMPRT repair.

Level of evidence: IV.

Keywords: Medial meniscus; Posterior root tear; MMPRT; Transtibial pullout repair; Clinical outcome

1. Introduction

Medial meniscus posterior root tears (MMPRTs) accelerate degradation of the knee joint cartilage and rapid progression of knee osteoarthritis by disrupting the biomechanical functions of the medial meniscus (MM) [1, 2]. Nonoperative management and partial meniscectomy are associated with poor clinical outcomes, worsening arthritis, and a high rate of knee arthroplasty to treat MMPRT [3, 4]. To treat MMPRT, transtibial pullout repair has many clinical advantages in preventing the progression of degenerative knee joint diseases and knee-related symptoms [1, 5-7]. Many surgical options are available in terms of the suture configuration, suturing material, number of sutures, location of the tibial tunnel, and initial tension of suture fixation in pullout repair techniques [1, 5, 8-12]. Transtibial pullout repair using two or three simple stitches demonstrate favorable clinical outcomes in patients with MMPRT during the 5- to 10-year follow-up [13]. A meta-analysis revealed that MMPRT repair results in significant improvements in clinical outcome scores [14]. However, postoperative progression of radiographic knee osteoarthritis in the Kellgren−Lawrence (K−L) grade and worsening of the knee cartilage status are occasionally observed [14]. In a previous study, the overall pooled event rate of K−L grade progression was 10.6% following pullout repair [14]. In a systematic review, 49% of the MMPRT patients who underwent pullout repair showed K−L grade progression (at least 1 grade) at a mean follow-up of 4 years, and 5% of the patients required conversion to total knee arthroplasty (TKA) at a mean follow-up of 6.3 years [15]. Several types of revision surgeries, such as subsequent meniscectomy, re-repair of the MM, and unicompartmental knee arthroplasty, may be required during the follow-up after MMPRT repair. However, the frequency of these revision surgeries is unclear, except for conversion to TKAs. This study was aimed at investigating the midterm clinical outcomes following transtibial pullout repair in patients with MMPRT. The secondary objective was to assess the frequency of revision surgery. We hypothesized that pullout repair of MMPRT would obtain satisfactory clinical outcomes with no conversion to knee arthroplasty during the midterm follow-up.

2. Materials & methods

This study protocol was approved by our institutional review board (Okayama University, KEN2006-027), and written informed consent was obtained from all patients. A total of 38 consecutive patients who underwent transtibial pullout repair to treat MMPRT [10] between October 2016 and September 2018 were initially enrolled in the study (Fig. 1). Of these patients, those patients who underwent concomitant lateral meniscus repair and/or osteochondral autograft transplantation were excluded (n = 4). Thirty-four patients who underwent MMPRT repair and second-look arthroscopy were included. All included patients were diagnosed with isolated MMPRT based on magnetic resonance imaging (MRI) findings [16] and met operative indications for MMPRT repair [2, 9, 10, 17, 18]. Two patients were lost to follow-up after second-look arthroscopy associated with implant removal. Thirty-two (94.1%) patients with a follow-up of > 2 years were retrospectively investigated as the final cohort (Fig. 1, Table 1). Table 1 lists the pre-existing conditions of the contralateral knees at primary pullout repair.

2.1. Surgical procedures and postoperative cares

Indications for pullout repair of MMPRT were provided to patients with an ipsilateral femorotibial angle ≤ 180° and the K–L grade 0–2, which was confirmed on preoperative standing radiographs. Subchondral insufficiency fractures and/or spontaneous osteonecrosis of the knee associated with MMPRT were considered to be contraindications for pullout repair. Patients with relatively large cartilage loss on MRI and International Cartilage Research Society grade 4 at primary surgery were excluded. Standard arthroscopic examination was performed through routine anteromedial and anterolateral portals. An outside-in pie-crusting technique was used to obtain sufficient arthroscopic working space in the medial compartment [10]. The types of MMPRT were determined by careful arthroscopic examination according to the meniscal root tear classification [19]. Pullout repair was performed using the No. 2 Ultrabraid and FasT-Fix 360 reverse curve (Smith & Nephew, Andover, MA, USA) to stabilize the end of the MMPRT in a modified Mason–Allen (MMA) suture configuration [10]. No. 2 Ultrabraid was used to penetrate the MM posterior horn using a suture passer. Two anchors of the FasT-Fix were then inserted through the MM posterior horn to the posterior joint capsule using the oblique or horizontal mattress suture technique. The free end of the FasT-Fix suture was preserved for the transtibial pullout repair. The No. 2 suture and FasT-Fix were set at a crossed position for the FasT-Fix MMA (F-MMA) suture configuration [6, 7, 10, 20, 21]. A specially designed MMPRT guide (Smith & Nephew) was placed at the anatomical insertion of the MM posterior root [17]. A 2.4-mm guide pin was inserted at an angle of 50° to the articular surface, and a tibial tunnel was created using a 4.5-mm cannulated drill. The Ultrabraid and uncut free end of the FasT-Fix sutures were retrieved via the tibial tunnel. Tibial fixation of the sutures was performed using a double-spike plate and screw (Meira, Aichi, Japan) at 45˚ knee flexion with an initial tension of 20 N. One experienced surgeon performed the F-MMA pullout repair. Subsequently, the patients were initially kept non-weight-bearing with a knee immobilizer for 2 weeks. Between 2 and 4 weeks, knee flexion exercise was gradually increased to 30˚, 60˚, and 90˚ under partial weight-bearing conditions (1/3, 1/2, and 2/3 of the body weight). After 5 or 6 weeks, the patients were allowed full weight-bearing and 120˚ of knee flexion. Patients were not allowed to assume a posture that required an excessively high knee flexion angle under weight-bearing conditions during the postoperative follow-up. Second-look arthroscopy and implant removal (plate and screw) were performed in all patients at a mean interval of 13.9 months postoperatively. The postoperative meniscal healing status was evaluated using an arthroscopic scoring system following MMPRT repair [22-24].

2.2. Clinical outcomes and subsequent knee-related surgical events

Clinical evaluations were performed at the time of pullout repair and final follow-up, with a minimum interval of 25 months postoperatively (Table 2). Clinical outcomes were assessed using the Lysholm knee score, Tegner activity score, pain score evaluated using the visual analog scale (VAS), International Knee Documentation Committee (IKDC) subjective knee evaluation form, and Japanese Knee Injury and Osteoarthritis Outcome Score (KOOS). The KOOS comprises five subscales: pain, symptoms, activities of daily living (ADL), sport and recreation function (Sport/Rec), and knee-related quality of life (QOL). Pain intensity in the knee was assessed using a 100-mm VAS, ranging from 0 (no pain) to 100 (worst possible pain) mm. Postoperative knee-related surgical treatments except for second-look arthroscopy and implant removal, were also investigated. Ipsilateral and contralateral knee surgeries following MMPRT repair were also evaluated (Table 3).

2.3. Statistical analysis

Data are expressed as mean ± standard deviation. Differences between the preoperative and postoperative values were compared using the Wilcoxon signed-rank test. Statistical analyses were performed using EZR (Saitama Medical Center, Saitama, Japan), a graphical user interface for R (The R Foundation for Statistical Computing). Statistical significance was set at $P < 0.05$. The sample size was calculated using EZR. With an α of 0.05 and power of 0.80, the required sample size was calculated to be 6−14 patients in each value for comparative assessments of clinical outcomes.

3. Results

The mean postoperative follow-up duration was 36.1 (range, 25−53) months. The mean duration between a sudden posteromedial painful popping episode, indicating the onset of MMPRT [25, 26] and pullout repair was 90.7 days (n = 26, Table 1). The mean arthroscopic meniscal healing score was 6.1 ± 1.8 points (perfect score, 10 points) on second-look arthroscopy. F-MMA pullout repair significantly improved all clinical scores (Lysholm, Tegner, VAS pain, IKDC, and KOOS) at the final follow-up in patients with MMPRT (Table 2). The VAS-based pain scores decreased to a mean value of 6.6 points at the final follow-up. In addition, the postoperative KOOS QOL reached a mean value of 69.3 points at the final follow-up. Figure 2 shows a representative case.

Subsequent arthroscopic debridement was required for one patient at 4 months postoperatively because of range-of-motion loss (10°−80°) of the operated knee. An additional all-inside MM repair using FasT-Fix was performed in one patient on second-look arthroscopy because of a poor/unstable meniscal healing status (3 points, Table 3). None of the patients required ipsilateral knee arthroplasty during the follow-up. In the contralateral knees, one patient underwent pullout repair of a newly developed MMPRT 26 months postoperatively. Unicompartmental knee arthroplasty for the progression of contralateral knee osteoarthritis was performed in one patient at 16 months postoperatively. Contralateral TKA (n = 1) was required at 3 months postoperatively in the other osteoarthritic knees (Table 3). The rates of subsequent knee-related surgical treatments were 6.3% in the pullout-repaired knees and 9.4% in the contralateral knees during the midterm follow-up.

4. Discussion

A major finding in this study was that F-MMA transtibial pullout repair yielded satisfactory clinical outcomes in patients with MMPRT at a mean follow-up of 36.1 months. However, subsequent knee-related surgical treatments were required in 6.3% of the pullout-repaired knees and 9.4% of the contralateral knees during the midterm follow-up. No conversion to knee arthroplasty was required in the ipsilateral knees following pullout repair. Thus, our hypothesis was confirmed. Our results suggest that surgeons should be aware of the worsening and/or occurrence of contralateral knee joint disease, even when postoperative clinical outcomes are satisfactory following MMPRT repair.

Transtibial pullout and suture anchor repairs could result in favorable clinical outcomes in patients with MMPRT [8, 13, 14]. Pullout repair using two simple stitches and two tibial tunnels improved pain VAS from 74 preoperatively to 25 at a mean follow-up of 33 months [27]. Postoperative Lysholm knee scores usually increase to a mean of 83−93 points following MMPRT repair [8, 13, 14, 27]. In our study, F-MMA pullout repair improved the VAS-based pain score from 39.9 preoperatively to 6.6 at a mean follow-up of 36.1 months. Additionally, the mean Lysholm knee score increased from 65.2 to 88.3 at the final follow-up (Table 2). These findings suggest that F-MMA pullout repair compares favorably with other pullout repair techniques to treat MMPRT. Pullout repair reduced tibiofemoral contact pressure by increasing the tibiofemoral contact area in an experimental MMPRT model using the human cadaveric knees [28]. F-MMA pullout repair improves posterior/posteromedial extrusion of the MM and restores tibial rotation during knee flexion [29-31]. A three-dimensional MRI analysis revealed that F-MMA pullout repair increased the functional volume of the MM between the tibial and femoral joint surfaces by decreasing MM posteromedial extrusion at knee flexion [21]. We consider that F-MMA pullout repair can significantly improve clinical outcome scores by restoring biomechanical functions of the MM in patients with MMPRT.

Previous studies have demonstrated the superiority of the MMA suture configuration in a load-to-failure test compared to two simple stitches [32, 33]. The ultimate failure load is significantly greater with F-MMA than with the two simple stitches and similar to that with the conventional MMA suture [10, 33]. Furumatsu et al. reported that pullout repair using the F-MMA suture configuration can achieve good meniscal healing and favorable clinical outcomes in patients with MMPRT 1 year postoperatively [6]. However, Kodama et al. described that knee cartilage degradation of the medial compartment progressed slightly on second-look arthroscopy after F-MMA pullout repair [7]. Postoperative progression of the K–L grade is observed in 4%–49% of the patients following pullout repair [14, 15, 34]. In addition, 0%–22% of the patients underwent TKA conversions of the ipsilateral knees following MMPRT repair [15, 35, 36]. In our study, no patient required ipsilateral knee arthroplasty following F-MMA pullout repair during the mid-term follow-up. However, contralateral knee arthroplasties were performed in two (6.3%) patients at a mean interval of 9.5 months postoperatively (Table 3). Of these, one patient underwent unicompartmental knee arthroplasty of the contralateral knee because of medial compartmental knee osteoarthritis probably induced by chronic MMPRT. Hiranaka et al. reported that a longer time between the occurrence of MMPRT and the surgery is a risk factor for the development of bilateral MMPRT in the contralateral knee [37]. These findings suggest that surgeons should pay close attention to the worsening of clinical symptoms of the contralateral knee in addition to the pullout-repaired knees during the postoperative follow-up.

4.1. Limitations

This study had several limitations. First, this was a retrospective study. Second, the sample size was small. Third, radiographic assessments of joint space narrowing and progression of knee osteoarthritis were not performed. Finally, the minimum 25-month postoperative follow-up period may be too short to evaluate the clinical outcomes and subsequent knee-related surgical treatments following pullout repair in patients with MMPRT.

5. Conclusions

This study demonstrated that F-MMA pullout repair yielded satisfactory clinical outcomes in patients with MMPRT at a mean follow-up of 36.1 months. However, subsequent knee-related surgical treatments were required in 6.3% of the pullout-repaired knees and 9.4% of the contralateral knees during the midterm follow-up. Our results suggest that surgeons should be aware of the worsening and/or occurrence of contralateral knee joint disease, even when postoperative clinical outcomes are satisfactory following the pullout repair of MMPRT.

Acknowledgments

We thank Drs. Tadashi Yamawaki, Masataka Fujii, Takaaki Tanaka, Hiroto Inoue, Tomohito Hino, and Shin Masuda for their clinical supports. We also thank Editage (www.editage.jp) for the English language editing. This study was partly supported by JSPS KAKENHI (grant number: 21K09279).

Compliance with ethical standards

Informed consent

Informed consent was obtained from all patients for being included in this study.

Conflict of interest

The authors have no conflict of interest.

Funding information

No funding sources were provided for this study.

References

1. Bhatia S, LaPrade CM, Ellman MB, LaPrade RF. Meniscal root tears: significance, diagnosis, and treatment. Am J Sports Med 2014;42:3016-30.
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;29:295-301.
3. Krych AJ, Reardon PJ, Johnson NR, Mohan R, Peter L, Levy BA, Stuart MJ. Non-operative management of medial meniscus posterior horn root tears is associated with worsening arthritis and poor clinical outcome at 5-year follow-up. Knee Surg Sports Traumatol Arthrosc 2017;25:383-9.

4. Bernard CD, Kennedy NI, Tagliero AJ, Camp CL, Saris DBF, Levy BA, Stuart MJ, Krych AJ. Medial meniscus posterior root tear treatment: a matched cohort comparison of nonoperative management, partial meniscectomy, and repair. Am J Sports Med 2020;48:128-32.
5. Bonasia DE, Pellegrino P, D'Amelio A, Cottino U, Rossi R. Meniscal root tear repair: why, when and how? Orthop Rev (Pavia) 2015;7:5792.
6. 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;26:653-9.
7. 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 doi: 10.1007/s00167-019-05810-x.
8. 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;27:1644-53.
9. 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;102:951-4.
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;27:559-62.
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;29:705-9.
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;29:1805-9.

13. 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;34:530-5.

14. 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;24:1455-68.

15. Chang PS, Radtke L, Ward P, Brophy RH. Midterm outcomes of posterior medial meniscus root tear repair: a systematic review. Am J Sports Med 2021 doi: 10.1177/0363546521998297.

16. 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;22:731-6.

17. 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;103:367-71.

18. 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;103:1179-82.

19. 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;43:363-9.

20. 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 doi: 10.1016/j.knee.2020.02.025.

21. 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 doi: 10.1007/s00167-020-05953-2.

22. 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;43:1239-45.

23. 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 2021;26:237-42.

24. Furumatsu T, Hiranaka T, Okazaki Y, Kintaka K, Kodama Y, Kamatsuki Y, Ozaki T. Medial meniscus posterior root repairs: A comparison among three surgical techniques in short-term clinical outcomes and arthroscopic meniscal healing scores. J Orthop Sci 2021 doi: 10.1016/j.jos.2020.11.013.

25. Bae JH, Paik NH, Park GW, Yoon JR, Chae DJ, Kwon JH, Kim JI, Nha KW. Predictive value of painful popping for a posterior root tear of the medial meniscus in middle-aged to older Asian patients. Arthroscopy. 2013;29:545-9.

26. 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;105:107-11.

27. Moon HK, Koh YG, Kim YC, Park YS, Jo SB, Kwon SK. Prognostic factors of arthroscopic pull-out repair for a posterior root tear of the medial meniscus. Am J Sports Med 2012;40:1138-43.

28. 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;43:912-20.

29. Masuda S, Furumatsu T, Okazaki Y, Kamatsuki Y, Okazaki Y, Kodama Y, Hiranaka T, Nakata E, Ozaki T. Transtibial pullout repair reduces posterior extrusion of the medial meniscus. Acta Med Okayama 2019;73:495-501.

30. 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;27:132-9.

31. Okazaki Y, Furumatsu T, Kodama Y, Hino T, Kamatsuki Y, Okazaki Y, Masuda S, Miyazawa S, Endo H, Tetsunaga T, Yamada K, Ozaki T. Transtibial pullout repair of medial meniscus posterior root tear restores

physiological rotation of the tibia in the knee-flexed position. Orthop Traumatol Surg Res 2019;105:113-7.

32. 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;41:2784-90.

33. 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;41:2113-8.

34. 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;30:1439-46.

35. Chung KS, Ha JK, Yeom CH, Ra HJ, Jang HS, Choi SH, Kim JG. Comparison of clinical and radiologic results between partial meniscectomy and refixation of medial meniscus posterior root tears: a minimum 5-year follow-up. Arthroscopy 2015;31:1941-50.

36. Chung KS, Ha JK, Ra HJ, Yu WJ, Kim JG. Root repair versus partial meniscectomy for medial meniscus posterior root tears: comparison of long-term survivorship and clinical outcomes at minimum 10-year follow-up. Am J Sports Med 2020;48:1937-44.

37. Hiranaka T, Furumatsu T, Okazaki Y, Yamawaki T, Okazaki Y, Kodama Y, Kamatsuki Y, Ozaki T. Steep medial tibial slope and prolonged delay to surgery are associated with bilateral medial meniscus posterior root tear. Knee Surg Sports Traumatol Arthrosc 2021;29:1052-7.

Figure legends

Fig. 1. Flow chart of patient selection in this study.

Fig. 2. A case presentation (54-year-old man, left knee). (A) MMPRT type 2A. (B) F-MMA pullout repair. (C) Arthroscopic meniscal healing score (10 points, at 1 year postoperatively). (D, E) Radiographic images. (F-H) MRI scans. Arrow, cleft sign. Note the time-dependent change in intra-meniscal signal intensity of the MM.