A posterior anchoring method decreases pullout suture translation of the medial meniscus posterior root repair during knee flexion

Yuki Okazaki[a, b], Takayuki Furumatsu[b]*, Takaaki Hiranaka[b], Keisuke Kintaka[b], Naohiro Higashihara[b], Masanori Tamura[b], Toshifumi Ozaki[b]

[a]*Department of Orthopaedic Surgery, Tsuyama Chuo Hospital, 1756 Kawasaki, Tsuyama, Okayama 708-0841, Japan*

[b]*Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences, 2-5-1 Shikata-cho, Kita-ku, Okayama 700-8558, Japan*

*Correspondence to:

Takayuki Furumatsu

Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences, 2-5-1 Shikata-cho, Kita-ku, Okayama 700-8558, Japan

Tel: +81 862 357 273

Fax: +81 862 239 727

E-mail: matino@md.okayama-u.ac.jp

[1]

[1] Abbreviations list: MM, Medial meniscus; MMME, Medial meniscus medial extrusion; MMPRT, Medial meniscus posterior root tear; MMBW, Medial meniscus body width; MMPH, Medial meniscus posterior height; MMPW, Medial meniscus posterior width; MRI, Magnetic resonance imaging; MTP, Medial tibial plateau; PRT, Posterior root tear

1. Introduction

Medial meniscus (MM) posterior root tear (PRT) is of interest to several researchers, and a number of clinical, biomechanical, and histological studies on MMPRT have been conducted [1-6]. Transtibial pullout repair of MMPRT is recommended to regulate MM medial extrusion (ME)/femorotibial relation (rotation), increase contact area, reduce contact pressure, and prevent the subsequent development of osteoarthritis [1, 4, 7, 8]. Alternative techniques for PRT even without special instruments have been reported [9]. The MM shows minimal posteromedial shifts during knee flexion in normal knees because the MM posterior root serves as an anchor to limit meniscal shifts during knee movement and load bearing [10]. In knees with MMPRT, the MM translates posteriorly and extrudes severely from the medial tibial plateau (MTP) during knee flexion. Notably, MM posterior root repair reduces the extruded meniscus area/volume during knee flexion with favorable clinical outcomes [11-13], along with the factors leading to better correction of the MMME (younger age [< 50], low-grade cartilage damage [International Cartilage Repair Society grade of 1 or 2], and reduced varus alignment [<2.5°]) [14].

The location of the repair and suture configurations have been reported to be important to obtain better failure load [15-17]. Repairs located in the substance of the meniscus were significantly stronger than those in the transition zone and root ligament [15]. The cinch suture has more biomechanical strength than other suture techniques and is advantageous because it causes fewer perforations of the meniscal tissue when using all-inside suture devices, and a simple cinch suture showed less cyclic displacement than a locking loop but a similar ultimate failure load [16, 17]. With the above development regarding the pullout technique, MMME in the coronal plane does not always decrease even after repair [18], and patients with increased MMME after repair have low clinical scores [19, 20]. Furthermore, changes in MM posterior extrusion at 90° of knee flexion were significantly correlated with 12-month postoperative clinical scores [13]. Therefore, novel surgical techniques to reduce MM posteromedial extrusion have been developed. Although there are some surgical techniques to reduce MM extrusion after pullout repair, such as anatomic bone tunnel creation [21-23], posterior anchoring [24], and in combination with the centralization technique [25-28], no study has reported the effect of preventing MM posterior translation *in vivo*.

Hiranaka et al. examined preoperative morphological features of the MM, and measured intraoperative suture translation during knee flexion using two simple stitches with an additional all-inside suture [29]. They concluded that longer meniscal translations during knee flexion were associated with larger preoperative MMME, and a greater MM posterior height (MMPH). However, suture translation using two cinch sutures, or the change in translation before and after additional sutures, have yet to be clarified.

To address these gaps in the literature, this study aimed to evaluate (1) suture translation using two cinch sutures, during knee flexion before and after the posterior anchoring method in transtibial pullout repair of the MMPRT; and (2) to assess the correlation between the preoperative morphological features of the MM and suture translation before posterior anchoring. We hypothesized that suture translation after posterior anchoring would be significantly decreased relative to that before posterior anchoring, and that a preoperative larger MMME and greater MMPH would correlate with suture translation.

2. Materials and methods

2.1. Patients and ethical considerations

Between December 2020 and April 2021, 46 patients who underwent surgery for MMPRT at our hospital were prospectively evaluated. Transtibial pullout repair of the MMPRT was indicated in patients with a femorotibial angle <180°, radiographic Kellgren-Lawrence grade of 0–2, and a body mass index <35 kg/m^2. Of the 46 patients, 11 were excluded because it was not clear if they had a painful popping episode, of a lack of measurement of the suture translation, or had undergone different surgical techniques including the technique combined with centralization [26]. After applying the exclusion criteria, 35 patients were included for further analyses. All included patients underwent the posterior anchoring method with pullout repair of the MMPRT as previously described [24]. Medical records were reviewed to examine patient characteristics including age, height, body weight, and duration from injury to magnetic resonance imaging (MRI). All patients were diagnosed with MMPRT based on MRI findings, such as cleft, giraffe neck, and ghost signs, as well as radial tear and meniscal extrusion (>3 mm) [30, 31]. The MMPRT classification was defined using arthroscopy according to a previous study [32]. All protocols were approved by the institutional review board (# 1857), and informed consent was obtained from all the participants included in the study.

2.2. Surgical technique

A standard arthroscopic examination was performed using a 4-mm-diameter 30° view angle arthroscope (Smith & Nephew, London, UK). A probe was introduced through the anteromedial portal to confirm the MMPRT (Fig. 1a). To increase the space in patients with tight medial compartments, we used outside-in pie-crusting of the medial collateral ligament with a standard 18-gauge (1.2×40 mm) hypodermic needle (Terumo Corporation, Tokyo, Japan) [33].

We used a Knee Scorpion™ suture passer (Arthrex, Inc., Naples, FL, USA) to pass two No. 2 strong sutures vertically through the meniscal tissue (Fig. 1b). The suture was placed as a first cinch stitch with a safety margin of approximately 10 mm from the edge of the tear to prevent suture cut-out and loss of fixation. The first suture was inserted into the inner part of the MM posterior horn, and the second suture was inserted into the outer part, more than 5 mm away from the tear.

MM posterior root attachment was confirmed before placing a custom-made posterior root-aiming device (Posterior Root Tear guide, Smith & Nephew; Unicorn Meniscal Root guide, Arthrex Inc.) [34] at the anatomic center of the posterior root attachment, as described previously (Fig. 1c) [35]. A 2.4-mm guide pin was inserted at a 45° angle to the root attachment with the aiming device, and a

4.0-mm cannulated drill was used to overdrill the tibial tunnel. After removing the inner guide pin alone, all cinch sutures were pulled out through the cannulated drill using a suture relay technique. Gentle tension was applied to the sutures until the posterior horn reached its tibial attachment area (Fig. 1d).

In the next step, a further bone tunnel was created using a flexible reamer for a 1.8 mm Q-Fix anchor (Smith & Nephew), aiming at the posterior corner of the MTP (approximately 15 mm away from the posterior root attachment) in externally rotated knee flexion (Fig. 2a). The first anchor of the JuggerStitch (Zimmer Biomet, Warsaw, IN, USA) all-inside meniscal repair device was inserted through the inferior surface of the MM posterior horn while tensioning two cinch sutures (Fig. 2b) during knee extension, and the second anchor of the same JuggerStitch repair device was inserted into the second bone tunnel during knee flexion and flipped on the cortex (Fig. 2c). Once moderate tension of the posterior anchoring suture was confirmed during 30° knee flexion, the free end of the all-inside suture was cut. Tibial fixation of the pullout sutures was performed using a 5.0-mm bioabsorbable screw with an initial tension of 10 N during 30° knee flexion, as previously described (Fig. 2d) [36].

2.3. Measurement method

The measurement method was performed by an experienced surgeon three times intraoperatively, and the mean value was recorded as previously described by Hiranaka et al. [29] (Fig. 3). The sutures were marked to evaluate outer suture translation during knee flexion because the outer suture's translation was the largest in their report. Ultrabraid #2 suture (Smith & Nephew) was cut into two sutures (outer and inner) at its midpoint, and each suture was folded into two sutures. The marking point of the outer suture was made on the Ultrabraid at 10 cm from the folded point. A measurement bar was created using the pipe attached to the all-inside suture device, JuggerStitch. The accessory pipe attached to the JuggerStitch was cut at 5 cm, and the surgical tape was rolled at 2 cm from the edge of the bar to fix it at the bone aperture [29] (Fig. 3a). All sutures were pulled out through the bar, and the bar was inserted into the tibial bone aperture. The outer suture was pulled out and tensioned at 5 N using the Kocher clamp and spring tensioner (Fig. 3c, d). The knee flexion angle was confirmed using a goniometer (MMI goniometer, Muranaka Medical Instruments, Osaka, Japan). The distance between the edge of the bar and the marking point was measured using a ruler (Hogy Medical, Tokyo, Japan) with the knee flexed at 0° and 90° (Fig. 3b-d). The translation distance was calculated using the following formula: (distance from bar to mark at 0°) – (distance from bar to mark at 90°).

2.4. Radiographic assessments

The measurement of the medial tibial posterior slope was performed on lateral radiographs by drawing two lines, as described by Brandon et al. [37], defined by the longitudinal axis of the tibia and the medial tibial slope, respectively. The medial tibial posterior slope was defined as 90° minus the angle made by the intersection of the line of the longitudinal axis of the tibia and the medial tibial slope (a line tangent to the medial tibial plateau connecting the uppermost superior anterior and posterior cortex edges). The longitudinal axis of the tibia was defined by the line created by connecting the midpoint of the anteroposterior diameter of the tibia just inferior to the tibial tubercle to the midpoint of the anteroposterior diameter of the tibial shaft, measured no less than 5 cm distal to the tibial tubercle.

An MRI evaluation was performed using an Achieva 1.5T scanner (Philips, Amsterdam, The Netherlands) or Excelart Vantage^{TM} powered by Atlas 1.5T with an integrated coil (Toshiba Medical Systems, Tochigi, Japan). The MRI-based MM body width (MMBW) and MMME were assessed using a coronal view, as previously described [29] (Fig. 4a). The MMBW was measured from the inner to the outer border of the MM on the coronal image that crossed the midpoint of the MM anteroposterior length. MMME was measured from the medial margin of the tibial plateau to the outer border of the MM. The MM size was different between patients; therefore, the relative MMME (rMMME) was calculated as 100 × MMME/MMBW (%). MM medial height was defined as the distance from the lowest to the highest MM point. MRI-based MM posterior width (MMPW) and MMPH were assessed using a sagittal view, as previously described [29] (Fig. 4b). The reference line was drawn along the subchondral bone from the anterior to the posterior aspect of the articular surface. The MMPW was measured as the distance from the anterior to the posterior edge of the MM (parallel to the reference line), and the MMPH was measured from the bottom to the top of the MM (perpendicular to the reference line).

2.5. Statistical analyses

Data are reported as means ± standard deviations. All statistical analyses were performed using EZR software (Saitama Medical Center, Jichi Medical University, Tochigi, Japan) [38]. Intra-patient differences in measured values were evaluated using the Wilcoxon signed-rank test. Statistical significance was set at $p < 0.05$.

3. Results

Patient demographic information is shown in Table 1. Thirty-five patients were enrolled in this study (mean age, 67.1±8.5), and duration from injury to MRI was 7.7±6.3 weeks. The average outer suture translations before and after the posterior anchoring method were 2.5±1.7 mm and 1.6±1.5 mm, respectively (Fig. 5). A significant difference was observed between the two groups ($p<0.01$, power=0.87). The preoperative MM morphological features are shown in Table 2. The absolute medial meniscus extrusion was 3.3±0.9 mm, and relative medial meniscus extrusion was 35.8±10.4%. No significant correlations were observed between the preoperative MM morphological features and the outer suture translation.

4. Discussion

The most important finding of this study was that suture translation after posterior anchoring was significantly decreased relative to that before posterior anchoring, although there was no significant correlation between any preoperative MM morphological features and suture translation. Our hypothesis was partially supported: the hypothesis that suture translation after posterior anchoring would be significantly decreased relative to that before posterior anchoring was supported, whereas the hypothesis that a preoperative larger MMME and greater MMPH would correlate with suture translation was refuted.

Recently, several studies have investigated meniscal root properties, kinematics, and biomechanics [39-42]. MMPRT leads to significant changes in the *in vivo* knee kinematics and the loading profile of the medial joint compartment [43], resulting in a loss of hoop resistance, meniscus extrusion [44], and early degenerative changes [45]. Other studies have found no difference between the peak contact pressure after total medial meniscectomy and that associated with a root tear, and established that root repair was successful in restoring joint biomechanics and knee rotation to within normal conditions [1, 7]. Furthermore, augmentation with the centralization technique reduces biomechanical properties of load distribution and contact area/pressure [25-28]. Hiranaka et al. first examined and reported intraoperative suture translation during transtibial pullout repair using two simple stitches [29]. However, the current study is the first to report changes in suture translation using two cinch sutures before and after additional sutures.

A previous technical note described the reduction of a severely extruded MM using three-dimensional MRI [24]; however, that study did not describe the exact distance of MM translation before and after the posterior anchoring method. The current study has clarified that posterior suture translation of the MM is regulated using the posterior anchoring method combined with transtibial pullout repair (average 0.9 mm). This surgical technique may lead to favorable clinical outcomes because the changes in MMPE at 90° of knee flexion were significantly correlated with 12-month postoperative clinical scores [13]. Furthermore, another advantage of this technique is that it allows for the creation of additional bone tunnels and all-inside sutures without the need for any accessory portal because it can be performed through a standard anteromedial portal when manipulating the knee rotation and flexion angles. We consider that this posterior anchoring method is a simple, safe, and reproducible technique and that this method can serve as a candidate for additional sutures because of its ease of use and the absence of additional accessory portals.

Suture translation with two cinch sutures even before the posterior anchoring method was smaller than those with two simple stitches previously described (4.8±2.1 mm) [29]. We consider that this is one of the reasons for the lack of correlation between MM morphological features and suture translation. The findings that suture translation with two cinch sutures were smaller than that with two simple stitches also indicates the advantage of the use of cinch sutures. When we perform pullout repair of the MMPRT using two cinch sutures rather than two simple stitches, we find that the sutures elongate to some extent (average 2.3 mm, calculated as the results of this study and the previous study [29]), and overloading on the MM posterior root/horn might be partially prevented because the loading may be distributed to knots of the cinch. Therefore, even after starting rehabilitation, the risk of suture cut-out would decrease, and second-look arthroscopic findings (synovial coverage/suture cut-out) [46] or MRI findings (root healing [continuity and signal intensity], MMME, and cartilage status) [47] would be better.

This study has some limitations. First, the sample size was small, which may have resulted in the lack of a correlation between the preoperative morphologic features of MM and suture translation. Second, suture translation was only evaluated under 5 N tension. Third, the morphologic predictors of only the outer suture translation were evaluated because it was longer than inner suture translation. Fourth, a biomechanical study was not performed and the safety of the atypical use of the JuggerStitch for bone tunnel insertion has not been ensured, although the anchor is expected to stay in a similar position to that for the common use. Finally, the correlation between suture translation and clinical results, including MRI parameters, meniscal healing status, or complications, such as postoperative suture cut-out, was not demonstrated. Further evaluation with long-term follow-up or biomechanical testing is needed to deepen our knowledge in the future.

5. *Conclusion*

The posterior anchoring method with MM posterior root repair is useful in decreasing posterior translation of the pullout suture during knee flexion, which might have an advantage in preventing suture pullout from the repaired MM and may lead to good clinical outcomes.

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Declaration of interest

None.

Availability of data and material

Data and material of the study are available upon request by contacting the corresponding author.

References

[1] Allaire R, Muriuki M, Gilbertson L, Harner CD. Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. J Bone Joint Surg Am 2008;90(9):1922-31.

[2] Sahoo K, Garg A, Saha P, Dodia JV, Raj VR, Bhairagond SJ. Study of Imaging Pattern in Bone Marrow Oedema in MRI in Recent Knee Injuries and its Correlation with Type of Knee Injury. Journal of clinical and diagnostic research : JCDR 2016;10(4):Tc06-11.

[3] Hino T, Furumatsu T, Miyazawa S, Fujii M, Kodama Y, Kamatsuki Y, et al. A histological study of the medial meniscus posterior root tibial insertion. Connect Tissue Res 2020;61(6):546-53.

[4] Bernard CD, Kennedy NI, Tagliero AJ, Camp CL, Saris DBF, Levy BA, et al. Medial Meniscus Posterior Root Tear Treatment: A Matched Cohort Comparison of Nonoperative Management, Partial Meniscectomy, and Repair. The American journal of sports medicine 2020;48(1):128-32.

[5] Chung KS, Noh JM, Ha JK, Ra HJ, Park SB, Kim HK, et al. Survivorship Analysis and Clinical Outcomes of Transtibial Pullout Repair for Medial Meniscus Posterior Root Tears: A 5- to 10-Year Follow-up Study. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2018;34(2):530-5.

[6] Sharif B, Ashraf T, Saifuddin A. Magnetic resonance imaging of the meniscal roots. Skeletal Radiol 2020;49(5):661-76.

[7] Okazaki Y, Furumatsu T, Kodama Y, Hino T, Kamatsuki Y, Okazaki Y, et al. Transtibial pullout repair of medial meniscus posterior root tear restores physiological rotation of the tibia in the knee-flexed position. Orthopaedics & traumatology, surgery & research : OTSR 2019;105(1):113-7.

[8] Chung KS, Ha JK, Ra HJ, Kim JG. A meta-analysis of clinical and radiographic outcomes of posterior horn medial meniscus root repairs. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2016;24(5):1455-68.

[9] Helito CP, Melo LDP, Guimaraes TM, Sobrado MF, Helito PVP, Pecora JR, et al. Alternative Techniques for Lateral and Medial Posterior Root Meniscus Repair Without Special Instruments. Arthroscopy techniques 2020;9(7):e1017-e25.

[10] Bhatia S, LaPrade CM, Ellman MB, LaPrade RF. Meniscal root tears: significance, diagnosis, and treatment. The American journal of sports medicine 2014;42(12):3016-30.

[11] Okazaki Y, Furumatsu T, Okazaki Y, Masuda S, Hiranaka T, Kodama Y, et al. Medial meniscus posterior root repair decreases posteromedial extrusion of the medial meniscus during knee flexion. The Knee 2020;27(1):132-9.

[12] Okazaki Y, Furumatsu T, Yamauchi T, Okazaki Y, Kamatsuki Y, Hiranaka T, et al. Medial meniscus posterior root repair restores the intra-articular volume of the medial meniscus by decreasing posteromedial extrusion at knee flexion. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2020;28(11):3435-42.

[13] Zhang X, Furumatsu T, Okazaki Y, Okazaki Y, Hiranaka T, Xue H, et al. Medial meniscus posterior root repair reduces the extruded meniscus volume during knee flexion with favorable clinical outcome. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2021.

[14] Sundararajan SR, Ramakanth R, Sethuraman AS, Kannan M, Rajasekaran S. Correlation of factors affecting correction of meniscal extrusion and outcome after medial meniscus root repair. Arch Orthop Trauma Surg 2021.

[15] Robinson JR, Frank EG, Hunter AJ, Jermin PJ, Gill HS. The Strength of Transosseous Medial Meniscal Root Repair Using a Simple Suture Technique Is Dependent on Suture Material and Position. The American journal of sports medicine 2018;46(4):924-32.

[16] Anz AW, Branch EA, Saliman JD. Biomechanical comparison of arthroscopic repair constructs for meniscal root tears. The American journal of sports medicine 2014;42(11):2699-706.

[17] Krych AJ, Johnson NR, Wu IT, Smith PA, Stuart MJ. A simple cinch is superior to a locking loop for meniscus root repair: a human biomechanical comparison of suture constructs in a transtibial pull-out model. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2018;26(8):2239-44.

[18] Kaplan DJ, Alaia EF, Dold AP, Meislin RJ, Strauss EJ, Jazrawi LM, et al. Increased extrusion and ICRS grades at 2-year follow-up following transtibial medial meniscal root repair evaluated by MRI. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2018;26(9):2826-34.

[19] Chung KS, Ha JK, Ra HJ, Nam GW, Kim JG. Pullout Fixation of Posterior Medial Meniscus Root Tears: Correlation Between Meniscus Extrusion and Midterm Clinical Results. The American journal of sports medicine 2017;45(1):42-9.

[20] Chung KS, Ha JK, Ra HJ, Kim JG. Preoperative varus alignment and postoperative meniscus extrusion are the main long-term predictive factors of clinical failure of meniscal root repair. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2021.

[21] Moatshe G, Chahla J, Slette E, Engebretsen L, Laprade RF. Posterior meniscal root injuries. Acta Orthop 2016;87(5):452-8.

[22] Starke C, Kopf S, Grobel KH, Becker R. The effect of a nonanatomic repair of the meniscal horn attachment on meniscal tension: a biomechanical study. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2010;26(3):358-65.

[23] Kamatsuki Y, Furumatsu T, Hiranaka T, Okazaki Y, Kodama Y, Kintaka K, et al. Accurate placement of a tibial tunnel significantly improves meniscal healing and clinical outcomes at

1 year after medial meniscus posterior root repair. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2021.

[24] Okazaki Y, Furumatsu T, Hiranaka T, Kintaka K, Zhang X, Kodama Y, et al. Novel posterior anchoring method associated with medial meniscus posterior root repair. Tech Orthop 2021.

[25] Koga H, Nakamura T, Nakagawa Y, Ozeki N, Ohara T, Shioda M, et al. Arthroscopic Centralization Using Knotless Anchors for Extruded Medial Meniscus. Arthroscopy techniques 2021;10(3):e639-e45.

[26] Koga H, Watanabe T, Horie M, Katagiri H, Otabe K, Ohara T, et al. Augmentation of the Pullout Repair of a Medial Meniscus Posterior Root Tear by Arthroscopic Centralization. Arthroscopy techniques 2017;6(4):e1335-e9.

[27] Ozeki N, Koga H, Matsuda J, Kohno Y, Mizuno M, Katano H, et al. Biomechanical analysis of the centralization procedure for extruded lateral menisci with posterior root deficiency in a porcine model. Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association 2019.

[28] Ozeki N, Muneta T, Kawabata K, Koga H, Nakagawa Y, Saito R, et al. Centralization of extruded medial meniscus delays cartilage degeneration in rats. Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association 2017;22(3):542-8.

[29] Hiranaka T, Furumatsu T, Okazaki Y, Kodama Y, Kamatsuki Y, Ozaki T. Preoperative morphologic changes of the medial meniscus correlate with suture translations during knee flexion in pullout repair of medial meniscus posterior root tear. The Knee 2021;28:346-53.

[30] Choi SH, Bae S, Ji SK, Chang MJ. The MRI findings of meniscal root tear of the medial meniscus: emphasis on coronal, sagittal and axial images. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2012;20(10):2098-103.

[31] 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. Journal of orthopaedic science : official journal of the Japanese Orthopaedic Association 2017;22(4):731-6.

[32] LaPrade CM, James EW, Cram TR, Feagin JA, Engebretsen L, LaPrade RF. Meniscal root tears: a classification system based on tear morphology. The American journal of sports medicine 2015;43(2):363-9.

[33] Todor A, Caterev S, Nistor DV. Outside-In Deep Medial Collateral Ligament Release During Arthroscopic Medial Meniscus Surgery. Arthroscopy techniques 2016;5(4):e781-e5.

[34] Furumatsu T, Okazaki Y, Kodama Y, Okazaki Y, Kamatsuki Y, Masuda S, et al. 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;31(1):7.

[35] Hiranaka T, Furumatsu T, Kamatsuki Y, Miyazawa S, Okazaki Y, Masuda S, et al. 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. The Knee 2020;27(3):899-905.

[36] 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 stiches under an expected initial tension. European journal of orthopaedic surgery & traumatology : orthopedie traumatologie 2019;29(3):705-9.

[37] Brandon ML, Haynes PT, Bonamo JR, Flynn MI, Barrett GR, Sherman MF. The association between posterior-inferior tibial slope and anterior cruciate ligament insufficiency. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2006;22(8):894-9.

[38] Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant 2013;48(3):452-8.

[39] Markolf KL, Jackson SR, McAllister DR. Force measurements in the medial meniscus posterior horn attachment: effects of anterior cruciate ligament removal. The American journal of sports medicine 2012;40(2):332-8.

[40] Starke C, Kopf S, Lippisch R, Lohmann CH, Becker R. Tensile forces on repaired medial meniscal root tears. Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2013;29(2):205-12.

[41] LaPrade CM, Jansson KS, Dornan G, Smith SD, Wijdicks CA, LaPrade RF. Altered tibiofemoral contact mechanics due to lateral meniscus posterior horn root avulsions and radial tears can be restored with in situ pull-out suture repairs. J Bone Joint Surg Am 2014;96(6):471-9.

[42] Ellman MB, LaPrade CM, Smith SD, Rasmussen MT, Engebretsen L, Wijdicks CA, et al. Structural Properties of the Meniscal Roots. The American journal of sports medicine 2014;42(8):1881-7.

[43] Marsh CA, Martin DE, Harner CD, Tashman S. Effect of Posterior Horn Medial Meniscus Root Tear on In Vivo Knee Kinematics. Orthopaedic journal of sports medicine 2014;2(7):2325967114541220.

[44] Masuda S, Furumatsu T, Okazaki Y, Kodama Y, Hino T, Kamatsuki Y, et al. Medial meniscus posterior root tear induces pathological posterior extrusion of the meniscus in the knee-flexed position: An open magnetic resonance imaging analysis. Orthopaedics & traumatology, surgery & research : OTSR 2018;104(4):485-9.

[45] Marzo JM, Gurske-DePerio J. Effects of medial meniscus posterior horn avulsion and repair on tibiofemoral contact area and peak contact pressure with clinical implications. The American journal of sports medicine 2009;37(1):124-9.

[46] Furumatsu T, Miyazawa S, Fujii M, Tanaka T, Kodama Y, Ozaki T. Arthroscopic scoring

system of meniscal healing following medial meniscus posterior root repair. International orthopaedics 2019;43(5):1239-45.
[47] de Oliveira CV, Lôbo CFT, Helito PVP, Bordalo-Rodrigues M, Helito CP. The role of MRI in evaluation of arthroscopic transtibial pullout repair for medial meniscus posterior root tears. Clinical imaging 2021;77:158-68.

Table 1. Patient demographics

	Values
Number of patients	35
Sex (male/female)	7/28
Age (years)	67.1±8.5
Height (m)	1.55±0.1
Weight (kg)	61.4±12.6
Body mass index (kg/m^2)	25.5±3.7
Duration from injury to MRI (weeks)	7.7±6.3
Kellgren-Lawrence grade (1/2)	15/20
Femorotibial angle (°)	177.8±1.9
Medial tibial posterior slope (°)	10.5±3.6
Posterior root tear classification (1/2/4)	2/32/1

Data are presented as mean ± standard deviation or number.
MRI, magnetic resonance imaging.

Table 2. Medial meniscus morphological features measured using magnetic resonance imaging

	Values
Coronal view	
Absolute medial meniscus extrusion (mm)	3.3±0.9
Medial meniscus body width (mm)	9.4±2.1
Relative medial meniscus extrusion (%)	35.8±10.4
Medial meniscus medial height (mm)	7.4±1.1
Sagittal view	
Medial meniscus posterior width (mm)	13.7±2.0
Medial meniscus posterior height (mm)	6.9±1.1

Data are presented as mean ± standard deviation or number.

Figure legends

Fig. 1. Arthroscopic findings of pullout repair using two cinch sutures.

(a) A complete radial tear of the medial meniscus posterior root is confirmed by a probe.

(b) Two cinch sutures are applied using the Knee Scorpion™ (Arthrex, Inc., Naples, FL, USA) suture passer.

(c) The tibial tunnel is created using an aiming guide.

(d) Configuration of the two cinch sutures

MFC, medial femoral condyle; MM, medial meniscus; MTP, medial tibial plateau.

Fig. 2. Arthroscopic findings of an additional all-inside anchoring suture.

(a) Additional bone tunnel is created using flexible reamer.

(b) An all-inside first suture is inserted through the inferior surface of the MM posterior horn with tensioning two cinch sutures.

(c) An all-inside second suture is inserted into the bone tunnel in knee flexion.

(d) A final appearance following pullout and anchoring repair. Adequate tension of each suture is confirmed.

MFC, medial femoral condyle; MM, medial meniscus; MTP, medial tibial plateau.

Fig. 3. Intraoperative measurement of outer suture translation. The suture is pulled out and tensioned at 5 N using the Kocher clamp and a spring tensioner.

(a) Measurement bar

(b) Measurement of the distance from the edge of the bar to the marking point

(c) Lateral view of the extended knee during measurement

(d) Lateral view of the knee flexed at 90°during measurement

Fig. 4. Magnetic resonance imaging-based measurement of the medial meniscus morphology

(a) The white solid line shows the edge of the medial tibial plateau, and the white dashed line shows the edge of the medial meniscus. Medial meniscus medial extrusion (white solid double arrowhead), medial meniscus body width (red dotted double arrowhead), medial meniscus medial height (yellow dashed double arrowhead).

(b) A white solid line is drawn along the subchondral bone from the anterior to the posterior aspect of the articular surface. Medial meniscus posterior width (red dotted double arrowhead). Medial meniscus posterior height (yellow dashed double arrowhead).

Fig. 5. Values of suture translation from 0° to 90° of knee flexion before and after posterior anchoring (presented as mean and standard error). *P<0.01.