An MRI-based suspension bridge sign can predict an arthroscopically favorable meniscal healing following the medial meniscus posterior root repair.
Abstract

Background

Medial meniscus (MM) posterior root repairs show favorable clinical outcomes in patients with MM posterior root tears (MMPRTs). However, there is no useful magnetic resonance imaging (MRI) finding to determine a functionally good meniscal healing following MM posterior root repairs. We hypothesized that a characteristic postoperative MRI finding can predict a good meniscal healing following pullout repairs. The aim of this study was to investigate a clinical usefulness of several MRI findings for estimating an actual meniscal healing following MMPRT repairs.

Methods

Fifty eight patients who had a posteromedial painful popping of the injured knee and underwent an arthroscopic pullout repair for the MMPRT were included. Arthroscopic meniscal healing was assessed according to the Furumatsu scoring system at 1 year postoperatively. We evaluated postoperative MRI-based meniscal healing using signal intensity, continuity, suspension bridge-like sign of the MM posterior root, and MM medial extrusion on coronal images. Postoperative clinical outcome evaluations were performed at second-look arthroscopy.

Results

Twenty three patients showed good arthroscopic healing scores (≥ 7 points). Thirty five patients had moderate/poor arthroscopic healing scores (< 7 points). At 1-year follow-up period, clinical outcome scores
were significantly higher in the good healing group than in the moderate/poor healing group. A characteristic
meniscal shape, termed “suspension bridge sign”, was highly observed in the good meniscal healing group
(83%) compared with in the moderate/poor healing group (26%, P < 0.001). High signal intensity and continuity
of the MM posterior root and MM medial extrusion showed no differences between both groups.

Conclusions

Our study demonstrated that the MRI-based suspension bridge sign can predict an arthroscopically
favorable meniscal healing following the MM posterior root repair. The suspension bridge-like MRI finding of
the MM would be a useful indicator to evaluate the actual meniscal healing in patients who underwent pullout
repairs for MMPRTs.
**Introduction**

Medial meniscus posterior root tears (MMPRTs) lead to rapid progression of knee osteoarthritis by disrupting meniscal functions [1, 2]. Therefore, early diagnosis and appropriate surgical treatment are important in obtaining successful clinical outcomes and preventing progression of degenerative knee joint diseases in patients with MMPRTs [1, 3]. Medial meniscus (MM) posterior root repair will be required if the patients meet an operative indication of arthroscopic meniscus repair for the treatment of MMPRTs [1, 3-9]. Several authors report qualitative classifications of postoperative meniscal healing in patients who underwent MM posterior root repairs using magnetic resonance imaging (MRI) examinations. These qualitative classifications are 2- or 3-staged evaluation systems to presume the postoperative meniscal healing after surgery on MR images. In an MRI-based structural healing assessment, MM posterior root is considered completely healed if the configuration of the repaired posterior root is normal on T1-weighted images without hyperintense defect on both T2-weighted semi-coronal and axial MRI scans. Incomplete healing is defined as partial (more than one-third of root diameter) absence of the MM posterior root or high signal intensity on semi-coronal and axial images [10]. In the other MRI analysis, good healing is defined as confirmed continuity of posterior root in all 3 (sagittal, coronal, and axial) MRI views. Partial healing is defined as loss of continuity in 1 of the 3 views following the MM posterior root repair [11, 12]. Chung et al. evaluate the postoperative meniscal healing status using 3-staged MRI-based classification: complete healing (confirmed continuity in all 3 planes: sagittal, coronal, and axial), partial healing (loss of continuity in any 1 or 2 planes), or nonhealing (loss of continuity in all planes) [13]. However, it is difficult to obtain an accurate axial image of repaired posterior root for
52 determining the postoperative meniscal healing status in each patient. Moreover, it would be difficult to judge
53 one-third loss of posterior root thickness/width in coronal/axial images.

Furumatsu et al. demonstrate a semi-quantitative arthroscopic scoring system of meniscal healing
54 following the MM posterior root repair [14]. In this literature, a postoperative clinical outcome score correlates
55 with the semi-quantitative meniscal healing score. However, there is no useful MRI finding to determine a
56 functionally good meniscal healing status following the MM posterior root repair. In a clinical field, some useful
57 MR findings will be required to precisely judge a postoperative effect of the MM posterior root repair for
58 orthopaedic surgeons and patients. We hypothesized that a characteristic postoperative MRI finding can predict
59 a good status of meniscal healing following the MM posterior root repair. The aim of this study was to
60 investigate a clinical usefulness of several MRI findings for estimating an actual meniscal healing following
61 transtibial pullout repair in patients with the MMPRT at 1 year postoperatively.

63

64 **Materials and Methods**

65 This study received the approval of our Institutional Review Board (XX University No. 1857), and
66 written informed consent was obtained from all patients. Fifty eight patients (49 women and 9 men) who had a
67 posteromedial painful popping event of the injured knee [15] and underwent an arthroscopic MM posterior root
68 repair for the MMPRT between February 2016 and July 2018 were included (Table 1). Clinical records, scores,
69 and image findings were investigated retrospectively (a retrospective cohort study). Indications for transtibial
70 pullout repair of the MMPRTs were patients with femorotibial angle ≤ 180°, radiographic Kellgren–Lawrence
grade 0–II, body mass index (BMI) \( \leq 35\, \text{kg/m}^3 \), and high patient compliance in our institute. Patients who had radiographic knee osteoarthritis involved in the Kellgren-Lawrence grade III or more, insufficiency fracture of the knee, and previous history of meniscus injury or knee surgery were excluded. All the patients were diagnosed having complete types of the MMPRT [16] with arthroscopic observation and characteristic MRI findings such as giraffe neck, clef, ghost, and MM extrusion signs [17-19]. A mean age of the patients was 62.9 years at the pullout repair.

Surgical procedure and second-look arthroscopic evaluation

Standard anteromedial and anterolateral portals were used for primary pullout repairs of the MMPRT and second-look arthroscopy. A modified Mason-Allen suture using the FaSt-Fix (F-MMA) or two simple stitches (TSS) using No. 2 Ultrabraid (Smith & Nephew, Andover, MA, USA) were used to stabilize the MM posterior horn [7, 20]. A 4.5-mm tibial tunnel was created at an anatomic attachment of the MM posterior root using a MMPRT guide (Smith & Nephew) [21]. Tibial fixation of the pullout sutures was performed using double-spike plate (Meira, Aichi, Japan) or Biosure RG interference screw (Smith & Nephew) 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. Second-look arthroscopic evaluation and fixation device removal were performed in all patients at 1 year 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 and cartilage status by second-look arthroscopy and expected to remove the metal implant simultaneously. Meniscal healing status was assessed according to the Furumatsu scoring system (0-10 points) [14]. 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. 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 [14]. 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. We defined a good meniscal healing score as 7–10 points (moderate, 4–6 points; poor, 0–3 points).

Clinical outcome assessment

Postoperative clinical evaluations were performed at the time of second-look arthroscopy (Table 2). We assessed clinical outcomes using Lysholm knee score, Tegner activity score, pain score evaluated by visual analogue scale (VAS), 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 quality of life (QOL).

MRI-based meniscal healing status

MRI examination was performed using Achieva 1.5 T (Philips, Amsterdam, The Netherlands) with a knee coil at 1 year postoperatively. 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. Slice thickness was 3 mm with a 0.6-mm gap. Field of view was 16 cm with an acquisition matrix size of 205 × 256 [19]. Medial extrusion of the MM was assessed on a coronal plane showing maximal meniscal extrusion [18]. MM medial extrusion was defined as the distance between the medial edge of the tibial plateau and the outer margin of the MM. Osteophytes were excluded for determining the tibial margin. In addition, we evaluated postoperative MRI-based MM healing status using signal intensity, continuity [10-12], and “suspension bridge sign” of the MM posterior root on coronal images. The positive “suspension bridge sign” was defined as the presence of a pointed shape of the thickened MM posterior root at the femoral side of the intercondylar space (Fig. 1). To validate the MRI-based evaluation, we assessed inter-observer and intra-observer reliabilities using the intraclass correlation coefficient (ICC). Four orthopaedic surgeons retrospectively examined MR images in a blinded manner. The ICC was calculated for each MRI assessment by two-way, random, and single evaluation with absolute agreement.
Statistical analysis

Data were presented as means ± standard deviations. Differences between the good and moderate/poor healing status were compared using Mann-Whitney U-test and Fisher’s exact test. 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 at P < 0.05.

Results

Twenty three patients (40% of the patients) showed good healing scores (≥ 7 points) at second-look arthroscopic evaluations (Table 1). Thirty five patients had moderate/poor arthroscopic healing scores (< 7 points). Of these, a poor healing status (3 points) was observed in two patients (3% of all the patients). At preoperative assessments, no significant differences between good and moderate/poor healing groups were observed in gender, age, height, body weight, BMI, and injured knee. Duration from injury to pullout repair and suture configuration at the MM posterior horn showed no significant differences between two groups (Table 1).

At 1-year follow-up period, pain VAS score, KOOS Sport/Rec, and KOOS QOL subscales were significantly higher in the good healing group than in the moderate/poor healing group (Table 2).

We noticed that a characteristic MRI finding like a “suspension bridge” at the MM posterior segment was often observed on coronal MR images, especially in the patients who had good arthroscopic healing scores following the MM posterior root repair (Fig. 1, A-C). A distinctive meniscal shape, termed “suspension bridge
“sign”, was highly observed in the good meniscal healing group (19 of 23 patients, 83%) compared with in the moderate/poor healing group (9 of 35 patients, 26%). The absence of “suspension bridge sign” was often observed in patients who showed moderate/poor meniscal healings (Fig. 1, D-F). A significant difference between two groups was observed in the positive ratio of the suspension bridge sign (P < 0.001, Table 3). On the other hand, high signal intensity of the MM posterior segment and continuity of the MM posterior root were equally detected in both groups. A mean of postoperative MM medial extrusion in the good healing score group (5.4 mm) was similar to that in the group showing meniscal healing score < 7 (5.2 mm, Table 3). A good reliability (ICC value > 0.87) was obtained in each MRI-based evaluation. The inter- and intra-observer reliabilities for detecting high signal intensity were considered high, with mean ICC values of 0.92 and 0.94, respectively. The inter/intra-observer reliabilities for evaluating continuity, suspension bridge sign, and MM medial extrusion were also considered high, with mean ICC values of 0.91/0.94, 0.92/0.93, and 0.89/0.88, respectively.

Discussion

The most important finding in this study was that the suspension bridge sign of the MM posterior segment was highly observed on postoperative coronal MR images in patients who showed good meniscal healing at second-look arthroscopy following arthroscopic pullout repairs of the MMPRTs. In addition, several clinical outcomes in patients who had good arthroscopic meniscal healing scores ≥ 7 were higher than those in moderate/poor meniscal healing group < 7.
In previous MRI-based evaluations following the MM posterior root repair, continuity of the MM posterior root was the only indicator to judge the postoperative meniscal healing [10-13]. However, the positive ratio of meniscal continuity to the MM posterior root attachment is extremely high in patients who underwent pullout repairs for the treatment of MMPRTs. Our study also showed that continuity of the repaired MM posterior root was mostly observed in postoperative coronal MR images (96.6%, 56/58 knees). On the other hand, an intra-meniscal high signal intensity of the MM posterior segment was not fully recovered by pullout repairs at 1 year postoperatively. These findings suggest that the MRI-based continuity sign around the MM posterior root is not useful to evaluate an actual meniscal healing status in each patient with the MM posterior root repair. Postoperative meniscal healing should be assessed by several factors such as meniscal width, thickness, stability, and synovial coverage at the repaired posterior root [14], not by meniscal continuity alone.

Our study demonstrated that the MRI-based suspension bridge sign can predict an arthroscopically favorable meniscal healing following the MM posterior root pullout repair. The presence of suspension bridge-like meniscal findings on coronal MR images was highly detected in the good meniscal healing group showing an arthroscopic healing score ≥ 7 points (Table 3). In addition, the suspension bridge sign was not observed in patients who had the Furumatsu score ≤ 4 [14]. Several studies classify the meniscal healing using 3- or 4-staged evaluation systems at second-look arthroscopy following the MM posterior root repair [22, 23]. However, these qualitative classifications are assessed by lifting/mobility of meniscal root on probing alone. We consider that the semi-quantitative Furumatsu score is more suitable to evaluate postoperative meniscal healing following the MM posterior root repair than these two classifications. In our study, an arthroscopic meniscal healing status
was associated with the presence or absence of the MRI-based suspension bridge sign. The pointed shape of the repaired MM posterior root at the intercondylar region may represent an abundant thickness of the repaired tissue and indicate a sufficient space filling between the root attachment and posterior cruciate ligament. The suspension bridge sign of the MM posterior root would be a simple and useful indicator for orthopaedic surgeons and radiologists to evaluate the actual meniscal healing in patients who underwent transtibial pullout repairs for the treatment of MMPRTs. In our study, 4 patients (out of 23 patients) had good meniscal healings during second-look arthroscopy although they showed no suspension bridge sign. There was a tendency to narrower anteroposterior width of bridging tissues at second-look arthroscopy in these patients (a mean of 5.7 mm) compared with the remaining 19 patients (a mean of 8.0 mm). However, the difference in meniscal width more than 5 mm was not reflected in the semi-quantitative arthroscopic score of meniscal healing. We consider that the presence of suspension bridge sign may be highly associated with meniscal width > 5 mm in the scoring system but would not be a necessary and sufficient condition for the good meniscal healing score ≥ 7 points. Several factors may affect the relationships between meniscal healing status and MRI-based suspension bridge sign.

Several authors describe that MM medial extrusion usually remains unchanged or increases following the MM posterior root repair [12, 24, 25]. Pullout repairs of the MMPRTs can result in favorable clinical outcomes in spite of the unchanged or deteriorated MM medial extrusion. On the other hand, Chung et al. report that patients with decreased MM medial extrusion at postoperative 1 year have more favorable clinical scores and radiographic findings at a mean of 70 months follow-up than those with increased MM medial extrusion.
However, the relationship between arthroscopic meniscal healing and MM medial extrusion remains unclear in previous studies. In our study, postoperative MM medial extrusion was similar in both the good and moderate/poor meniscal healing groups (Table 3). Masuda et al. demonstrate that posterior extrusion of the MM clearly increases when the knee is flexed to 90°, while MM medial extrusion does not change in patients with MMPRTs [19]. A three dimensional MRI analysis reveals that a mean volume of the extruded MM and its ratio increased during knee flexion in patients with MMPRTs [26]. In addition, MM posterior root pullout repair can reduce the MM posteromedial extrusion during knee flexion [27]. These findings suggest that reducing the posterior and/or posteromedial extrusion of the MM during knee flexion may be important to obtain favorable clinical outcomes and good meniscal healing in the MM posterior root repair. Further investigations will be required to obtain a reliable MRI measurement value in evaluating postoperative clinical effects of pullout repairs.

There are several limitations in this study. Sample size was small in understanding the precise relationship between arthroscopic meniscal healings and postoperative clinical outcomes. This study was a retrospective study. Differences between suture configurations were not fully investigated in postoperative meniscal healings. In the Furumatsu’s scoring system, a direct probing sensation of the repaired meniscal root was necessary to determine the healing status. Thus, a separate and/or repeated evaluation of the meniscal healing by multiple surgeons was not suitable for video analysis in a blinded manner. An independent scoring by multiple surgeons will be required to assess the healing status randomly in the further arthroscopic evaluation. In addition, postoperative MRI-based meniscal findings might change during the follow-up period. Multiple
MRIs will be required to investigate the transition of suspension bridge sign during the longer follow-up period after the MM posterior root repair.

Conclusions

Our study demonstrated that the MRI-based suspension bridge sign can predict an arthroscopically favorable meniscal healing following the MM posterior root pullout repair. The suspension bridge-like MRI finding of the MM would be a useful indicator to evaluate the actual meniscal healing in patients who underwent transtibial pullout repairs for the MMPRTs.

Conflicts of interest

The authors have no conflict of interest.
References


14. Furumatsu T, Miyazawa S, Fujii M, Tanaka T, Kodama Y, Ozaki T. Arthroscopic scoring system of


Figure legends

Fig. 1. A schematic illustration of the “suspension bridge sign”. The suspension bridge sign (A-C). Note a pointed shape of the repaired posterior root (open arrows). (D-F) The suspension bridge sign was not detected despite meniscal continuity (open arrowheads).