Pullout Repair of the Medial Meniscus Posterior Root Tear Reduces Proton Density-Weighted Imaging Signal Intensity of the Medial Meniscus

Yuki Okazaki, Takayuki Furumatsu*, Shin Masuda, Shinichi Miyazawa, Yuya Kodama, Yusuke Kamatsuki, Tomohito Hino, Yoshiki Okazaki, and Toshifumi Ozaki

Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan

Medial meniscus (MM) posterior root tear (PRT) results in joint overloading and degenerative changes in the knee. MM root repair is recommended to prevent subsequent cartilage degeneration following MMPRT. Favorable clinical outcomes have been reported after transtibial pullout repair of MMPRT. However, it is unclear whether pullout repair can cause compositional change in the MM posterior segment. We examined this question in 14 patients who underwent MMPRT pullout repair. Magnetic resonance imaging examinations were performed preoperatively and 3 months postoperatively at 10° knee flexion. The region-of-interest was marked along the MM posterior segment edge. Intra-meniscal signal intensity (IMSI) was expressed as the signal intensity ratio of the repaired MM to the intact lateral meniscus, which was used as a control. MMPRT pullout repair reduced IMSI from 1 to 0.915 ± 0.096 (range, 0.760-1.074) 3 months postoperatively (p = 0.006, power = 0.90). Meniscal degeneration causes high proton density-weighted imaging signal intensity of the meniscal body. In our study, MMPRT pullout repair reduced IMSI contrary to other tears. This technique may decrease the MM posterior segment signal intensity by restoring the hoop tension mechanism. Measuring IMSI may be useful to assess the effect of MMPRT pullout repair on meniscal healing.

Key words: medial meniscus, posterior root tear, magnetic resonance imaging, signal intensity, arthroscopic surgery

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*Corresponding author. Phone: +81-86-235-7273; Fax: +81-86-223-9727
E-mail: matino@md.okayama-u.ac.jp (T. Furumatsu)

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used to confirm the reduction of the MM posterior root to the original footprint of the tibial surface by disappearance of the giraffe neck sign or cleft/truncation sign after pullout repair [12]. However, to our knowledge, no previous studies have reported changes in intra-meniscal signal intensity (IMSI) after MMPRT pullout repair, and it remains unclear whether pullout repair can affect a compositional change to the MM posterior segment.

In this study, we sought to investigate postoperative changes in the MRI signal intensity of the MM posterior segment, which may be caused by a compositional change following MMPRT pullout repair. We hypothesized that MMPRT pullout repair would decrease the signal intensity of the MM posterior segment on MRI caused by a compositional change.

**Patients and Methods**

The study was approved by our Institutional Review Board (#1857) and all patients provided informed consent. This retrospective study was designed to analyze changes in IMSI preoperatively and 3 months after MMPRT pullout repair. Twenty patients who underwent MMPRT pullout repair between March 1, 2016 and June 30, 2017 were included. Four patients were excluded because MRI was unavailable, and 2 patients were excluded because their MMPRT type was 4. The final sample size (n = 14) had adequate power (0.90) to detect a significant difference between pre- and postoperative IMSI. The Kellgren-Lawrence grade was determined from plain radiographs and MMPRT type, using careful arthroscopic examinations [10]. Lysholm and International Knee Documentation Committee (IKDC) scores were obtained preoperatively and 6 months postoperatively. MRI examinations were performed preoperatively and 3 months postoperatively (Fig. 1).

Transtibial pullout repair was performed arthroscopically. A standard anterolateral portal (longitudinal incision) was used for arthroscopic visualization with a 30° arthroscope (Smith & Nephew, Andover, MA, USA). An anteromedial portal (transverse incision) was used for the PRT guide (Smith & Nephew) [13]. Patients were treated with a FasT-Fix® (Smith & Nephew)-dependent modified Mason–Allen suture with the all-inside technique after creating a tibial bone tunnel with a PRT guide [14-17]. Tibial fixation was performed using a double-spike plate and screw (Meira, Nagoya, Japan), with the knee flexed 45° and a 20-N initial tension. Patients were allowed 45° flexion and one-third weight bearing 2 weeks postoperatively, 90° flexion and full weight bearing 4 weeks postoperatively, and a full range of motion starting 8 weeks postoperatively.

Open MRI scanning was performed preoperatively and 3 months postoperatively using an OASIS 1.2 T device (Hitachi Medical, Chiba, Japan) with a coil under the knee in the 10° flexed position. Standard OASIS sequences included coronal (repetition time/echo time of 1,718 msec/12 msec) proton density-weighted imaging (PDWI) using a driven-equilibrium pulse with a 90° flip angle. The slice thickness was 4 mm with a 0-mm gap. The field of view was 16 cm with an acquisition matrix size of 320 × 416.

After assessing all coronal slices for each knee, measurements were taken from 2 slices, the most posterior and second-most posterior, in order to obtain a high positive predictive value [18]. The signal intensity of the MM posterior segments was compared to that of the 2 middle segment slices of the intact lateral meniscus (LM) on the ipsilateral side. IMSI of the posterior segment was measured with the free-line region-of-interest (ROI) tool in a picture archiving and communication system (PACS, FUJIFILM Holdings Corporation,
Tokyo, Japan). The ROI was marked by drawing a line freehand along the edge of the MM posterior segment. Because IMSI can appear to vary between examinations due to inconsistency in the degree of screen contrast, the IMSI value was expressed as the ratio of signal intensity of the repaired MM posterior segments to that of the control intact LM middle segments to standardize the signal intensity [19].

Data were presented as mean ± standard deviation. Statistical analysis was performed using EZR software (Saitama Medical Center Jichi Medical University, Saitama, Japan). A paired t-test was used to compare pre- and postoperative values. Statistical significance was set to p < 0.05. Two orthopedic surgeons independently measured the signal intensity of the MM posterior segments and ipsilateral control intact LM middle segments. Each observer performed each measurement twice, at least 2 weeks apart. The inter-observer and intra-observer reliabilities were assessed with the intra-class correlation coefficient (ICC), with ICC > 0.83 considered a reliable measurement.

**Results**

The patients’ demographic and clinical characteristics are shown in Table 1. None of the 14 enrolled patients (3 men and 11 women) were lost during follow-up. Patients’ mean age at the time of pullout repair was 58 years (range, 35-69), and the mean duration from injury to surgery was 16.9 weeks (range, 4-42). Patients’ median Lysholm score increased from 70 (range, 52-86) preoperatively to 85.5 (range, 61-99) at 6 months postoperatively (p = 0.001). The mean IKDC score increased from 44.9 (range, 16.1-69.0) preoperatively to 57.2 (range, 37.9-80.5) at 6 months postoperatively (p < 0.001).

MMPRT pullout repair reduced IMSI from 1 to 0.915 ± 0.096 (range, 0.760-1.074) at 3 months postoperatively (p = 0.006, power = 0.90) (Fig. 2). All IMSI values are shown in Table 2. Giraffe neck signs were observed in 13/14 patients (92.9%) and cleft/truncation signs were observed in 12/14 patients (85.7%) before surgery. Those signs each became negative in 12/13 patients (92.3%) and 11/12 patients (91.7%) after surgery.

**Discussion**

In this study, we analyzed IMSI change after pullout repair using serial MRI examinations. We found that MMPRT pullout repair reduced signal intensity of the MM posterior segment. Favorable clinical outcomes and meniscal healing on MRI and arthroscopy have been reported after transtibial pullout repair of MMPRT [10, 20]. Alternatively, non-operative treatment of MMPRT is associated with poor clinical outcomes, worsening arthritis, and a relatively high arthroplasty rate at the 5-year follow-up [3]. Similarly unfavorable results have been reported in partial meniscectomy for complete MMPRT [4, 5]. Although MMPRT repair is recommended to prevent subsequent cartilage degeneration, to our knowledge, no previous studies have examined whether IMSI changes after pullout repair using MRI. Although some studies have assessed the change of IMSI after meniscal suture repair excluding

![Fig. 2 MRI-based IMSI value preoperatively and 3 months postoperatively. *p = 0.006.](image-url)
PRT, this study is the first to report a change of IMSI after MMPRT pullout repair [11, 21].

MMPRT pullout repair was previously shown to achieve significantly better clinical and radiologic results than partial meniscectomy [20]. In that study, healing after root repair was classified as follows: complete, defined as confirmed continuity in all 3 (sagittal, coronal, and axial) MRI views (immediate-weighted or T2-weighted); partial, defined as loss of continuity in any 1 view; or repeat tear, defined as no continuity in any view. Twenty-eight of 30 patients (93.3%) showed healing on MRI (17 complete and 11 partial) after a mean of 48.5 months of follow-up, which was similar to the results of second-look arthroplasty, with sound restoration of hoop tension. However, this study did not examine IMSI.

Histological examination of the meniscus was reported to correlate with MRI in a canine meniscus radial tear model. During healing, the meniscal gap filled with translucent and then fibrocartilaginous tissue at 3 and 6 months postoperatively, respectively, and consistently yielded an increased MRI signal, compared with normal meniscal tissue. Therefore, normal fibrovascular repair tissue in the healing meniscus can emit persistently increased signals on MRI examination (repetition time/echo time of 1,000 msec/20 msec) [22]. Similarly, grade 3 signal intensity on MRI of peripheral meniscal tears after conservative treatment or arthroscopic repair may persist long after the tear has become asymptomatic and presumably healed [23].

Pullout repair is essential for MMPRT because the end-to-end suture technique is not suitable, and the MMPRT healing process may differ from that of radial tears. Lateral posterior meniscal root tear is traumatic and always associated with anterior cruciate ligament injury, while the medial posterior root is prone to chronic degenerative meniscal disease, which commonly affects middle-aged women [24, 25]. The sex and age distribution of the present cohort is consistent with these reports. Minimal tearing and degeneration of the meniscus, and even jogging, can cause high signal intensity of the meniscal body on MRI (T1 and T2-weighted imaging), and high MM posterior segment signal intensity in patients with MMPRT may be expected [26-28]. In our study, MMPRT pullout repair significantly reduced MM posterior segment signal intensity. Meniscal tissue remodeling following MMPRT pullout repair may lead to a compositional change of the MM posterior segment by restoring the hoop tension mechanism.

This study has several limitations. Because of its retrospective design, relatively small number of patients, and short-term follow-up, we could not consider the duration from injury to surgery, although longer duration may lead to the progression of degenerative change. However, the sample size had acceptable statistical
power for the endpoint. Further MRI investigations involving long-term follow-up and larger sample sizes are required. The second limitation is that we used LM to standardize IMSI, and the LM might undergo some change in 3 months. The third limitation is the absence of an immediate postoperative MRI to use as a baseline for IMSI. As T2-weighted imaging signal intensity may decrease in the displaced bucket-handle injury of the MM after reduction [29], we cannot rule out the possibility that a meniscal reduction caused change of IMSI. Detailed assessments of the repaired MM posterior root by recurrent arthroscopy are needed to address this possibility.

In conclusion, MMPRT pullout repair reduced IMSI. Measuring IMSI may be useful to assess the effect of MMPRT pullout repair on recovering meniscal function.

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