Acta Med. Okayama, 2021
Vol. 75, No. 4, pp. 423–430

Acta Medica Okayama
http://escholarship.lib.okayama-u.ac.jp/amo/

Original Article

Medial Meniscus Posterior Root Repair Using a Modified Mason-Allen Suture Can Prevent the Progression of Cartilage Degeneration on the Loading Surface of the Medial Compartment: A Second-Look Arthroscopic Evaluation

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The treatment of medial meniscus posterior root tears (MMPRTs) has evolved to include a variety of repair strategies. This study investigated the location of the articular cartilage degeneration during second-look arthroscopy after transtibial pullout repair with a modified Mason-Allen suture using FasT-Fix (F-MMA) in 22 patients with MMPRTs. Second-look arthroscopy was performed approximately 1 year postoperatively to evaluate the healing status of the medial meniscus (MM). Articular cartilage degeneration was assessed using the International Cartilage Repair Society grade at primary surgery and again at second-look arthroscopy. Articular surfaces of the medial/lateral femoral condyles, the medial/lateral tibial plateaus, the patella and the trochlea were divided into several subcompartments (MF 1-9, LF 1-9, MT 1-5, LT 1-5, P 1-9, T 1-3). Clinical evaluations used the Japanese Knee Injury and Osteoarthritis Outcome, Lysholm, and International Knee Documentation Committee scores. Second-look arthroscopic findings showed complete healing of the MM posterior root in all patients. Significant differences between pullout repair and second-look arthroscopy were observed for MF 2 and 4, LF 7, and P 7. All clinical outcomes were improved. Our results indicate that this technique improves clinical outcomes postoperatively and may prevent the progression of cartilage degeneration on the loading surface of the medial knee compartment.

Key words: articular cartilage, medial meniscus, modified Mason-Allen suture technique, posterior root tear, second-look arthroscopy

The meniscus, a crescent-shaped fibrous cartilage structure, is known to be essential for the congruity of contact surfaces, stability, shock absorption, and proprioception of the knee joint [1]. Each meniscus is oriented to allow for the conversion of tibiofemoral axial loads into hoop stress during knee flexion and extension [2-4]. With root tears, the transmission of circumferential hoop stresses is impaired and the meniscal biomechanics and kinematics are affected, leading to accelerated degenerative changes in the knee joint [2]. Medial meniscus (MM) posterior root tears (PRTs) cause the rapid degeneration of articular cartilage and the loss of knee function. Therefore, early diagnosis and appropriate surgical intervention are profoundly important in the treatment of medial meniscus posterior root tears (MMPRTs) [2].

Traditionally, MMPRT has been treated by menis-

Received July 31, 2020; accepted January 22, 2021.
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Conflict of Interest Disclosures: No potential conflict of interest relevant to this article was reported.

cectomy. However, a recent biomechanical study showed that an MMPRT caused a 25% increase in the peak contact pressure, whereas repair restored the peak contact pressure to normal [4]. The treatment of meniscal root tears has recently evolved to include a variety of repair strategies to restore meniscal function [5]. Although several surgical techniques have been described, the optimal treatment approach is yet to be identified. Current studies have shown that transtibial pullout repair for MMPRTs has led to favorable clinical outcomes, but few reports have evaluated the postoperative progression of cartilage degeneration using an arthroscope after a transtibial pullout repair has been performed [6].

Accordingly, this study aimed to investigate the location of the articular cartilage degeneration using second-look arthroscopy after transtibial pullout repair in patients with MMPRT.

Materials and Methods

Patient characteristics and ethical considerations. This retrospective review was approved by the institutional review board (IRB ID #Rin1857) and examined retrospectively collected data. Between January 2016 and March 2018, 32 patients who underwent transtibial pullout repair with a modified Mason-Allen suture using FasT-Fix (F-MMA) (Smith & Nephew, Andover, MA, USA) combined with Ultrabraid (Smith & Nephew) for a radial tear (meniscal root tear classification: type 2) were included. This procedure was performed in patients who met the following inclusion criteria: (1) Kellgren-Lawrence grade < 3 on radiography; (2) body mass index (BMI) < 30 kg/m^2; (3) age over 50 years, and (4) femorotibial angle < 180°. Exclusion criteria consisted of: (1) lateral meniscus injuries or posterior tears; (2) additionally performed osteochondral autograft transfer; and (3) unclear onset of MMPRT. Two patients were excluded because of their age, 4 patients because of their BMI, and 4 patients due to a concomitant injury or unclear onset of MMPRT. Ultimately, 22 patients met these criteria and were included in the cohort. Second-look arthroscopy was performed approximately 1 year postoperatively. The mean time to the second-look arthroscopy was 13.4 months (range, 12.0-17.9 months). Table 1 presents the patients' demographic data.

This study and all protocols were approved by our institutional review board, and informed consent was obtained from all individual participants included in the study.

Surgical techniques and management. A standard arthroscopic examination was performed through routine anteromedial and anterolateral portals. The presence of a meniscal tear was evaluated via the anterolateral portal, and the type of PRT was defined [7]. Ultrabraid and FasT-Fix were used to repair the MM posterior horn in a modified Mason-Allen suture configuration [8,9]. A 4.5-mm tibial tunnel was created at the anatomic insertion of the MM posterior root using a MMPRT aiming guide (Smith & Nephew) [10]. Ultrabraid and uncut free-ends of the FasT-Fix sutures were retrieved through the tibial tunnel. Tibial fixation of the sutures was performed using a double-spike plate and screw (Meira, Aichi, Japan) at 45° of knee flexion with an initial tension of 20 N.

After the pullout repair, patients were initially limited to non-weight-bearing conditions in a knee immobilizer for 2 weeks. Between 2 and 4 weeks after the repair, knee flexion exercise was gradually increased up

Table 1 Patient demographics and clinical characteristics

Age, years (range)	65.6 (53–77)
Gender, male/female	5/17
Height, m (range)	1.56 (1.46–1.72)
Body weight, kg (range)	62.4 (45–80)
Body mass index, kg/m^2 (range)	25.4 (18.7–29.8)
Interval from injury to primary surgery, months (range)	3.4 (0.8–11.2)
Duration from primary surgery to second-look arthroscopy, months (range)	13.4 (12.0–17.9)
MMPRT type (1/2/3/4/5)	0/22/0/0/0
KL grade (0/1/2/3/4)	0/10/12/0/0
Preoperative FTA, ° (range)	177.3 (175–179)

Values are presented as a mean or number.
MMPRT, medial meniscus posterior root tear; KL, Kellgren-Lawrence; FTA, femorotibial angle.

to 90° under partial weight-bearing conditions. After 5-6 weeks, patients were allowed full weight-bearing and 120° of knee flexion. Limited deep knee flexion was allowed beginning at 12 weeks postoperatively. Athletic activities (jogging, cycling, and/or golf) were allowed following a magnetic resonance imaging (MRI) evaluation of the repaired MM posterior root at 12 weeks.

Arthroscopic meniscal healing scores. The healing status of the MM posterior root was assessed during second-look arthroscopy according to a semi-quantitative scoring system described by Furumatsu *et al.* [11]. The scoring system comprised 3 evaluation criteria: (i) the anteroposterior width of the bridging tissues between the MM posterior horn and root attachment (0, 2, and 4 points); (ii) the stability of the repaired MM posterior root (0, 1, 2, 3, and 4 points); and (iii) synovial coverage of the sutures (0, 1, and 2 points). The maximum meniscus healing score was 10 points. The mean of each evaluation score was determined for each patient.

MRI-based measurements. MRI evaluation was performed using an Achieva 1.5 T device (Philips, Amsterdam, The Netherlands) with a knee coil. Standard sequences included sagittal [repetition time (TR)/echo time (TE), 742/18], coronal (TR/TE, 637/18), and axial (TR/TE, 499/18) T2-weighted fast-field echo with a 20° flip angle. The slice thickness was 3 mm with a 0.6-mm gap. The field of view was 16 (or 17) cm with an acquisition matrix size of 205 × 256 (or 200 × 368). MM extrusion (MME) was measured from the medial margin of the tibial plateau (excluding osteophytes) to the outer border of the MM on the coronal MR image that crossed the midpoint of the anteroposterior length of the MM. Two orthopaedic surgeons (S.T. and Yu.O.) independently measured the MME in a blinded manner. MRI measurements were completed by two independent orthopaedic surgeons to determine inter-observer and intra-observer reliabilities using the intra-class correlation coefficient (ICC). Each observer repeated the measurements at a 2-week interval to determine intra-observer reliability.

Clinical assessments. Clinical evaluations using the Japanese Knee Injury and Osteoarthritis Outcome Score (KOOS) and the Lysholm, International Knee Documentation Committee, and Visual Analogue Scale pain scores were performed before the primary operation and the second-look arthroscopy.

Evaluation of cartilage injury. Arthroscopic assessment of the cartilage lesions was performed using arthroscopic images and video. Evaluation and documentation of the cartilage were carried out using the International Cartilage Repair Society (ICRS) articular cartilage lesion classification system and the knee cartilage lesion mapping system at both the primary surgery and second-look arthroscopy. The articular surfaces on the medial/lateral femoral condyles were divided into 9 subcompartments (MF 1-9/LF 1-9). The medial/lateral tibial plateaus were divided into 5 subcompartments (MT 1-5/LT 1-5). The patella was also divided into 9 subcompartments (P 1-9), and the trochlea was divided into 3 subcompartments (T 1-3) (Fig. 1).

Statistical analysis. Statistical analyses were performed using EZR (Saitama Medical Center Jichi Medical University, Saitama, Japan). Wilcoxon signed-rank tests were used to compare the differences in the cartilage status (ICRS grade) of each compartment and

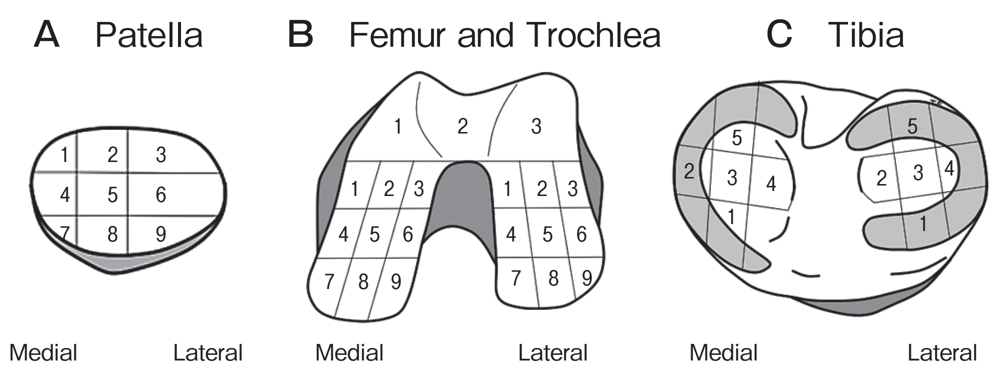

Fig. 1 Schematic illustrations of the patella, femoral condyle, trochlea, and tibial plateau. (**A**) The patella is divided into 9 subcompartments. (**B**) The medial and lateral femoral condyles are divided into 9 subcompartments. (**C**) The medial and lateral tibial plateaus are divided into 5 subcompartments.

in the clinical outcome scores between the primary operation and second-look arthroscopy. Spearman's rank correlation was calculated to assess the correlation between the meniscus healing score and the MME, and between the MME and the cartilage status in the area with significant change in cartilage degeneration. The statistical significance level was set at $p < 0.05$. To determine the number of test samples, the outcome ICRS grade was used for the sample size calculation under a significance level of 0.05 and a power of 0.80. As a result, the required sample size was 22 patients in each group (difference, 0.3; standard deviation, 0.25). Inter-observer and intra-observer reliabilities were assessed with the ICC. An ICC > 0.80 was considered to represent a reliable measurement.

Results

Complete meniscus healing was observed in all cases at second-look arthroscopy. The mean value of the total arthroscopic meniscal healing score was 6.5 (range, 4-10) (Table 2). Our study demonstrated that semi-quantitative meniscal healing scores were positively correlated with the KOOS-quality of life ($r = 0.473$, $p < 0.05$) (Fig. 2). Significant differences in cartilage degeneration between the pullout repair and second-look arthroscopy were observed at the MF 2/4, LF 7, and P 7 areas, whereas no significant difference was observed for the tibial plateau and the trochlea (Tables 3-5). The pullout repair had improved all clinical outcomes as assessed at the second-look arthroscopy in patients with MMPRTs, although there were significant differences between the preoperative and postoperative MMEs (Table 6). The postoperative MMEs were positively correlated with the postoperative ICRS grade at MF4 ($r = 0.547$, $p < 0.05$) (Table 7), although there was no correlation between the meniscus healing score and the degenerative location in the articular cartilage. The inter-observer/intra-observer reliabilities with respect to the meniscal healing score and cartilage damage evaluation were considered to be high, with ICC values of 0.86/0.89 and 0.83/0.85, respectively.

Discussion

The most important finding of this study is that transtibial pullout repair of MMPRT can prevent the progression of cartilage degeneration on the loading surface of the medial compartment of the knee.

MMPRTs have historically been treated with partial or total meniscectomy [12]. In fact, partial meniscectomy for degenerative MMPRTs relieved acute pain and resulted in favorable 5-10 year survival rates in well-aligned nonarthritic knees [13]. However, previous studies reported that the knee kinematics after menis-

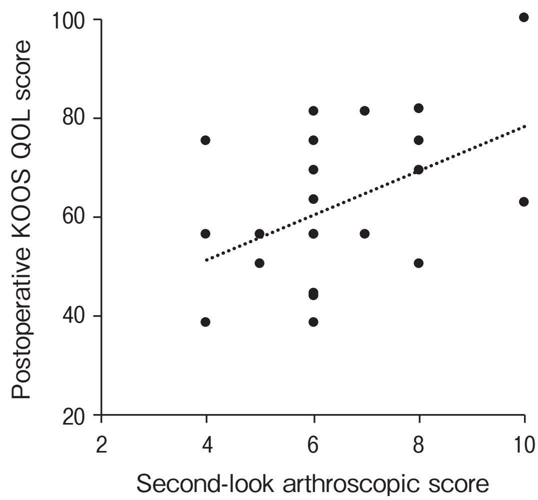

Fig. 2 Correlation between the meniscus healing score and the Knee Injury and Osteoarthritis Outcome Score-quality of life (KOOS-QOL) at second-look arthroscopy. The meniscus healing score was positively correlated with the KOOS-QOL score ($R^2 = 0.224$).

Table 2 Meniscal healing scores

	Width	Stability	Synovial coverage	Total
Arthroscopic score*	3.5 ± 0.9	2.3 ± 0.9	0.6 ± 0.7	6.5 ± 1.7

Data are displayed as a mean ± standard deviation.
Width, anteroposterior width of bridging tissues between the medial meniscus posterior horn and root attachment (0, 2, and 4 points). Stability, stability of the repaired medial meniscus posterior root (0, 1, 2, 3, and 4 points). Synovial coverage, synovial coverage of the suture (0, 1, and 2 points).
*Meniscal healing score at second-look arthroscopy (total, 10 points).

Table 3 Differences in patella and trochlear cartilage status (ICRS grade) between primary and second-look arthroscopy

	Patella			Trochlear		
Area	Primary	Second-look	*P* value	Primary	Second-look	*P* value
1	0.9 ± 0.8	1.3 ± 0.9	n.s.	1.9 ± 1.2	1.9 ± 0.8	n.s.
2	1.0 ± 1.0	1.3 ± 1.0	n.s.	2.0 ± 1.1	2.3 ± 0.9	n.s.
3	0.7 ± 0.8	0.9 ± 0.7	n.s.	0.4 ± 0.6	0.4 ± 0.7	n.s.
4	1.2 ± 0.8	1.5 ± 0.8	n.s.			
5	1.7 ± 1.0	1.9 ± 0.8	n.s.			
6	0.8 ± 0.7	0.9 ± 0.7	n.s.			
7	0.9 ± 1.0	1.2 ± 1.0	0.04*			
8	0.9 ± 1.0	0.9 ± 0.9	n.s.			
9	0.5 ± 0.8	0.6 ± 0.9	n.s.			

Data are displayed as a mean ± standard deviation. Significance was determined with use of Wilcoxon signed-rank test. *$p < 0.05$. ICRS, International Cartilage Research Society.

Table 4 Differences in femoral cartilage status (ICRS grade) between primary and second-look arthroscopy

	Medial femoral condyle			Lateral femoral condyle		
Area	Primary	Second-look	*P* value	Primary	Second-look	*P* value
1	0.8 ± 1.0	1.2 ± 0.6	n.s.	0.5 ± 0.9	0.6 ± 0.7	n.s.
2	0.8 ± 0.9	1.2 ± 0.8	0.04*	0.1 ± 0.3	0.1 ± 0.3	n.s.
3	1.0 ± 0.8	1.2 ± 0.7	n.s.	0.1 ± 0.4	0.0 ± 0.2	n.s.
4	1.2 ± 1.0	1.7 ± 1.0	0.007*	0.5 ± 0.8	0.5 ± 0.6	n.s.
5	1.8 ± 1.0	2.0 ± 0.9	n.s.	0.4 ± 0.6	0.2 ± 0.4	n.s.
6	1.8 ± 0.8	1.8 ± 0.7	n.s.	0.1 ± 0.3	0.1 ± 0.2	n.s.
7	0.9 ± 1.0	1.2 ± 0.8	n.s.	0.5 ± 0.5	0.8 ± 0.6	0.03*
8	1.2 ± 1.0	1.4 ± 0.8	n.s.	0.4 ± 0.6	0.6 ± 0.8	n.s.
9	0.9 ± 0.7	1.0 ± 0.8	n.s.	0.1 ± 0.3	0.3 ± 0.5	n.s.

Data are displayed as a mean ± standard deviation. Significance was determined with use of Wilcoxon signed-rank test. *$p < 0.05$. ICRS, International Cartilage Research Society.

Table 5 Differences in tibial cartilage status (ICRS grade) between primary and second-look arthroscopy

	Medial tibial plateau			Lateral tibial plateau		
Area	Primary	Second-look	*P* value	Primary	Second-look	*P* value
1	1.0 ± 0.7	1.2 ± 0.7	n.s.	0.8 ± 0.8	1.0 ± 0.7	n.s.
2	1.5 ± 0.8	1.5 ± 0.7	n.s.	1.4 ± 0.7	1.4 ± 0.7	n.s.
3	1.9 ± 0.3	2.0 ± 0.5	n.s.	1.3 ± 0.5	1.6 ± 0.7	n.s.
4	1.5 ± 0.5	1.4 ± 0.6	n.s.	0.5 ± 0.7	0.8 ± 0.6	n.s.
5	1.3 ± 0.7	1.7 ± 0.9	n.s.	1.2 ± 0.7	1.2 ± 0.7	n.s.

Data are displayed as a mean ± standard deviation. Significance was determined with use of Wilcoxon signed-rank test. *$p < 0.05$. ICRS, International Cartilage Research Society.

cectomy were similar to those associated with MMPRTs [14,15], and that pullout repair was superior to partial meniscectomy for the treatment of MMPRT in terms of clinical and radiologic outcomes and survival with at least 5 years of follow-up [16,17]. Further, patients with MMPRTs treated by meniscectomy tended to undergo subsequent total knee arthroplasty [18,19]. In contrast to meniscectomy, posterior root repair has been reported to restore the hoop-strain function and to lead to better meniscus healing, resulting in better clinical outcomes [11,18-23]. Similarly, pullout repair led to favorable results in terms of arthroscopic scores and

Table 6 Clinical outcomes and medial meniscus extrusion

	Preoperative score	Postoperative score	*P* value
KOOS			
Pain	55.1 ± 28.7	85.6 ± 16.3	< 0.001*
Symptoms	68.1 ± 17.3	84.8 ± 11.5	0.001*
ADL	68.7 ± 17.4	91.2 ± 8.4	< 0.001*
Sport/Rec	28.6 ± 26.5	63.6 ± 25.0	< 0.001*
QOL	32.4 ± 18.8	62.5 ± 16.1	< 0.001*
Lysholm knee score	63.8 ± 12.0	90.1 ± 6.7	< 0.001*
Tegner activity score	1.9 ± 1.1	3.4 ± 0.6	< 0.001*
IKDC score	42.3 ± 17.4	67.8 ± 10.5	< 0.001*
Pain score (VAS)	43.1 ± 25.1	9.4 ± 18.9	< 0.001*
Medial meniscus extrusion	3.8 ± 0.9	4.8 ± 1.3	0.001*

Data are displayed as a mean ± standard deviation. Significance was determined with use of Wilcoxon signed-rank test. *$p < 0.05$.
KOOS, Knee Injury and Osteoarthritis Outcome Score; ADL, activities of daily living; Sport/Rec, sport and recreation function; QOL, knee-related quality of life; IKDC, International Knee Documentation Committee; VAS, visual analogue scale.

Table 7 Correlation between MME and the area with significant change in cartilage degeneration (International Cartilage Research Society grade)

Area	r	*P* value
MF 2	0.32	n.s
MF 4	0.54	0.006*
LF 7	0.38	n.s
P 7	0.22	n.s

The Spearman rank correlation was performed to calculate the correlation between MME and the area with signifcant change in cartilage degeneration. *$p < 0.05$
MME, medial meniscus extrusion; MF, medial femoral condyle; LF, lateral femoral condyle; P, patella.

clinical outcomes in this study.

Some reports have shown that degenerative changes were found to have progressed on postoperative MRI and second-look examinations regardless of the presence of good knee stability and clinical outcomes [6, 24, 25]. However, there have been no reports evaluating the location of the degeneration of articular cartilage after pullout repair using second-look arthroscopy. Once the loading pattern changes, the vulnerable portion of the articular cartilage also changes. As the hoop-strain function was lost in MMPRT knees, the loading pattern also changed to a more posteromedial location on the medial femoral condyle [16, 17], and Kim *et al.* [20] reported that pullout repair restored the peak contact area of MMPRT knees to that of normal knees. In this study, pullout repair prevented the progression of cartilage degeneration on the main loading surface, although partial cartilage degeneration progressed in the mid-medial area (MF 4). The axial loading pattern might not have been completely restored to the original pattern, although a good clinical outcome was obtained.

Regarding cartilage degeneration that progressed in the MF 4 and 5 areas in MMPRT knees [26], the peak contact areas were more posteromedially located, namely, in the MF 4 and 7 areas [14]. Also, bone marrow lesions, such as spontaneous osteonecrosis of the knee, could be observed in the excessive loading area, namely, the MF 5 and 8 areas [26, 27]. Given that all these studies reported elevated contact pressure at the femoral condyle during flexion, one might predict that the progressive cartilage deformation proceeded from the medial-middle to the medial-posterior areas, such as MF 4, 5, 7, and 8 and MT 2, 3, and 5, as a mirror lesion of the MF. In this study, however, although partial progression of degenerative change (MF 4) was observed, the center-medial to posterior loading surface, namely MF 5 and 8, did not show any progression of cartilage degeneration. This may indicate that the approximate restoration of the original knee hoop-strain function obtained by pullout repair is effective for preventing significant worsening in posterior knee subcompartments, especially the posteromedial site (MF 7) and the most loaded area (MF 5, 8).

Several studies have reported that MME is a significant risk factor for the progression of cartilage degeneration [3, 28, 29]. In this study, significant differences were observed between preoperative and postoperative

MMEs. The progress of the degeneration of cartilage in MF 4 could be caused by the increase of contact pressure resulting from MME progression and by the direct impingement of the extruded MM.

Other factors, such as rotational changes in MMPRT knees, may have been partially responsible for progressive cartilage injury to the MF 2 and P 7 areas. In normal kinematics, the tibia internally rotates with respect to the femur during flexion in the healthy knee. However, the tibia does not display an increase in the internal rotation angle during flexion in MMPRT knees [3,30]. Pullout repair has been shown to successfully restore joint biomechanics, such as rotation and contact pressure, to their normal conditions [3]. We consider that pullout repair could not completely restore the original rotation and might increase contact pressure in the pattelofemoral joint, resulting in the progression of articular cartilage degeneration on the facing P 7 and MF 2 areas during knee flexion.

This study has several limitations. First, the number of cases studied was small, which limited the generalizability of our findings. Second, this research involved a short-term assessment limited to only MMPRT-repaired knees and did not make comparisons with other treatments, such as meniscectomy. Third, potential kinematic changes that resulted from rotational variation after the repair of the MM posterior root were not assessed. Further investigations that include a control group and a long-term follow-up are needed to evaluate these factors.

In conclusion, transtibial pullout repairs using a modified Mason-Allen suture can improve clinical outcomes postoperatively and may be useful for preventing the progression of cartilage degeneration on the loading surface of the medial compartment of the knee. Early diagnosis and posterior root repair are recommended before the progression of cartilage degeneration occurs in order to preserve the knee joint.

Acknowledgments. We would like to thank Editage (*www.editage.com*) for English language editing.

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