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The effect of a longitudinal tear of the medial meniscus on medial meniscal extrusion in anterior cruciate ligament injury patients

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ABSTRACT

Purpose: The purpose of this study was to investigate the effect of a longitudinal tear of the medial meniscus (MM) and its meniscal repair on MM extrusion in anterior cruciate ligament (ACL)-injured patients. The hypothesis underlying this study was that a longitudinal tear of the MM is correlated with MM extrusion, and that the extrusion would persist after ACL reconstruction with concomitant MM repair.

Methods: Forty-three ACL-injured patients with a concomitant MM longitudinal tear were included in the MM tear group. Thirty-four solely ACL-injured patients without any meniscal injuries were included in the Control group. Medial meniscus extrusion width (MEW) was measured pre-operatively and three months after surgery on magnetic resonance imaging.

Results: Pre-operative MEW in the MM tear group was significantly larger than that in the Control group (MM tear group: 1.5 mm, Control: 0.3 mm, $P < 0.001$). The MEW change in the MM tear group was significantly greater than that in the Control group three months after operation (MM tear group: 0.8 mm, Control: −0.2 mm, $P < 0.001$). The number of sutures required for repair was correlated with MEW both pre-operatively and postoperatively in the MM tear group (pre-operative: $P = 0.005$, $R = 0.42$, postoperative: $P < 0.001$, $R = 0.54$).

Conclusion: Longitudinal tear of the MM was correlated with MM extrusion and the MM extrusion persisted after ACL reconstruction with concomitant MM repair in the MM tear group. The initial meniscal tear size was directly correlated with the pre-operative MEW. Therefore, meniscal extrusion after longitudinal tears of the medial meniscus should be taken into careful consideration.

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Table 1
Meniscus tear location, region, and suture methods.

Location	
Anterior horn	0
Mid-body	2
Posterior horn	17
Mid-body-posterior horn	23
Anterior horn-posterior horn	1
Region	
Red-red	20
White-red	23
White-white	0
Suture methods	
All-inside	20
Inside-out	4
All-inside and inside-out	19

1. Introduction

Medial meniscus (MM) tears result in the progression of post-traumatic knee osteoarthritis (PTOA) [1–3]. Different morphologies of MM tears show different severities of PTOA progression. Recently, the morphology of meniscal tears has been considered important to better understand their relevance in the occurrence and progression of PTOA [4]. A longitudinal tear is associated with traumatic injuries in the younger age group; 63% of MM tears in anterior cruciate ligament (ACL)-injured knees are longitudinal tears [5]. Biomechanical studies have shown that longitudinal tears of the MM increase contact pressure on the medial tibial plateau by two-fold and result in cartilage degeneration [6,7].

Medial meniscus extrusion is defined as medial displacement of the meniscus beyond the outer margin of the tibial plateau and is strongly associated with the progression of knee PTOA [8,9]. Biomechanical studies have reported that the meniscus converts axial load into circumferential hoop stress and MM extrusion reduces the conversion to circumferential hoop stress [10,11]. Several factors have been reported to be associated with MM extrusion, including: posterior meniscal root tear, meniscal radial tear, varus malalignment, and cartilage damage [12]. However, because the subjects of those studies were old osteoarthritic (OA) patients, it remains to be clarified whether a meniscal tear with a traumatic injury in young patients is the causal factor for MM extrusion. Therefore, further investigation of the independent causal factors for MM extrusion in traumatic knee injuries is essential and could help to prevent MM extrusion and further progression of PTOA in such patients.

A meta-analysis comparing meniscal repair with meniscectomy in the treatment of meniscal tears reported that meniscal repair has better long-term clinical outcomes than meniscectomy [1]. Conversely, ACL-reconstructed patients with a meniscal repair show more rapid progression of PTOA in comparison with ACL-reconstructed patients without any meniscal injury [13,14]. A biomechanical study has shown that the contact area of the meniscus after meniscal repair for a longitudinal tear is slightly smaller than the intact state [6]. However, there is limited evidence of residual MM extrusion after MM repair for a longitudinal tear.

The purpose of the present study was to investigate the effect of a longitudinal tear of the MM and its meniscal repair on MM extrusion in ACL-injured patients. The hypothesis underlying this study was that a longitudinal tear of the medial meniscus is correlated with MM extrusion and the extrusion would persist after ACL reconstruction with concomitant MM repair.

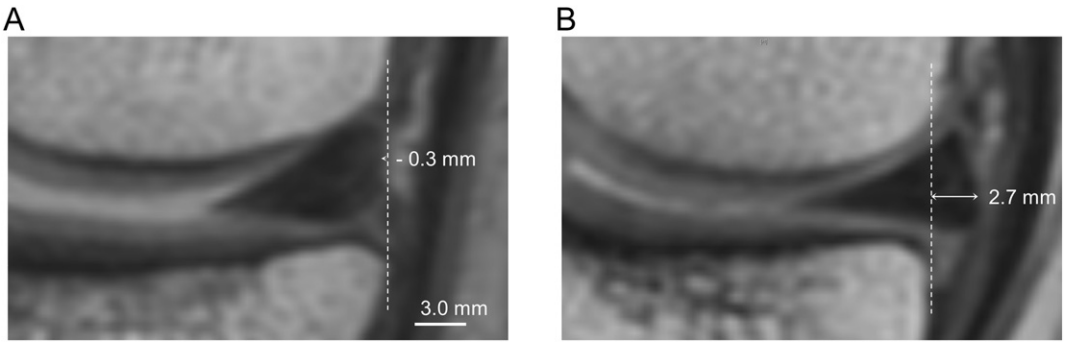

Figure 1. Coronal proton density weighted images showing measurement technique for medial meniscal extrusion. (A) The image demonstrates no medial meniscal extrusion in a patient after solely anterior cruciate ligament reconstruction without any concomitant medial meniscus repair. (B) The image demonstrates medial meniscal extrusion in a patient after anterior cruciate ligament reconstruction with concomitant medial meniscus repair.

Table 2
Patients' characteristics.

	Control group	MM tear group	*P*
Age, years (range)	24 (14–50)	26 (13–52)	0.90
Female	16	19	0.65
Male	17	24	
Height, cm (range)	165.8 (151.5–190.0)	166.4 (150.2–180.9)	0.65
Weight, kg (range)	67.2 (49.4–93.2)	65.9 (49.0–100.3)	0.63
Body mass index, kg/m^2	24.4 (20.3–30.7)	23.6 (19.6–36.5)	0.11
Pre-injury Tegner score (range)	6.8 (3–9)	7.2 (3–9)	0.32
Pre-operative periods, months (range)	5 (1–36)	14 (1–146)	0.09

2. Methods

2.1. Subjects

A retrospective review was undertaken of unilateral primary ACL reconstruction (ACLR) between 2011 and 2015 at Tokyo Medical and Dental University Hospital of Medicine. Patients gave their full written informed consent for participation in this study prior to the operative procedure. Fifty patients were included who underwent only ACLR without any concomitant meniscal treatment. Thirty-four of the 50 solely ACLR patients, who had appropriate magnetic resonance imaging (MRI) scans recorded pre-surgery and three months after surgery, were included as a Control group. Sixty-one patients were included who underwent ACLR, with a concomitant MM repair for a longitudinal tear and without any treatment of lateral meniscal tear. Forty-three of the 61 patients who had appropriate MRI scans recorded pre-surgery and three months after surgery were included as an MM tear group. Demographic data, including age, gender, height, weight, body mass index (BMI), and sport level were reviewed. This study was approved by the Institutional Review Board of Tokyo Medical and Dental University (research protocol identification number: 1547).

2.2. Operative procedures

All surgeries were performed by two senior surgeons who had more than 15 years of experience in orthopedic surgery or under their supervision. Standard arthroscopic evaluation was performed before ACLR. Meniscal tears were classified by size, location, tear type, instability, and tissue quality, according to the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine (ISAKOS) criteria (Table 1). Unstable meniscal tears were repaired by the all-inside suture technique, using the Fast-Fix device (Smith & Nephew, Andover, MA, USA) and/or the inside-out suture technique, using the Henning meniscal suture kit (Stryker, Kalamazoo, MI, USA). Generally, the inside-out technique was used for middle-to-posterior segments, and the all-inside technique was used for the posterior horn. The number of sutures was decided according to the initial tear size.

For ACLR, an anatomic double-bundle technique using an autologous semitendinosus tendon was employed, which was previously described in detail [15]. Briefly, the semitendinosus tendon was harvested, cut into halves, and folded, creating two double-stranded bundles. Both tibial and femoral tunnels were created at the anatomic insertion sites of each bundle: the anteromedial bundle and posterolateral bundle. The femoral sides of the grafts were fixed with an Endobutton CL-BTB (Smith & Nephew Endoscopy). Tibial sides of grafts were fixed with two anchor staples.

Postoperative rehabilitation followed a standard protocol and the protocol did not vary with surgical meniscal treatment. Patients began to practice range of motion and quadriceps setting exercises one day after surgery. Weightbearing and walking exercises with crutches and a knee brace were instructed at three days after surgery. Crutches were removed at four weeks. Running exercises started at three months and patients progressed to full activity after six months.

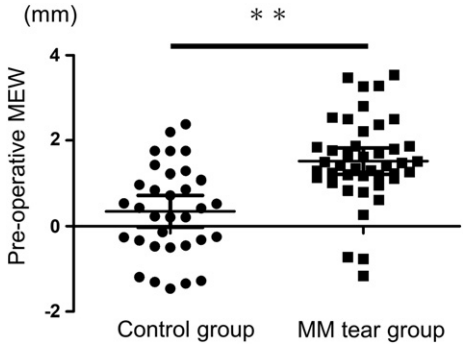

Figure 2. Scatter plot of pre-operative medial meniscal extrusion width (MEW) in the Control group and medial meniscal (MM) tear group. **$P < 0.001$.

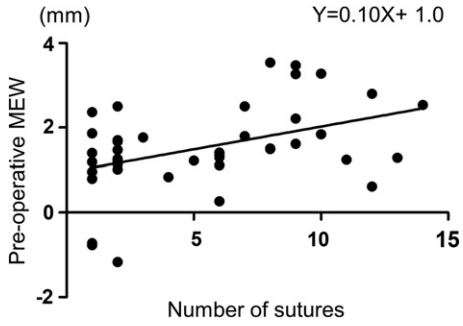

Figure 3. Correlation between the number of sutures at surgery with pre-operative medial meniscal extrusion width (MEW) in the medial meniscal tear group.

2.3. Measurement of MRI scans

One doctor (H.K) who had more than 12 years of experience in the orthopedic field retrospectively reviewed medial meniscal extrusion width (MEW). The MRI examination was performed in the supine position pre-operatively and three months after surgery. The MEW was measured from the most peripheral aspect of the meniscus to the border of the tibia, excluding osteophytes on the mid-coronal slice, in proton density weighted images (Figure 1) [8]. Intra-observer measurement reproducibility was assessed with the intra-class correlation coefficient (ICC). The observer was blinded to the previous results. The intra-observer ICC was 0.97; therefore, the results were considered to be excellent [16].

2.4. Statistical analysis

Statistical analyses were performed by GraphPad Prism 5. A *t*-test was used to compare continuous variables between the two groups, after confirming normality using the histogram, and the assumption of equal variance was examined using the F test. A paired *t*-test was performed to compare continuous variables between pre-operative data and 3-months postoperative data in the same patients. The relationship between MEW and the number of sutures was assessed using a scatterplot graph and a calculation of Pearson's correlation coefficient. *P*-values <0.05 were considered statistically significant. Data were expressed as the mean with 95% confidence interval (CI).

3. Results

3.1. Patient characteristics

Age at surgery, sex, height, weight, BMI, and preinjury Tegner scores did not show significant between-group differences (Table 2).

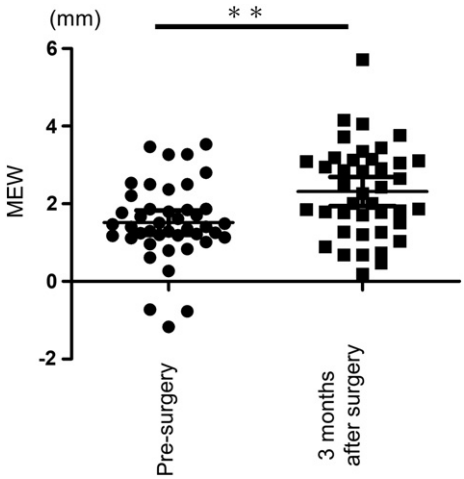

Figure 4. Scatter plot of medial meniscal extrusion width (MEW) in the medial meniscal tear group pre-surgery and 3 months after surgery. $^{**}P < 0.001$.

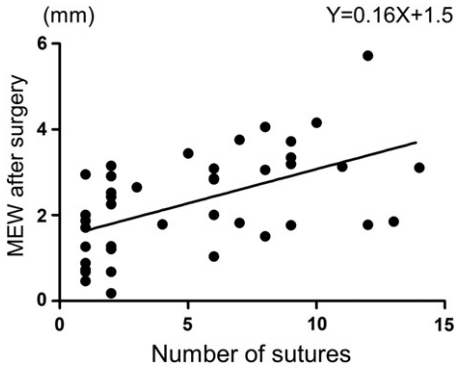

Figure 5. Scatter plot of change of medial meniscal extrusion width (MEW) in the Control group and medial meniscal tear group 3 months postoperatively. $^{**}P < 0.001$.

3.2. Effects of medial meniscal tear on extrusion

Pre-operative MEW in the MM tear group was significantly greater than that in the Control group (MM tear group: 1.5 mm [1.2–1.8 mm], Control: 0.3 mm [0.0–0.7 mm], $P < 0.001$; Figure 2). Pre-operative MEW in the MM tear group was significantly correlated with the number of sutures, representing an initial meniscal tear size intraoperatively ($P = 0.005$, $R = 0.42$; Figure 3).

3.3. Effects of medial meniscal repair on extrusion

In the MM tear group, MEW at three months post-operation was significantly greater than pre-operative MEW (MM tear group at three months: 2.3 mm [1.9–2.7 mm], $P < 0.001$: Figure 4). The MEW after surgery in the MM tear group was correlated with the number of sutures required for repair ($P < 0.001$, $R = 0.54$: Figure 5). An MEW change after surgery in the Control group was evaluated in order to eliminate the effect of ACLR on MEW. The MEW change in the MM tear group was significantly greater than that in the Control group three months postoperatively (MM tear group: 0.8 mm (0.6–1.1 mm) Control: −0.2 mm [0.4–0.0 mm], $P < 0.001$: Figure 6). The MEW increased after surgery in the MM tear group, although MEW in the Control group did not increase after surgery.

4. Discussion

The most important findings of the current study were that a longitudinal tear of the medial meniscus was correlated with an increased MM extrusion in ACL-injured patients, and the MM extrusion persisted after ACLR with concomitant MM repair in the MM tear group. The initial tear size of the longitudinal meniscal tear was directly correlated with MEW both pre-operatively and postoperatively. Therefore, MM extrusion after longitudinal tear of the medial meniscus should be taken into careful consideration.

Most commonly, meniscal extrusion is seen in the presence of a posterior root tear. Because posterior root tears interrupt the continuity of the circumferential fibers in the meniscus, posterior root tear severely induces meniscal extrusion [17–20]. Thus, MEW after posterior root tear increases by 3.6–5.8 mm. Radial tear is also known to be associated with MM extrusion [21]. The relative risk for pathological meniscal extrusion after radial tear, defined as ≥3 mm, is 4.4 times higher than those without meniscal tear [22]. Furthermore, a few earlier reports have shown that partial meniscectomy and horizontal tear induce moderate

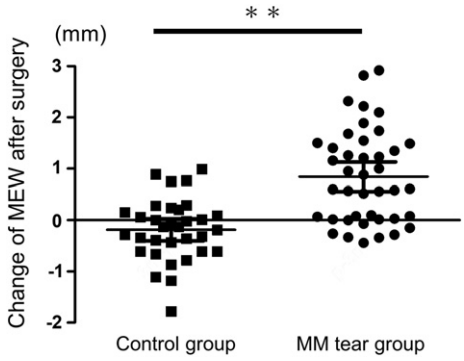

Figure 6. Correlation between the number of sutures at surgery and medial meniscal extrusion width (MEW) after surgery, in the medial meniscal (MM) tear group.

MM extrusion, because circumferential fibers are partially preserved [23,24]. The MEW after horizontal tear was 0.2 mm in one study [23]. Conversely, whether longitudinal tear results in MM extrusion remains to be clarified. In this study, a longitudinal tear induced a three-times smaller MM extrusion compared with a posterior root tear. The results of the current study paralleled those of partial meniscectomy and horizontal tear, because continuity of the circumferential fibers is partially preserved.

The current results also revealed that MM extrusion persisted after ACLR with a concomitant MM repair in the MM tear group. A previous study showed that meniscal repair changed the meniscal shape through excessive peripheral stabilization, which would induce transposition of the medial meniscus [25]. The current results were consistent with the previous report. In contrast, MM repair with concomitant ACLR is recommended. A systematic review including 15 studies with 642 untreated MM tears with concomitant ACLR showed that 12–15% of untreated MM tears underwent reoperation [26]. Furthermore, a recent review article concluded that regarding the risk of reoperation, MM tears with concomitant ACLR are an indication for surgical MM repair [27].

A meta-analysis and long-term study, comparing meniscal repair with meniscectomy for the treatment of meniscal tears, have demonstrated that meniscal repair has better long-term outcomes and cartilage protection than meniscectomy [28,29]. Meniscal repair is the recommended treatment for MM tears with concomitant ACLR. However, the current study showed that MEW in the MM tear group was correlated with the initial meniscal tear size pre-operatively and the MM extrusion persisted after ACLR with concomitant MM repair in the MM tear group. Hence, the surgical technique of meniscal repair should be improved for persistent meniscal extrusion. Koga et al. reported that arthroscopic centralization of the extruded meniscus, where the capsule adjacent to the meniscus was repaired to the edge of the tibial plateau, decreased meniscal extrusion [30,31]. An animal model of centralization for the MM extrusion revealed that the centralization technique was able to delay cartilage degeneration [32]. In the future, studies on the effectiveness of arthroscopic centralization against cartilage degeneration in large meniscal injuries with large meniscal extrusion, as well as the development of new procedures that will prevent meniscal extrusion and cartilage degeneration, are needed.

4.1. Limitations

This study had several limitations. First, it included a small number of subjects. However, the meaningful results had significant differences and were consistently in line with previous reports. Second, the follow up period was short. However, MEW as a critical complication occurred with significant correlation during this short follow up period. These findings are considered valuable.

5. Conclusions

In conclusion, a longitudinal tear of the medial meniscus correlated with MM extrusion, and MM extrusion persisted after ACLR with concomitant MM repair in the MM tear group. The initial meniscal tear size was directly correlated with the pre-operative MM extrusion width. Therefore, meniscal extrusion after longitudinal tear of the medial meniscus and its meniscal repair should be taken into careful consideration.

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HK conceived the study, performed all the experiments, and participated in its design. KM participated in its design and performed analysis. YN and KO acquired the data. TO and MS analyzed and calculated the data. IS participated in its design. HK had full access to all of the data in the study and takes responsibility for the integrity of the data and accuracy of the data analysis.

All authors read and approved the final manuscript, and take responsibility for the integrity of the data and the accuracy of the data analysis.

This study was conducted at Tokyo Medical and Dental University Hospital of Medicine.

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