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Effect of meniscus repair on pivot-shift during anterior cruciate ligament reconstruction: Objective evaluation using triaxial accelerometer

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ABSTRACT

Background: Some types of meniscus tear, especially lateral meniscus tear, have been reported to be associated with rotatory knee laxity. However, precise information regarding the effect of meniscus repair on rotatory laxity is limited. The purpose of this study was to investigate the effects of lateral and medial meniscus repair on rotatory laxity in anterior cruciate ligament (ACL) injured knees.
Methods: Forty-one patients who underwent ACL reconstruction were included in the study. The tibial acceleration during the pivot shift test was measured using a triaxial accelerometer preoperatively under anesthesia and intraoperatively before and after medial and lateral meniscus repair and ACL reconstruction during surgery. Effects of meniscus tear and its repair on rotatory laxity were analyzed.
Results: Preoperative measurements revealed that patients with lateral meniscus tear showed significantly higher tibial acceleration compared to the patients without meniscus tear ($P = 0.006$). Intraoperative measurements revealed that medial and lateral meniscus repair significantly reduced tibial acceleration by 1.46 m/s^2 ($P = 0.002$) and 1.91 m/s^2 ($P < 0.001$), respectively.
Conclusion: In ACL injured knees, knees with lateral meniscus tear showed greater rotatory laxity compared to the knees without meniscus tear. In addition, lateral meniscus repair, and to a lesser degree medial meniscus repair, reduced rotatory laxity during ACL reconstruction surgery. Therefore, the meniscus should be repaired as much as possible for its role as a secondary stabilizer of rotatory laxity. Besides, the effect of meniscus repair on rotatory laxity should be considered when the indication of anterolateral augmentation is determined.

1. Introduction

The pivot-shift test [1] is widely used to assess the dynamic rotatory laxity of the knee, especially for evaluating anterior cruciate ligament (ACL) injury and the results of ACL reconstruction. The positive pivot-shift test after ACL reconstruction has been reported

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to be associated with patient dissatisfaction [2] and poor functional outcomes [3], however, a relatively high incidence of persisting pivot-shift phenomenon after ACL reconstruction has been reported [2,4]. Thus, controlling rotatory laxity is one of the keys to improving outcomes after ACL reconstruction, and there has been an increasing interest in the roles of secondary restraints for rotatory laxity.

It is widely accepted that lateral meniscus plays an important role as a secondary stabilizer to the pivot-shift in the ACL-deficient knee. Biomechanical studies using cadaveric knees have shown that, in response to a simulated pivot-shift test, lateral meniscectomy or lateral meniscus posterior root tear after ACL transection resulted in significantly increased additional anterior translation of the lateral knee compartment [5,6]. Conversely, the effect of medial meniscus on the pivot-shift is still controversial, although medial meniscus is well known as an important secondary restraint to anterior tibial translation in the ACL-deficient knee [5,7,8]. Some reports have indicated that the medial meniscus also plays a role as a secondary restraint for rotatory knee laxity of ACL-injured knees [9,10], whereas a biomechanical study using cadaveric knees has shown that medial meniscectomy had no significant effect on anterior tibial translation during a mechanized pivot-shift test [5]. Accordingly, meniscal preservation, especially lateral meniscus preservation, has the theoretical advantage of controlling rotatory laxity; however, information regarding the effects of lateral and medial meniscus repair on rotatory laxity in clinical settings is still limited.

Several tools to quantitatively evaluate rotatory knee laxity have been developed recently, such as surgical navigations, electromagnetic sensor systems and accelerometers [11]. Among them, a triaxial accelerometer is a small and noninvasive system which is easy to apply in clinical settings. It evaluates the pivot-shift phenomenon by measuring tibial acceleration, which has been reported to be well correlated to the clinical grading [12,13].

Therefore, the purpose of the present study was to investigate the effects of lateral and medial meniscus repair on rotatory laxity in ACL-injured knees by evaluating pivot-shift phenomenon quantitatively using a triaxial accelerometer. The hypotheses underlying this study were that lateral meniscus repair reduces the rotatory instability of knee in contrast to the medial meniscus repair.

2. Material and methods

2.1. Patients

This study was approved by the institutional review board of Tokyo Medical and Dental University (research protocol identification number: 1566), and all patients provided informed consent before participating. Patients with an ACL injury who were scheduled to undergo ACL reconstruction surgery between August 2016 and September 2017, regardless of the ACL graft material and whether the ACL reconstruction was primary or revision, were prospectively enrolled in the study. Patients were excluded if they had severe osteoarthritis, concomitant ligament tears requiring surgery, meniscus injuries requiring resection, and history of injuries in contralateral knees. In addition, as we had only one pivot-shift measurement system, if there was more than one ACL reconstruction surgery at a time, we randomly included one patient. Patients were then divided into four groups depending on the status of the meniscus; patients who underwent ACL reconstruction surgery alone and did not need meniscus repair were defined as the 'without meniscus repair' group, patients who underwent medial meniscus repair in addition to ACL reconstruction were the 'MM' repair group, patients who underwent lateral meniscus repair were the 'LM' repair group, and patients who underwent both medial and lateral meniscus repair were the 'MM and LM' repair group.

2.2. Quantitative evaluation of the pivot-shift test

One of two attending surgeons (H.K. and M.H.) performed standardized pivot-shift tests [1] preoperatively under anesthesia for both injured and uninjured knees and intraoperatively for injured knees. The intraoperative measurement was performed just after arthroscopic evaluation, medial meniscus repair (if present), lateral meniscus repair (if present), and ACL reconstruction. The same surgeon performed the pivot-shift test throughout the duration of each surgery.

Quantitative assessment of the test was performed during every pivot-shift test by obtaining triaxial tibial acceleration during a pivot-shift phenomenon using a kinematic rapid assessment (KiRA) triaxial accelerometer (OrthoKey, Lewes, DE, USA) [14]. Tibial acceleration during the pivot-shift test measured by this system has been reported to be useful to detect ACL injury [12,14,15] and moreover to deduce grading of the pivot-shift phenomenon [12,15]. This system is composed of a sensor embedding a triaxial accelerometer wirelessly connected to a tablet. The sensor was non-invasively fixed securely on the skin by a belt between the lateral aspect of the anterior tibial tuberosity and the Gerdy tubercle; the main axis of the sensor was aligned with the tibial mechanical axis [14] (Figure 1(A)). This position was selected since the lateral tibial compartment has been shown to produce the largest acceleration during tibial reduction [16]. The sensor measured the triaxial acceleration of the tibia and transmitted the data to a customized program for analysis. During the pivot-shift test, the sudden tibial reduction could be visualized in each tracing, so a part of the pivot-shift phenomenon was identified from the tracing. Then the program calculated the difference between the maximum value (a_{max}) and minimum value of the acceleration (a_{min}) (a_{range}: $a_{max} - a_{min}$) (Figure 1(B)), which has been reported to indicate the magnitude of the pivot-shift phenomenon [12,15], and this a_{range} was defined as 'acceleration' in the following analyses.

Each pivot-shift test was performed five times, and the acceleration was measured for each test. Then maximum and minimum values were excluded, and the three remaining values were averaged and used for the analyses. Intra-observer repeatability for each of the two attending surgeons was analyzed using all the acceleration data. In addition, four patients were randomly selected from the without meniscus repair group, and analyses of inter-observer reliability were performed for the acceleration data of both ACL-injured and uninjured knees between the two examiners.

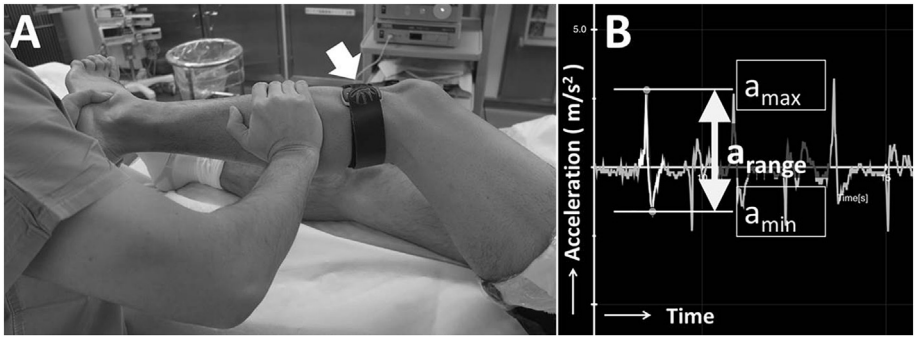

Figure 1. Evaluation of the pivot-shift using a triaxial accelerometer. (A) A sensor (white arrow) was attached to the lateral aspect of the tibia, and its main axis was aligned with the tibial mechanical axis. (B) Example of a wave during the pivot-shift test obtained by triaxial accelerometer KiRA. The difference between maximum value (a_{max}) and minimum value (a_{min}) of the acceleration (a_{range}: $a_{max} - a_{min}$) was used to evaluate the magnitude of subluxation during the pivot-shift phenomenon.

2.3. Surgical techniques

The procedures were performed by two attending surgeons or under their supervision. First, standard arthroscopy was undertaken through anterolateral and anteromedial (AM) portals to confirm ruptured ACL and evaluate the status of the menisci. If meniscus injury was identified, a meniscal rasp was utilized to lightly debride the tear edges and adjacent synovia to promote healing. It was then repaired appropriately. The method of suturing and the number of sutures needed were determined by each surgeon in consideration of the type, size and complexity of the tear. Basically, tears in the posterior, middle, and anterior part of the meniscus were repaired using all-inside, inside-out, and outside-in techniques, respectively. Longitudinal tears including bucket handle tears were generally repaired with vertical mattress sutures placed above and/or below the meniscus [17,18]. Radial tears were mostly repaired with tie-grip sutures: the vertical sutures were first positioned near both edges of the tear site. Then two or three horizontal mattress sutures were placed perpendicular to and over the vertical sutures and the tear site and tied over the joint capsule [19]. Most of the lateral posterior root tears were repaired using a pull-out technique [20]: the torn edge of the lateral meniscus posterior root was securely held with two 2-0 FiberWires (Arthrex) by a racking hitch knot. These sutures were passed through a tunnel for PLB or a six-millimeter-diameter tunnel to the AM aspect of the proximal tibia then fixed to an anchor staple. Centralization of the meniscus was added if extrusion of the lateral meniscus was confirmed by pushing the mid body of the meniscus out of the lateral tibial plateau by use of a probe [21]. After suturing the meniscus, it was confirmed by using the probe that the gap of the meniscus tear was securely closed and became stable.

ACL reconstruction was performed by either a double-bundle technique using semitendinosus tendon or a rectangular tunnel technique using bone–patellar tendon–bone (BPTB) graft. Regarding double-bundle ACL reconstruction, the AM and posterolateral (PL) bundles were created using the autologous semitendinosus tendon, which was cut into halves and folded to create two double-stranded bundles. Both femoral and tibial tunnels were created at the anatomic position of the insertion sites of each bundle [15]. The femoral tunnel was created using the outside-in or transportal approach. The tibial tunnel was created from the AM surface of the tibia. Both the AM and PL grafts were inserted through the tibial tunnel to the femoral tunnel, and the femoral sides of both grafts were fixed with the EndoButton-CL (Smith & Nephew Endoscopy). Then the AM bundle graft was fixed to an anchor staple with sutures at the tibial site, at 20° of knee flexion with the applied initial tension adjusted to be equal per cross-sectional area on a basis of 25 N per six millimeters in diameter [22]. The PL graft was then fixed to another anchor staple in the same manner. As for ACL reconstruction using BPTB, a 10-mm-wide BPTB graft was harvested from the medial portion of the patellar tendon with 15-mm-long bone plugs on both ends. These bone plugs were shaped into a rectangular parallelepiped shape, five millimeters thick × 10 mm wide × 15 mm long. Rectangular, oblong tunnels were created at the anatomic position of the insertion sites in accordance with the rectangular cross-section of the graft [23]. The femoral tunnel was created by an outside-in technique, and the tibial tunnel was created from the AM surface of the tibia. The BPTB graft was inserted through the tibial tunnel to the femoral tunnel, and the femoral side of the graft was fixed with the EndoButton-CL (Smith & Nephew Endoscopy). Then the graft was fixed to the anchor staple with sutures at the tibial site, at 20° of knee flexion with the initial tension of 40 N.

2.4. Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) (version 24.0; SPSS, Chicago, IL, USA). Shapiro–Wilk tests were performed to check for normality. Kruskal–Wallis tests were performed comparing the background (age, sex, period from injury to surgery and the anterior knee laxity measured with the KT-1000 arthrometer (MEDmetric, San Diego, CA) at manual maximum pull at 25° of flexion, expressed as the difference between the injured and uninjured legs in 0.5-mm increments) and the acceleration of both injured and uninjured knees during pivot-shift test before surgery under anesthesia among four groups; without meniscus repair, MM repair, LM repair, and MM and LM repair groups. Post hoc Mann–Whitney U-tests with Bonferroni correction were applied when differences across these four groups were found. To evaluate the effect of each procedure, such as medial meniscus

Table 1
Patients' backgrounds[a].

	Without meniscus repair (n = 13)	MM repair (n = 6)	LM repair (n = 11)	MM, LM repair (n = 11)	*P*
Age, years (range)	22 (15–45)	19 (16–23)	19 (16–51)	21 (14–43)	n.s.
Gender, male/female	8/5	1/5	1/10	3/8	0.037
Period[b], months (range)	3.5 (1–420)	8.5 (2–20)	2 (1–40)	25 (1.5–74)	n.s.
KT measurement, mm (range)	4 (2.5–8)	5.5 (3–9)	7 (1–9)	7 (4–12)	n.s.

LM, lateral meniscus; MM, medial meniscus; n.s., not significant.
[a] Data are shown with median (range).
[b] Period from injury to surgery.

repair, lateral meniscus repair and ACL reconstruction, a Wilcoxon signed-rank test was performed comparing the acceleration during pivot-shift test just before and just after each procedure. The Wilcoxon signed-rank test was also used to compare the acceleration during the pivot-shift test measured intraoperatively in the without meniscus repair group. Friedman tests with a post hoc Wilcoxon signed-rank test with Bonferroni correction were used to compare the acceleration during the pivot-shift test measured intraoperatively within each group (MM repair group, LM repair group and MM and LM repair group). Intra-observer repeatability for each surgeon (H.K. and M.H.) was assessed with intra-class correlation coefficient using all the acceleration data. Intra-class correlation coefficient using all the acceleration data for both surgeon 1 and surgeon 2 was 0.97. In addition, analyses of inter-observer reliability were performed using the acceleration data from randomly selected four patients in the without meniscus repair group for both ACL-injured and uninjured knees between the two examiners. The analyses yielded an intra-class correlation coefficient of 0.99 for the ACL-injured knees, and 0.97 for the uninjured knees.

3. Results

One-hundred and nine patients met the inclusion criteria, and 31 patients were excluded according to the exclusion criteria. Thirty-seven patients declined to be included in this study or were excluded because of a shortage of measurement systems. Consequently, 41 patients with a median age of 20 years (range 14–51 years; 13 males and 28 females) were included in this study. The median time from injury to surgery was five months (range one to 420). Among these patients, two patients underwent revision ACL reconstruction. Patients were divided into four groups depending on the status of the meniscus; 13 patients were classified as the without meniscus repair group, whereas six patients were in the MM repair group, 11 patients in the LM repair group, and 11 patients in the MM and LM repair group. There was no significant difference regarding the distribution of meniscus repairs between the two examiners. No statistical difference was observed among the four groups regarding age, period from injury to surgery and KT measurement. A significant difference was detected regarding gender among the four groups ($P = 0.037$), however, post hoc analysis did not reveal any significant differences (Table 1).

The types of meniscus tears among 28 patients who underwent meniscus repair are shown in Table 2. Most of the MM tears were longitudinal tears (17) and most of the LM tears were either a longitudinal tear (14) or a posterior root tear (eight).

3.1. Preoperative measurement

Regarding the preoperative tibial acceleration, there was no statistically significant difference among the four groups regarding uninjured knees, whereas for injured knees, tibial acceleration of the LM repair group was significantly greater than that of the without meniscus repair group ($P = 0.006$) (Figure 2).

3.2. Intraoperative measurement

Comparing the tibial acceleration just after each procedure to the acceleration just before MM repair (n = 17), LM repair (n = 22) and ACL reconstruction (n = 41) significantly reduced tibial acceleration, by 1.46 m/s^2 ($P = 0.002$), 1.91 m/s^2 ($P < 0.001$) and 1.64 m/s^2 ($P < 0.001$), respectively (Figure 3).

Table 2
Types of the meniscus tears.

	MM repair (n = 6)	LM repair (n = 11)	MM and LM repair (n = 11)	
			MM	LM
Longitudinal	6	8	11	6
Radial	0	0	1	3
Horizontal	0	1	0	1
Posterior root	0	3	0	5

LM, lateral meniscus; MM, medial meniscus.

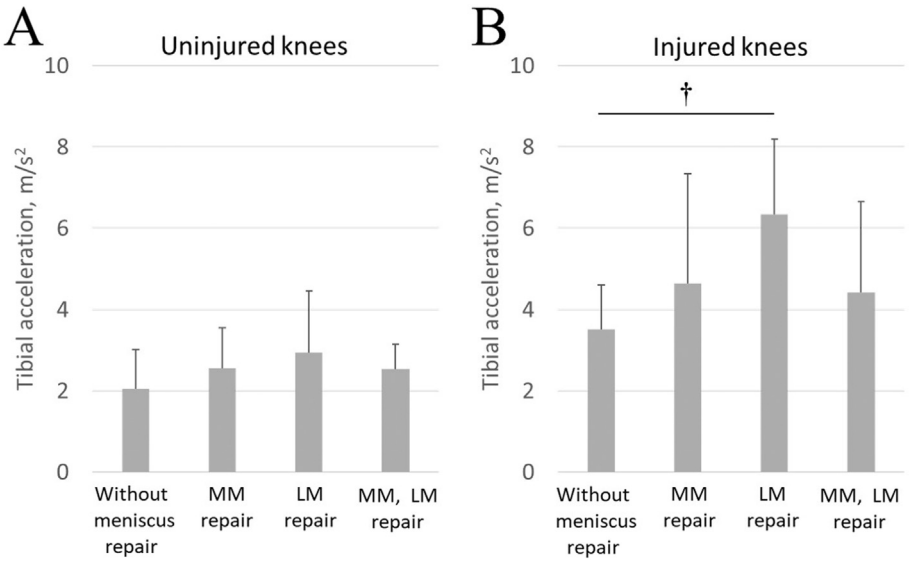

Figure 2. Preoperative tibial acceleration under anesthesia for (A) uninjured knees and (B) injured knees. †$P < 0.01$. LM, lateral meniscus; MM, medial meniscus.

The change in tibial acceleration for each group is shown in Figure 4. The tibial acceleration after ACL reconstruction was significantly smaller than that of the ACL-injured knees in the without meniscus repair group ($P = 0.001$) (Figure 4(A)). In the MM repair group, the tibial acceleration was reduced by 1.25 m/s^2 on average (Figure 4(B)), however, it did not reach significance ($P = 0.084$). In the LM repair group, the tibial acceleration was significantly reduced after LM repair ($P = 0.015$); it was reduced by 2.54 m/s^2 (Figure 4(C)). In the MM and LM repair group, the tibial acceleration was reduced by 1.28 m/s^2 after MM repair on average, however, it did not reach significance ($P = 0.078$). Conversely, LM repair significantly reduced tibial acceleration by 1.58 m/s^2 ($P = 0.030$) (Figure 4(D)).

4. Discussion

The most important finding of the present study was that in ACL injured knees, those with lateral meniscus tear showed significantly greater tibial acceleration during the pivot-shift test compared to knees without meniscus tear, and the tibial acceleration was significantly reduced by repairing these meniscus tears. In addition, besides lateral meniscus repair, medial meniscus repair also reduced tibial acceleration, although its degree tended to be less than that of the lateral meniscus repair.

Our finding that the lateral meniscus plays an important role for rotatory laxity is consistent with previous reports. Some biomechanical studies using cadavers have reported that lateral meniscectomy or lateral meniscus posterior root tear after ACL transection significantly increased the anterior translation of the lateral knee compartment in response to the simulated pivot-shift load [5,6]. Some clinical studies have also shown that ACL-injured patients with lateral meniscus posterior root tear or lateral meniscus tear

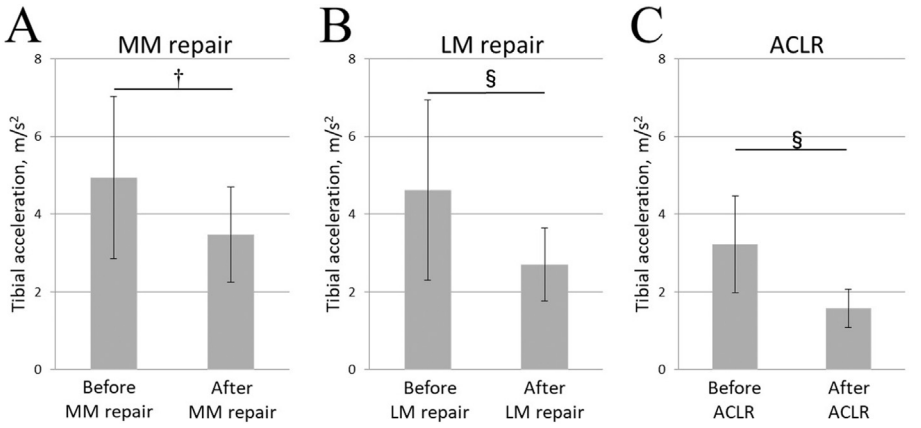

Figure 3. Tibial acceleration before and after each procedure. (A) Medial meniscus (MM) repair (n = 17); (B) lateral meniscus (LM) repair (n = 22); (C) anterior cruciate ligament reconstruction (ACLR) (n = 41). †$P < 0.01$; §$P < 0.001$.

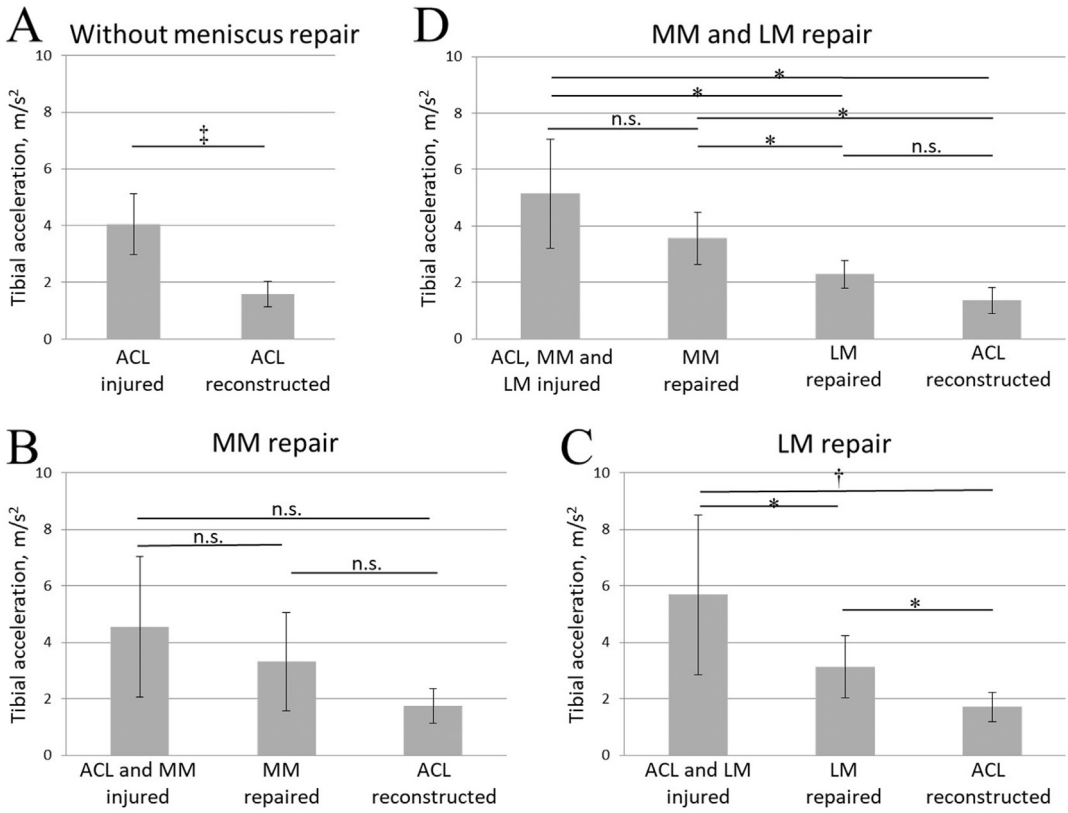

Figure 4. Intra-operative change of tibial acceleration: (A) without meniscus repair group (n = 13); (B) medial meniscus (MM) repair group (n = 6); (C) lateral meniscus (LM) repair group (n = 11); (D) MM and LM repair group (n = 11). $^{*}P < 0.05$; $^{\dagger}P < 0.01$; $^{\ddagger}P < 0.005$. n.s., nonsignificant.

showed larger pivot-shift phenomena before reconstruction surgery [24,25]. In addition, the current study gave a new insight into the point of evaluating the effect of meniscus repair quantitatively in clinical settings.

Regarding the medial meniscus, it is well known and accepted that the medial meniscus is a secondary restraint to anterior–posterior displacement in the ACL-deficient knee during an anterior load [26], however, the effect of medial meniscus on rotatory laxity is still controversial [5,9,10]. Conversely, the current study showed that tibial acceleration just after medial meniscus repair was significantly less than that before surgery, suggesting that medial meniscus repair has some effect on reducing rotatory knee laxity. However, further research with more cases of medial meniscus tear is warranted since the number of medial meniscus tears was not enough to statistically analyze the effect of medial meniscus tear as well as its repair.

This study identified a significant effect of repairing lateral meniscus, and to a lesser degree, medial meniscus, on controlling rotatory laxity in addition to ACL reconstruction. These results suggest that the meniscus should be repaired instead of resected, not only for load distribution or preserving cartilage, but also for its role as a secondary stabilizer of rotatory laxity. The current study also suggests that the effect of meniscus repair on rotatory laxity should be considered when the indication of anterolateral augmentation is determined. Recent descriptions of anterolateral ligament [27] have refocused attention on the anterolateral structures of the knee and its role as a secondary stabilizer for rotatory laxity. Some surgeons add anterolateral ligament reconstruction or anterolateral augmentation to ACL reconstruction in patients with large pivot-shift before surgery [28,29]. However, meniscus repair has such a large effect on the magnitude of the pivot-shift phenomenon in ACL-injured knees as shown in this study; indication of additional anterolateral augmentation might have to be determined after meniscus repair.

Previous works have demonstrated that medial meniscectomy produced an increase in in situ forces in the ACL or ACL graft [7,8] and an increase in anterior tibial displacement during anterior load. Likewise, according to some prior reports, the resultant forces on the medial meniscus are greater in ACL-deficient knee compared to the intact knee [7,26]. Our results suggest, in the absence of more conclusive evidence, that similar interdependence might occur between meniscus and ACL during rotatory load, and loss of one of these structures could predispose the other to injury. The meniscus repair during ACL reconstruction surgery might reduce excessive force experienced by the graft during rotatory load. Further work is needed to evaluate the functional interdependence of meniscus and ACL during rotatory load.

Several tools have been reported that can quantitatively evaluate rotatory knee laxity, such as surgical navigations, electromagnetic sensor systems and accelerometers [11]. Among them, the triaxial accelerometer is a small, noninvasive system and requires only a small amount of time to perform measurements, thus it is easy to apply in the clinical setting and is useful for a study such as the present work, which requires repetitive measurements during surgery. Besides, tibial acceleration during the pivot-shift test,

which is the parameter measured by this system, has been reported to have the best correlation to the clinical grading among several knee kinematics measurements [13]. The usefulness of this system has been validated in past studies, which have shown that acceleration of ACL-injured knees was greater than that of uninjured knees, and this acceleration was correlated with the subjective manual grading [12,14,15]. In addition, according to the data from the previous study [15], one clinically relevant manual grading difference in pivot-shift acceleration was (mean) ± (standard deviation) 1.5 ± 0.4 m/s^2, suggesting that the mean tibial acceleration reduction by the meniscus repair observed in the current study was clinically significant. Moreover, although this device can only measure triaxial acceleration and not precise kinematics, a previous work that validated this system using a navigation system revealed that the acceleration ranges measured with this system demonstrated a good positive correlation with the anterior–posterior acceleration measured with the navigation system [30]. An inevitable learning curve for using this device has been reported [12] so two knee surgeons who were well experienced in knee surgery and had more than two years of experience using this triaxial accelerometer performed the pivot-shift tests. We also confirmed that intra- and inter-observer reliabilities of the two surgeons were quite high.

This study has several limitations. First, it included various types of meniscus tears and the sample size was small. Further study with a large-enough sample size to analyze the effect of different types of meniscus tears and their repairs on rotational laxity is warranted. Second, the order of medial and lateral meniscus repair was not randomized. Third, the pivot-shift test was performed manually by two different surgeons and they were not blinded to the status of the meniscus. However, these two surgeons were experienced, and the pivot-shift test technique was standardized before starting the present research to minimize the variation of the pivot-shift technique. We also confirmed that the intra- and inter-observer reliabilities of the two surgeons were quite high. Further limitation was that various types of ACL reconstruction were performed, however, as the main focus of this study was the effect of the meniscus repair, this limitation did not significantly affect the conclusion.

The clinical relevance of this study is that the meniscus should be repaired as much as possible, not only for load distribution or preserving cartilage, but also for its role as a secondary stabilizer of rotatory laxity. Another clinical relevance is that the effect of meniscus repair on rotatory laxity should be considered when the indication of anterolateral augmentation is determined.

5. Conclusions

Quantitative evaluation of the pivot-shift test using a triaxial accelerometer revealed that in ACL injured knees, knees with lateral meniscus tear showed greater rotatory laxity compared with knees without meniscus tear. In addition, lateral meniscus repair, and to a lesser degree medial meniscus repair, reduced rotatory laxity during ACL reconstruction surgery. Therefore, the meniscus should be repaired as much as possible because of its role as a secondary stabilizer of rotatory laxity. Besides, the effect of meniscus repair on rotatory laxity should be considered when the indication of anterolateral augmentation is determined.

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Conflict of interest

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