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MRI-Determined Anterolateral Capsule Injury Did Not Affect the Pivot-shift in Anterior Cruciate Ligament Injured-Knees

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Author contributions:

NM, YH, TM, and RK contributed to the study concept and design. NM, YH, TT, KN, DA, and TM contributed to the acquisition, analysis, and interpretation of the data. NM and YH drafted the article and NM, YH, KN, TM, and RK critically revised the article for important intellectual content. All authors had final approval of the version to be submitted for publication. NM, YH, and RK agreed to be held accountable for all aspects of the work to ensure that questions related to the accuracy or integrity of any part of the work are appropriately addressed.

Abstract

Purpose The purpose of this study was to quantitatively compare the results of pivot-shift test between knees with anterior cruciate ligament (ACL) injury with and without anterolateral capsule (ALC) injury detected on MRI. ALC injury was hypothesized to worsen rotatory knee laxity.

Methods We enrolled 82 patients with unilateral ACL injury. The pivot-shift test was performed under anesthesia before ACL reconstruction. Two evaluations were conducted simultaneously: IKDC clinical grading and the quantitative evaluation using an electromagnetic measurement system that determined tibial acceleration (m/s^2). Two examiners identified the ALC injury on magnetic resonance imaging (MRI) and stratified patients into two groups: ALC−injured (ALC+) and ALC−intact (ALC−). ALC injury was diagnosed if the signal intensity on coronal T2-weighted sequences is increased. After confirming the reliability of the MRI, the difference in the pivot-shift between two groups was assessed.

Results: Because of the poor agreement between examiners with respect to the ALC evaluations (kappa coefficient of 0.25 and 58.5% concordance), the result from each examiner was analyzed separately. Examiner 1 found ALC injury in 42/82 knees (51%). The two groups had similar clinical grading (glide/clunk/gross: ALC+ group 21/18/3cases vs. ALC− group 21/16/3cases) (n.s.). Tibial acceleration during pivot-shift was also similar in the ALC+ (1.4±1.2 m/s^2) and ALC− (1.7±1.3 m/s^2) groups (n.s.). Examiner 2 found ALC injury in 28/82 knees (34%). Differences in clinical grading were not observed (glide/clunk/gross: ALC+ group 16/9/3 vs. ALC− group 26/25/3) (n.s.). However, the tibial acceleration in the ALC+ group (1.2±0.8 m/s^2) was significantly lower than that in the ALC− group (1.7±1.3 m/s^2, $p=0.03$).

Conclusion Concomitant ALC injury in knees with ACL injury was not consistently detected on MRI and did not affect rotatory knee laxity.

Level of evidence Case–control study, Level III.

Keywords Anterior cruciate ligament; Anterolateral capsule; Pivot-shift; Quantitative measurement; MRI; Electromagnetic measurement system

Introduction

The potential impact of the anterolateral capsule (ALC) injury on the internal rotational laxity of knees with the anterior cruciate ligament (ACL) injury has been suggested in several studies [1, 4, 5, 7, 36]. However, most of those studies are basic *in vitro* studies that utilized their own original rotational stress tests to evaluate rotational laxity instead of the clinically used pivot-shift test [11, 19, 25, 31-34]. Rotatory knee laxity is not a simple rotational laxity against the axial rotational torque but has to be clinically evaluated by the pivot-shift test [28]. Because the clinical pivot-shift test is biomechanically complicated, perfect replication of this test in the *in vitro* studies is technically difficult [2, 27]. Meanwhile, several devices that can be used in clinical settings have been developed to accurately measure the pivot-shift [15, 21, 23, 24, 30]. Recently, Musahl et al. [29] reported the first *in vivo* clinical study that demonstrated that concomitant ALC injury increases the anterior tibial translation on the pivot-shift, as detected by an iPad measurement [29]. In contrast, there are other types of *in vivo* quantitative measurement systems for the pivot-shift test, which provides tibial acceleration values [15, 21, 23, 24, 30].

This study aimed to compare tibial acceleration during the pivot-shift test between knees with ACL injury with and without the ALC injury identified on magnetic resonance imaging (MRI). ALC injury has been hypothesized to affect rotatory knee laxity of knees with ACL injury.

Materials and Methods

Eighty-two patients with unilateral ACL injuries (38 men and 44 women; mean age, 25±12 years) who were scheduled to undergo ACL reconstruction between March 2013 and August 2016 in our hospital were prospectively enrolled for data collection. The diagnosis of the ACL injury was made based on clinical findings and MRI, and diagnosis was confirmed arthroscopically. Patients who had fractures, cartilage injuries, and other ligamentous knee injuries, including medial/lateral collateral ligament and posterior cruciate ligament injuries on either knee, were excluded. Informed consent was obtained from all participants.

Measurements

Before ACL reconstruction, the pivot-shift test was performed under general anesthesia. A single examiner performed the pivot-shift test in all participants and was blinded to the ALC conditions. Two evaluations of the pivot-shift test were conducted simultaneously. First, the standard clinical grading was determined by the examiner based on the International Knee Documentation Committee (IKDC) guidelines: none (-), glide (+), clunk (++), and gross (+++) [17]. Next, a quantitative evaluation of the pivot-shift test was executed by another independent orthopedic researcher using an electromagnetic measurement system that provided the tibial acceleration of the pivot-shift (Fig. 1).

The electromagnetic motion tracking device (Liberty, Polhemus, Colchester, VT, USA) was used. Two electromagnetic sensors were fixed on the thigh and the shank using plastic straps. The three-dimensional positions of seven anatomic bony landmarks (greater trochanter, medial and lateral epicondyles, the crossing point between the medial joint line and the medial collateral ligament, fibular head, and the medial and lateral malleoli) were electronically recorded using the third electromagnetic sensor. The positions of the femur and the tibia were accurately captured based on the spatial relationship between the anatomic bony landmarks and the sensors on the skin. The anatomic knee coordinate system was configured based on the report from Grood and Suntay [10]. The 6 degrees-of-freedom knee kinematics during the pivot-shift test was then monitored with a sampling rate of 240 Hz. The tibial acceleration (m/s^2) for posterior tibial reduction during the pivot-shift was then calculated from the data of the tibial anteroposterior translation over time [15, 30]. The accuracy of this system was surveyed by Hoshino et al. [15], and the mean standard deviation of the three measurements was 0.2±0.1 m/s^2.

The concomitant ALC injury was identified using MRI (Ingenia 3.0 T, Philips Medical System, Best, the Netherlands), because no other clinical diagnostic methodologies, including manual and instrumental tests, were available during this experiment. Similar to our clinical routine, knee MRI was carried out in the supine position with the leg extended. Three-plane (sagittal, coronal, and axial) sequences using both proton-density-weighted images and fat-suppressed proton-density-weighted images were obtained with 3-mm slice thickness. The concomitant ALC injury in the knees with ACL injury was investigated on MRI on separate occasions by two experienced orthopedic surgeons based on the report of Helito et al.[13]. Each examiner was blinded to the results of the other examiner's MRI and pivot-shift evaluations. Two groups were formed based on the MRI finding. Knees with and without ALC injury were stratified into the ALC−injured (ALC+) and ALC−intact groups (ALC−), respectively. Finally, the clinical grading and tibial acceleration in the pivot-shift test was retrospectively compared between the ALC+ and the ALC− groups.

Institutional review board approval of Kobe University (ID No.341) was obtained from our institutional ethics committee before this study.

Statistical analysis

An *a priori* sample size calculation indicated that 46 subjects were required to detect a 0.5 m/s^2 difference in tibial acceleration in the pivot-shift, assuming the use of a two-sided Student t-test for comparison between the two groups, with a power and significance level of 0.90 and 0.05, respectively. The common variance of the measurement was set at 0.5 m/s^2, based on previous reports using the same technology [15, 30].

The reliability of MRI for diagnosing concomitant ALC injury was determined using Cohen kappa coefficients for categorical variables [18]. Agreement/disagreement rates (percentage of all inter-observer comparisons with agreement/disagreement on a parameter) were also reported. Kappa values were classified as described by Landis and Koch, with values of 0–0.20, slight agreement; 0.21–0.40: fair agreement; 0.41–0.60: moderate agreement; 0.61–0.80: substantial agreement; and 0.80–1.00: excellent agreement [22].

The Chi-squared test was used to compare the clinical grading between the ALC+ and ALC− groups as determined by the two examiners. The independent t-test was used to assess the differences in the tibial acceleration (m/s^2) during the pivot-shift test in the knee with ACL injury with and without ALC injury. All statistical analyses were performed using SPSS software version 22 (SPSS Inc., Chicago, IL, USA). Statistical significance was defined as $p<0.05$.

Results

Examiner 1 assessed the MRI and diagnosed ALC injury in 42 of 82 knees (51.2%), whereas examiner 2 diagnosed 28 knees (34.1%) with ALC injury (Table 1). No significant difference was found in the concomitant ALC injury with respect to patient age (n.s.) or the waiting period between the time of ACL injury and ACL reconstruction (n.s.) in the demographic data judged by each of the two examiners (Table 2). Only a fair agreement was noted between the two examiners with respect to the detection of ALC injury on MRI, as demonstrated by the kappa coefficient of 0.25, although the statistical power for the kappa coefficient was only 0.65. The concordance ratio between the examiners was only 58.5%. As the diagnosis of ALC injury was not consistent between the two examiners, the comparison of the pivot-shift evaluations between the ALC+ and the ALC− groups was separately performed by the two examiners.

Based on the judgement of examiner 1, the ALC+ group had similar clinical grading results in the pivot-shift test (glide/clunk/gross: 21/18/3) compared with the ALC− group (21/16/3, n.s.). The tibial acceleration during the pivot-shift test was similar in the ALC+ (1.4±1.2 m/s^2) and ALC− groups (1.7±1.3 m/s^2, n.s.) (Table 3). The ALC+ group evaluated by examiner 2 also had similar clinical grading (glide/clunk/gross: 16/9/3) for the ALC− group (26/25/3, n.s.). However, the acceleration in the ALC+ group (1.2±0.8 m/s^2) was significantly less than that in the ALC− group (1.7±1.3 m/s^2, p=0.03) (Table 4).

Discussion

The most important finding from this study was that the ALC injury in conjunction with the ACL injury did not affect rotatory knee laxity in our clinical cases based on both clinical grading and quantitative evaluation. In addition, the diagnosis of ALC injury based on MRI findings was not consistent between the two examiners with significant experience in orthopedics (i.e., more than 10 years). Interestingly, neither examiner found the concomitant ALC injury on MRI that significantly impacted the pivot-shift in the knees with ACL injury.

Several reports indicated that residual rotatory knee laxity existed after ACL reconstruction alone in patients with isolated ACL injuries [5, 16]. Therefore, some factors other than ACL injury have been suggested, for example ALC injury might be involved in rotatory knee laxity [1, 4, 5, 7, 36]. ALC injury has been suspected as a major aggravating factor in rotatory knee laxity, leading to high-grade pivot-shift [25, 29, 31, 33]. However, this *in vivo* study did not find that the ALC injury influenced the pivot-shift, even by quantitative evaluations.

Identification of the impact of the ALC injury on the pivot-shift in clinical cases has been difficult mainly due to the lack of precise evaluations by the pivot-shift test. Recently, Musahl et al. reported a clinical case study of ALC injury that affected tibial translation during the pivot-shift using a quantitative measurement on the iPad system [29]. The differences between the report by Musahl et al.[29] and our study can be attributed to the time interval between the MRI and the evaluation by the pivot-shift test. In the current study, the time interval was slightly longer than that reported by Musahl et al. [29]. Spontaneous healing of the ALC injury might have occurred in such knees with severely limited range of motion and might have taken an extended length of time to sufficiently recover before the surgery. Moreover, it is well known that ALC injury cannot always be accurately identified, particularly in clinical cases, due to its anatomic variation and immature definition [8, 11, 36]. Our MRI diagnostic criteria for ALC injury might be different from those of Musahl et al. [29], but such a difference was unavoidable due to the paucity of established methods for detecting ALC injury on MRI. In addition, there was an obvious technical difference in the pivot-shift measurement methods. The iPad system evaluated the tibial translation during the pivot-shift [14], whereas tibial acceleration was evaluated in the current study. Both parameters can be used to quantify the pivot-shift, but the clinical characteristics and implications of each parameter might be different.[24]

In vitro studies testing the effects of ALC injury on rotatory knee laxity are also controversial. Some supported the effects of ALC injury on rotatory knee laxity [25, 31, 33], but others did not [11, 19, 32, 34].

Those studies utilized original rotational stress tests and did not sufficiently simulate the clinically performed pivot-shift test. Considering that the pivot-shift test involves quite complex rotational stress while moving the knee [2, 27], simulating the test using cadaveric knees is very difficult. Only clinically performed pivot-shift test has been proven to have a relationship to the subjective knee function and early osteoarthritis development.[20]. Evaluation of the pivot-shift using a quantitative measurement in clinical cases is important.

In our study, the agreement/disagreement ratio and Cohen kappa coefficients were found to be poor between two experienced orthopedic surgeons could not find a validity about. Until now, most of the imaging diagnoses of ALC injury in clinical cases have been achieved using MRI [6, 12, 13, 35], except in the study by Cianca et al. that used ultrasonography [3]. Previous studies have demonstrated variations in the visibility of ALC injury on MRI [6, 12, 13, 35]. Taneja et al. reported that the visibility of the anterolateral ligament was 51% [35], and this was the lowest reported figure. Other reports showed that anterolateral ligament could be detected >80% on MRI. The highest visibility was 97.8%, which was shown by Helito et al. [12]. Clear and reliable criteria for diagnosing the ALC injury on MRI are still needed to ensure consistent evaluation and detection. The difficulty of MRI diagnosis for ALC injury could be due to their inconsistent features, resulting in the low kappa coefficient in the present study.

Another possible reason for the low rate of detection of the concomitant ALC injury on the MRI is the time lag between the injury and MRI acquisition. More than one month has passed from the time of the

ACL injury to MRI acquisition in our subjects, and we might have detected the healing scar of the ALC injury. The natural prognosis of concomitant ALC injury in ACL injury is still unknown, and there could have been a spontaneous healing of the ALC injury, which would leave a visible scar but would be mechanically stable against the pivot-shift leading.

In this study, consistent diagnosis of ALC injury using MRI was difficult. Therefore, the impact of ALC injury on rotatory knee laxity could not be confirmed. Thus, we should pay more attention to other common and identifiable injuries, such as meniscal and cartilaginous tears.

This study has some limitations. First, we did not grade the ALC injury as detection of the ALC injury was inconsistent among the examiners. The reason for the low rate of agreement was the difficulty of discriminating between the lateral collateral ligament, iliotibial band, and the capsule, particularly in the tibial attachment. Furthermore, we did not distinguish between those that were damaged partially, such as the femoral, meniscal, and tibial portion, and those that were damaged in multiple areas. If the mechanical effect of ALC injury is different depending on the site of the injury, some types of ALC injury might affect the pivot-shift and others might not. However, such sub-categorization of ALC injury could induce much wider variability in the MRI reading. Second, the ratio of concordance and kappa coefficient could be underpowered. Shortness of statistical power might cause type II error, i.e., sufficiently high kappa coefficient was falsely underrated. If so, it would conversely indicate that both examiners could similarly diagnose ALC injury on MRI. The conclusion of this study would be that MRI-diagnosed concomitant ALC injury did not affect the rotatory knee laxity regardless of who evaluated the ALC on MRI. Third, the ALC injury, which we evaluated on MRI, was not confirmed by direct visualization during surgery. Ferreti et al. reported anterolateral capsule injuries in 90% of their clinical cases under direct visualization [9]. However, additional surgical incisions solely to diagnose ALC injury was not allowed in our clinical setting. In this experiment, MRI images were performed at 3-mm slice; hence, missing an ALC injury that was smaller than the slice thickness is possible. However, there was still a lack of consensus regarding MRI sequences and settings for the anterolateral structures [26]. Finally, the meniscal conditions were not considered here, although the effect of meniscal injury on the pivot-shift has been established. However, the morbidity of associated with concomitant meniscal injury was not significantly different between the ALC+ and ALC− groups based on the judgement of both examiners in this study. The clinical relevance of this study was that we demonstrated that MRI diagnosis of concomitant ALC injury in knees with ACL injury is unreliable and clinically irrelevant because of its limited potential to affect the pivot-shift.

Conclusions

Although concomitant ALC injury in knees with ACL injury might not be consistently diagnosed on MRI, the quantitative evaluations obtained by pivot-shift testing using an electromagnetic measurement system did not reveal rotatory knee laxity caused by the ALC injury.

Conflict of Interest

We have no conflicts to disclose.

Author contributions

NM, YH, TM, and RK contributed to the study concept and design. NM, YH, TT, KN, DA, and TM contributed to the acquisition, analysis, and data interpretation. NM and YH drafted the article, and NM, YH, KN, TM, and RK critically revised the article for important intellectual content. All authors had final approval of the version to be submitted for publication. NM, YH, and RK agreed to be held accountable for all aspects of the work to ensure that questions related to the accuracy or integrity of any part of the work are appropriately addressed.

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Figure legends

Figure 1

The electromagnetic measurement system (EMS) for the pivot-shift test. Six degrees-of-freedom knee kinematics during the pivot-shift test was recorded based on the relative motion between the sensors and was used to calculate the tibial acceleration.

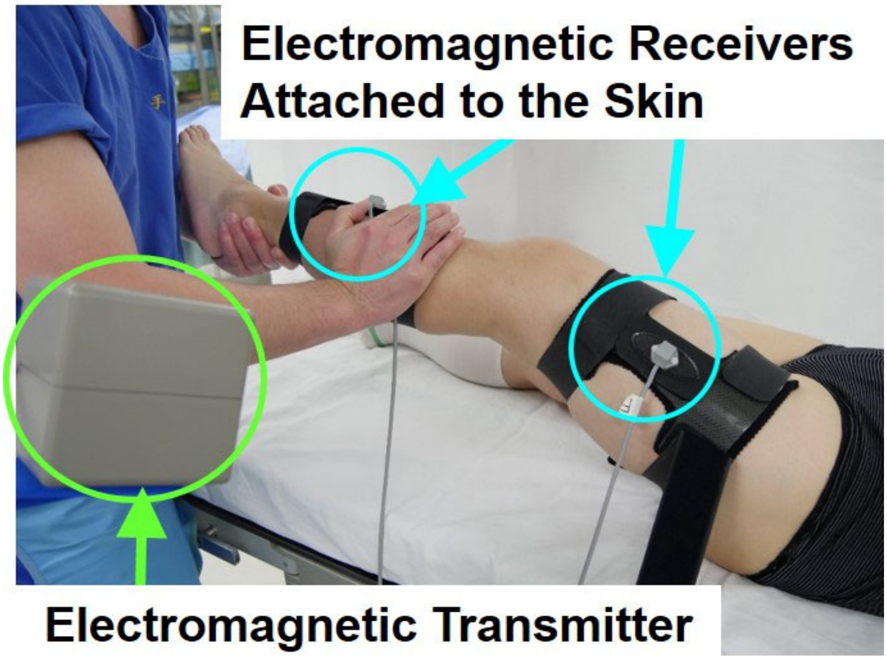

Table 1 ALC injury diagnosed on MRI.

Judgement	ALC injury +	ALC injury -
Examiner 1	42 (Men: 19; Women: 23)	40 (Men: 19; Women: 21)
Examiner 2	28 (Men: 13; Women: 15)	54 (Men: 25; Women: 29)

Table 2 The demographic data of the ALC−injured patients determined by the two examiners.

	Examiner 1	Examiner 2	p value
Number of ALC injuries	42	28	0.03
Age (years)	26±12	27±13	n.s.
Waiting period (days)	275	238	n.s.

Table 3 Patient demographic data and results of the evaluation by examiner 1.

Examiner 1	ALC + group	ALC–group	p value
Age (years)	26±12	25±12	n.s.
Waiting period (days)	275	257	n.s.
Pivot-shift test manual grade	Glide (+): 21 Clunk (++): 18 Gross (+++): 3	Glide (+): 21 Clunk (++): 16 Gross (+++): 3	n.s.
Acceleration (m/s^2)	1.4±1.2	1.7±1.3	n.s.

Table 4 Patient demographic data and evaluation by examiner 2.

Examiner 2	ALC + group	ALC–group	p value
Age (years)	27±13	25±11	n.s.
Waiting period (days)	238	294	n.s.
Pivot-shift test manual grade	Glide (+): 16 Clunk (++): 9 Gross (+++): 3	Glide (+): 26 Clunk (++): 25 Gross (+++): 3	n.s.
Acceleration (m/s^2)	1.2±0.8	1.7±1.3	0.03