Differences in Knee Kinematics Between Awake and Anesthetized Patients During the Lachman and Pivot-Shift Tests for Anterior Cruciate Ligament Deficiency

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Background: The Lachman and pivot-shift tests have been widely used for detecting anterior cruciate ligament (ACL) deficiency. However, it still remains unclear whether these manual tests can be quantified accurately while patients are awake.

Purpose: To assess the differences in knee kinematics of awake and anesthetized patients.

Study Design: Case series; Level of evidence, 4.

Methods: A total of 50 patients with unilateral ACL rupture were examined. Anteroposterior tibial translation was assessed using a KT-1000 arthrometer at maximal manual power. Anterior tibial translations during the manual Lachman test and the acceleration of tibial posterior translation (APT) during the pivot-shift test were also measured using an electromagnetic measurement system (EMS). All 3 measurements were performed on the day previous to surgery while the patients were awake and on the operative day before the surgery while the patients were under general anesthesia.

Results: The mean side-to-side difference in anteroposterior tibial translation was 5.6 $\pm$ 2.6 mm in the awake state and 5.9 $\pm$ 3.5 mm under anesthesia, indicating a nonsignificant difference. According to the EMS, the mean side-to-side difference in anteroposterior tibial translation during the Lachman test was 4.6 $\pm$ 3.6 mm in the awake state and 6.9 $\pm$ 4.3 mm under anesthesia, indicating a significant difference ($P < .01$). The mean APT during the pivot-shift test was -0.8 ± 0.3 m/s^2 in intact knees and -1.1 ± 0.4 m/s^2 in ACL-deficient knees when the patients were awake and was -0.7 ± 0.2 m/s^2 and -1.7 ± 1.0 m/s^2, respectively, when the patients were under anesthesia. In ACL-deficient knees, the APT pivot-shift test result was significantly higher when the patients were under anesthesia than when they were awake ($P < .01$).

Conclusion: In ACL-deficient knees, the knee kinematics during the Lachman and pivot-shift tests is significantly affected by patient consciousness, and caution is needed in quantifying anterior knee laxity during these tests when the patients are awake.

Keywords: anterior cruciate ligament; awake; under anesthesia; manual test

In sports activities, anterior cruciate ligament (ACL) injury is one of the most common ligament injuries.[8,9] ACL rupture is detected through history taking, clinical examination, magnetic resonance imaging (MRI), and arthroscopy. For detecting ACL deficiency, various types of manual examinations are carried out. Among them, the Lachman and pivot-shift tests have been widely used for detecting ACL deficiency as well as for assessing the clinical results after ACL reconstruction.[3,6,7,13,22] The Lachman test has been recognized as the most reliable and sensitive clinical test for detecting ACL deficiency. Likewise, the pivot-shift test is recognized as a reliable clinical test for detecting ACL deficiency.[19] In addition, positive pivot-shift tests have been reported to be associated with a patient's subjective clinical symptoms.[14] Although both tests are effective for diagnostic purposes and easily performed in routine practice, subjective classifications lack objectivity and are influenced by many factors, such as the examiner's estimation of the displacement, amount of applied forces, joint angles, and muscle relaxation during the testing. Both tests have also been used to assess knee laxity before and after ACL

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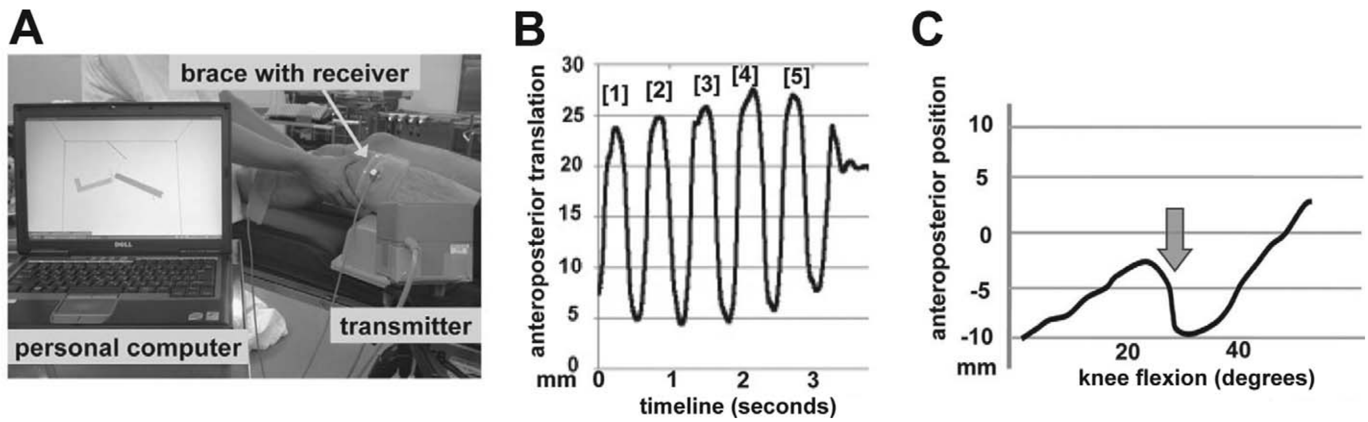

Figure 1. Electromagnetic measurement system and analysis. (A) Configuration of the electromagnetic measurement system. (B) Quantitative analysis of the Lachman test as measured by the electromagnetic measurement system displayed as tibial anteroposterior position versus time line. The numbers in brackets signify the order of the Lachman test. (C) Tibial anteroposterior position versus flexion angle during the pivot-shift test. Arrow indicates tibial posterior translation.

reconstruction. Recent evidence suggests the importance of manual tests, especially the pivot-shift test, for better understanding of knee kinematics before and after ACL reconstruction.[2] Therefore, sophisticated methods and devices are necessary to objectively quantify knee laxity during the Lachman and pivot-shift tests.

We developed an electromagnetic measurement system (EMS) to quantitatively measure knee kinematics during the Lachman and pivot-shift tests,[1,12,15] and we also previously reported its utility in preoperative and postoperative evaluations.[1] However, previously, several studies were conducted when the patients were under anesthesia, and it remained unclear whether the manual tests could be performed accurately in daily practice while the patients were awake. In this study, we used the EMS to assess knee kinematics during the Lachman and pivot-shift tests and compared the differences between the findings obtained in the awake and anesthetized states.

MATERIALS AND METHODS

Fifty patients (28 males, 22 females; mean age, 26.6 years) with unilateral ACL ruptures and undergoing ACL reconstruction were assigned to this study; signed informed consent was obtained from all study participants. At the time of the surgery, 2 patients had an extension deficit of 5° and 4 patients had a flexion loss of 5°. All other patients had a full range of motion. A mild effusion was observed in the injured knees of 3 patients. The ACL ruptures were detected by physical examination, MRI, and arthroscopy. The mean time from injury to operation was 11.5 months (range, 18-33 months). During arthroscopic examination, 6 patients were diagnosed as having a partial ACL tear. Twenty-four patients underwent meniscectomy or meniscal repair combined with ACL reconstruction. No patients had displaced or locked meniscus. The mean range of motion was not significantly different when the patients were awake or when they were under anesthesia.

The EMS

The details of the EMS were previously reported. Briefly, the EMS consists of 3 electromagnetic receivers and a transmitter that produces an electromagnetic field.[4] Two of the receivers were used for measuring the tibial and femoral motion and were attached to a plastic brace by a circumferential Velcro™ strap (Velcro USA Inc, Manchester, New Hampshire) placed 10 cm above the patella on the thigh and 7 cm below the tibial tubercle on the calf. A third receiver, which was attached to a specially made stylus, was used for digitizing the anatomical landmarks before measuring the 6 degrees of freedom kinematics. Seven anatomic landmarks were chosen to define the coordinate system. By modifying the principle of a 3-cylinder open-chain mechanism proposed by Grood and Suntay,[10] the 6 degrees of freedom knee kinematics was calculated, using the bone axis of the femur instead of the mechanical axis. The 6 degrees of freedom in the knee can be recorded at a sampling rate of 240 Hz (Figure 1A).

Measurements

With the use of an EMS, the anterior tibial translations were measured during the manual Lachman test. The Lachman test was performed as previously proposed by Torg et al.[22] We set the knees at a flexion angle of 15° and used the thigh support to maintain the same knee flexion angle throughout the procedure. The Lachman test was performed by holding the thigh from the outside and holding the tibia such that it was slightly externally rotated relative to the femur while maintaining the speed of the procedure at 2 times/s (Figure 1B). With the use of internal rotation, valgus, and axial stresses, the pivot-shift test was performed. The acceleration of tibial posterior translation (APT) during the pivot-shift test was also measured using the EMS (Figure 1C). The examiner performed the Lachman and pivot-shift tests 5 times each. The first and last measurements of each of the 5 measurements of each series were omitted as outliers, and the median data of the other 3 measurements were used for the analysis. The tests were performed by a single experienced surgeon, and the clinical grading of the pivot-shift test was evaluated by the examiner. The reliability of the procedures was previously reported.[1,12] In this study, the reliability of the EMS was also evaluated by taking the average of standard deviation and correlation coefficients among the tests.

Following a procedure described previously, the anterior tibial translation was also assessed using a KT-1000 knee ligament arthrometer (MEDmetric Corp, San Diego, California) at maximal manual power.[4,5,20] During the arthrometer measurement, patients' limbs were placed on a platform and foot holder. The arthrometer measurement was performed 3 times to confirm the value. In the KT-1000 and EMS, the side-to-side differences in the anteroposterior tibial translation during the Lachman test were calculated. All assessments were performed on the day previous to surgery in the outpatient clinic room while the patients were awake and on the operative day before the surgery in the operating room while the patients were under general anesthesia.

Statistics

The statistical evaluation was carried out by a paired t test. A P value <.01 was considered statistically significant. Results are provided as means $\pm$ standard deviations.

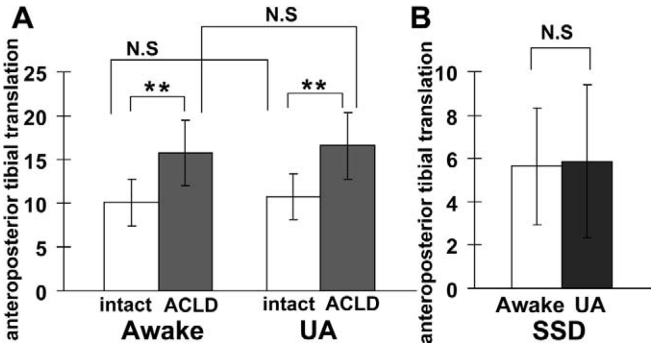

Figure 2. (A) Mean anteroposterior tibial translation measured using the KT-1000 arthrometer; results shown for intact and anterior cruciate ligament–deficient (ACLD) knees in both the awake and under anesthesia (UA) conditions. (B) Mean side-to-side difference (SSD) in anteroposterior tibial translation between awake and UA conditions. N.S, not statistically significant. $^{**}P < .0001$.

RESULTS

KT-1000 Arthrometer Measurements

According to the arthrometer measurements, when the patients were awake, the mean anteroposterior tibial translation for intact knees was 10.0 $\pm$ 2.7 mm, and for ACL-deficient knees, it was 15.7 $\pm$ 3.8 mm (Figure 2A). When the patients were under anesthesia, the mean anterior tibial translation for the intact knees was 10.7 $\pm$ 2.5 mm, and for the ACL-deficient knees, it was 16.6 $\pm$ 3.8 mm (Figure 2A), indicating a significant difference between intact and ACL-deficient knees, regardless of whether the patients were awake or under anesthesia ($P < .0001$). When the patients were awake, the mean side-to-side difference in anterior tibial translation was 5.6 $\pm$ 2.6 mm and when under anesthesia, it was 5.9 $\pm$ 3.5 mm, indicating a nonsignificant difference (Figure 2B).

Lachman Test

According to the EMS, when the patients were awake the mean anteroposterior tibial translation for the intact knees was 10.0 $\pm$ 3.0 mm and for the ACL-deficient knees it was 14.8 $\pm$ 3.7 mm (Figure 3A). When the patients were under anesthesia, the mean anterior tibial translation for the intact knees was 10.0 $\pm$ 3.6 mm and for the ACL-deficient knees was 16.8 $\pm$ 5.2 mm, indicating a significant difference for total anteroposterior tibial translation (Figure 3A). Regarding the effect of the patient's consciousness, in the ACL-deficient knees, there was a significant difference in the total anteroposterior translation when the patients were awake and when they were under anesthesia (Figure 3A). However, in the intact knees, there was no significant difference in the total anteroposterior translation when the patients were awake and when they were under anesthesia (Figure 3A). The mean side-to-side difference in anteroposterior tibial translation during the Lachman test was 4.6 $\pm$ 3.6 mm when the patients were awake and was 6.9 $\pm$ 4.3 mm when they were under anesthesia, indicating a significant difference ($P = .006$; Figure 3B). In the injured knees, the mean standard deviation of the 3 measurements for the anteroposterior tibial translation during the Lachman test was 0.72 $\pm$ 0.44 mm and 0.66 $\pm$ 0.43 mm, respectively, when the patients were awake and when they were under anesthesia. The matrixes of the correlation coefficients indicated high repeatability (Table 1).

Pivot-Shift Test

The clinical grades of the pivot-shift test for the ACL-deficient knees were evaluated as none (–) in 15 knees, glide (+) in 23 knees, and clunk (++) in 12 knees when the patients were awake and none (–) in 3 knees, glide (+) in 28 knees, clunk (++) in 16 knees, and gross (+++) in 3 knees when the patients were under anesthesia (Figure 4A). Of the 15 knees graded as negative pivot shift under the awake condition, 3 knees were diagnosed as partial ACL tear and 2 knees showed extension deficit before surgery. All the contralateral intact knees were evaluated as none (–). When the patients were awake, the mean APT was -0.8 ± 0.3 m/s^2 in intact knees and -1.1 ± 0.4 m/s^2 in ACL-deficient knees; and when the patients were under anesthesia, the mean APT was -0.7 ± 0.2 m/s^2 in intact knees and -1.7 ± 1.0 m/s^2 in ACL-deficient knees. The mean APT in the ACL-deficient knees was significantly larger than that in the intact knees, both when the patients were awake and when the patients were under anesthesia. In the ACL-deficient knees, the mean APT was significantly larger when the patients were under anesthesia than when the patients were

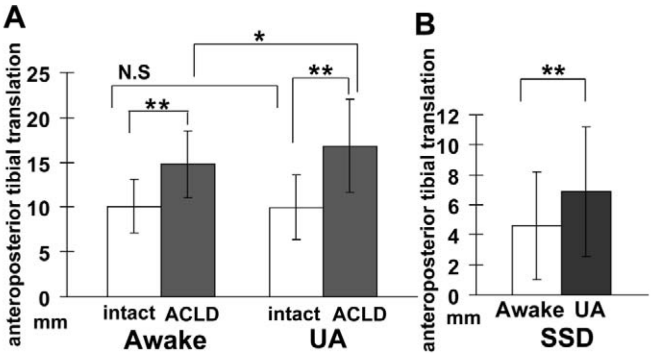

Figure 3. (A) Mean anteroposterior tibial translation during the Lachman test as measured by the electromagnetic measurement system; results shown for intact and ACL-deficient (ACLD) knees in both the awake and under anesthesia (UA) conditions. (B) Mean side-to-side difference (SSD) in anteroposterior tibial translation between awake and UA conditions. N.S, not statistically significant. *$P < .01$; **$P < .0001$.

TABLE 1
Correlation Coefficient Matrixes[a]

Anteroposterior translation measurements during the Lachman test

Awake			
	1st test	2nd test	3rd test
1st test	1		
2nd test	0.97	1	
3rd test	0.95	0.96	1

Under anesthesia			
	1st test	2nd test	3rd test
1st test	1		
2nd test	0.97	1	
3rd test	0.96	0.97	1

ATP measurements during the pivot-shift test

Awake			
	1st test	2nd test	3rd test
1st test	1		
2nd test	0.86	1	
3rd test	0.87	0.80	1

Under anesthesia			
	1st test	2nd test	3rd test
1st test	1		
2nd test	0.89	1	
3rd test	0.97	0.93	1

[a]Correlations among the 3 measurements for tibial anteroposterior translation during the Lachman test and acceleration of tibial posterior translation (APT) during the pivot-shift test in anterior cruciate ligament–deficient knees.

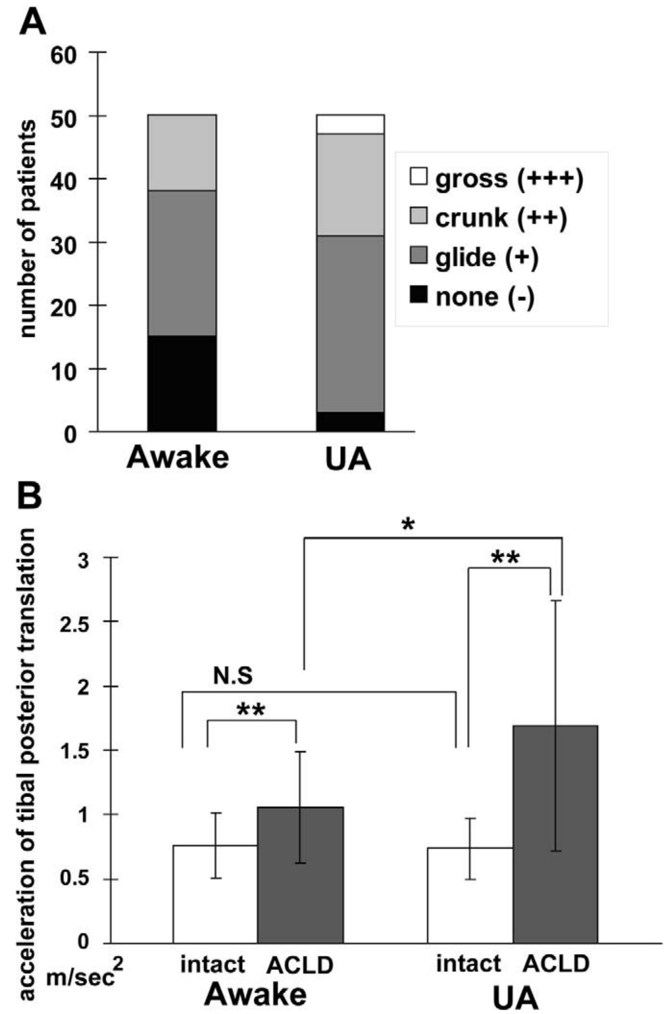

Figure 4. (A) Clinical grading of the pivot-shift test. (B) Mean acceleration of tibial posterior translation during the pivot-shift test as measured by the electromagnetic measurement system. N.S, not statistically significant; ACLD, anterior cruciate ligament–deficient; UA, under anesthesia. *$P < .01$; **$P < .0001$.

awake (Figure 4B). During the pivot-shift test in the injured knees, the mean standard deviation of the 3 APT measurements was 0.15 ± 0.13 m/s^2 and 0.27 ± 0.23 m/s^2 when the patients were awake and when they were under anesthesia, respectively. The matrixes of the correlation coefficients indicated high repeatability (Table 1).

Discussion

In the present study, we found that the side-to-side difference in anteroposterior tibial translation during the Lachman test was significantly smaller when patients were awake than when they were under anesthesia. In addition, the APT during the pivot-shift test was significantly smaller when patients were awake than when they were under anesthesia. Consistently, the clinical grade of the pivot-shift test tended to be smaller when the patients were awake than when they were under anesthesia, although some patients had partial ACL tears and stiff knees. These observations suggest that patient consciousness tends to have an impact on knee kinematics during the Lachman and pivot-shift tests in ACL-deficient knees, and knee laxity tends to become lower when patients are awake than when they are under anesthesia. Therefore, to assess knee laxity with the Lachman and the pivot-shift tests, the examiner should perform those tests on patients under anesthesia to avoid any effect of the patients' consciousness. In addition, in reports about those tests, the authors should clearly state how knee laxity was assessed.

It has been reported that the presence of a pivot-shift phenomenon after ACL reconstruction relates to subjective functional impairment and patient satisfaction.[14,17] The pivot-shift test appears to reflect the patient's feeling of instability; therefore, when the patients are awake, they tend to avoid eliciting the pivot-shift phenomenon subconsciously. Consistent with this idea, we did not observe a significant difference in APT of the intact knees in which pivot-shift movement does not occur, when the patients were awake or when they were under anesthesia. Recently, quantitative assessments of the pivot-shift test are an important approach for evaluating the clinical outcomes of ACL reconstruction.[16,23] We have reported that the EMS can be used as a tool to quantitatively measure knee kinematics during the pivot-shift test.[12,15] In the present study, we observed a significant difference in the the mean APT between intact and ACL-deficient knees both when the patients were awake and when they were under anesthesia, suggesting that the EMS can be a useful diagnostic tool for detecting ACL deficiency. However, based on our observation that there was a significant difference in the mean APT when the patients were awake and when they were under anesthesia, it appears that, currently, quantitative assessment by the pivot-shift test should be performed under anesthesia to precisely evaluate knee laxity.

Interestingly, we observed a significant difference in anteroposterior tibial translation during the Lachman test in ACL-deficient knees when the patients were awake and when they were under anesthesia, while there was no significant difference in intact knees. This observation suggests that patients are not comfortable with dynamic tibial anteroposterior movement and may not be able to relax during the Lachman test. On the other hand, according to our KT-1000 arthrometer measurement, we did not observe any significant difference in anterior tibial translation when the patients were awake and when they were under anesthesia. There have been several studies using the KT-1000 arthrometer to examine the difference between conscious and unconscious patients, and conflicting results have been reported. Highgenboten et al[11] reported that the values obtained using the KT-1000 arthrometer with 15, 20, and 30 pounds of applied force when the patients were under anesthesia were significantly higher than the values obtained when they were awake. On the other hand, Sernert et al[21] reported that there were no significant differences between the measurements obtained using a KT-1000 arthrometer at 20 pounds of applied force when the patients were awake and when they were under anesthesia. Monaco et al[18] examined 30 patients and reported that there was no significant difference in the side-to-side difference when the patients were in conscious state and when they were under anesthesia, although there was a significant difference in the total anteroposterior translation in both intact and injured knees. These differences are likely due to a difference in the patients' condition, patients' position, and amount of force applied.

Although results of KT-1000 arthrometer measurement and the quantitative analysis of the Lachman test are similar in both the measures of anteroposterior tibial translation, there were several differences between the 2 examinations. During the arthrometer measurement, patients' limbs were placed on a platform and a foot holder; but during the Lachman test, the patients' legs were held by the examiner. Therefore, it is possible that when the patients are awake muscle relaxation can be more easily achieved during KT-1000 arthrometer measurement compared with the Lachman test. Another difference between the measurements was the speed with which the tests were performed. We performed the Lachman test at a speed of about 1 time/s; while during the arthrometer measurements, we stopped moving at the maximum translated position, resulting in a more static measurement than that of the Lachman test. Thus, the speed of the maneuver may contribute to the difference, and a patient may be more apprehensive about dynamic movement during the Lachman test than with the anteroposterior drawer test during KT-1000 arthrometer measurement.

There are some limitations to this study. First, although a single experienced examiner performed all the tests in this study, different examiners may generate different results. Second, as aforementioned, although the examination maneuvers, the speed of the maneuver, and the applied force were relatively consistent, the results may vary with the application of different speeds and forces. Third, patients with meniscal injury were included in the present study, which may affect the knee kinematics and muscle relaxation, especially when the patients are awake. However, we did not find a significant difference in all measured values in patients with and without meniscal injury. Therefore, we believe that its effect was minimal in the present study. Fourth, since we performed the tests in two different conditions on consecutive days, the results of the first examination may bias the result of the second.

CONCLUSION

Knee kinematics measurements during the Lachman and pivot-shift tests in ACL-deficient knees were significantly affected by patients' conscious state. We need to be cautious in quantifying knee laxity during the pivot-shift test, especially when the patients are awake, to avoid underestimating knee laxity.

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