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

Takehiko Matsushita,* MD, PhD, Shinya Oka,* MD, Kouki Nagamune,† PhD, Tomoyuki Matsumoto,* MD, PhD, Yuichiro Nishizawa,* MD, Yuichi Hoshino,* MD, PhD, Seiji Kubo,* MD, PhD, Masahiro Kurosaka,* MD, PhD, and Ryosuke Kuroda‡ MD, PhD

Investigation performed at Kobe University, Kobe, Japan

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 ± 2.6 mm in the awake state and 5.9 ± 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 ± 3.6 mm in the awake state and 6.9 ± 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/s² in intact knees and −1.1 ± 0.4 m/s² in ACL-deficient knees when the patients were awake and was −0.7 ± 0.2 m/s² and −1.7 ± 1.0 m/s², 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.5,9 ACL rupture is detected through history taking, clinical examination, magnetic resonance imaging (MRI), and arthroscopy.1

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.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 reconstruction.
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. 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, and we also previously reported its utility in preoperative and postoperative evaluations. 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 details of the EMS were previously reported. Briefly, the EMS consists of 3 electromagnetic receivers and a transmitter that produces an electromagnetic field. 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, 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. 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. 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. 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 $<$0.01 was considered statistically significant. Results are provided as means ± standard deviations.

RESULTS

**KT-1000 Arthrometer Measurements**

According to the arthrometer measurements, when the patients were awake, the mean anteroposterior tibial translation for intact knees was $10.0 ± 2.7$ mm, and for ACL-deficient knees, it was $15.7 ± 3.8$ mm (Figure 2A). When the patients were under anesthesia, the mean anterior tibial translation for the intact knees was $10.7 ± 2.5$ mm, and for the ACL-deficient knees, it was $16.6 ± 3.8$ 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 $5.6 ± 2.6$ mm and when under anesthesia, it was $5.9 ± 3.5$ 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 $10.0 ± 3.0$ mm and for the ACL-deficient knees it was $14.8 ± 3.7$ mm (Figure 3A). When the patients were under anesthesia, the mean anterior tibial translation for the intact knees was $10.0 ± 3.6$ mm and for the ACL-deficient knees was $16.8 ± 5.2$ 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 $4.6 ± 3.6$ mm when the patients were awake and was $6.9 ± 4.3$ 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 $0.72 ± 0.44$ mm and $0.66 ± 0.43$ 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 awake.
During the pivot-shift test in the injured knees, the mean standard deviation of the 3 APT measurements was $0.15 \pm 0.13$ m/s$^2$ and $0.27 \pm 0.23$ 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).

**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 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. $^{*}P < .01; ^{**}P < .0001.$

**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. $^{*}P < .01; ^{**}P < .0001.$

**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 (Figure 4B). During the pivot-shift test in the injured knees, the mean standard deviation of the 3 APT measurements was $0.15 \pm 0.13$ m/s$^2$ and $0.27 \pm 0.23$ 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).
The pivot-shift test can be a useful diagnostic tool to evaluate knee laxity and instability. In this context, it is important to consider the effect of the patients' conscious state on the test results. Studies have reported that patients are not comfortable with dynamic maneuvers, and the speed of the maneuver may contribute to the difference in 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 more apprehensive about dynamic movements when they are awake, 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 meniscal injury included in the present study, which may affect the knee kinematics and muscle relaxation, especially when the patients are awake. Nevertheless, we did not find any significant difference in anterior tibial translation when the patients were awake and when they were under anesthesia.

There are several 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 injuries 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.

REFERENCES

1. Araki D, Kuroda R, Kubo S, et al. The use of an electromagnetic measurement system for anterior tibial displacement during the Lachman test. Arthroscopy. 2011;27(6):792-802.
2. Ayeni OR, Chahal M, Tran MN, Sprague S. Pivot shift as an outcome measure for ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):767-777.

3. Benjaminse A, Gokeler A, van der Schans CP. Clinical diagnosis of an anterior cruciate ligament rupture: a meta-analysis. *J Orthop Sports Phys Ther*. 2006;36(6):267-288.

4. Daniel DM, Malcom LL, Losse G, Stone ML, Sachs R, Burks R. Instrumented measurement of anterior laxity of the knee. *J Bone Joint Surg Am*. 1985;67(5):720-726.

5. Daniel DM, Stone ML, Sachs R, Malcom L. Instrumented measurement of anterior knee laxity in patients with acute anterior cruciate ligament disruption. *Am J Sports Med*. 1985;13(6):401-407.

6. Frank C. Accurate interpretation of the Lachman test. *Clin Orthop Relat Res*. 1986;(213):163-166.

7. Galway HR, Maclntosh DL. The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. *Clin Orthop Relat Res*. 1980;(147):45-50.

8. Gianotti SM, Marshall SW, Hume PA, Bunt L. Incidence of anterior cruciate ligament injury and other knee ligament injuries: a national population-based study. *J Sci Med Sport*. 2009;12(6):622-627.

9. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*. 2000;8(3):141-150.

10. Grood ES, Sunatow WJ. A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *J Biomech Eng*. 1983;105(2):136-144.

11. Highgenboten CL, Jackson AW, Jansson WA, Meske NB. KT-1000 arthrometer: conscious and unconscious test results using 15, 20, and 30 pounds of force. *Am J Sports Med*. 1992;20(4):450-454.

12. Hoshino Y, Kuroda R, Nagamune K, et al. In vivo measurement of the pivot-shift test in the anterior cruciate ligament-deficient knee using an electromagnetic device. *Am J Sports Med*. 2007;35(7):1098-1104.

13. Katz JW, Fingeroth RJ. The diagnostic accuracy of ruptures of the anterior cruciate ligament comparing the Lachman test, the anterior drawer sign, and the pivot shift test in acute and chronic knee injuries. *Am J Sports Med*. 1986;14(1):88-91.

14. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Relationships between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2004;32(3):629-634.

15. Kudo S, Muratsu H, Yoshiya S, Mizuno K, Kurosaka M. Reliability and usefulness of a new in vivo measurement system of the pivot shift. *Clin Orthop Relat Res*. 2007;454:54-58.

16. Kuroda R, Hoshino Y, Araki D, et al. Quantitative measurement of the pivot shift, reliability, and clinical applications. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):686-691.

17. Leitz J, Losee RE, Jokl P, Johnson TR, Feagin JA. Implications of the pivot shift in the ACL-deficient knee. *Clin Orthop Relat Res*. 2005;436:229-236.

18. Monaco E, Labianca L, Maestri B, De Carli A, Conteduca F, Ferretti A. Instrumented measurements of knee laxity: KT-1000 versus navigation. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(6):617-621.

19. Prins M. The Lachman test is the most sensitive and the pivot shift the most specific test for the diagnosis of ACL rupture. *Aust J Physiother*. 2006;52(1):66.

20. Rangger C, Daniel DM, Stone ML, Kaufman K. Diagnosis of an ACL disruption with KT-1000 arthrometer measurements. *Knee Surg Sports Traumatol Arthrosc*. 1993;1(1):60-66.

21. Sernert N, Kartus J, Köhler K, Ejerhed L, Karlsson J. Evaluation of the reproducibility of the KT-1000 arthrometer. *Scand J Med Sci Sports*. 2001;11(2):120-125.

22. Torg JS, Conrad W, Kalen V. Clinical diagnosis of anterior cruciate ligament instability in the athlete. *Am J Sports Med*. 1976;4(2):84-93.

23. Zaffagnini S, Marcheggiani Muccioni GM, Lopomo N, et al. Can the pivot-shift be eliminated by anatomic double-bundle anterior cruciate ligament reconstruction? *Knee Surg Sports Traumatol Arthrosc*. 2012;20(4):743-751.