# The concomitant lateral meniscus injury increased the pivot shift in the anterior cruciate ligament-injured knee

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| **Abstract:** | Abstract<br>Purpose  Concomitant meniscus injuries in the anterior cruciate ligament (ACL) injuries have been suggested to exacerbate rotational laxity. However, the effect is supposed to be so small, if any, that some quantitative pivot-shift measurement is needed. The purpose of this prospective study was to determine the effect of meniscus tear on rotational laxity in ACL-deficient knees by an quantitative measurement. We hypothesized that a concomitant meniscus tear, especially a lateral one, would induce greater pivot-shift.<br>Methods  Fifty-seven unilateral ACL-injured patients (26 men and 31 women, mean age: 24±10 years) were included. The pivot-shift test was performed prior to ACL reconstruction while a quantitative evaluation using an electromagnetic system to determine tibial acceleration and a clinical grading according to the IKDC were performed. Meniscus injuries were diagnosed arthroscopically, and concomitant meniscus tear was confirmed in 32 knees. Chi-squared and Mann-Whitney U tests were used to assess the difference between knees with and without meniscus tear. A subgroup analysis was subsequently performed for the medial, bilateral, and lateral meniscus-torn groups compared with the meniscus-intact group, using the chi-squared test and analysis of variance. Statistical significance was defined at p<0.05. |

# The concomitant lateral meniscus injury increased the pivot-shift in the anterior cruciate ligament-injured knee

**Abstract**

*Purpose* Concomitant meniscus injuries in the anterior cruciate ligament (ACL) injuries have been suggested to exacerbate rotational laxity. However, the effect is supposed to be so small, if any, that some quantitative pivot-shift measurement is needed. The purpose of this prospective study was to determine the effect of meniscus tear on rotational laxity in ACL-deficient knees by an quantitative measurement. It was hypothesized that a concomitant meniscus tear, especially a lateral one, would induce greater pivot-shift.

*Methods* Fifty-seven unilateral ACL-injured patients (26 men and 31 women, mean age: 24±10 years) were included. The pivot-shift test was performed prior to ACL reconstruction while a quantitative evaluation using an electromagnetic system to determine tibial acceleration and a clinical grading according to the IKDC were performed. Meniscus injuries were diagnosed arthroscopically, and concomitant meniscus tear was confirmed in 32 knees.

*Results* The clinical grade was not different between the ACL-injured knees of patients with and without meniscus tear (n.s.). Tibial acceleration did not show a statistical significant difference (meniscus-injured knees: 1.6±1.1 m/sec$^2$ vs. meniscus-intact knees: 1.2±0.7 m/sec$^2$, n.s.). However, the subgroup analysis demonstrated that there was increased tibial acceleration in ACL-deficient knees with lateral meniscus tear (2.1±1.1 m/sec$^2$, n=13) compared with meniscus-intact knees ($p<0.05$), whereas rotational laxity did not increase in the medial meniscus-injured and bilateral-injured knees (1.2±0.9 m/sec$^2$, n=12, n.s. and 1.4±1.1 m/sec$^2$, n=7, n.s. respectively).

*Conclusion* A concomitant meniscus tear, especially a lateral meniscus tear, has a significant impact on rotational laxity in ACL-injured knees. When a large pivot-shift is observed in the ACL-injured knee, a concomitant meniscus tear should be suspected and an aggressive treatment would be considered. Meniscus injuries should be inspected carefully when substantial pivot shift is encountered in ACL-injured knees.

*Level of evidence* Diagnostic Study Level III

**Keywords:** Anterior cruciate ligament, Meniscus injury, Pivot-shift test, Quantitative measurement

## Introduction

Residual pivot shift is a persistent problem that can be observed in anterior cruciate ligament (ACL)-reconstructed knees, even those undergoing an anatomic procedure [6]. Researchers have increasingly focused upon the secondary restraints of rotational laxity to address this problem, but it is still undetermined which anatomic structure is the most clinically relevant secondary restraint. Some structures have been suggested as the secondary restraint, such as the anterolateral complex [5,7,40], iliotibial band [15,33], and meniscus [21,25,28]. ACL injuries are frequently accompanied by meniscus injuries [9,24,35,37], and their impact on rotational laxity has been reported frequently in previous studies [21,25-28,36,38]. Typically, the aggravated rotational laxity of the ACL insufficient knee was observed by the meniscus resection. Shybut et al. reported a significant increase in rotational laxity after the lateral meniscus root was cut following ACL resection [36]. However, because most of these studies were cadaveric studies which were not able to apply true pivot-shift loading in *in-vivo* setting, the *in vivo* effect of a concomitant meniscus injury on rotational laxity is largely unknown due to the lack of a quantitative system for evaluating pivot shift. In an *in vivo* study using an iPad system, Musahl et al. first reported that there was increased anterior tibial translation of the lateral compartment during the pivot-shift in ACL-injured knees with a meniscus injury or anterolateral capsule injuries compared with isolated ACL-injured knees [28]. Meanwhile, tibial acceleration is another measurement parameter to quantify the pivot-shift test [13,18,19,22,31], and it is superior to tibial translation in terms of its correlation to clinical grading systems [1,18].

The purpose of this study was to determine the *in vivo* effect of concomitant meniscus tear on rotational laxity in ACL-deficient knees using quantitative measurements for the pivot-shift test. It was hypothesized that a meniscus tear, especially a lateral one, that is associated with an ACL injury would induce greater pivot-shift. The information about the effect of the meniscus tear on the rotational laxity would be clinically useful for the detection and treatment of concomitant meniscus injury in the ACL injured knee.

## Materials and Methods

### *Ethical Considerations*

Ethical approval was obtained from the institutional review board in Kobe University prior to this study (No. 341). Informed consent was obtained from all individual participants.

### *Patients*

Patients with a unilateral ACL injury who were scheduled to undergo ACL reconstruction between March 2013 and August 2016 at our hospital and were aged 15-50 years were prospectively enrolled in this study. An ACL deficiency was diagnosed based on clinical findings and magnetic resonance imaging (MRI), and was subsequently confirmed arthroscopically. Patients who had fractures, cartilage injuries, posterolateral corner injuries, and other knee ligament injuries including medial collateral ligament and posterior cruciate ligament injuries on either side of the knee were excluded. Fifty seven patients (26male/31female, 24±10y.o.) were inluded in the study. Time from injury to the testing/surgery was 166±186 days.

*Pivot-Shift Test*

The pivot-shift test was performed with the patient under general anesthesia prior to ACL reconstruction. One of the two experienced orthopaedic surgeons who was not in charge of the patient was assigned to perform the pivot-shift test without knowing the preoperative MRI assessment of the meniscus status, and both surgeons were instructed to perform the pivot-shift test as similarly as possible before this study using the standardized technique [11]. The pivot-shift movement was quantitatively assessed using an electromagnetic measurement system.

An electromagnetic motion-tracking device (Liberty, Polhemus, Colchester, VT, USA) was used. This system had a root mean square accuracy of 0.76 mm for position and 0.06º for orientation with the transmitter-to-receiver separation within 180 cm. Two electromagnetic sensors were fixed on the thigh and shank with the original plastic straps. The three-dimensional positions of seven anatomic bony landmarks, including the greater trochanter, medial and lateral epicondyles, the crossing point between the medial joint line and the medial collateral ligament, fibula head, and medial and lateral malleoli, were electronically recorded using a third electromagnetic sensor, and the positions of the femur and tibia were accurately captured based on the spatial relationship between the anatomic bony landmarks and sensors on the skin. The anatomic coordinates of the knee, according to the system of Grood and Suntay, were set [10]. The 6 degree-of-freedom knee kinematics during the pivot-shift test were then monitored, with a high sampling rate of 240 Hz. Eventually, tibial acceleration (m/sec$^2$) of the posterior shift during the pivot-shift test was calculated from the data of the tibial anteroposterior translation. The tibial acceleration was one of the quantitative measurements for the pivot-shift test and related to clinical grading of the pivot-shift test [13,31].

The clinical grade of the pivot shift was also determined by the surgeon, according to the International Knee Documentation Committee's guidelines, as: none (-), glide (+), clunk (++), and gross (+++) [14].

The condition of the meniscus was assessed under arthroscopy for the primary ACL reconstruction. A concomitant meniscus tear was observed in 32 knees out of 57. Twelve knees had medial meniscus tear only, while only the lateral meniscus was torn in 13 knees. Bilateral meniscus injuries were observed in 7 knees.

*Statistical Analysis*

The clinical grade and tibial acceleration of the pivot-shift test were compared between ACL-injured knees with a meniscus tear and those without, using a chi-square test and independent t-test, respectively. A subgroup analysis was then performed by separating all of the meniscus tear into the medial meniscus-torn group, bilateral meniscus-torn group, and lateral meniscus-torn group. The differences of the pivot-shift clinical grade and tibial acceleration among the groups were tested using a chi-square test and analysis of variance, respectively, followed by a post-hoc Tukey HSD test for separate comparisons between two groups.

All statistical analyses were performed with SPSS Version 22 (SPSS Inc., Chicago, IL, USA). Statistical significance was set at $p<0.05$.

An a priori power analysis showed that total number of 46 subjects were required to detect a 0.5 m/sec$^2$ difference in tibial acceleration, assuming a power of 0.90, significance level of 0.05, and common variance of 0.5 m/sec$^2$ in a two-sided Student's t-test, based on data from previous reports [3,13,30,31]. Subgroup analysis between four groups by analysis of variance achieved a power of 0.82 if each group had 14 cases. Thus, the targeted sample size was 56.

## Results

There was no significant difference in the clinical grade of the pivot-shift test between the ACL-injured knees with and without meniscus tear (n.s.). Similar results were obtained when medial, lateral, and bilateral meniscus-torn knees were separately compared with meniscus-intact knees (n.s., all) (Table 1).When all meniscus-torn knees were compared with meniscus-intact knees, there was no significant difference in tibial acceleration during the pivot-shift test (meniscus-torn knees: 1.6±1.1 m/sec$^2$ and meniscus intact knees: 1.2±0.7 m/sec$^2$, n.s.).

However, the subgroup analysis demonstrated that ACL-deficient knees with lateral meniscus tear had significantly larger tibial acceleration (2.1±1.1 m/sec$^2$) than did meniscus-intact knees (p=0.014). A significant difference was not found when the medial meniscus-torn knees (1.2±0.9 m/sec$^2$) and bilateral meniscus-torn knees (1.4±1.1 m/sec$^2$) were compared (n.s., both) (Fig. 1).

## Discussion

The most important finding of this study was that increased tibial acceleration during the pivot-shift was detected in the ACL-injured knees with concomitant lateral meniscus tear in comparison to that without meniscus tear by using a quantitative evaluation of the pivot-shift test using an electromagnetic system. Previous studies have suggested that the meniscus influences rotational laxity secondary to the ACL [25,36], but the impact of meniscus tear is difficult to determine in a clinical setting, mainly due to the lack of a sensitive and quantitative method for evaluating rotational laxity. Recently, several measurement systems have become available to quantify the pivot-shift in clinical setting, such as iPad [12], electromagnetic system [13] and accelerometer [19]. They evaluate different aspect of the pivot-shift movement, such as tibial translation and acceleration. Tanaka et al. compared these systems and demonstrated better sensitivity and specificity to detect the pivot-shift in the electromagnetic system over iPad and accelerometer [39]. Using an iPad measurement system, Musahl et al. reported a large anterior tibial translation of the lateral compartment during the pivot-shift in ACL-injured knees with an associated meniscus tear [28].

Interestingly, in our study, we did not recognize an additional increase in the pivot-shift because of either medial or lateral meniscus tear when we used a manual grading system. However, the manually performed pivot-shift test is undoubtedly inconsistent among surgeons [17,29,32]. Peeler et al reported only a moderate level of inter-rater reliability in the manually performed pivot-shift test [34]. The sensitivity of the manual pivot-shift test is assumed to be too low to detect the additional injury in the ACL injured knees. Therefore, any method to quantitatively measure rotational laxity appears to be essential for detecting the influence of meniscus tear on the rotational laxity of the knee.

The influence of bilateral meniscus tear on the pivot-shift was indefinite in this study mainly due to small number of bilateral meniscus-torn knees, i.e. possible type II error. However, from a biomechanical point of view, since the axis of the pivot-shift movement is on the medial side of the knee, around the medial collateral ligament [25], a concomitant medial meniscus tear might destabilize the medial compartment of the knee joint and inhibit the pivot-shift movement. A further investigation with an increased number of subjects, including bilateral meniscus-torn knees, is needed to address this issue.

The biomechanical effect of the medial and lateral menisci on rotational laxity is different. Lateral meniscus has long been considered as a buttress against anterior subluxation of the lateral tibial plateau [8]. In a recent cadaveric study, the lateral tibial translation was proven to correlate with pivot-shift grading [4]. Musahl et al. compared medial and lateral menisectomy in an ACL-resected knee model and showed that lateral menisectomy, in addition to ACL resection, worsened anterior tibial translation during the pivot-shift test, whereas no such effect was observed after medial menisectomy [26]. Some studies have demonstrated that a medial meniscus tear has a positive impact on rotational laxity [20,41], but not all types of medial meniscus tear affect anterior stability against combined rotational stress [2]. Contrary to expectations, there was no significant increase of the pivot-shift in the bilateral meniscus torn knees compared to the meniscus intact knees in the current study.

This study has some limitations. First, the sample size could be insufficient, though statistically significant finding was obtained between lateral meniscus torn group and meniscus intact group in host-hoc analysis. The total number of patients, 57, surpassed the originally targeted number from the sample size calculation to assess the overall impact of the concomitant meniscus tear on the pivot-shift and to compare the subgroup analysis, but the final number of patients in each group for the following analysis, i.e. the comparisons between bilateral or medial meniscus torn group vs meniscus intact group, seems to be limited. Because of the small sample size, type II error might be suspected for the negative results in medial and bilateral meniscus torn groups. Furthermore, the tear type and location of the meniscus tear were not considered in this study. In order to form multiple groups of meniscus-torn knees depending on tear type and location, more than 10 times the number of current subjects would be required. Also, the threshold of the quantitative measurement to detect the meniscus tear could not be determined with this small number of sample size in this study. Increased number of cases and some validation studies could possibly provide a definite threshold to identify the meniscus tear in the ACL injure knees. A larger multicenter study might be ideal to analyze meniscus injuries further. Second, most study subjects were chronic ACL injury cases in this study, and the chronicity of ACL injuries was not controlled in each group. It was reported that chronic ACL tear increases the risk of a greater pivot-shift [23]. Some stable type of meniscus tear might have been healed spontaneously. Finally, meniscus injury was confirmed under arthroscopy and was not determined preoperatively with manual testing or MRI. Meniscus injuries could definitely be diagnosed with an arthroscopic assessment, and the most definitive method to diagnose the meniscus tear was preferable for this study. Meniscus tear is not necessarily detected preoperatively by MRI, especially for lateral meniscus root tear [16].

The clinical relevance of this study finding is that meniscus injuries should be inspected carefully when substantial pivot shift is encountered in ACL-injured knees. Meniscal repair might be prepared in addition to the ACL reconstruction when the ACL injured knee has large pivot-shift and is suspected to have concomitant lateral meniscus tear preoperatively. The concomitant lateral meniscus tear, if any, would be repaired as much as possible to inhibit the pivot-shift.

## *Conclusions*

Quantitatively measurement of the pivot-shift test revealed that a concomitant lateral meniscus tear in ACL-injured knees had a significant impact on the rotational laxity of the knee. An objective and quantitative evaluation with the pivot-shift test could be helpful to detect concomitant meniscus tear in ACL-injured knees.

## References

1. Ahlden M, Araujo P, Hoshino Y, Samuelsson K, Middleton KK, Nagamune K, et al. (2012) Clinical grading of the pivot shift test correlates best with tibial acceleration. Knee Surg Sports Traumatol Arthrosc 20(4):708-712.
2. Ahn JH, Bae TS, Kang KS, Kang SY, Lee SH. (2011) Longitudinal tear of the medial meniscus posterior horn in the anterior cruciate ligament-deficient knee significantly influences anterior stability. Am J Sports Med 39(10):2187-2193.
3. Araki D, Kuroda R, Matsushita T, Kuroda R, Matsushita T, Matsumoto T, et al. (2013) Biomechanical analysis of the knee with partial anterior cruciate ligament disruption: quantitative evaluation using an electromagnetic measurement system. Arthroscopy 29(6):1053-1062.
4. Bedi A, Musahl V, Lane C, Citak M, Warren RF, Pearle AD. (2010) Lateral compartment translation predicts the grade of pivot shift: a cadaveric and clinical analysis. Knee Surg Sports Traumatol Arthrosc 18(9):1269-1276.
5. Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. (2013) Anatomy of the anterolateral ligament of the knee. J Anat 223(4):321-328.
6. Desai N, Bjornsson H, Musahl V, Bjornsson H, Musahl V, Bhandari M, et al. (2014) Anatomic single- versus double-bundle ACL reconstruction: a meta-analysis. Knee Surg Sports Traumatol Arthrosc 22(5):1009-1023.
7. Dodds AL, Halewood C, Gupte CM, Williams A, Amis AA. (2014) The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. Bone Joint J 96-B(3):325-331.
8. Fetto JF, Marshall JL. (1979) Injury to the anterior cruciate ligament producing the pivot-shift sign. J Bone Joint Surg Am 61(5):710-714.

9. Granan LP, Forssblad M, Lind M, Engebretsen L. (2009) The Scandinavian ACL registries 2004-2007: baseline epidemiology. Acta Orthop 80(5):563-567.

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

11. Hoshino Y, Araujo P, Ahlden M, Moore CG, Kuroda R, Zaffagnini S, et al. (2012) Standardized pivot shift test improves measurement accuracy. Knee Surg Sports Traumatol Arthrosc 20(4):732-736.

12. Hoshino Y, Araujo P, Ahldén M, Samuelsson K, Muller B, et al. (2013) Quantitative evaluation of the pivot shift by image analysis using the iPad. Knee Surg Sports Traumatol Arthrosc 21(4):975-980

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

14. Irrgang JJ, Ho H, Harner CD, Fu FH. (1998) Use of the International Knee Documentation Committee guidelines to assess outcome following anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 6(2):107-114.

15. Kittl C, El-Daou H, Athwal KK, Gupte CM, Weiler A, Williams A, et al. (2016) The role of the anterolateral structures and the ACL in controlling laxity of the intact and ACL-deficient knee: response. Am J Sports Med 44(2):345-354.

16. Krych AJ, Wu IT, Desai VS, Murthy NS, Collins MS, Saris DBF, et al. (2018) High Rate of Missed Lateral Meniscus Posterior Root Tears on Preoperative Magnetic Resonance Imaging. Orthop J Sports Med 9;6(4):2325967118765722

17. Kuroda R, Hoshino Y, Kubo S, Araki D, Oka S, Nagamune K, et al. (2012) Similarities and differences of diagnostic manual tests for anterior cruciate ligament insufficiency: a global survey and kinematics assessment. Am J Sports Med 40(1):91-99.

18. Labbe DR, de Guise JA, Mezghani N, de Guise JA, Mezghani N, Godbout V, et al. (2010) Feature selection using a principal component analysis of the kinematics of the pivot shift phenomenon. J Biomech 43(16):3080-3084.

19. Lopomo N, Signorelli C, Bonanzinga T, Marcheggiani Muccioli GM, Visani A, Zaffagnini S. (2012) Quantitative assessment of pivot-shift using inertial sensors. Knee Surg Sports Traumatol Arthrosc 20(4):713-717.

20. Lorbach O, Kieb M, Herbort M, Weyers I, Raschke M, Engelhardt M. (2015) The influence of the medial meniscus in different conditions on anterior tibial translation in the anterior cruciate deficient knee. Int Orthop 39(4):681-687.

21. Lording T, Corbo G, Bryant D, Burkhart TA, Getgood A. (2017) Rotational laxity control by the anterolateral ligament and the lateral meniscus is dependent on knee flexion angle: a cadaveric biomechanical study. Clin Orthop Relat Res 475(10):2401-2408.

22. Maeyama A, Hoshino Y, Debandi A, Kato Y, Saeki K, Asai S, et al. (2011) Evaluation of rotational instability in the anterior cruciate ligament deficient knee using triaxial accelerometer: a biomechanical model in porcine knees. Knee Surg Sports Traumatol Arthrosc 19(8):1233-1238.

23. Magnussen RA, Reinke EK, Huston LJ, MOON Group, Hewett TE, Spindler KP. (2016) Factors associated with high-grade Lachman, pivot-shift, and anterior drawer at the time of ACL reconstruction. Arthroscopy 32(6): 1080-1085.

24. Maletis GB, Granan LP, Inacio MC, Funahashi TT, Engebretsen L. (2011) Comparison of community-based ACL reconstruction registries in the U.S. and Norway. J Bone Joint Surg Am 93 Suppl 3:31-36.

25. Matsumoto H. (1990) Mechanism of the pivot shift. J Bone Joint Surg Br 72(5):816-821.

26. Musahl V, Getgood A, Neyret P, Claes S, Burnham JM, Batailler C, et al. (2017) Contributions of the anterolateral complex and the anterolateral ligament to rotatory knee stability in the setting of ACL injury: a roundtable discussion. Knee Surg Sports Traumatol Arthrosc 25(4):997-1008.

27. Musahl V, Citak M, O'Loughlin PF, Choi D, Bedi A, Pearle AD. (2010) The effect of medial versus lateral meniscectomy on the stability of the anterior cruciate ligament-deficient knee. Am J Sports Med 38(8):1591-1597.

28. Musahl V, Rahnemai-Azar AA, Costello J, Arner JW, Fu FH, Hoshino Y, et al. (2016) The influence of meniscal and anterolateral capsular injury on knee laxity in patients with anterior cruciate ligament injuries. Am J Sports Med 44(12):3126-3131.

29. Musahl V, Hoshino Y, Ahlden M, Araujo P, Irrgang JJ, Zaffagnini S, et al. (2012) The pivot shift: a global user guide. Knee Surg Sports Traumatol Arthrosc 20(4):724-731.

30. Nagai K, Araki D, Matsushita T, Nishizawa Y, Hoshino Y, Matsumoto T, et al. (2016) Biomechanical function of anterior cruciate ligament remnants: quantitative measurement with a 3-dimensional electromagnetic measurement system. Arthroscopy 32(7):1359-1366.

31. Nagai K, Hoshino Y, Nishizawa Y, Araki D, Matsushita T, Matsumoto T, et al. (2015) Quantitative comparison of the pivot shift test results before and after anterior

cruciate ligament reconstruction by using the three-dimensional electromagnetic measurement system. Knee Surg Sports Traumatol Arthrosc 23(10):2876-2881.

32. Noyes FR, Grood ES, Cummings JF, Wroble RR. (1991) An analysis of the pivot shift phenomenon. The knee motions and subluxations induced by different examiners. Am J Sports Med 19(2):148-155.

33. Noyes FR, Huser LE, Levy MS. (2017) Rotational knee instability in ACL-deficient knees: role of the anterolateral ligament and iliotibial band as defined by tibiofemoral compartment translations and rotations. J Bone Joint Surg Am 99(4):305-314.

34. Peeler J, Leiter J, MacDonald P.(2010) Accuracy and reliability of anterior cruciate ligament clinical examination in a multidisciplinary sports medicine setting. Clin J Sport Med 20(2):80-85

35. Rotterud JH, Sivertsen EA, Forssblad M, Engebretsen L, Aroen A. (2013) Effect of meniscal and focal cartilage lesions on patient-reported outcome after anterior cruciate ligament reconstruction: a nationwide cohort study from Norway and Sweden of 8476 patients with 2-year follow-up. Am J Sports Med 41(3):535-543.

36. Shybut TB, Vega CE, Haddad J, Alexander JW, Gold JE, Noble PC, et al. (2015) Effect of lateral meniscal root tear on the stability of the anterior cruciate ligament-deficient knee. Am J Sports Med 43(4):905-911.

37. Slauterbeck JR, Kousa P, Clifton BC, Naud S, Tourville TW, Johnson RJ, et al. (2009) Geographic mapping of meniscus and cartilage lesions associated with anterior cruciate ligament injuries. J Bone Joint Surg Am 91(9):2094-2103.

38. Tanaka M, Vyas D, Moloney G, Bedi A, Pearle AD, Musahl V. (2012) What does it take to have a high-grade pivot shift? Knee Surg Sports Traumatol Arthrosc. 20(4):737-742.

39. Tanaka T, Hoshino Y, Miyaji N, Ibaragi K, Nishida K, Nishizawa Y, et al. (2018) The diagnostic reliability of the quantitative pivot-shift evaluation using an electromagnetic measurement system for anterior cruciate ligament deficiency was superior to those of the accelerometer and iPad image analysis. Knee Surg Sports Traumatol Arthrosc 26(9):2835-2840

40. Vincent JP, Magnussen RA, Gezmez F, Magnussen RA, Gezmez F, Uguen A, et al. (2012) The anterolateral ligament of the human knee: an anatomic and histologic study. Knee Surg Sports Traumatol Arthrosc 20(1):147-152.

41. Zaffagnini S, Signorelli C, Bonanzinga T, Grassi A, Galan H, Akkawi I, et al. (2016) Does meniscus removal affect ACL-deficient knee laxity? An in vivo study. Knee Surg Sports Traumatol Arthrosc 24(11):3599-3604.

**Tables**

Table 1. Clinical Grade of the Pivot-Shift Test in ACL-Injured Knees with and without Meniscus Tear

| | | Meniscus-intact knees (n=25) | All meniscus-torn knees* (n=32) | Medial meniscus-torn knees (n=12) | Lateral meniscus-torn knees (n=13) | Bilateral meniscus-torn knees (n=7) |
|---|---|---|---|---|---|---|
| | Glide (+) | 15 | 12 | 6 | 5 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Pivot shift clinical grade | Clunk (++) | 10 | 18 | 5 | 7 | 6 |
| | Gross (+++) | 0 | 2 | 1 | 1 | 0 |

*: "All meniscus-torn knees" includes all ACL-injured knees with medial, lateral, or bilateral meniscus tear.

**Figures**

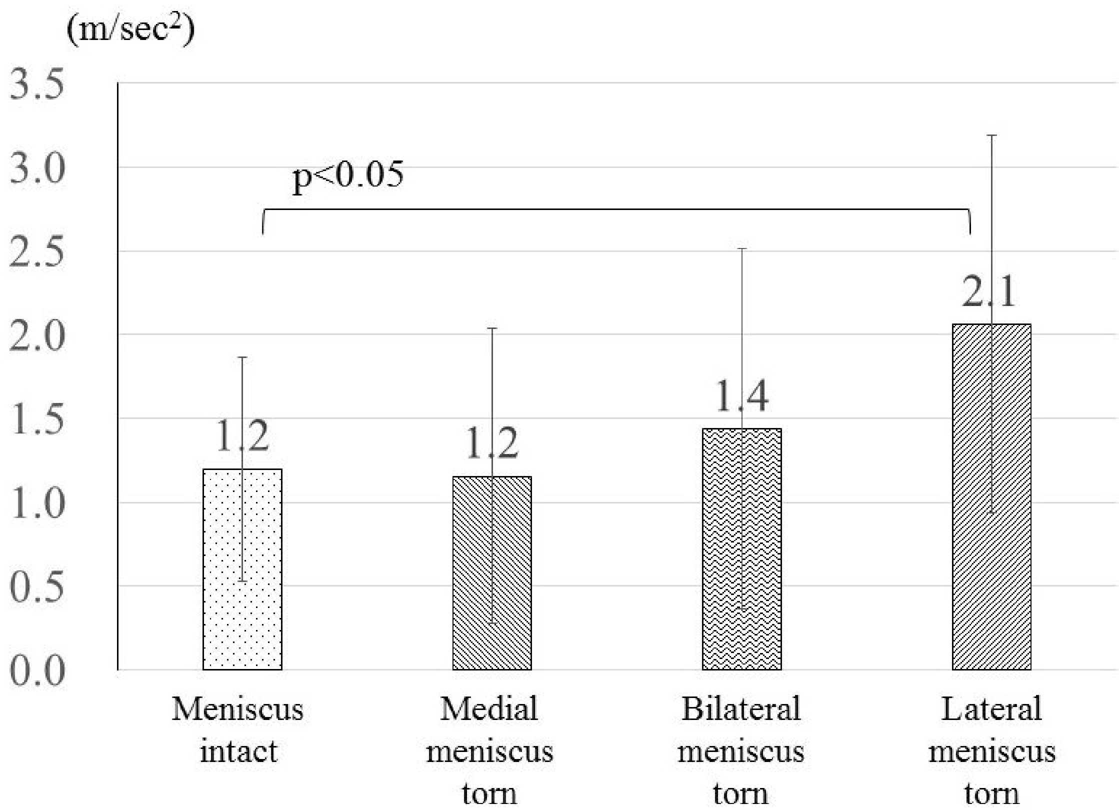

Fig. 1. Tibial acceleration during the pivot-shift test in ACL-injured knees with different ;meniscus conditions. A statistically significant difference was observed only between the meniscus-intact and lateral meniscus-torn groups.