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**Ramp lesions of the medial meniscus are associated with greater preoperative
anterior knee laxity in anterior cruciate ligament injury**

Takeo Tokura, MD, Kanto Nagai, MD, PhD, Yuichi Hoshino, MD, PhD,

Kenjiro Okimura, MD, Yuhei Otsuki, MD, Kyohei Nishida, MD, PhD,

Noriyuki Kanzaki, MD, PhD, Takehiko Matsushita, MD, PhD,

Ryosuke Kuroda, MD, PhD

Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine,
Kobe, Hyogo, Japan

Corresponding Author

Kanto Nagai M.D., Ph.D.

Department of Orthopaedic Surgery,

Kobe University Graduate School of Medicine

7-5-1 Kusunoki-cho, Chuo-ku, Kobe, Hyogo, 650-0017, Japan.

Tel: +81-78-382-5985 / Fax: 81-78-351-6944

E-mail: nagaik@med.kobe-u.ac.jp

ORCID ID:

Kanto Nagai: <https://orcid.org/0000-0002-8996-0299>

Abstract

Purpose: To assess the incidence of the ramp lesions in anterior cruciate (ACL) injuries and to compare preoperative knee laxity between the patients with and without ramp lesion by using an electromagnetic measurement system (EMS).

Methods: Two hundred six patients who underwent primary ACL reconstruction with preoperative EMS measurements were retrospectively enrolled in the present study. The diagnoses of the ramp lesions were made by arthroscopic inspections. The patients with ramp lesion and no other meniscal lesions were allocated to ‘ramp group’, and the patients without any meniscal lesions were allocated to ‘control group’. Prior to ACL reconstruction under general anesthesia, the side-to-side difference (SSD) in anterior tibial translation (ATT) during Lachman test (mm), and tibial acceleration (m/s^2) of posterior tibial reduction during the pivot-shift test were measured using the EMS. The SSD in tibial internal/external rotation angle ($^\circ$) at 30, 60, and 90 were further measured using the EMS. The SSD in ATT using KT-2000 was also measured. Knee laxity measurements were compared between two groups using unpaired student t-test.

Results: Ramp lesions were observed in 30 patients (14.7%). Subsequently, 17 patients were allocated to ‘ramp group’ and 77 patients to ‘control group’, and there were no statistical differences with regard to background demographics. ATT-SSD during

Lachman test was significantly greater in 'ramp group' (9.1 [95%CI: 5.7-12.5] mm vs. 6.2 [95%CI: 5.1-7.3] mm, $P=0.037$). However, SSD in ATT with KT-2000, tibial acceleration during pivot-shift test, and SSD in tibial rotational angles were not significantly different between two groups.

Conclusion: Presence of ramp lesion was associated with increased anterior knee laxity during Lachman test, suggesting ramp lesions may need to be addressed at the time of ACL reconstruction.

Level of evidence: IV.

272/300 words

Key words: anterior cruciate ligament; ramp lesion; medial meniscus; anterior knee laxity; electromagnetic measurement system

Declarations:

- **Data availability statement**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

- **Conflict of interest**

All authors declare that they have no conflict of interest.

- **Funding**

There is no funding source.

- **Ethical approval**

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (the Institutional Review Board of Kobe University (ID No. B190055) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

- **Informed consent**

Informed consent was obtained from all the participants.

- **Authors' contribution**

Takeo Tokura (T.T.), Kanto Nagai (Ka.N.), Yuichi Hoshino (Y.H.), Kenjiro Okimura (K.O.), Yuhei Otsuki (Y.O.), Noriyuki Kanzaki (N.K.), Kyohei Nishida (Ky.N.), Takehiko Matsushita (T.M.), and Ryosuke Kuroda (R.K.) conceived the study. T.T. and Ka.N. participated in the design of the study. T.T., K.O., and Y.O. conducted the data collection. T.T., Ka. N. conducted the pertinent statistical tests and analyses. All authors participated in the interpretation of the data. T.T. and Ka.N. wrote the manuscript, and all authors performed critical revision of the manuscript for intellectual content. All authors have read and approved the final manuscript.

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Introduction

Ramp lesions are defined as a particular type of meniscus injury within the posterior horn of the medial meniscus around meniscocapsular junction [38]. These lesions are often associated with anterior cruciate ligament (ACL) injuries. The incidence of ramp lesion varies from 9-78% according to the previous studies [6, 7, 9, 11]. Similar to other types of meniscal injuries, there are several biomechanical and clinical studies advocating that ramp lesions are associated with increased anterior laxity and rotatory instability of the knee [1, 6, 12, 30, 34, 37, 39, 41]. On the other hand, some authors have reported conflicting results, which might be attributable to difference in study design (in vitro vs. in vivo) or measurement methods (subjective evaluation vs. arthrometer) [2, 26, 32]. Thus, the debate about the effect of ramp lesion on knee biomechanics is still underway.

In addition, most of the clinical studies investigating the effect of ramp lesions are evaluated by KT-1000 (MEDmetric, San Diego, CA) arthrometer and subjective gradings [39]. KT-1000 arthrometer has been widely used for diagnosis and perioperative evaluation of anteroposterior tibial translation in ACL-deficient knees. Although several reports have substantiated the high relevancy of KT-1000 arthrometric measurements, some previous studies question its accuracy and reproducibility. Graham et al. showed that KT-1000 measurements were significantly different from subjective Lachman test

results [14], and Forster et al. demonstrated substantial inter- and intra-rater variation [13]. Interclass correlation coefficient values for inter-examiner reliability ranges from 0.38 to 0.84 [35]. Therefore, KT-1000 might not be sufficient to evaluate possibly small effect of ramp lesion on the knee laxity.

An electromagnetic measurement system (EMS) has been used to quantify Lachman test and pivot-shift test in ACL-deficient knees. It can measure the acceleration of the tibial posterior reduction (m/s^2) [19], and has been shown to have high diagnostic accuracy. Araki et al. reported in the literature that anteroposterior tibial translation measured by EMS during Lachman test has better correlation with anteroposterior tibial translation evaluated by plain X-ray than the measurements by KT-1000 [5]. Therefore, evaluation by EMS may be able to evaluate the effect of ramp lesion on knee laxity more precisely than previously used methods. There are several clinical studies evaluating laxity of ACL-deficient knees with concomitant ramp lesion by conventional subjective gradings or using KT measurement [16, 30, 39]. However, there is no study to date investigating the association between ramp lesions and knee laxity using EMS.

Thus, the purpose of the present study was to quantitatively compare preoperative knee laxity, including anterior laxity, anterolateral rotatory instability (ALRI), and axial rotational laxity, using EMS between a group of ACL injured patients without

concomitant meniscal lesion and those with a ramp lesion to the medial meniscus. It was hypothesized that the presence of ramp lesion would increase the anterior laxity, but would not increase rotational laxity.

Materials and Methods

Subjects

Retrospective cohort study was conducted on series of consecutive patients from November 2014 to July 2022 who suffered from unilateral ACL tear and underwent ACL reconstruction with preoperative EMS measurements in the university hospital and affiliated hospitals. The diagnoses of ACL tears were made based on clinical examinations and MRI findings. Exclusion criteria were as follow: multi-ligament injury requiring additional procedures; concomitant knee osteotomy; history of ipsilateral knee injury; history of contralateral knee injury and surgery; revision surgery. Originally, 302 patients were detected from the medical records. Of these patients, 206 (107 males and 99 females, mean age: 26.9 ± 12.6 years old) fulfilled the criteria and were retrospectively reviewed in the present study. The study was approved by the Institutional Review Board in our institution.

Patient demographics

Demographic data included age, bone mass index (BMI), time from injury to surgery. From medical and surgical records, presence of knee hyperextension and meniscus lesions were also reviewed.

Arthroscopic evaluation and patient allocation

Thorough arthroscopic inspections of the knee were conducted in all the patients before ACL reconstruction by experienced knee surgeons, using standard anteromedial and anterolateral portals. The presence of medial and lateral meniscus lesions was evaluated and their types, sizes, and locations were recorded. Ramp lesion was carefully examined by the trans-notch view, as well as standard anterior views, and diagnosed as ramp lesion according to the previous study [3, 40]. According to the arthroscopic findings, the patients were divided into two groups: ramp group, patients with ramp lesion and without any other meniscal lesions; control group, patients without any meniscal lesions.

Preoperative measurements

Following measurements were conducted under general anesthesia just before the surgery. The standardized pivot-shift test was performed, as previously reported [17]. For the quantitative evaluation of pivot-shift test, acceleration of the posterior tibial reduction was measured using the originally developed EMS (JIMI Kobe; Arthrex Japan) as previously described (**Fig. 1**) [4, 19, 33]. Briefly, two electromagnetic sensors were secured on the thigh and the shank with plastic straps. Before the measurements, seven

anatomic bony landmarks of the femur and tibia (greater trochanter, medial and lateral femoral epicondyles, the intersection of medial joint line and the medial collateral ligament, fibular head, and medial and lateral malleoli) were digitized with a probe with a sensor to register three-dimensional positions of the landmarks in relation to the two sensors. Each femoral and tibial coordinate system was then configured based on the report by Grood and Suntay [15]. The six degree-of-freedom knee kinematics was monitored with a sampling rate of 240Hz. This system has a root mean square accuracy of 0.76 mm for position and 0.15° for orientation when it is used within an optimal operational zone with the transmitter-to-receiver separation within 106 cm and magnetic objects removed from the area [28]. The acceleration (m/s^2) of posterior tibial reduction during the pivot-shift phenomenon was calculated by the second derivative of anteroposterior translation velocity over time. Maximum internal and external rotation forces were applied during range of motion and rotation angles at 30, 60, and 90° of knee flexion were recorded. Sum of internal and external angles was used for an evaluation. The anterior tibial translation (ATT) during the Lachman test and axial rotation angles were also measured by EMS. The accuracy of this system was verified in previous studies [5, 18, 19, 33]. For the ATT and axial rotation angles, the side-to-side difference (SSD) was used for the data analysis. Each measurement was conducted five times, and average

of three measurements, excluding maximum and minimum values, were used for the data analysis. ATT was also evaluated using KT-2000 arthrometer at approximately 30° of knee flexion by manual maximum anterior force. KT measurements were conducted three times and median values were used for the analysis.

The manual grade of the pivot-shift test was assessed according to the International Knee Documentation Committee (IKDC) guidelines: none (-); glide (+); clunk (++); gross (+++) [21]. All the measurements were conducted by five experienced knee surgeons, all of whom have more than 10 years of experience as a knee surgeon doing the measurements with regard to EMS and KT-2000. All the testing maneuvers were standardized among all the examiners. Results from the measurements and arthroscopies were blinded during data collection and evaluation.

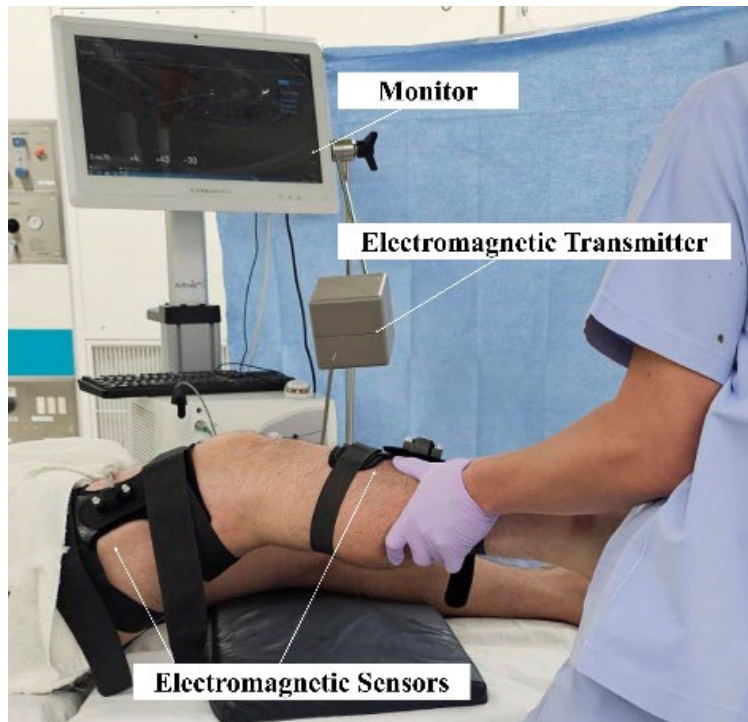


Fig. 1

Statistical analysis

The unpaired t test was used to analyze differences of KT-2000 measurements and EMS measurements of ATT, acceleration of posterior tibial reduction, and axial rotation angle between two groups. For the continuous data, the distribution of the data was checked by Shapiro-Wilk test. The unpaired t test and Pearson's chi-squared test were used to

compare demographic data between two groups. Statistical significance was set at $P<0.05$.

All statistical analyses of recorded data were performed using the Excel statistical software package (BellCurve for Excel; Social Survey Research Information Co., Ltd., Tokyo, Japan). A priori power analysis performed by G*Power 3.1.9.4 (Franz Paul, Kiel, Germany), according to the previous study, showed that at least 76 subjects were required to compare the value of ATT between two groups with a power of 0.8 and an alpha error of 0.05, and assuming the incidence of ramp lesion to be 10% [39].

Results

Among the 206 patents evaluated, a ramp lesion was found in 30 patients (14.6%). According to the arthroscopic evaluation of the meniscal status, 17 patients were allocated to ramp group and 77 patients to noninjury group (**Fig. 2**). The patient demographics of two groups are shown in **Table 1**.

Mean ATT-SSD during Lachman test measured by EMS was 9.1 mm [95%CI: 5.7-12.5] for ramp group, and 6.2 mm [95%CI: 5.1-7.3] for control group, showing significantly greater ATT in the ramp group ($P=0.037$). Other results, including KT-SSD (mm) measurements and tibial acceleration during pivot-shift test were comparable between two groups (**Table 2**). The SSD in axial rotation angle at 30°, 60°, and 90° were also comparable between two groups (**Table 3**). Moreover, there was no significant difference in manual grading of the pivot-shift test between two groups (**Table 4**).

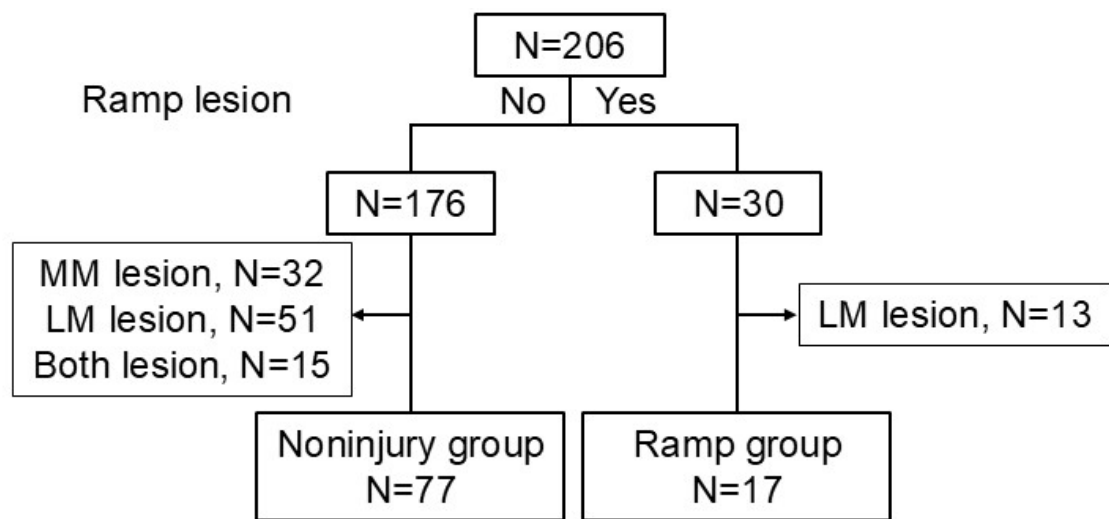


Fig. 2

Discussion

The most important finding of the present study was that ACL injuries with ramp lesions were associated with greater anterior knee laxity, which was evaluated by EMS, compared to that of ACL injuries without any meniscal lesions. However, anterior laxity measured by KT-2000 arthrometer and rotational laxity, both ALRI and axial rotational laxity, were not significantly different between two groups, suggesting that ramp lesions may influence only anterior knee laxity in ACL-injured knees, which may not be detected by the measurements using KT-2000. These findings should help understanding the impact of ramp lesion on knee laxity, and may help deciding the indication for the treatment.

In the present study, there were no difference between two groups, in terms of patients' gender, age, and chronicity of the injury, unlike some of the previous studies [22, 23, 39]. This discrepancy is probably from multiple factors. It may be partially due to the difference in inclusion criteria, since all the other meniscal lesions were excluded in the present study, whereas some of the other studies have included those patients in their cohort. This would definitely influence the results in terms of time from injury, because as it becomes chronic injury, ramp lesions increase, but other types of meniscal lesions also increase, in which case, patients are excluded from the present cohort. It may also come from heterogeneity of each study as well.

It is widely known that the medial meniscus works as an important secondly stabilizers of the knee, especially in the ACL-deficient knees. There are several studies showing that the medial meniscal deficiency can lead to increased anteroposterior instability, whereas the lateral meniscal deficiency leads to increased rotatory instability [20, 31, 36, 42]. Recent biomechanical studies have shown increased laxity by creating ramp lesion along with ACL tear. Several studies have shown that additional ramp lesion to ACL resection has increased knee instability, including anterior rotational, and it was only been restored by ACL reconstruction with concomitant ramp lesion repair [1, 37]. However, Naendrup et al. showed that ramp lesion did not increase in situ force of ACL and anteroposterior and rotational laxity of the tibia. The discrepancy among these studies may come from the difference in the resection method. The location, size, and stability of the created ramp lesions were different among these studies, all of which could have impacted the results. Stephen et al. created ramp lesion arthroscopically at meniscocapsular junction of posterior horn of the medial meniscus, extending medially to the junction of the posterior one-third and anterior two-thirds of the meniscus, and confirmed instability of the meniscus with the probe after the procedure, whereas Naendrup et al. created ramp lesion arthroscopically at similar location, but only 25mm long, and meniscus was still stable even after the procedure [22, 26]. In addition, the

former study seemed to be making the incision slightly closer to the body of the meniscus compared to the latter study, which might have led to different findings. Similar controversies are seen in the clinical researches as well. There are a couple of literature showing increased knee instability, either anteroposterior or rotational, with the presence of ramp lesion in ACL-deficient knees [30, 39]. On the other hand, Albayrak et al. showed that the presence of ramp lesion did not increase preoperative instability [2]. Lambrey et al. also reported that anteroposterior laxity wasn't a significant predictor of ramp lesion [25]. These studies acquire heterogeneity in the stability of the ramp lesion, presence of other meniscal injuries, and diagnostic measurement methods, all of which may confound the results. The current study excluded all the other meniscal injuries to minimize the confounding factor, and used EMS, which is a reliable objective measurement, and showed increased anteroposterior laxity in 'ramp group' [5, 19, 33]. The fact that all the measurements were done under general anesthesia in the present study might have also affected the result. According to previous study, ATT-SSD during Lachman test measured by EMS was approximately two millimeters greater when measured under general anesthesia compared to measurement during the awake state [27]. The present study didn't show significant difference in terms of rotational laxity, which was in line with some of the previous literatures [1, 2, 16]. The incidence of preoperative grade 3 pivot-

shift was less frequent (3.2%) compared to some of the previous studies [2, 30]. Excluding all the concomitant meniscal lesions except for ramp lesions might have affected the results. Since pivot-shift test is a subjective test, the results could vary among facilities [24].

The novelty of the present study was that it objectively evaluated the impact of ramp lesion on instability in ACL-deficient knee by using EMS, which can measure the six degree-of-freedom of knee kinematics with high sampling rates (240 Hz). Several previous literatures have used this system to quantitatively evaluate pivot-shift test in ACL-deficient patients [19, 29, 33]. In the present study, the increase in anterior knee laxity was only seen in the measurements by EMS and not in KT-1000. Araki et al. has reported that the measurements by EMS during the Lachman test were better correlated to fluoroscopic measurements than those by KT-1000 measurements, which indicates that EMS can more precisely measure anterior knee laxity than arthrometers [5]. This may result in EMS being more sensitive to detect subtle increase in anterior knee laxity caused by concomitant ramp lesion than KT-2000 measurement. The discrepancy may also come from the difference in maneuvers as well. The Lachman test was performed at a speed of about once per second as previously reported [27], whereas the KT-2000 arthrometer measurements, we stop at the maximum translated position, may result in a more static

measurement than that of the Lachman test. Moreover, knee flexion angles of two maneuvers were also slightly different, which may also result in the different values.

There are several limitations in the present study. First, the sample size is relatively small. However, priori power calculation showed that the present study had enough sample size for data analysis for evaluating anterior instability. Second, the ramp lesion was only diagnosed by the standard arthroscopic inspection including trans-notch view, without posteromedial portal. Trans-notch view along with meticulous probing has shown to have high diagnostic capability, and we think it is efficient way for screening ramp lesions during ACL reconstruction surgeries. Third, the forces applied during each maneuver could vary among different patients. In order to minimize the variance, experienced knee surgeons preformed each examination consistently. Moreover, examiners were blinded to the meniscal status, so this should have only minimal impact on the results of the present study. Fourth, the type or size of the ramp lesions were not considered in the present study. Both could have affected the results, but due to small sample size, we could not perform subgroup analysis. At last, postoperative data were not included in the present study, so its impact on the clinical outcome was not evaluated. The indication for the treatment of ramp lesion has not reached consensus yet [8, 10]. Further study is necessary to evaluate the impact of ramp lesion on patients' outcomes and to see whether concomitant ramp

repair along with ACL reconstruction can restore sufficient stability.

Conclusions

Presence of ramp lesion was associated with increased anterior knee laxity during Lachman test, while it did not have significant influence on rotational laxity in ACL injured patients. These findings imply the function of medial meniscus as a secondary restraint of anterior knee laxity, and suggest that ramp lesions may need to be addressed at the time of ACL reconstruction to avoid residual anterior knee laxity near extension.

Abbreviations

ACL, anterior cruciate ligament

EMS, electromagnetic measurement system

ALRI, anterolateral rotatory instability

BMI, body mass index

ATT, anterior tibial translation

SDD, side-to-side difference

IKDC, International Knee Documentation Committee

CI, confidence interval

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Figure legends

Fig. 1 The electromagnetic measurement system for the pivot-shift test.

Two electromagnetic sensors were secured on the thigh and shank with straps. The anatomic coordinates of the knee were set via electromagnetic transmitter.

Fig. 2 The flow chart of the patient allocation. LM, lateral meniscus; MM, medial meniscus.

Table 1. Patient demographics^a

	Ramp group (n=17)	Control group (n=77)	<i>P</i> value
Sex, male / female	10 / 7	39 / 38	0.38
Age at surgery, years old	26.5 ± 11.1	27.2 ± 12.6	0.85
BMI, kg/cm ²	22.9 ± 2.4	23.4 ± 4.2	0.65
Injury–Surgery period, days	209.1 ± 235.1	206.9 ± 454.2	0.98
Hyperextended knee, n (%)	3 (17.6%)	15 (19.5%)	1.00
Tegner activity scale	6.7 ± 1.9	7.1 ± 2.0	0.47

^a Data reported as mean ± SD unless otherwise indicated.

BMI, body mass index

Table 2. Measurements of anterior and rotational laxity^a

	Ramp group (n=17)	Control group (n=77)	<i>P</i> value
ATT SSD during Lachman test (mm)	9.1 (5.7-12.5)	6.1 (5.1-7.3)	0.037*
KT-2000 SSD (mm)	5.5 (4.2-6.7)	5.1 (4.5-5.6)	0.55
Tibial acceleration (m/s ²)	1.3 (0.9-1.8)	1.4 (1.2-1.6)	0.69

^a Data reported as mean (95% confidence interval) unless otherwise indicated.

ATT, anterior tibial translation; SSD, side-to-side difference

* $P < 0.05$

Table 3. Measurements of axial rotational angle^a

	Ramp group (n=17)	Control group (n=77)	<i>P</i> value
SSD in axial rotation angle at 30° of knee flexion (°)	3.5 (-3.5-10.6)	4.0 (1.5-6.4)	0.90
60° of knee flexion (°)	2.7 (-1.5-7.1)	3.7 (1.8-5.7)	0.70
90° of knee flexion (°)	3.3 (0.3-6.3)	1.8 (0.2-3.5)	0.45

^a Data reported as mean (95% confidence interval) unless otherwise indicated.
SSD, side-to-side difference

Table 4. Manual grading of pivot-shift test

		Ramp group	Control group	<i>P</i> value
Pivot-shift test (Grade)	0	0 (0%)	1 (1.3%)	0.87
	1	10 (58.8%)	47 (61.0%)	
	2	6 (35.3%)	27 (35.1%)	
	3	1 (5.9%)	2 (2.6%)	
Total		17	77	