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Standardized pivot shift test improves measurement accuracy

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Abstract
Purpose The variability of the pivot shift test techniques greatly interferes with achieving a quantitative and generally comparable measurement. The purpose of this study was to compare the variation of the quantitative pivot shift measurements with different surgeons' preferred techniques to a standardized technique. The hypothesis was that standardizing the pivot shift test would improve consistency in the quantitative evaluation when compared with surgeon-specific techniques.
Methods A whole lower body cadaveric specimen was prepared to have a low-grade pivot shift on one side and high-grade pivot shift on the other side. Twelve expert surgeons performed the pivot shift test using (1) their preferred technique and (2) a standardized technique. Electromagnetic tracking was utilized to measure anterior tibial translation and acceleration of the reduction during the pivot shift test. The variation of the measurement was compared between the surgeons' preferred technique and the standardized technique.
Results The anterior tibial translation during pivot shift test was similar between using surgeons' preferred technique (left 24.0 ± 4.3 mm; right 15.5 ± 3.8 mm) and using standardized technique (left 25.1 ± 3.2 mm; right 15.6 ± 4.0 mm; n.s.). However, the variation in acceleration was significantly smaller with the standardized technique (left 3.0 ± 1.3 mm/s^2; right 2.5 ± 0.7 mm/s^2) compared with the surgeons' preferred technique (left 4.3 ± 3.3 mm/s^2; right 3.4 ± 2.3 mm/s^2; both $P < 0.01$).
Conclusion Standardizing the pivot shift test maneuver provides a more consistent quantitative evaluation and may be helpful in designing future multicenter clinical outcome trials.
Level of evidence Diagnostic study, Level I.

Keywords Anterior cruciate ligament (ACL) · Pivot shift test · Electromagnetic measurement system · Acceleration measurement · Image analysis

Introduction

The pivot shift test is often called "the gold standard" clinical examination for rotational instability in the anterior cruciate ligament (ACL) insufficient knee [6, 7]. The pivot shift is frequently related to subjective knee function [14, 20] and to the long-term osteoarthritis (OA) [13]. Although the appropriate evaluation and comparison of the pivot shift test is desirable, there has still not been an established

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quantitative evaluation for this test mainly due to the wide variation of testing maneuvers among surgeons [16, 27]. There was no consensus of the pivot shift testing maneuver in terms of knee movement (flexion or extension) and applied force (internal or external rotation etc.) [16].

Improvements in terms of measurement technology have afforded quantitative exploration of the dynamic knee motion during the pivot shift test. Specifically, the pivot shift can be characterized by tibial anterior translation and/or tibial acceleration [2, 3, 11, 17, 18, 21, 23, 28]. However, the quantitative measurement results of the pivot shift test were widely varied due to the variation of the testing techniques [16]. Other conventional reporting of pivot shift measurements utilizes a single examiner or few examiners in order to avoid pivot shift maneuver variability. Therefore, the variability of the pivot shift measurements due to the variation of the testing maneuvers has not been properly evaluated and remains unsolved.

We therefore posed the research question whether maneuver differences could be resolved simply by setting a standardized technique. We invited 12 experienced surgeons from worldwide who all are accustomed to their own techniques. The purpose of this study was to compare the variation of the quantitative pivot shift measurements with different surgeon-specific techniques to a standardized technique. It was hypothesized that a standardized technique would provide more consistent measurements than surgeon-specific techniques.

Materials and methods

A whole lower body specimen (Male, 70 years old) was used. There was no significant bony abnormality or knee joint pathology, which were confirmed by radiography, arthroscopy, and physical examinations prior to the experiment. The ACL was dissected in both knees, while the anterior horn of the lateral meniscus was additionally detached from the anterior root attachment in the right knee. Twelve expert surgeons were asked to perform the pivot shift test using (1) their preferred technique and (2) a standardized technique. The knee movement during the pivot shift test was measured by an electromagnetic measurement system to provide anterior tibial translation and acceleration of the reduction for quantitative evaluation of the pivot shift.

Standardized technique of the pivot shift test was designed on the basis of Galway and MacIntosh procedure [7]. Flexion type of the pivot shift test was adopted, because this type of procedure was advocated by a majority of ACL surgeons [16]. Also the internal rotational stress was widely used [16] and was included in the first step of the standardized procedure to maximize the subluxation of the lateral tibial plateau. The detailed procedure is available as a movie at ESSKA journal web site (see the attached video file).

An electromagnetic motion tracking system (LIBERTY, Pholhemus, VT) was applied for the six degree-of-freedom knee kinematics measurement (Fig. 1). Direct measurement of the bony movement was obtained by rigidly fixing the electromagnetic sensors to the femur and the tibia using K-wires. The same direct measurement was conducted in previous reports where the detailed procedure was elaborated [8, 26]. The calculation of the tibial anterior translation and acceleration of the reduction during the pivot shift test using the electromagnetic measurement data has also previously been utilized in several studies [1, 5, 10, 11, 15, 16]. The knee kinematics coordinate system defined by Grood and Suntay [8] was digitally configured after digitizing the three-dimensional (3D) position of the anatomical landmarks. This electromagnetic system had a root mean square accuracy of 0.03 mm for position and 0.15° for orientation [24]. An accelerometer, a potential interference to the electromagnetic field, was employed on the tibia for another study in the multidisciplinary project, but it was preliminarily confirmed by the on-site assessment of the tracking accuracy that this accelerometer did not affect the electromagnetic field in this experimental setting. The anterior tibial translation during the pivot shift test was calculated as the difference from the baseline kinematics data, which was preliminarily recorded during a passive knee flexion test (0°–120°). Additionally, the acceleration of the pivot shift reduction movement was computed as reported by Hoshino et al. [11].

Preliminarily, the knee kinematics during passive knee flexion with no rotational stress was recorded for providing baseline kinematics. Each of the twelve expert surgeons

Fig. 1 Pivot shift test using a standardized technique. Electromagnetic transmitter (indicated by a *white arrow*) was placed nearby the examiner so that the sensors (indicated by *black arrows*) are located within the range of the electromagnetic field

performed the pivot shift test three times utilizing their preferred technique while recording the knee kinematics simultaneously.

Subsequently, a standardized pivot shift test maneuver was introduced to the expert surgeons by use of a short instructional video. The pivot shift test with simultaneous measurement was then performed three times using the standardized maneuver. Each surgeon's experimental session was completely separated and blinded to others.

Statistical analysis

Linear mixed models stratified by knee was used to examine differences of the tibial anterior translation and acceleration between both sides of the knee and between two techniques on the same knee. Linear mixed models stratified by technique were utilized to determine whether the variation of the tibial anterior translation and acceleration across surgeons was different between using surgeons' preferred technique and the standardized technique. The statistical significance was set at p value less than 0.05. All statistical calculations were performed using SAS v9.2 (SAS Institute Inc., Cary, NC, USA).

Results

Anterior tibial translations during the pivot shift test were similar when using the surgeons' preferred technique and the standardized technique (n.s. for both sides, Table 1). The side-to-side difference was statistically significant for either surgeon' preferred or the standardized technique, respectively ($P < 0.01$ for both techniques, Fig. 2). The variation of the translation was not different between techniques on either side (n.s. for both sides, Table 1).

The side-to-side difference of acceleration was not statistically significant (both n.s., Fig. 3). The variation of the acceleration with the instructed technique was smaller than that with the surgeons preferred technique ($P < 0.01$ for both sides) (Table 1).

Table 1 Tibial anterior translation and acceleration of the tibial reduction during the pivot shift test

	Preferred technique	Standardized technique	*P* value
Tibial anterior translation (mm)			
Left	24.0 ± 4.3	25.1 ± 3.2	n.s.
Right	15.5 ± 3.8	15.6 ± 4.0	n.s.
Acceleration of the tibial reduction (mm/s^2)			
Left	4.3 ± 3.3	3.4 ± 2.3	<0.01
Right	3.0 ± 1.3	2.5 ± 0.7	<0.01

P value was assessed for the difference of variation between preferred and standardized techniques (average ± SD)

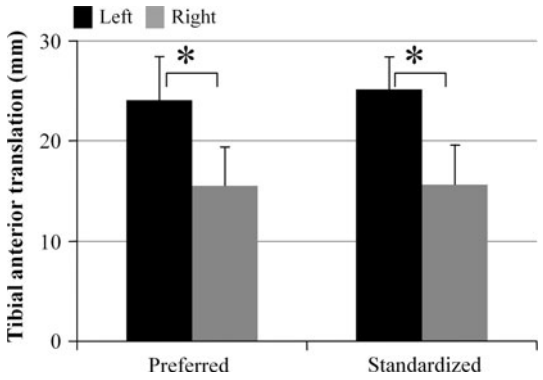

Fig. 2 Tibial anterior translation during the pivot shift test (average ± SD). *Statistically significant difference, $P < 0.01$

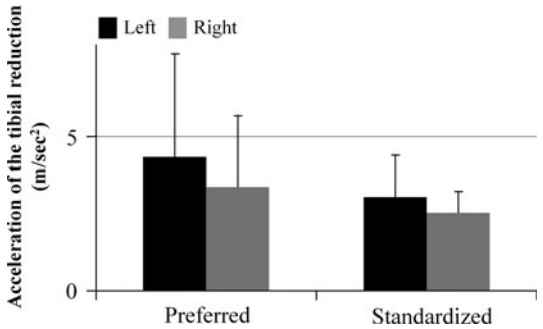

Fig. 3 Acceleration of the tibial reduction during the pivot shift test. (average ± SD)

Discussion

The most important finding of this study was, as hypothesized, that the variation of the acceleration during the pivot shift test across different surgeons utilizing their preferred technique was significantly reduced by performing the pivot shift test in a standardized manner. The variation of the tibial translation was not different between surgeons' preferred and the standardized maneuver.

The pivot shift test was introduced to reproduce the pivot shift movement on the examination table [6, 7]. Various different techniques for the pivot shift test have been introduced to provoke either dislocation or reduction of the pivot shift phenomenon [7, 12, 19, 22, 24, 25, 29, 30]. Kuroda et al. [16] were able to show that the variation of the pivot shift test technique results in different knee kinematics during the pivot shift test [16]. Although the tibial antero-posterior translation and its acceleration were relatively constant and reliable to detect the ACL insufficiency compared with knee rotation [4, 9, 11, 16, 17], there was still a wide variation of those parameters across

examiners. This finding let us to propose developing a standard measurement of the pivot shift test. However, the measurement variation of the pivot shift acceleration was successfully reduced by applying a standardized testing maneuver in this study. This would encourage the future use of this parameter with the standardized pivot shift test maneuver for clinical and research purposes.

Acceleration of the pivot shift reduction has been drawing attention due to its relationship to clinical grading [11, 17, 18, 21]. Labbe et al. [17] reported that the acceleration and velocity of the tibial translation are more related to clinical grading rather than to simple knee kinematics, such as tibial translation and rotation [17]. Even though the intra-examiner repeatability of the acceleration measurement is quite acceptable [11, 17, 21], the acceleration is also readily susceptible to the difference of testing maneuvers across examiners [16]. Therefore, it is of importance for future improvements of the pivot shift quantification that a standardized technique could successfully reduce the variability of the acceleration measurement during the pivot shift test.

Interestingly, variation of the tibial translation during the pivot shift test among surgeons was not different between surgeons' preferred maneuver and the standardized technique in this experiment. The translation measurement might provide a consistent evaluation for the pivot shift test even with different testing maneuvers. However, the measurement system for the tibial translation during the pivot shift test, that is, electromagnetic device, is not widely available as of now mainly due to high cost. Also, the clinical importance of the translation measurement could be limited because of its weaker relationship to the clinical grading than acceleration measurements [17]. Conversely, Lane et al. showed that translation measurement of the lateral compartment was related to clinical grading [2, 18]. Thus, a modification of the translation measurement during the pivot shift test, that is, focusing on the lateracompartment, could have a potential to provide more consistent and clinically valuable measurement.

There are some limitations for this study. First, the standardized technique was instructed to the participating experts at the time of the experiment using a short (2 min) video, and the experts performed this technique of the pivot shift test for the first time. Some surgeons could not acquire the technique sufficiently to perform in a constant manner, which could overestimate the variability of the measurement results with the standardized technique. Both techniques should be proficient in order to achieve an appropriate comparison. Second, this cadaveric experiment eliminated the patients' guarding which is frequently seen in clinical cases and can reduce both the tibial translation and the acceleration of the pivot shift. It remains unknown whether the standardized technique could achieve sufficient level of patient relaxation. However, the standardized technique was developed as a modification of the common procedures that have been used in clinical practice for a long time [7]. Thus, this standardized procedure is supposed to be equally applicable to actual patients, though further investigations using clinical patients are warranted. Lastly, only two knees with different level of positive pivot shift test were used for this study only to examine the effect of testing maneuver variability. Future investigations will focus on a larger scale study with several different instability patterns, including intact knees. Thereby, a positive threshold of the measurement could be established, and sensitivity and specificity of the quantitative evaluation of the pivot shift test could be assessed for future clinical application of the pivot shift measurements.

Advanced measurement technology with a standardized testing maneuver for the pivot shift test could overcome the problem of measurement variability across examiners and provide quantitative parameter with better consistency, which can be used to compare between different surgeons and institutions.

Conclusion

Standardizing the pivot shift test maneuver could achieve better consistency in quantitative evaluation of the pivot shift test and may be helpful in designing future multicenter clinical outcome trials.

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