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Clinical grading of the pivot shift test correlates best with tibial acceleration

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Abstract

Purpose Recently, different measurement systems have been developed to quantitatively measure the pivot shift in vivo. These systems lack validation and a large inter-examiner variability for the manually performed pivot shift test exists. The purpose of this study was to perform objective measurements of the pivot shift using three different measurement devices and to examine the correlation of the measurements with clinical grading of the pivot shift.

Methods A cadaver knee on a whole lower body specimen was prepared to display a high-grade pivot shift. The pivot shift tests were performed three times by 12 blinded expert surgeons using their preferred technique. Simultaneous data samplings were recorded using three different measurement devices: (1) electromagnetic tracking system using bone-attached and skin-fixed sensors, respectively, (2) triaxial accelerometer system, and (3) simple image analysis. The surgeons graded the knee clinically using pivot shift grades I–III. Correlations were calculated using the Spearman's rank correlation coefficient.

Results The expert surgeons average clinical grading was 2.3 (SD $\pm$ 0.5). Clinical grading displayed best correlation with the acceleration of reduction as measured by electromagnetic tracking system with bone-attached sensors ($r = 0.67$, $P < 0.05$). Similar correlation coefficient was found for the acceleration of reduction ($r = 0.58$, $P = 0.05$) and the "jerk" component of acceleration ($r = 0.61$, $P < 0.05$) measured by means of the triaxial accelerometer system.

Conclusion The pivot shift can be quantified by several in vivo measurement devices. Best correlation with clinical grading was found with tibial acceleration parameters. Future studies will have to analyze how quantitative parameters can be utilized to standardize clinical grading of the pivot shift.

Level of evidence Diagnostic study, Level II.

Keywords Knee · Anterior cruciate ligament · Pivot shift · Laxity · Kinematics

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Introduction

Control of rotatory laxity is necessary to improve anatomic anterior cruciate ligament (ACL) reconstruction [15, 25, 27]. In contrast to anterior–posterior (AP) laxity testing, the pivot shift has been correlated with functional outcome after ACL injury and ACL reconstruction [13, 14, 16]. The pivot shift test also represents the patients' most typical symptom of ACL insufficiency, that is, "giving-way." The pivot shift has been reported to most specifically display the abnormal knee kinematics in ACL-deficient or ACL-reconstructed knees compared with static testing of rotational laxity or AP laxity [2, 10, 18–22, 26]. However, the pivot shift test has repeatedly been shown to be subjective in terms of interpretation and conduction [1, 11, 17, 23].

Therefore, in order to standardize the technique and evaluation of the pivot shift test, a common language and clear definitions for grading of the pivot shift test would be in favor. Today, clinical grading of the pivot shift is used as an outcome measure in many studies reporting results after ACL reconstruction. New technology has produced improved measurement devices for quantification of the complicated pivot shift phenomenon, but it is still unclear which components of the pivot shift have a relationship with clinical grading.

Therefore, the purpose of the present study was to examine correlations of clinical grading of the pivot shift test by 12 blinded examiners with quantified parameters of the pivot shift using three different devices. It was hypothesized that quantitative parameters measured by the three devices would correlate well with the clinical grading.

Materials and methods

The right knee of a fresh whole lower body specimen was used (70-year-old male). The specimen was evaluated by clinical examination, radiographs, and diagnostic arthroscopy to rule out previous injuries and osteoarthritis. During arthroscopy, the right knee was prepared to display a high-grade pivot shift by means of resection of the ACL and anterior horn of the lateral meniscus. The pivot shift tests were performed three times by 12 blinded expert surgeons using their preferred technique. The surgeons clinically graded the pivot shift using grades I–III according to the IKDC guidelines [6].

Simultaneous data samplings were recorded using three different measurement devices:

1. Electromagnetic tracking system (LIBERTY™, Polhemus, VT, USA) with bone-attached and skin-fixed sensors, respectively. The bone sensors were fixed by means of two half pins (4.0-mm diameter) located in the femur and tibia each. The two skin sensors were attached to a plastic brace fixed by a circumferential Velcro® strap 10 cm above the patella on the thigh and 7 cm below the tibial tubercle on the lower leg. In order to set up the knee coordinate system, an additional sensor was used to digitize the three dimensional locations of the anatomic landmarks. The three dimensional positions of the femur and the tibia were then identified from the positional data, and the knee coordinate system was configured according to Grood and Suntay [5]. The sampling rate of 240 Hz was used to measure the 6 degree of freedom knee kinematics during motion [8–10] (Fig. 1a, b).
2. Triaxial accelerometer (KiRA, Orthokey LLC, Lewes, DE, USA), wirelessly connected to a regular laptop. The sensor was non-invasively mounted between the lateral aspect of the tibial tubercle and Gerdy's tubercle. Parameters assessed were maximal acceleration (a_{max} = "acceleration of reduction"), minimal acceleration (a_{min}), range of acceleration ($a_{max} - a_{min}$), and "jerk" or "slope" of acceleration, which is an average value of first derivative of acceleration as a suggestion of the smoothness of the pivot shift phenomenon [21] (Figs. 1a, b, 2).
3. Simple image analysis. Small target stickers (white portable reinforcements, item #636156, Staples, Inc., Framingham, MA, USA) were placed on bony landmarks of the lateral compartment, that is, lateral epicondyle, Gerdy's tubercle, and fibula head. Movement of the stickers was captured using a digital camera (Nikon COOLPIX S8100, Nikon Corp., Tokyo, Japan). Movies were analyzed frame by frame for lateral compartment translation using Image J Software (NIH, Bethesda, MD, USA) [7] (Fig. 1a, b).

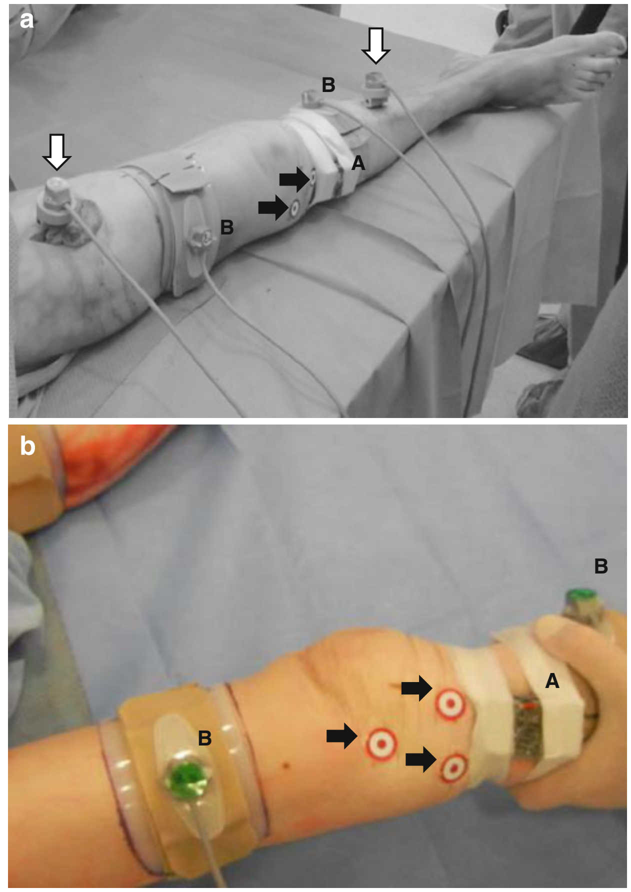

Fig. 1 Experimental setup of cadaver knee. Electromagnetic sensors attached to the bones (indicated by *white arrows*). Electromagnetic sensors fixed to the skin (indicated by *letter B*). Accelerometer (indicated by *letter A*). Stickers for simple image analysis (indicated by *black arrows*)

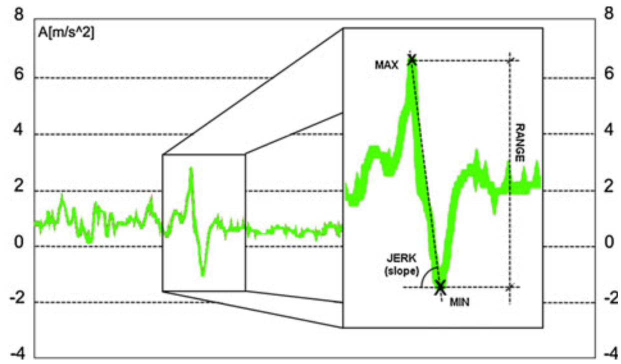

Fig. 2 Accelerometer graphical output (unpublished material, courtesy provided by Lopomo N and Zaffagnini S, Instituto Ortopedico Rizzoli, Bologna, Italy)

Statistical analyses

Correlations were calculated using the Spearman's rank correlation coefficient. Statistical significance was set at P value < 0.05. All statistical calculations were performed using SAS v9.2 (SAS Institute Inc., Cary, NC, USA). Correlation coefficients were interpreted as poor ($r < 0.3$), moderate ($0.3 < r < 0.6$), and good ($0.6 < r < 0.8$).

Results

The expert surgeons average clinical grading was 2.3 (SD ± 0.5). One surgeon clinically graded the pivot shift as 1.5, six surgeons as grade 2, one surgeon as 2.5, and four as grade 3.

Clinical grading displayed good correlation with the maximal acceleration of reduction measured by electromagnetic tracking system with bone-attached sensors ($r = 0.67$, $P < 0.05$). Similar correlation coefficients were found for maximal acceleration of reduction ($r = 0.58$, $P = 0.05$) and the "jerk" component of acceleration ($r = 0.61$, $P < 0.05$) measured by means of the triaxial accelerometer system. The range of acceleration, that is, the difference between maximum and minimum acceleration, displayed no significant correlations (Table 1). No statistically significant correlations were shown for anterior tibial translation measured by electromagnetic tracking system or for lateral compartment translation measured with simple image analysis (Table 1).

Discussion

The most important finding of this study was that parameters of acceleration correlated best with clinical grading of the pivot shift test. Several devices for quantification of the pivot shift test were tested in this study. Different components of the pivot shift have been reported to correlate with clinical grading, such as coupled anterior translation [10, 26], coupled lateral compartment anterior translation [2], tibial posterior acceleration [10, 18, 19, 21], velocity of tibia translation [18], and "angle of p" [19]. Tibial rotation was reported to display weak or no correlation [8, 10]. Nonetheless, the pivot shift test is frequently referred to as a test for "rotational laxity." In the present study, clinical grading correlated best with parameters of acceleration measured by means of two different devices, that is, electromagnetic tracking device and accelerometer.

Tibial acceleration is important when defining the pivot shift. Specifically, the parameter measured by the triaxial accelerometer, which correlated best with clinical grading was the derivative of acceleration ("jerk" or "slope"), which can be considered an indicator of the smoothness of the reduction [21]. Lopomo et al. [21] have reported on the use of the same triaxial accelerometer. They found that the probability of a correct diagnosis of ACL deficiency was 70% using the slope of acceleration and 80% using the

Table 1 Correlation between quantitative measurements of pivot shift and clinical grading using different measurement devices

Parameter	Device							
	Electromagnetic tracking with bone sensors		Electromagnetic tracking with skin sensors		Accelerometer		Simple image analysis	
	r	P	r	P	r	P	r	P
Acceleration max	0.67	0.02	0.35	0.26	0.58	0.05		
Acceleration min					0.26	0.41		
Acceleration range					0.45	0.15		
Acceleration slope					0.61	0.04		
Anterior tibial translation	0.42	0.18	0.32	0.32				
Lateral anterior tibial translation							0.26	0.42

r Spearman's rank correlation coefficient

P significance

range of acceleration. In the present study, utilizing the accelerometer, there was no significant correlation of clinical grading with range of acceleration in contrast to earlier reports [21]. Possibly, this can be explained by a beta error related to a small sample size in the present study.

Clinical grading of the pivot shift test is commonly used in the assessment of outcome in studies after ACL reconstruction, although the evaluation is based largely on the examiners' subjective decision [3, 12, 24]. Usually, a few or only one experienced examiner performs the pivot shift test in order to improve reliability in studies measuring the pivot shift [2, 10, 19, 21]. In the present study with 12 different examiners, the clinical grading of the pivot shift test varied greatly between examiners, which confirm the previous reports [4, 20, 23]. Clinical grading relates to the examiners perception and naturally, different examiners evaluate different components of the pivot shift such as force, velocity, and/or translation. Kuroda et al. [17] performed a global survey where one part of the study consisted 33 surgeons answering a questionnaire on their preferred technique for manual tests. With regard to the pivot shift test, almost all of the surgeons depended on the "feeling" of the reduction (70%) or dislocation (24.2%). Only 3 surgeons (9.1%) appraised tibial translation. Obviously, the subjectivity of IKDC grading of pivot shift (glide/clunk/gross clunk) affects the validity of the scoring system.

Hoshino et al. [10] reported that both coupled anterior translation and acceleration were correlated with the pivot shift test using electromagnetic tracking. Bedi et al. [2] showed an excellent correlation of anterior translation in the lateral compartment with clinical grading using computer navigation. A specific distinction between a grade 0 and grade 1 pivot shift could be made using a cut off at 6–7 mm of anterior translation in the lateral compartment [2]. Therefore, it appears that both coupled anterior translation and more dynamic parameters such as velocity and acceleration may be essential to clinical grading of the pivot shift test.

However, Labbe et al. [18] reported, in line with the present study, that acceleration and velocity accounted for greater differences of kinematic recordings of the pivot shift test, than the actual magnitude of displacement between the femur and tibia. The question remains whether several components of the pivot shift have to be evaluated to quantify the pivot shift test. Further studies are needed to examine whether decomposition of the pivot shift into one parameter, such as acceleration or lateral compartment translation can provide valid measurements of the pivot shift. Future goals will be to establish a reliable clinical grading system that uses several different quantitative parameters that are both intuitive and are validated. Ultimately, quantitative parameters should be utilized to standardize clinical grading of the pivot shift.

A limitation of the present study is the use of only one cadaveric specimen with a single rotatory laxity condition. In the future, a larger scale study is planned to analyze the quantitative parameters of pivot shift grading in the clinical setting.

Conclusion

Tibial acceleration parameters during the pivot shift test most closely correlated with the clinical grading performed by 12 expert surgeons. Quantification of pivot shift in the clinical setting warrants a device that is easily applicable, however, more valid and reliable than simple subjective evaluation of a manual pivot shift test. This study implicates that devices measuring parameters of acceleration need further evaluation. Acceleration of tibial reduction besides the more traditional parameters of coupled anterior or lateral compartment translation should be utilized to standardize clinical grading of the pivot shift.

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