

## Variability in knee laxity in anterior cruciate ligament deficiency using a mechanized model

Courtney K. Dawson · Eduardo M. Suero ·  
Andrew D. Pearle

Received: 28 November 2011 / Accepted: 28 July 2012 / Published online: 10 August 2012  
© Springer-Verlag 2012

### Abstract

**Purpose** To establish normative values for the magnitude of anterior tibial translation (ATT) in the Lachman and pivot shift tests in the intact and anterior cruciate ligament (ACL)-deficient states, and to explore whether a correlation in ATT magnitude exists between the Lachman and pivot shift tests.

**Methods** Twenty-six fresh frozen cadaveric hip-to-toe specimens were used. Mechanized testing was performed to simulate both a Lachman and pivot shift test with the ACL intact. Tests were repeated after sectioning the ACL. ATT was recorded using a computer navigation system. Difference in ATT after sectioning was calculated for each specimen.

**Results** For the Lachman, mean lateral compartment ATT in the intact knee was 5.3 mm (SD = 2.8 mm). After sectioning the ACL, translation increased to 11.4 mm (SD = 3.9 mm;  $P < 0.05$ ). For the mechanized pivot shift, mean lateral compartment ATT in the intact knee was -0.2 mm (SD = 2.6 mm). After sectioning the ACL, translation increased to 8.2 mm (SD = 3.1 mm;  $P < 0.05$ ). No correlation in the magnitude of ATT was found between the intact and ACL-deficient knees for either the Lachman or pivot shift tests, or between both tests (Cronbach's  $\alpha < 0.7$ ).

**Conclusions** No correlation was found between the Lachman and pivot shift test in both the intact and ACL-deficient knee. This suggests that the Lachman cannot be used as a surrogate for the pivot shift as the magnitude of

the Lachman did not predict the magnitude of the pivot shift.

**Keywords** Pivot shift · Anterior cruciate ligament · Knee laxity · Lachman

### Introduction

Injury to the anterior cruciate ligament (ACL) is common among the athletic population. Recently, much attention has been paid to the evaluation of risk factors and potential predictive factors for injury as well as preventative training programs. Gender-based anatomical and biomechanical differences have been noted to be potentially responsible for the higher incidence of ACL injury seen among young female athletes in several studies. Ligamentous laxity has been a specific study subject, with implications for injury prevention and treatment strategies [6].

The clinical evaluation of a patient suspected to have an ACL injury centres around the Lachman and pivot shift tests. The Lachman test is used to quantify the amount of anterior tibial translation (ATT) with the knee in 20–30° of knee flexion [16, 20]. This objective measure can be used to grade the injury and to predict the level of functional instability. Typically, the Lachman should be compared to the uninvolved extremity to gauge the patient's inherent knee laxity [13]. The pivot shift has been described as the most specific test in detecting ACL injury [1, 7, 18]. A positive pivot shift occurs when the tibia translates anteriorly and then reduces during a flexion manoeuvre with a valgus-directed force [1, 7, 18]. A three-grade continuum has been used most commonly to describe the increasing degree of translation in an injured knee [11].

C. K. Dawson · E. M. Suero · A. D. Pearle (✉)  
Hospital for Special Surgery, 535 E 70th Street,  
New York, NY 10021, USA  
e-mail: PearleA@hss.edu

C. K. Dawson  
e-mail: courtneykdawson@gmail.com

Both the Lachman and pivot shift are clinical tests whose results may vary in the hands of different observers [5, 8, 18]. Discrepancy in the magnitude of tibial translation has been observed through clinical experience among patients when compared to the uninjured extremity. Some ACL-deficient knees demonstrate a large magnitude of translation while others may seem more stable despite the same degree of internal injury.

Prior studies have used a cadaveric model to objectively quantify and evaluate the amount of lateral compartment translation in a mechanized pivot shift test [2, 10, 18]. Normative values were determined for translation correlating with each clinical grade of the pivot [2]. In the current study, this mechanized model was used to assess the degree of laxity within intact and ACL-deficient knees. The study aimed to establish normative values for the magnitude of ATT in the Lachman and pivot shift tests in the intact and ACL-deficient states, and to explore whether a correlation in ATT magnitude exists between the Lachman and pivot shift tests.

## Materials and methods

Twenty-six frozen cadaveric hip-to-toe lower extremity specimens were used for this study. The group included fourteen matched pairs and two outlier extremity specimens. There were 24 male and 6 female individual knee specimens. The median age of the donors was 59 years (range, 40–69 years). The specimens were thawed for 48 h at room temperature prior to testing. Specimens underwent just one thawing cycle. Testing lasted about 2 h per knee. On the day of the test, the specimens were placed supine on an operating room table with the pelvis secured proximally. This allowed free motion of the hip and knee within the testing apparatus distally. Two specimens were excluded due to signs of advanced osteoarthritis.

Instrumented Lachman and pivot shift tests were performed on knees with the ACL intact. Tests were repeated after sectioning the ACL. ATT was recorded in real time using a computer navigation system (Praxim, Grenoble, France), with dedicated ACL software with an accuracy of 1 mm and 1° [19]. Reflective reference arrays were attached to the femur and the tibia, 15 cm above and below the joint line, using two pairs of 4-mm Schanz pins.

A mechanized pivot shifter was used to perform the pivot shift manoeuvres [5, 18]. A standardized mean valgus force of 5 kg was applied 5 cm below the joint line on the lateral side of the proximal third of the leg using a load cell connected to the mechanized pivot shifter through a three-degree-of-freedom arm. For the Lachman test, an anterior pulling force of a mean 12 kg

was applied using a hand-held pull-type spring scale attached to the tibia through an eyelet screw fixed to the anterior tibial crest, 7 cm below the joint line. ATT was defined as the range in translation from the tibiofemoral resting point at the beginning of each trial to the maximum anterior position of the tibia in the sagittal plane, compared to a reference motion path taken during the navigation system's registration process [19].

## Statistical analysis

It was determined through an a priori sample size analysis, using data from previous research, that at least 22 specimens would be required to detect significant differences in ATT between conditions and to detect significant correlation between tests. Paired Student's *t* tests were used to detect a significant difference in ATT between the ACL-intact and ACL-deficient conditions in both the Lachman and the pivot shift tests. Cronbach's  $\alpha$  and  $R^2$  values were used to test whether a significant correlation in the magnitude of ATT existed between the Lachman and the pivot shift tests, with a Cronbach's  $\alpha > 0.7$  deemed to be satisfactory [4]. Descriptive data are presented as mean, standard deviation (SD), 95 % confidence interval (95 % CI) and range, whenever appropriate. Stata/SE 11.2 (StataCorp LP, College Station, TX, USA) was used for all analyses. Statistical significance was set to  $\alpha = 0.05$ .

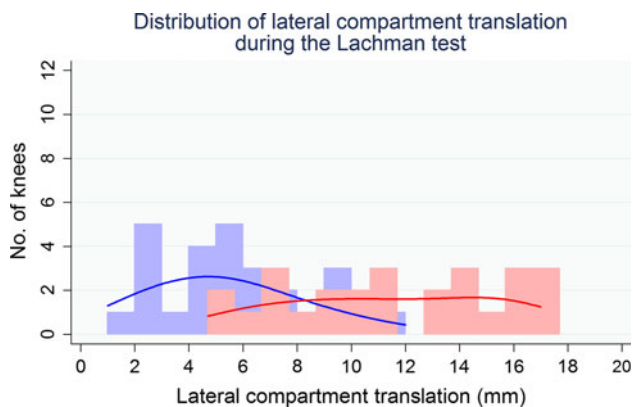
## Results

### Lachman test

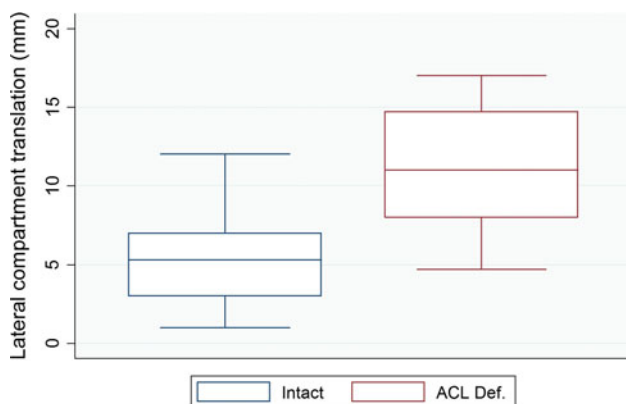
For the Lachman test, mean ATT in the intact knee was 5.3 mm (SD = 2.8 mm; 95 % CI = 4.2–6.4 mm; range, 1–12 mm) in the lateral compartment. After sectioning the ACL, translation increased to 11.4 mm (SD = 3.9 mm; 95 % CI = 9.8–12.9 mm; range, 4.7–17 mm) ( $P < 0.05$ ) (Figs. 1 and 2). There was an average increase in translation from the intact condition of 6.1 mm (SD = 3.6 mm; 95 % CI = 4.6–7.6 mm; range, 1–12.7 mm).

### Mechanized pivot shift test

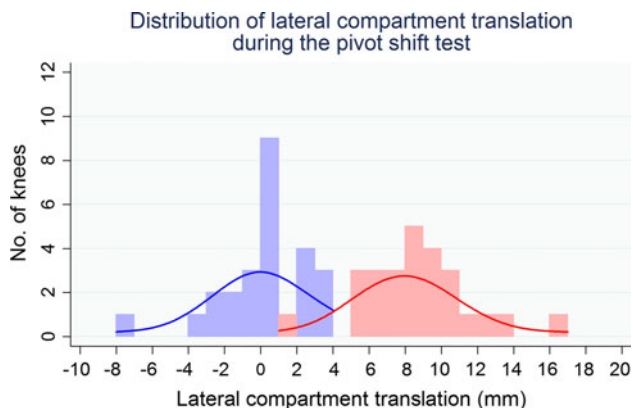
For the mechanized pivot shift, mean ATT in the intact knee was  $-0.2$  mm (SD = 2.6 mm; 95 % CI =  $-1.2$ – $0.9$  mm; range,  $-8$ – $4$  mm) for the lateral compartment. After sectioning the ACL, translation increased to 8.2 mm (SD = 3.1 mm; 95 % CI = 6.9–9.5 mm; range, 1–17 mm) ( $P < 0.05$ ) (Figs. 3 and 4). There was an average increase in translation from the intact condition of 8.4 mm (SD = 3.3 mm; 95 % CI = 7.1–9.7 mm; range, 1–15 mm).



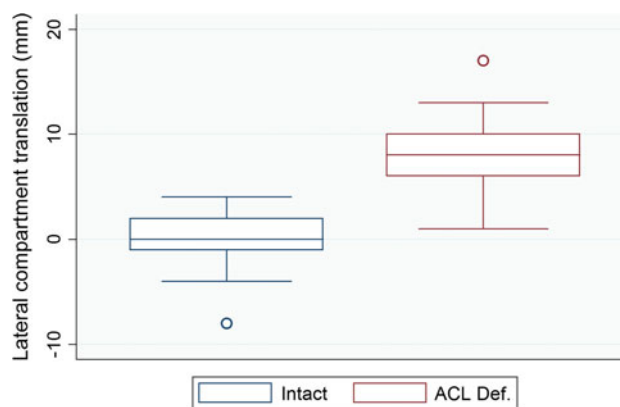
**Fig. 1** Variability in the magnitude of anterior tibial translation within the lateral compartment for ACL-intact knees (*blue*) and ACL-deficient knees (*red*) during the Lachman test showing wide variation between specimens



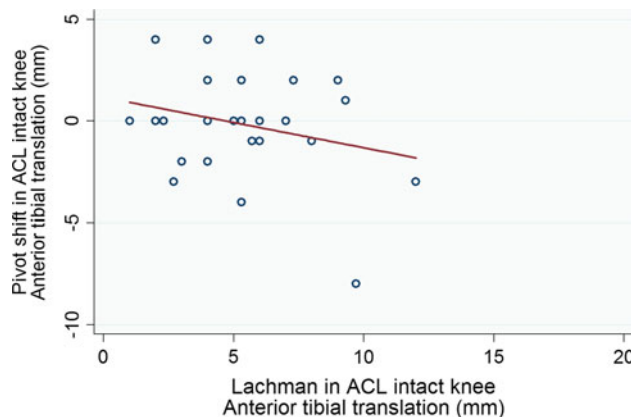
**Fig. 2** Box plots showing an average increase in translation of 6.1 mm (SD = 3.6 mm; 95 % CI = 4.6–7.6 mm) during the Lachman test after sectioning the ACL



**Fig. 3** Variability in the magnitude of translation within the lateral compartment for ACL-intact knees (*blue*) and ACL-deficient knees (*red*) during a mechanized pivot shift test showing minimal variation between specimens in the intact state and increased variation between specimens in the ACL-deficient state



**Fig. 4** Box plots showing an average increase in translation of 8.4 mm (SD = 3.3 mm; 95 % CI = 7.1–9.7 mm) during the pivot shift test after sectioning the ACL



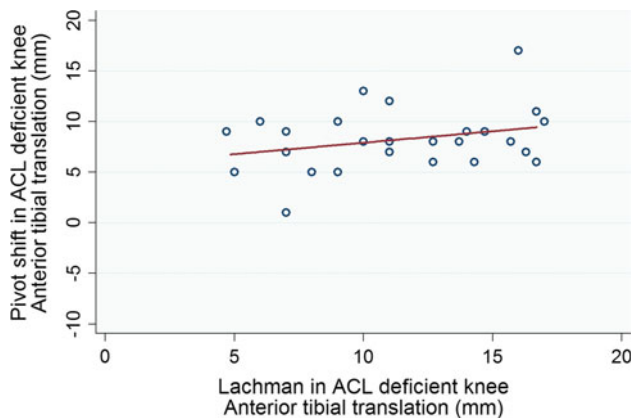
**Fig. 5** No correlation in the magnitude of anterior tibial translation in the ACL-intact knees was seen between the Lachman and pivot shift tests (Cronbach's  $\alpha = -0.70$ ;  $r = 0.07$ ,  $P > 0.05$ )

#### Correlation between Lachman and pivot shift tests

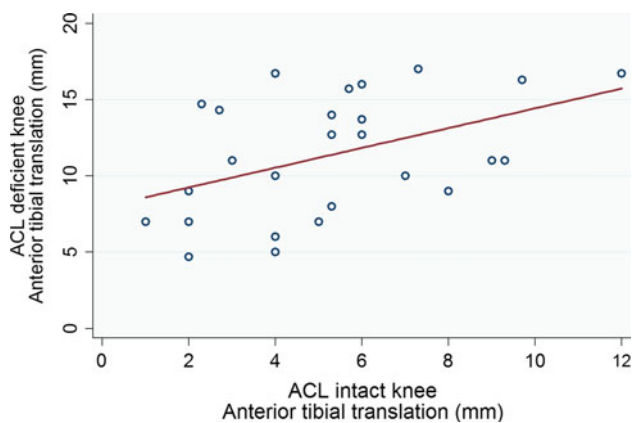
No correlation was seen between the Lachman and the pivot shift in either the intact (Cronbach's  $\alpha = -0.70$ ;  $r^2 = 0.07$ , n.s.) or ACL-deficient states (Cronbach's  $\alpha = 0.44$ ;  $r = 0.08$ , n.s.) (Figs. 5 and 6). Poor correlation in the magnitude of translation between the intact and ACL-deficient knees was seen in both the Lachman (Cronbach's  $\alpha = 0.59$ ;  $r = 0.21$ ,  $P < 0.05$ ) and pivot shift (Cronbach's  $\alpha = 0.52$ ;  $r = 0.13$ , n.s.) (Figs. 7 and 8).

#### Discussion

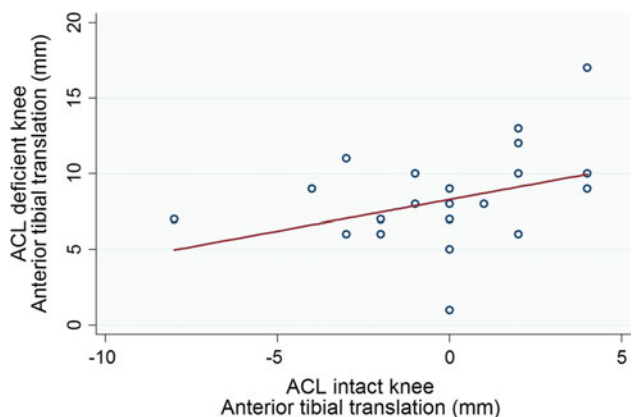
The most important finding of the current study was the establishment of normative values for the magnitude of ATT in the Lachman and pivot shift tests in the intact and ACL-deficient states. Prior work by Bedi et al. [2] established good correlation between the magnitude of lateral



**Fig. 6** No correlation in the magnitude of anterior tibial translation in the ACL-deficient knees was seen between the Lachman and pivot shift tests (Cronbach's  $\alpha = 0.44$ ;  $r = 0.08$ ,  $P > 0.05$ )



**Fig. 7** There was poor correlation in the magnitude of anterior tibial translation between the intact and ACL-deficient knees in the Lachman test (Cronbach's  $\alpha = 0.59$ ;  $r = 0.21$ ,  $P < 0.05$ )



**Fig. 8** There was poor correlation in the magnitude of anterior tibial translation between the intact and ACL-deficient knees in the pivot shift test (Cronbach's  $\alpha = 0.52$ ;  $r = 0.13$ ,  $P > 0.05$ )

compartment translation and the clinical grade of the pivot shift. The data from that study demonstrated that 6–7 mm of lateral compartment translation is required for a grade 1 clinical pivot shift, approximately 15 mm for a grade 2 and greater than 20 mm for a grade 3 pivot shift [2]. This study demonstrated that isolated ACL transection results in an average of 8.4 mm of lateral compartment translation during a controlled pivot shift manoeuvre, achieving the threshold for a grade 1 pivot. Of the 26 knees, only one knee approached the magnitude of translation that correlates with a grade 2 clinical pivot. These data suggest that grade 2–3 pivot shift examinations, which are commonly encountered clinically, often involve more extensive soft tissue or bony perturbations than a simple rupture of the ACL.

A surprising finding of this study is that the intact knee laxity does not predict the magnitude of the pivot shift or the Lachman after ACL transection. The fact that no correlation was found suggests that other factors such as bony morphology may determine the magnitude of the pivot shift after ACL injury. Previously, it was reported that the lateral meniscus is an important secondary restraint to the pivot shift; [17] loss of the lateral meniscus increased translation during the pivot shift by approximately 6 mm. Taken together with our current data, this suggests that the magnitude of the pivot shift in the clinical scenario may be much more beholden on associated soft tissue injury rather than inherent ligamentous laxity.

Markolf et al. [16] recently investigated the relationship between the pivot shift and Lachman tests in a cadaveric model. The data from our current study agree with the finding that the pivot shift and Lachman are poorly correlated tests as the degree of laxity of one does not correspond to the magnitude of laxity of the other. Taken together, these data suggest that the Lachman or KT-1000 cannot be used as a surrogate for the pivot shift examination as the magnitude of the Lachman did not predict the magnitude of the pivot shift.

Prior studies have established that the Lachman is a better qualitative than quantitative assessment of laxity and clinically varies between examiners [3, 10, 14, 16]. Findings have been similar with the pivot shift test [9, 12, 15, 16]. Our mechanized model provides a reproducible and reliable measure of the magnitude of translation but we recognize that there are limitations to how our findings can be translated clinically.

There are several limitations of this study. The cadaveric model used may not directly mimic the clinical scenario of an ACL-deficient knee. The influence of bony morphology on the magnitude of the pivot shift or the Lachman was not evaluated in this study. Clinically, the contribution of muscle forces may limit the utility of using normative stability values generated from cadaveric specimens.

Finally, as mentioned previously, an isolated ACL transection model may not reproduce the soft tissue damage incurred with a clinical subluxation of the knee that results in an ACL tear.

## Conclusion

No correlation was found between the Lachman and pivot shift test in the intact and ACL-deficient knee. The data suggest that the Lachman and pivot shift measure two distinct phenomena. As such, the Lachman cannot be used as surrogate for the pivot shift examination.

**Conflict of interest** The authors declare that they have no conflict of interest.

## References

- Bach BR Jr, Warren RF, Wickiewicz TL (1988) The pivot shift phenomenon: results and description of a modified clinical test for anterior cruciate ligament insufficiency. *Am J Sports Med* 16(6):571–576
- 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
- Benvenuti JF, Vallotton JA, Meystre JL, Leyvraz PF (1998) Objective assessment of the anterior tibial translation in Lachman test position. Comparison between three types of measurement. *Knee Surg Sports Traumatol Arthrosc* 6(4):215–219
- Bland JM, Altman DG (1997) Cronbach's alpha. *BMJ* 314(7080):572
- Citak M, Suero EM, Rozell JC, Bosscher MR, Kuestermeyer J, Pearle AD (2011) A mechanized and standardized pivot shifter: technical description and first evaluation. *Knee Surg Sports Traumatol Arthrosc* 19(5):707–711
- Gadikota HR, Seon JK, Chen CH, Wu JL, Gill TJ, Li G (2011) In vitro and intraoperative laxities after single-bundle and double-bundle anterior cruciate ligament reconstructions. *Arthroscopy* 27(6):849–860
- Galway HR, MacIntosh DL (1980) The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. *Clin Orthop Relat Res* 147:45–50
- Hoshino Y, Araujo P, Ahlden M, Moore CG, Kuroda R, Zaffagnini S, Karlsson J, Fu FH, Musahl V (2012) Standardized pivot shift test improves measurement accuracy. *Knee Surg Sports Traumatol Arthrosc* 20(4):732–736
- Hoshino Y, Kuroda R, Nagamune K, Yagi M, Mizuno K, Yamaguchi M, Muratsu H, Yoshiya S, Kurosaka M (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
- Hurley WL, Boros RL, Challis JH (2004) Influences of variation in force application on tibial displacement and strain in the anterior cruciate ligament during the Lachman test. *Clin Biomech (Bristol, Avon)* 19(1):95–98
- Jakob RP, Staubli HU, Deland JT (1987) Grading the pivot shift. Objective tests with implications for treatment. *J Bone Joint Surg Br* 69(2):294–299
- Lane CG, Warren R, Pearle AD (2008) The pivot shift. *J Am Acad Orthop Surg* 16(12):679–688
- Lin HC, Chang CM, Hsu HC, Lai WH, Lu TW (2011) A new diagnostic approach using regional analysis of anterior knee laxity in patients with anterior cruciate ligament deficiency. *Knee Surg Sports Traumatol Arthrosc* 19(5):760–767
- Logan MC, Williams A, Lavelle J, Gedroyc W, Freeman M (2004) What really happens during the Lachman test? A dynamic MRI analysis of tibiofemoral motion. *Am J Sports Med* 32(2):369–375
- Lopomo N, Zaffagnini S, Bigozzi S, Visani A, Marcacci M (2010) Pivot-shift test: analysis and quantification of knee laxity parameters using a navigation system. *J Orthop Res* 28(2):164–169
- Markolf KL, Jackson SR, McAllister DR (2010) Relationship between the pivot shift and Lachman tests: a cadaver study. *J Bone Joint Surg Am* 92(11):2067–2075
- 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
- Musahl V, Voos J, O'Loughlin PF, Stueber V, Kendoff D, Pearle AD (2010) Mechanized pivot shift test achieves greater accuracy than manual pivot shift test. *Knee Surg Sports Traumatol Arthrosc* 18(9):1208–1213
- Suero EM, Citak M, Choi D, Bosscher MR, Pearle AD, Plaskos C (2011) Software for compartmental translation analysis and virtual three-dimensional visualization of the pivot shift phenomenon. *Comput Aided Surg* 16(6):298–303
- Torg JS, Conrad W, Kalen V (1976) Clinical diagnosis of anterior cruciate ligament instability in the athlete. *Am J Sports Med* 4(2):84–93