

Novel Knee Arthrometer for Quantifying Lateral Compartment Translations During a Simulated Clinical Pivot Shift

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INTRODUCTION: The pivot shift maneuver is a common clinical exam that is used to diagnose injury to the anterior cruciate ligament (ACL) and is related to clinical outcome following ACL reconstruction [1]. This maneuver requires the examiner to apply a complicated sequence of multiplanar loads to the knee while qualitatively assessing the magnitude of the ensuing tibiofemoral translations and rotations. The degree of tibiofemoral subluxation is then subjectively graded by the examiner using an ordinal scale with four levels [2]. Despite its high specificity in diagnosing ACL rupture, the exam is unstandardized and qualitative with limited reliability making it examiner dependent [2]. As such, researchers have developed tools to objectively quantify the exam. These tools fall into several categories: (1) uniaxial arthrometers constrained to a single rotational degree of freedom, incapable of applying the multiplanar loads of the exam [3]; (2) multiplanar arthrometers or robotic systems whose technological complexity may impede clinical translation [4]; and (3) motion sensors affixed to the tibia and femur that quantify knee kinematics during the exam, but do not control the applied loads [5]. To overcome these limitations, we developed a multiplanar arthrometer that allows an examiner to manually apply key loads of the pivot shift exam while recording the resulting tibiofemoral kinematics [6]. This study had three objectives: (1) to quantify the safety of our device; and regarding the measured tibiofemoral kinematics (2) to assess the level of left-right symmetry; and (3) to characterize their reliability.

METHODS: The custom-designed arthrometer utilized an instrumented linkage with five degrees of freedom (DOF) (Fig. 1). Applied forces and moments were measured using a six DOF load cell (ATI, Inc), which was fixed to the arthrometer behind the subject's proximal tibia. To conduct a test, the subject sat reclined in a chair, their leg was aligned in the arthrometer at 20° of flexion, the femur was fixed to the chair, and the tibia was fixed to the arthrometer with controlled forces ranging from 90 to 133 N via ratcheting mechanisms. With IRB approval, a simulated pivot shift was performed on 20 healthy, uninjured volunteers (10 male, 10 females; mean age: 28 ± 6 years). To perform the simulated pivot shift, the examiner first applied a valgus moment of 8 Nm to the knee. While holding this valgus moment constant, the examiner then applied five cycles of anterior-posterior (AP) force from -10 posterior to 50 N anterior via the lateral handle of the arthrometer to subluxate and reduce the lateral compartment of the tibia. The primary outcome measure was AP translation of the lateral tibial compartment because it is associated with the grade of the pivot shift [7]. To maximize AP translation of the lateral tibial compartment, the medial handle was locked to fix the axis of rotation about the medial side of the knee. To achieve our first objective, safety was quantified using a visual analog pain scale from 0 (no pain) to 10 (unbearable pain). Regarding our second objective, left and right leg symmetry was quantified via mean left-right difference in lateral compartment translations. Outcomes for objectives one and two were expressed as means and standard deviations (SD). To achieve our third goal, two examiners conducted two independent tests on both the right and left knees of each volunteer with the patient exiting the chair between each test. Reliability of the measured lateral compartment translations within a single test and within (intra) and across (inter) examiners was characterized via intra-class correlation coefficients (ICC) and their 95% confidence intervals (CI).

RESULTS: All 20 volunteers successfully completed the entire protocol with a mean pain score of 1.1 ± 0.9. Lateral compartment translations averaged 13.8 ± 1.8 mm. Concerning left-right symmetry, the mean side-to-side difference was -0.4 ± 1.3 mm (Fig. 2). The intra-test reliability of the simulated pivot shift was excellent (0.90) (Table 1). Both intra- and inter-examiner reliabilities were good (ICC ≥ 0.61).

DISCUSSION: Our novel arthrometer can safely measure AP translations of the lateral tibial compartment in response to multiplanar loads simulating a clinical pivot shift exam with good to excellent reliability (Table 1). Importantly, applying standardized, controlled loads eliminates a key source of uncertainty that likely contributes to suboptimal reliability of the clinical exam. Lateral compartment translations were about 70% (13.8 vs 19.4 mm) of those measured under similar loads in a controlled cadaveric study [8]. Greater translations in cadaveric models are expected given resection of surrounding musculature and soft tissues including the iliotibial band, a known rotational constraint. The variability in left-right symmetry in our healthy cohort (SD: 1.3 mm) is 4-fold less than the increase in lateral compartment translation corresponding to an increase in pivot shift grade (6 mm) [1]. Therefore, using left-right differences, our novel arthrometer may have greater resolution to detect preoperative knee instability and postoperative ACL graft failure than the currently used ordinal classification system.

SIGNIFICANCE/CLINICAL RELEVANCE: Our novel device is safe and showed promising reliability for a simulated pivot shift. The uncertainties in left-right symmetry were small enough to potentially distinguish distinct pivot shift grades and may be useful in injury diagnosis and surgery indications.

REFERENCES: [1] Magnussen 2016 AJSM [2] Lane 2008 J Am Acad Orthop Surgery [3] Daniel 1985 AJSM [4] Hull 1991 JBiomech [5] Musahl 2020 Sports Med Arthrosc Rev [6] Kanamori 2000 J Arthroscopy. [7] Bedi 2010 KSSTA. [8] Noyes 2014 AJSM.

ACKNOWLEDGEMENTS: Clark and Kirby Foundations, Gosnell Family, Surgeon-in-Chief Fund, Stott Family, KL2TR002385, Ludwig Family

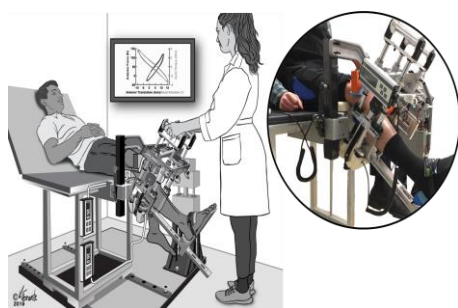


Figure 1: Knee arthrometer used to assess the simulated pivot shift exam.

Table 1: Reliability of the simulated pivot shift reported as ICC's and their 95% confidence intervals in brackets.

Examiner	Simulated Pivot Shift ICC's	
	1	2
Intra-Test	0.9 [0.85, 0.93]	
Intra-Examiner	0.67 [0.46, 0.81]	0.74 [0.56, 0.86]
Inter-Examiner	0.61 [0.37, 0.77]	

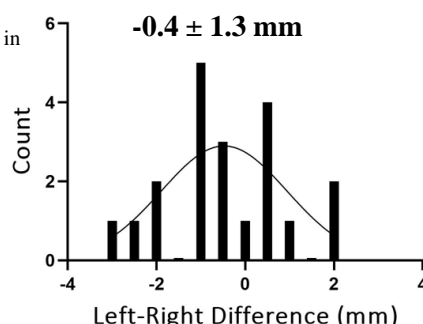


Figure 2: Histogram of left-right difference in lateral compartment translation of the pivot shift.