Comparison of a Novel Arthrometer to Measure Anterior-Posterior Laxity to the KT-1000

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INTRODUCTION: Anterior cruciate ligament (ACL) rupture is a debilitating and costly knee injury that is common among young athletes and military personnel [1,2]. ACL injury is diagnosed via physical examination of the knee including a subjective assessment of anterior-posterior (AP) laxity via the Lachman test. In addition to its diagnostic utility, increased AP laxity is related to heightened risk of first-time noncontact ACL injury while excessive preoperative side-to-side differences in AP laxity are related to increased risk of ACL graft failure [3]. Unfortunately, the physical exams used to assess AP laxity are both subjective and examiner dependent. Therefore, many custom-built and commercial devices have been developed to objectively quantify this measure. One of the most widely used arthrometers is the KT-1000 [4]; however, this device is no longer commercially available. To address this need, we developed a novel multiplanar arthrometer capable of measuring AP laxity. Given the KT-1000's historical ubiquity, we wished to establish the level of agreement between it and our device. Our custom arthrometer also attempts to correct for some of the soft tissue artifacts present in clinical laxity measurements. This study had three objectives: 1) to describe a novel method to correct for soft tissue artifact while measuring AP laxity; 2) to compare AP laxity from our arthrometer to laxity measured by the KT-1000; and 3) to compare left-right differences as obtained from our device to those of the KT-1000. We hypothesize that laxity measures from our arthrometer and from the KT-1000 will be correlated.

METHODS: With IRB approval, eight healthy, uninjured volunteers (5 males, 3 females; mean age: 31 ± 7 years) with no prior knee injuries were enrolled. Our custom-designed knee arthrometer integrated an instrumented linkage with five degrees of freedom and measured translations and rotations in response to applied forces and moments (Fig. 1). The applied loads were measured using a six-axis load cell (Mini58, ATI, Inc), which was fixed to the arthrometer. To conduct a test, the subject sat reclined in a chair, their leg was aligned and oriented at 20° of flexion, and via fixation mechanisms the femur was affixed to the chair and the tibia was secured to the arthrometer. After three preconditioning cycles, the examiner manually applied four cycles of AP forces (-60 N posterior to 105 N anterior). Two examiners each conducted two independent tests on both left and right knees, and laxity was reported as the average from all tests for each leg. Regarding objective one, a patient-specific method of correcting for soft tissue displacement in the AP direction was implemented. The fixation clamps were instrumented with custom force and position sensors with continuous data acquisition during fixation and testing. The correction algorithm consists of five steps: 1) Fit the loading and stress relaxation responses at both fixation sites to a Kelvin model standard linear solid (SLS); 2) Record the changes in fixation force during the test caused by AP loading; 3) Convert the changes in fixation force into stress exerted on the soft tissue; 4) Calculate a continuous estimate of soft tissue displacement using linear viscoelastic theory [5] and the outputs of steps one and three; 5) Subtract these displacements at the thigh and calf from the measured displacement, yielding the estimated bony displacement. In addition to being tested in our arthrometer, all volunteers were tested via KT-1000 by a licensed physical therapist with 30 years of experience using the device. The KT-1000 testing was performed at 30° of flexion, and the therapist manually applied AP forces (-60N posterior to 105 N anterior). Regarding objective two, AP laxity from our arthrometer from both left and right knees (yielding 16 total measurements) was related to AP laxity from the KT-1000 via simple linear regression ($\alpha = 0.05$). Concerning objective three, side-to side difference in AP laxity as measured using our device and using the KT-1000 were also related via simple linear regression. All regression coefficients (β) and their 95% confidence intervals and p-values were reported as were the coefficients of determination (R^2).

RESULTS: AP laxity measured with our arthrometer and the KT-1000 averaged 18.1 ± 3.4 mm and 14.9 ± 2.7 mm, respectively. AP laxity from our arthrometer and the KT-1000 were positively correlated ($\beta = 0.8 \pm 0.3$, $p = 0.01$, $R^2 = 0.4$) (Fig. 2). Similarly, there was a positive correlation in the left-right difference of AP laxity between the arthrometer and the KT-1000 ($\beta = 0.9 \pm 0.3$, $p=0.01$, $R^2 = 0.7$) (Fig. 3).

DISCUSSION: Our most important finding was that measurements of both AP laxity and left-right differences in AP laxity using our novel arthrometer were positively correlated with the KT-1000; thus, we accepted our hypothesis. This finding suggests that our custom-made arthrometer is a suitable clinical surrogate for the KT-1000. This finding is important because the KT-1000 is no longer commercially available nor is there access to maintenance or calibration resources. Therefore, alternatives are needed. Even though our device includes a mechanism to correct for soft tissue artifact, AP laxity as measured by our device still exceeded that of the KT-1000. A β value of 0.8 indicates that the KT-1000 measured about 20% less AP laxity than our arthrometer on average. This may indicate that our correction method is too conservative, as previous work has shown that the translations measured by the KT-1000 were 25-65% greater than the bony translations [6,7]. Therefore, direct measurement of the bony translations via biplanar radiography may be a "gold standard" method for calibrating our soft tissue correction.

SIGNIFICANCE/CLINICAL RELEVANCE: Measures of AP laxity made using a custom arthrometer are related to the KT-1000. Therefore, this new arthrometer may be a suitable alternative to the KT-1000, which is no longer commercially available.

REFERENCES: [1] Sanders 2016 AJSM [2] Owens 2007 Oxford [3] Magnussen 2016 AJSM [4] Daniel 1985 AJSM [5] Bartel 2006 Orthopaedic Biomechanics: Mechanics and design in musculoskeletal systems. [6] Fleming 2002 JOR [6] Staubli 1991 AJSM

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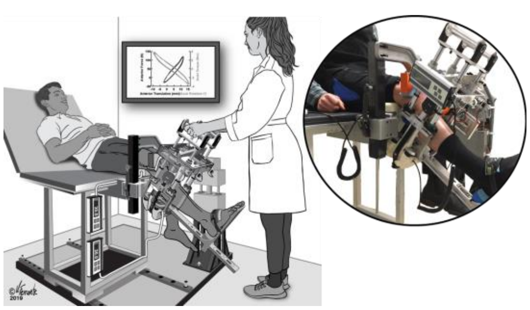

Figure 1: Custom knee arthrometer used to assess AP laxity

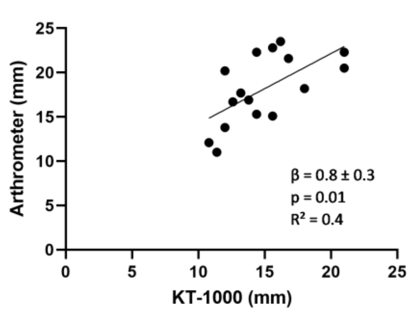

Figure 2: Scatterplot comparing AP laxity from the KT-1000 to the arthrometer measures.

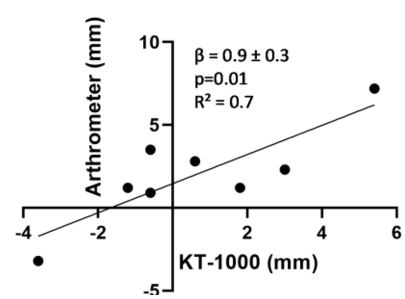

Figure 3: Scatterplot comparing left-right difference of AP laxity from the KT-1000 to the arthrometer measures.