Utility of Instrumented Knee Laxity Testing in Diagnosis of Partial Anterior Cruciate Ligament Tears

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Introduction: Over 125,000 anterior cruciate ligament (ACL) injuries occur annually in the United States, mainly affecting the young athletic population [1]. Partial ACL tears have been reported to account for 10% to 42% of all ACL tears [2]. Several studies have shown that progression to complete rupture is a common outcome for patients who desire to return to an active lifestyle [3]. Clinical diagnosis of the partial tears and their severity is important for the individual’s prognosis and course of treatment. Physical examination is the routine procedure to diagnose patients’ knees with compromised ACL integrity [4]. While the clinical utility of knee laxity assessment (i.e. Lachman and pivot shift tests, and arthrometry) in diagnosis of complete ACL tears has been widely studied [4], the sensitivity and ability of knee laxity testing in diagnosis of partial ACL tears remains unclear. Few studies have tried to investigate the clinical utility of knee laxity assessment using arthrometry to diagnose partial ACL tears [5-6]. However, these prior studies were limited to low sample size with high variability between the subjects and absence of the ability to conduct parametric analysis. In contrast, a modeling study can be used to examine the effect of various partial ACL injuries on the mechanical characteristics of the injured knee in a precisely controlled parametric setting. The purpose of this study was to use a validated Finite Element (FE) model of the knee joint to investigate the changes in knee arthrometry outcome (force-displacement) for different levels of partial ACL tear, simulating the instrumented knee laxity test using KT knee arthrometer.

Methods: A validated, anatomic non-linear FE model of the knee joint developed from imaging data of a young female athlete was utilized for this study (Figure 1)[7]. The model consists of 3D representations of the lower extremity bony structure, in addition to soft tissue structures of the knee joint, including major ligaments, trans-knee muscles, articular cartilage and menisci. The model was extensively validated against cadaveric measurements of tibiofemoral kinematics, ACL and MCL strains, and tibiofemoral cartilage pressure over a wide range of static, quasi-static and dynamic loading conditions [7]. A total of 9 cases of partial ACL tears were simulated based on 3 tear lengths (25%, 50% and 75% of ACL width in sagittal plane) and 3 tear locations (near femoral insertion, mid-substance and near tibial insertion). The FE outcomes of partial ligament tear models were compared against data of ACL-intact and ACL-deficient models. The knee arthrometry was simulated by applying cyclic of A-P shear loads (±134 N) to tibial tubercle with the knee at 25° of flexion and neutral alignment in frontal and axial planes [4]. The tibial rotation in axial plane was constrained based on standard knee arthrometry procedure [4]. The anterior tibial translation and ACL strain values under ACL-intact conditions were subtracted from the corresponding values for all other ACL injured simulations. The data under 0-134 N anterior shear force was used for final analysis. A general linear model was used to investigate the effect
of tear severity (depth) and location on increased anterior tibial translation and ACL strain under 134 N of anterior shear load.

**Results:** Simulated anterior shear load of 134 N resulted in 6.1 mm of anterior tibial translation and 5.3% ACL strain. The complete ACL tear (ACL-deficient model) showed a 4.1 mm increase in anterior tibial translation compared to the ACL-intact situation (Figure 2). The simulated partial ACL tears resulted in substantial increases in both the anterior tibial translation (by 3.2 mm) and ACL strain (by 2.4%) compared to the ACL-intact model. These maximum increases in anterior tibial translation and ACL strain were obtained under the simulated partial ACL tear of 75% of the ACL width in the mid-substance of the ACL (Figure 2). The minimum increases in anterior tibial translation (by 0.5 mm) and ACL strain (by 0.3%) were observed in the model with a simulated partial ACL tear of 0.25x width near the ACL femoral insertion site (Figure 2). Under 134 N of anterior shear load, the change in ACL tear length was responsible for a maximum of 2.4 mm increase in anterior tibial translation and a maximum of 1.8% increase in ACL strain (Figure 3). Increased in ACL tear severity (tear depth) was a significant predictor of the knee arthrometry outcomes and resulted in significant increase in both the anterior tibial translation (p=0.001) and ACL strain (p=0.002; Figure 3). Under 134 N of anterior shear load, the change in ACL tear location was responsible for a maximum of 1.2 mm increase in anterior tibial translation and a maximum of 0.9% increase in ACL strain (Figure 3). Although the tear location resulted in changes in both the anterior tibial translation and ACL strain, these changes were minimal and not statistically significant (ATT: p=0.760; ACL strain: p=0.729).

**Discussion:** Nine types of partial ACL injuries with 3 different tear depths (representing a range of tear severity) in 3 different locations across the ligament were simulated. The current findings indicated that the ability of the instrumented knee laxity testing (knee arthrometry) to diagnose partial ACL tear is significantly dependent upon the severity of the tear and is minimally affected by tear location. These findings further indicated that trivial to mild partial ACL tears (tear depth <50%) result in minor changes to anterior knee laxity (<1 mm) with respect to the ACL-intact knee, which makes it challenging to be diagnosed with knee arthrometry. On the other hand, the more severe partial tears (tear depth ≥50%) may be potentially diagnosed with knee arthrometry, as they result in major changes in anterior knee laxity (≥ 1mm). However, in more severe cases, the change in anterior knee laxity with respect to ACL-intact condition can be quite close to those changes observed under complete ACL tears, making it challenging for the clinician to distinguish between partial and complete ACL rupture based on knee arthrometry outcomes. Given the substantial compromise in the joint stability in these cases, further MRI imaging and arthroscopic observations may be required to confirm the state of ACL integrity and potential treatment course. Finally, despite the potential clinical use of knee arthrometry in diagnosis of partial ACL tears, the present findings showed that this technique may not be sufficiently sensitive to detect the location of the tear.

**Significance:** As opposed to complete ACL tears, the epidemiology of partial ACL tears is not well understood, mainly due to the challenges in their diagnosis, even with advanced imaging modalities. A misdiagnosed partial tear may lead to a complete tear if left treated, and may lead to a substantial socio-economical, as well as health related, burden in this patient population. Early diagnosis of these tears can result in significant reduction in risk of subsequent complete ACL tears, which may in turn help injured individuals to maintain an active lifestyle with the benefits of continuous sports participation and
help them to avoid long-term clinical complications associated with complete ACL tears, such as post-traumatic osteoarthritis.

Figure 1: FE model of the lower extremity [7].
Figure 2: Changes in anterior tibial translation (ATT; Top) and ACL strain (Bottom) under different simulated partial ACL tears during knee arthroscopy.
**Figure 3**: Changes in anterior tibial translation (Top) and ACL Strain under 134 N of anterior drawer load due to change in tear properties (F: femoral insertion; M: mid-substance; T: tibial insertion).

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