IS THE STRAIN CONCENTRATION AT THE FEMORAL ENTHESIS A RISK FACTOR FOR ANTERIOR CRUCIATE LIGAMENT INJURY?

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INTRODUCTION

The fibers of the anterior cruciate ligament (ACL) located near the femoral attachment (‘femoral enthesis’), especially of the posterolateral (PL) bundle, appear to be particularly prone to failure [1, 2]. The structural vulnerabilities of an enthesis with an acute “take-off” angle have been demonstrated as partial thickness rotator cuff tears, called ‘rim-rent’ tears [3], as well as the pubovisceral muscle enthesis [4], the reasons for the ACL’s susceptibility to injury near its femoral enthesis have not been investigated. Previously, we found that the majority of the knee specimens, which developed partial or complete visible ACL tears, exhibited macroscopic damages near the PL bundle of the femoral enthesis during an in vitro knee experiment [1]. Our goal here was to perform a secondary analysis on this data set to determine if the femoral enthesis angle of the ACL can explain the macroscopic damages near the PL bundle of the femoral enthesis. In addition we used a 3-D simulation of the knee and further investigated where the strain concentration occurs during a simulated pivot landing [5].

METHODS

Data from 10 pairs of knee specimens (sex: 5/5 males/females; age: 53 ± 7 years; height: 174 ± 9 cm; mass: 69 ± 9 kg) presented in Lipps et al. [1] were used for this study. As previously described [1], each knee specimen was subjected to repetitive loading that simulated a single-leg pivot landing (impulsive compression, knee flexion moment, internal tibial torque, and physiological muscle forces). From each pair, one knee was subjected to a three-time body weight loading, with the other knee subjected to a four-time body weight loading. The cyclic loading protocol ended when the ACL failed (macroscopic rupture or 3-mm increase in cumulative anterior tibial translation) or a minimum of 50 trials was collected.

Magnetic resonance (MR) images were also collected from which the ACL’s angle of origin from the distal femur (‘femoral enthesis angle’) was measured. Using an oblique-coronal view (along the longitudinal axis of the ACL) of the mid-portion of the ACL (Fig 1.a), the angle between (1) a line drawn along the edge of the lateral femoral condyle where the ACL inserts and (2) an average line of the outer edges of the proximal 25% of the ACL was calculated with custom Matlab code (Fig 1.b).

Figure 1: (a) Example of the oblique coronal plane of the mid-portion of the ACL, (b) definition of the femoral enthesis angle (a) and (c) schematic diagram of the knee model.

As previously described [5], a 3-D knee model (Fig 1.c) was constructed to replicate the in vitro experimental set-up using T2-weighted MR images (TR/TE: 1000/35 ms, slice thickness: 0.35 mm, FOV: 160 mm) of a male cadaveric knee. The segmented bones and ACL were treated as a rigid body and deformable body, respectively (MD...
To drive the knee model simulation, the impulsive compressive force, internal tibial torque, and knee abduction moment, measured from the *in vitro* experiment, were applied. The boundary loading condition for the ACL attachment sites was calculated using ADAMS, and then was transferred to finite element software in order to calculate the distribution of the strain throughout the model ACL (ANSYS 14, ANSYS, Inc., Canonsburg, PA).

**RESULTS AND DISCUSSION**

The femoral enthesis angles for the knee groups that exhibited either a partial tear of PL bundle near femoral enthesis or a permanent elongation were significantly smaller than for the group where the ACL did not fail (p <0.05, Fig 2).

**Figure 2:** Mean (SD) femoral enthesis angles for each group that showed (left) a partial tear of PL bundle near femoral enthesis, (middle) a 3-mm permanent elongation, and (right) no failure [3]. Error bars represent +1 standard deviation. The asterisk indicates a significant difference.

The knee model simulation confirmed that the highest von Mises elastic strain occurs at the anterior margin of the origin of the PL bundle of the ACL femoral enthesis. Contours of von Mises elastic strain are shown when the AM-ACL relative strain reaches its peak value at ~65 msec during a simulated pivot landing (Fig 3).

**CONCLUSIONS**

1. A smaller femoral enthesis angle is a significant predictor of *in vitro* ACL injuries.
2. The anterior margin of the origin of the PL bundle of the ACL femoral enthesis appears to be prone to injury because it exhibits the highest ACL strain concentration during a simulated pivot landing.

**REFERENCES**

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