Relation of Knee Extensor Moment Arm and Patellar Tendon Angles to Anterior Cruciate Ligament Injury Risk in Females

INTRODUCTION
Anterior cruciate ligament (ACL) injuries occur frequently in the athletic population, leading to early arthritis and a significant financial burden on the healthcare system. Recent studies have highlighted various anatomic features of distal femoral and proximal tibial anatomy as risk factors for ACL injury, including the posterior slope of the tibial plateau, the depth of the medial plateau, femoral notch stenosis, and a ridge within the femoral notch.

The quadriceps and the moment it generates through the patellar tendon and extensor moment arm also play a key role in ACL injury. Strong eccentric contraction of the quadriceps has been reported as a risk factor for ACL injury. The interaction of quadriceps and hamstring contractions in “quadriceps-dominant” knees has also been related to an increased risk of ACL injury. Internal tibial torque has been shown to increase anterior translation of the tibia, and a combination of valgus and internal tibial torques contributes to greater ACL strain than either torque in isolation. These biomechanical factors relating the action of the quadriceps, patellar tendon, and moment arm to tibial translation and rotation appear to be critical components of noncontact ACL injury, but their relation to the underlying anatomic risk factors is unclear.

In this study, the patellar tendon extensor moment arm, the sagittal patellar tendon angle (SPTA), and the coronal patellar tendon angle (CPTA) were measured (see Figure). The primary goal of this study was to investigate the relationship between the extensor moment arm and the orientation of the patellar tendon with the risk of sustaining a noncontact ACL injury. This study tested the hypothesis that the uninjured knees of ACL injured subjects would have 1) a shorter extensor moment arm, resulting in greater quadriceps force, 2) a greater SPTA, resulting in greater anterior tibial translation, and 3) a greater CPTA, causing in increased internal rotation compared to uninjured controls.

METHODS
This study utilized a matched case-control design and was approved by the Institutional Review Board. MRI scans of 35 uninjured female knees (ages 12-24 years) who had sustained a first-time non-contact ACL injury and 35 uninjured female control subjects matched by age and sports team were obtained. MRI data were obtained with knees in full extension using a Phillips Achieva 3.0T MRI system (Fletcher Allen Healthcare, Burlington, VT). The T2-weighted sagittal DICOM images were digitized using Osirix software (Pixmeo, version 3.6.1) and a Cintiq 21UX digitizing tablet (Wacom, 2010).

For comparison of the extensor moment arms, the articular surfaces of the most spherical portion of the medial and posterior femoral condyles were digitally segmented from sagittal MRI slices. The best-fit spheres were matched to this data using custom Matlab code (MathWorks, Natick, MA, USA). A line was plotted through the center of the spheres to approximate the flexion/extension axis of rotation of the tibiofemoral joint. The borders of the patellar tendon were also segmented in the axial view for the length of the tendon from its origin at the inferior pole of the patella to the tibial tuberosity. Using Matlab, the centroid of each axial tendon outline was found and a best-fit line was drawn through the centroids. This defined the patellar tendon’s line of action. The extensor moment arm was measured as the shortest distance between the axis of rotation and the patellar tendon line of action (Figure 1). This distance was compared between cases and controls using a paired students t-test.

The sagittal patellar tendon angle (SPTA) was defined as the acute angle between the long axis of the tibial shaft and the patellar tendon line in the sagittal plane. The coronal patellar tendon angle (CPTA) was defined in the same way in the coronal plane. A reproducibly accurate MRI digitization scheme of the proximal tibia provided the long tibial shaft axis, and the method described above produced the patellar tendon line. These angles were calculated in MatLab and comparisons were made between the case subjects and their matched controls.

RESULTS
No statistically significant differences existed between the extensor moment arms observed in the cases and controls. For the 35 matched pairs, the average extensor moment arm was 50.9 mm (σ=3.0mm), and the average difference between cases and controls was 1.0 mm (p=0.15).

Statistically significant differences between cases and controls were noted, however, for both the SPTA and the CPTA. The average SPTA was 26.0° (σ=3.6°) and the average difference between case subjects and controls was 2.5° (p=0.005). The average CPTA was 6.5° and the average difference was 2.1° (p=0.02). For both measurements, the case subject’s angle was smaller than the control subject’s angle.

DISCUSSION
Our initial hypothesis proposed that the patellar tendon extensor moment arm would be shorter for the injured subjects. By acting through a shorter extensor moment arm, it was thought that the quadriceps would generate a greater force to support a given body weight with the knee in near-extension, and this would result in greater ACL strain values. The results of this study, however, show no difference between the extensor moment arms of the ACL-injured case subjects and their case-matched controls.

We had hypothesized that the SPTA and the CPTA would be larger in injured subjects. Our findings, however, demonstrated the opposite finding: these angles were significantly smaller. We proposed that an increased SPTA would cause increased anterior tibial translation with quadriceps contraction, and an increased CPTA would produce increased internal tibial rotation with quadriceps contraction. The findings of this study suggest another framework for understanding ACL injury mechanism based upon these observed anatomic differences. It is possible that subjects with greater patellar tendon angles may have improved bony, cartilaginous, or soft tissue restraints to anterior tibial translation and internal rotation since their knees experience these motions to a greater degree with each quadriceps contraction and may remodel accordingly. These restraints may allow patients to be better equipped to avoid ACL injury than subjects with a more “vertically aligned” patellar tendon. More research in this area is needed to more fully understand the complex knee biomechanics related to ACL injury.

SIGNIFICANCE
Correctly identifying anatomic factors and their correlation with knee biomechanics of individuals at risk for ACL injury may help with the development of targeted prevention strategies to decrease the overall incidence of ACL injury and its long-term sequelae.

REFERENCES

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