ACL STRAINS ARE INFLUENCED BY DECELERATION FORCES DURING ACTIVITIES ASSOCIATED WITH ACL INJURY

*Chaudhari, A M; **Shin, C S; ***Andriacchi, T P; ****Withrow, T J; ***Ashton-Miller, J A; ***Wojty, E M; ***Huston, L J
**Stanford University, Stanford, CA
ajt.chaudhari@stanford.edu

INTRODUCTION:
Anterior cruciate ligament (ACL) injuries occur frequently while landing on a single limb from a jump, pivoting, or stopping abruptly from a run with the knee near full extension (1). The impact force of landing is often accompanied by a posterior tibial force associated with decelerating the body’s forward motion. One explanation for ACL injury during landing is that anterior tibial translation caused by quadriceps contraction causes ACL rupture (2). However, this explanation does not take into account the potential for the external posterior force on the tibia due to landing. Counteracting the anterior pull of the quadriceps mechanism. Thus, understanding the influence of the posterior force on the limb during landing is important for addressing the cause of ACL rupture.

This study conducted an analysis of the relationship between the external posterior force on the tibia during landing with deceleration and the strain in the ACL. The study combined in vivo measurements, a cadaver model and a simulation model.

METHODS:
A specimen-specific simulation model was developed using experimental test data from an instrumented cadaver knee. The knee was scanned using MRI, then tested under impact loading while applying and measuring muscle loadings for the quadriceps, medial and lateral hamstrings, and medial and lateral gastrocnemius. Initial muscle loads were chosen to hold the knee at 25° of flexion before applying the impact load. An implanted DVRT strain transducer on the anteromedial bundle of the ACL provided actual ACL strain data for this specimen. The MRI scans were then segmented to create a specimen-specific simulation model of the tibiofemoral and patellofemoral articulations complete with ligament insertion locations. The model included the ACL (2 bundles), PCL, MCL, LCL, posterior capsule, patellar ligament, quadriceps, medial and lateral hamstrings, and medial and lateral gastrocnemius. Dynamic simulations of impact loading were performed using MSC.ADAMS (MSC Software, Santa Ana, CA). Ligament properties were adjusted to calibrate the simulation to the cadaver tests, ensuring that the simulation and experimental tests gave similar kinematic and ACL strain results under the same loading conditions.

A parametric simulation study was used to test the influence of increasing external posterior force on the proximal tibia in 5% increments from 0% to 30% of the vertical impact force, applied at the midpoint of the trans-tibial line. In vivo measurements from a previous study (3) were used to determine the ratio of external posterior force to midpoint of the trans-tibial line.

RESULTS:
The theoretical simulation model output and cadaver test results compared favorably for the condition with only a vertical impact force, as exemplified by the ACL strain (Fig. 1).

The simulation model demonstrated that as the posterior force was increased, the average strain in the two bundles of the ACL decreased (Fig. 2a). This decrease was due primarily to a reduction in the strain in the posterolateral bundle of 56% when the posterior force was increased to 30% of the vertical force (Fig. 2b), while the anteromedial bundle strain remained relatively constant under all loading conditions (Fig. 2c).

DISCUSSION:
Under realistic landing conditions derived from in vivo measurements this study demonstrated that the external posterior force acting on the proximal tibia during landing significantly reduce the average strain on the ACL produced by quadriceps contraction.

The external posterior force on the proximal tibia is induced by foot-ground friction whenever whole-body forward momentum is arrested on landing. Our results suggest that it protects the ACL as long as foot-ground friction causes an adequate posterior force relative to the vertical foot reaction force. Under these conditions, it would seem unlikely that the predominant mechanism of ACL rupture in these activities is by excessive quadriceps force. Other mechanisms that are not protected against by external loading such as valgus rotation, internal tibial rotation, or a combination of both valgus and internal tibial rotation may instead be the predominant mechanisms of injury in landing and deceleration.

While there are a number of assumptions needed to conduct the simulation studies, the simulation model and the cadaver experiment were in good agreement for the condition with no posterior force, supporting the validity of the parametric study conducted with the simulation model.

This study has provided new insight into the in vivo conditions leading to non-contact ACL injury by demonstrating that it is important to include a combination of external and internal forces in order to fully represent realistic in vivo landing conditions.

REFERENCES:

AFFILIATED INSTITUTIONS FOR CO-AUTHORS:
** VA Palo Alto Rehabilitation & R&D Center, Palo Alto, CA
*** University of Michigan, Ann Arbor, MI

Figure 1. Comparison of ACL strain measured in experiment to average strain calculated in simulation.

Figure 2. Average strain (a), posterolateral bundle strain (b), and anteromedial bundle strain (c) during impact loading as external posterior force was increased from 0% of vertical force (lightest gray) to 30% of vertical force (black).