The Role of an Un-Opposed Quadriceps Force in Loading the Anterior Cruciate Ligament During Jump Landing: An In-Vitro Simulation

INTRODUCTION
It has been suggested that the application of an unopposed and large quadriceps force may result in excessive loading of the anterior cruciate ligament (ACL) and its subsequent rupture. This so-called quadriceps-pull mechanism has received significant attention as a possible sagittal plane mechanism of non-contact ACL injury. Theoretically, under the application of the quadriceps force, the patellar tendon pulls the tibia anteriorly while the patella pushes the femur posteriorly and if this action is unopposed (no hamstring force) it could result in ACL injury. This proposed mechanism has been controversial as other researchers who endorse a coronal plane mechanism of ACL injury (dynamic valgus) assert that the quadriceps pull mechanism is not viable for two reasons: 1) the suggested critical quadriceps force is too high and probably unachievable at low knee flexion angles and 2) as the quadriceps force increases, the tibia moves anteriorly but the anterior component of the patellar tendon force decreases as the tendon becomes more vertical (knee flexion angle decreases). In response, some researchers suggest that if the un-opposed quadriceps pull is superimposed on a dynamic ground reaction force (for instance during landing from a jump), then the combination may be damaging to the ACL. To address this controversy, in-vitro simulators that model specific athletic activities (such as jump landing) and integrate muscle forces may be most effective. In this study, one such simulator was used to investigate the role of an unopposed quadriceps force on ACL strain during the landing phase of a jump. We hypothesize that as quadriceps pre-activation force increases, the ACL strain increases in anticipation of landing, the pre-landing strain in the ACL increases but the strain during the actual landing phase (landing strain) decreases. We further hypothesize that the total strain in the ACL (pre-landing strain + landing strain) remains constant and is independent of the quadriceps load.

METHODS
A jump landing simulator was designed for dynamic loading of cadaveric knee joints with ability to apply dynamic muscle forces using servo-electric actuators. The system allows for the positioning of the desired anteero-posterior hip position, hip flexion angle, and knee flexion angle. A linear actuator is attached to the patella using cables and steel wires simulating the action of the quadriceps muscle. A differential variable reluctance transducer (DVRT) is mounted on the ACL to monitor strain during quadriceps pre-activation as well as during impact. An impact lever apparatus is utilized to impulsively load the tibia (upward) thus simulating the landing ground reaction force.

RESULTS
Nine frozen cadaveric knees were used for this experiment. Each knee was thawed and examined for joint disease and damage to the ligaments and the knee capsule. Each knee was placed in the simulator at a flexion angle of 20°. The ACL was instrumented with a DVRT at that position (the zero strain reference position). The QPF was increased incrementally after each test using the electric actuator attached to the patella via a steel cable that was aligned in the direction of the femur. The range of applied QPF was from 25 N to 700 N. In two knees the QPF range was extended to 1500 N. When the desired QPF level was reached, the strain in the ACL or the pre-activation strain was measured. At this point, to mimic the landing phase, the knee was loaded impulsively upward at the simulated ankle joint using the impact lever system. The strain in the ACL was also measured during the landing phase. This process simulates landing in reverse and is accepted as a viable method of landing simulation. Correlation analysis was performed for individual knees as well as the averaged response of all knees to assess the extent and nature of relationships between i) QPF vs. ACL pre-landing strain, ii) QPF vs. ACL landing strain, and iii) QPF vs. total strain (pre-landing + landing strain). The statistical significance of each correlation was assessed.

DISCUSSION
Pre-activation of the quadriceps in anticipation of landing increases the ACL pre-landing strain but it decreases the landing strain. Decreased landing strain as QPF increases is indicative of a more stable joint. The total ACL strain remains constant throughout the range of QPF. This result was observed in eight out of nine individual knees and in the averaged behavior of all knees. This suggests that each individual knee may have a “signature” for the jump landing activity. As total strain remains constant with increased QPF, it is apparent that there is no mechanism by which quadriceps could cause ACL injury during landing from a jump, even when un-opposed by other muscle forces and when aided by the ground reaction force. Although the total strain in the ACL remains constant, low QPF is more dangerous from an injury perspective. This is because under low QPF the landing strain is high. Higher ACL landing strains represent a less stable knee during the dynamic process of landing. If other factors such as inadequate response of the hip are superimposed with low QPF, the ACL may experience excessive strain and potential failure.

REFERENCES