Impact-induced Tibial Acceleration as a Mechanism for ACL Injury

INTRODUCTION
Anterior cruciate ligament (ACL) injury continues to present in epidemic proportions evoking substantial short and long-term debilitating conditions. Current efforts aimed at preventing ACL injuries focus on modifying neuromuscular control elicited during dynamic landings, as it directly influences joint mechanics and is amenable to training. Injury rates, however, have remained unchanged. We propose that by failing to consider critical additional components of the ACL injury mechanism, the current prevention model is flawed. In single-limb landings in which ACL injury is common, the large sagittal plane intersegmental accelerations arising at ground impact must be restrained by the internal joint structures and the pre-existing muscle-tendon loading across the joint. If an ineffective overarching neuromuscular strategy prevails, however, it is plausible that these accelerations may be large enough to injure the passive restraint mechanism. The purpose of this study was to demonstrate that impact-induced anterior tibial accelerations during a simulated single leg landing are directly associated with resultant peak ACL strain. Additionally, we aimed to show that this relation, and hence the potential for ACL injury via this novel mechanism is directly influenced by the posterior tibial slope.

METHODS
We have previously developed a cadaveric testing apparatus that simulates, in the presence of muscle forces, impulsive 3D loading during unipedal landings. This apparatus enables the lower extremity to be positioned (inverted) at various knee flexion angles and limb alignments, while the effects of impact-induced impulsive loads on peak relative ACL strain can be assessed (Fig. 1). Using this device, we subjected 12 female cadaveric specimens (65.3 ± 10.5 years) to five consecutive ACL strain can be assessed (Fig. 1). Using this device, we subjected 12 female cadaveric specimens (65.3 ± 10.5 years) to five consecutive impact trials at each of five knee flexion angles of 15°, 30°, 45°, 60°, and 90°, respectively. Each impact trial was designed to simulate a single leg landing, with peak anterior tibial accelerations and resultant ACL strains recorded. The impact force was applied to the tibia and femur, with the knee flexed at 90°, and the foot fixated. A miniature DVRT (Microstrain, VT) was secured to the distal third of the anteromedial bundle (AMB) of the ACL, with length changes synchronously recorded during each impact trial at 2 kHz.

RESULTS
Definitive peaks were evident in both anterior tibial accelerations (6,663.9 ± 2,748.2 mm.s⁻²) and AMB strain (4.70 ± 1.68 %) magnitudes soon after impact for all specimens (Fig 2). A mean (± SD) posterior tibial slope of 7.6 ± 2.6º was also calculated across specimens. Strong positive correlations were also observed between peak anterior tibial acceleration and strain magnitudes (R² = 0.59) and respective times to peak (R² = 0.67). Additionally, strong positive correlations were observed between posterior tibial slope and peak anterior tibial acceleration (R² = 0.59).

DISCUSSION
We have shown that impact-induced peak anterior tibial acceleration elicited during simulated sports landings is directly associated with peak AMB strain. Considering the extremely large tibiofemoral accelerations that are possible during jump landings, ACL injury via this mechanism seems feasible. Specifically, deleterious acceleration profiles likely manifest for movements with large sagittal plane decelerations and where an ineffective or delayed neuromuscular response prevails. The magnitude of the peak anterior tibial acceleration and hence the potential for ACL injury is also directly influenced by the posterior tibial slope. A larger slope orients the ACL in a more anterior-posterior direction and anteriorly shifts the point of tibiofemoral contact. In this position, the anterior shear component of the impact-induced joint reaction force will likely be larger, subsequently inducing larger anterior joint accelerations and resultant ACL loads.

The present results suggest that impact-induced anterior tibial acceleration represents a plausible mechanism of ACL injury during single leg landings. Further, the potential for injury via this mechanism appears dictated by the underlying tibiofemoral joint anatomy. Understanding relations between knee joint structure and resultant joint mechanics appears critical to elucidating and ultimately countering ACL injury risk. Consideration of individual knee joint vulnerabilities within the ACL injury prevention model is also necessarily warranted. We intend to explore more complex relationships between knee structure and 3D mechanics with the long-term goal of developing more effective ACL injury screening and prevention tools.

REFERENCES