TIBIAL ACCELERATION AND SLOPE CONTRIBUTIONS TO ACL LOADING DURING A SIMULATED LANDING IMPACT

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is a potentially traumatic injury evoking substantial short and long-term debilitation. Current efforts aimed at preventing these injuries focus on modifying neuromuscular control elicited during landings, as it is amenable to training. Injury rates, however, remain largely unchanged.[1] We propose that by failing to consider factors additionally contributing to causality, the current prevention model is flawed. In single-limb landings, the large intersegmental accelerations arising at 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, these accelerations may be large enough to compromise the passive restraint mechanism. This study aimed to demonstrate that impact-induced anterior tibial accelerations during single leg landings correlated with peak ACL strain. The impact of posterior tibial slope on this relation was additionally explored. This study was considered a critical initial step in determining whether this morphologic – mechanical interaction implicates within the ACL injury mechanism.

METHODS

An apparatus has been developed that simulates, in the presence of muscle forces, impulsive 3D loading during single limb landings (Fig 1A).[2] Using this device, 12 female cadaveric specimens (65.3 ± 10.5 years) were subjected to five consecutive impact load trials with a simulated impact load of 1299.1 ± 205.7 N. Each limb was initially fixed at 15° of knee flexion while quadriceps (180 N), hamstring (140 N), and gastrocnemius (140 N) muscle forces statically preloaded the joint. For each trial, 3D knee joint forces and moments were measured at 2 kHz via two 6 DOF load cells (AMTI, MA). Knee kinematic data were quantified based on the 3D positions of infrared (3 per segment) emitting diodes recorded at 400 Hz via a Certus system (Northern Digital, CN). Synchronous anteromedial bundle (AMB) relative strain was recorded at 2 kHz via a miniature DVRT (Microstrain, VT) inserted directly into the tissue. Lateral radiographs were taken of each specimen following testing, from which the lateral posterior tibial slope was calculated (Fig 1B).[3]

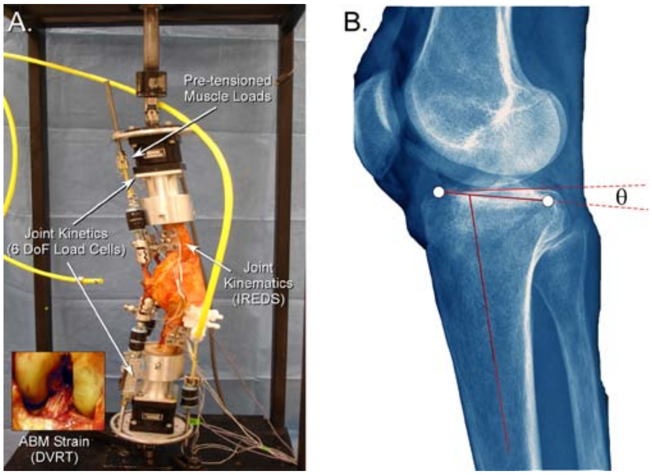

Fig 1: Knee kinetic and kinematic and AMB length changes were recorded for simulated impact trials (A). Posterior tibial slope was recorded via standard lateral radiographs (B).

Anterior tibial displacement data were filtered at 50 Hz and accelerations were quantified over the first 200 ms post-impact. Peak anterior tibial acceleration and AMB strain, the relative timings these peaks and posterior tibial slope measures obtained for all specimens were initially submitted to respective linear regression models to test for associations. Posterior tibial slope and peak tibial acceleration data were then submitted to a multiple linear step-wise regression model to examine their integrative association with peak AMB strain. Significance levels for inclusion and exclusion within this model were set at $p < 0.05$ and $p < 0.1$ respectively.

RESULTS AND DISCUSSION

Definitive peaks were evident in both tibial acceleration (7.87 ± 2.77 $m.s^{-2}$) and AMB strain magnitudes (3.35 ± 1.71 %) (Fig 2). The mean (± SD) lateral posterior tibial slope was 7.8 ± 2.1°.

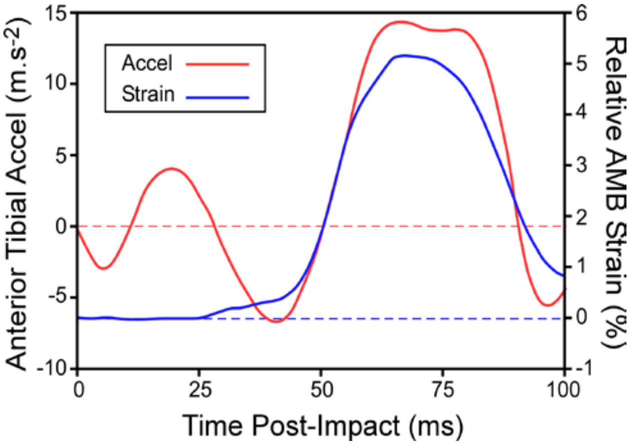

Fig 2: Sample impact-induced anterior tibial acceleration and relative AMB strain profiles.

Peak AMB strain significantly (p = 0.004) correlated with peak anterior tibial acceleration, explaining 62% of the variance (Table 1). The timing of the AMB strain peak (66 ± 4 ms) was also significantly (p = 0.001) correlated with peak tibial acceleration timing (66 ± 7 ms), explaining 67% of the variance. Peak anterior tibial acceleration was significantly (p = 0.004) correlated with posterior tibial slope, which explained 61.8% of the variance. Peak relative AMB strain also significantly (p = 0.007) correlated with posterior tibial slope, explaining 58% of the variance. Including both anterior tibial acceleration and posterior tibial slope within the step-wise regression model did not significantly (p = 0.304) improve AMB strain predictions. Specifically, the posterior tibial slope term only explained an additional 4.9% of the variance observed in AMB strain beyond that explained by peak anterior tibial acceleration alone.

We have shown that impact-induced peak anterior tibial acceleration elicited during simulated landings correlates with peak AMB strain. Considering extremely large tibiofemoral accelerations are possible during jump landings, ACL injury via this mechanism seems plausible. Impact-induced anterior tibial accelerations and hence the potential for ACL injury via this mechanism appear additionally dictated by tibiofemoral joint anatomy. Specifically, a larger posterior tibial slope appears to transfer high-rate compressive loading at impact to equally high anterior tibial shear loading rates, culminating in greater anterior tibial accelerations and AMB strains.[3] Further work is necessary to determine whether such associations extrapolate to explain actual injury causality. Current outcomes suggest improvements in ACL injury risk screening and intervention methods may be possible via non-invasive quantification of impact-induced tibial accelerations during landings. Understanding explicit relations between knee morphology and resultant joint mechanics appears equally critical to elucidating and countering the multi-factorial ACL injury mechanism. In particular, establishing prevention modalities that can successfully cater to individual joint vulnerabilities seems warranted. We intend to explore more complex relations between knee morphology and 3D mechanics with this specific goal in mind.

Table 1: Individual regression model coefficients associating peak AMB strain and peak anterior tibial acceleration, their respective timings, and lateral posterior tibial slope.

Variable / Predictor	SE	β	t	P
Peak AMB Strain / Peak Acceleration	0.000	0.787	4.041	0.004
Peak Acceleration / Tibial Slope	0.207	0.786	3.993	0.004
Peak AMB Strain / Tibial Slope	0.213	0.761	3.512	0.007
AMB Strain Timing / Acceleration Timing	0.000	0.819	4.124	0.001

CONCLUSIONS

Impact-induced peak anterior tibial acceleration is significantly correlated with peak AMB strain. This relation, and hence the potential for ACL injury via a tibial acceleration mechanism, is additionally governed by the posterior tibial slope. Improved understanding of the complex interactions between knee joint morphology and 3D knee mechanics during landings now appears warranted.

REFERENCES

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