Lateral Tibial Slope and Medial Tibial Spine Geometries Have Similar Impacts on Anterior Cruciate Ligament Force: A Sex-Specific Computational Modeling Study in 168 Athletes at the High School and College Levels

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Summary

Lateral tibial cartilage slope and medial tibial spine geometries are risk factors for ACL injury. However, their relationships with knee mechanics are not well understood. Knees from a cohort of 168 young male and female athletes (48 and 120, respectively) split between ACL-injured cases matched to uninjured controls were modeled using a computational workflow to estimate ACL force. Lateral slope was related to ACL force in both sexes; medial spine volume and AP position were related to ACL force in males and females, respectively. The relative impact on ACL force was similar for lateral slope and the medial spine geometries, indicating that both spine and slope geometries are important to consider in young male and female athletes.

Introduction

Young athletes participating in cutting and pivoting sports are vulnerable to noncontact anterior cruciate ligament (ACL) injury. Increased slope of the articular cartilage surface of the lateral tibial plateau (lateral slope) is a risk factor for non-contact ACL injury [1]. The size (spine volume) and anterior-posterior (AP) position (spine position) of the medial tibial spine are also related to injury risk [2,3]. Despite these clinical findings, how these tibial plateau geometries relate to knee mechanics is not well understood. Thus, we used imaging data from young male and female athletes and a computational knee modeling workflow to study sex-specific knee mechanics. We had two aims: 1) relate lateral slope, medial spine volume, and medial spine position to ACL force in males and females; and 2) compare the relative impact of these features on ACL force in both sexes.

Methods

Our cohort consisted of 168 high school and college athletes (120 females, 48 males) split between cases with first-time, unilateral noncontact ACL injury and uninjured controls matched by sex, age, and sports team. A previously published modeling pipeline was used to estimate ACL force [4]. Briefly, tibiofemoral bone, cartilage, and meniscal geometries were automatically segmented from magnetic resonance imaging scans. Subject-specific ligament insertions and origins were identified. Soft tissues were assigned standardized structural properties, and slack lengths were optimized [4]. Compression (100 N), a valgus moment (8 Nm), and an anterior force (30 N) were applied serially at 15° of flexion simulating a clinical pivot shift exam, and ACL force (ACLF) was measured at the peak applied load. Lateral slope (°), medial spine volume (mm^3), and medial spine position (mm) were measured using published methods (Figure 1) [2]. Relationships between geometries and ACLF were calculated using multiple linear regression and regression coefficients (β) and p-values (α = 0.05) were reported. To compare the relative impacts of knee geometries on ACL force within each sex, each regression coefficient (β) was scaled by a 2-standard deviation (SD) change for each tibial plateau geometry, respectively.

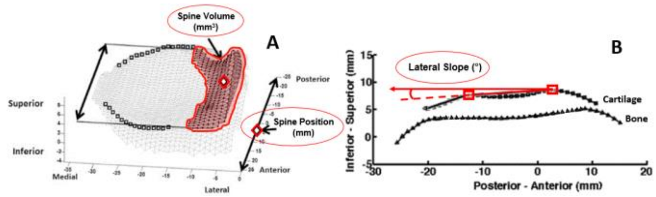

Figure 1. A) Bone volume superior to the medial tibial plateau rim is medial spine volume, and its anterior-posterior position is spine position. B) Lateral tibial articular cartilage slope is measured at the sagittal slice with the maximum depth of lateral cartilage concavity.

Results and Discussion

Increased lateral slope was associated with greater ACLF in both females ($p<0.001$) and males ($p=0.01$) (Table 1). A more anteriorly positioned medial spine was associated with lower ACLF in females ($p=0.002$), while larger medial spine volume was associated with lower ACLF in males ($p=0.03$). In females, the impact of a 2-SD change in spine position on ACLF (-23 N) was similar in magnitude to the impact of a 2-SD change in lateral slope (27 N) (Table 1). In males, a 2-SD change in spine volume had a similar impact on ACLF (-22 N) as a 2-SD change in lateral slope (26 N).

Table 1. Sex-specific relations between tibial plateau geometries and ACL force with regression coefficients (β) and p-values, and the impact of a 2-SD change for each tibial geometry on ACL force.

Knee Geometry	Relation to ACL Force (N) β; p-value	Δ 2 SD in Geometry = Δ ACL Force (N)
Females (n = 120, age: 17.2 ± 2.2 years)		
Lateral Slope (°)	β = +2.9 N per 1° increase; p < 0.001	+9° steeper Lateral Slope = +27 N ACLF
Spine Position (mm)	β = -5.4 N per 1 mm anterior; p = 0.002	+4 mm anterior Spine = -23 N ACLF
Males (n = 48, age: 18.0 ± 2.6 years)		
Lateral Slope (°)	β = +3.6 N per 1° increase; p = 0.01	+7° steeper Lateral Slope = +26 N ACLF
Spine Volume (mm³)	β = -5.9 N per 100 mm³; p = 0.03	+380 mm³ Spine Volume = -22 N ACLF

Conclusions

Our most important finding was that both lateral slope and medial spine geometries have similar impacts on ACL loading in both females and males. Interestingly, increased lateral slope was related to greater ACL force in both sexes, while the spine feature related to ACL force was sex specific. Our findings suggest that indications for utilizing surgical treatments like slope-leveling osteotomy should also consider medial spine geometry. If a knee has spine geometry that predisposes high ACL force, slope-leveling osteotomy may not adequately offload the ACL.

Acknowledgments

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References

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