Bone morphology features previously associated with knee kinematics and ACL injury risk may not be predictive of ACL elongation during high demand activities

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INTRODUCTION: Bony morphology has been proposed as a potential risk factor for anterior cruciate ligament (ACL) injury [1-3]. There have been several reports on the relationship between bony morphology and knee kinematics [4-6], but there are no reports on the association between bony morphology and ACL elongation during high demand activities. The purpose of this study was to determine if bone morphology features that have been associated with ACL injury risk and knee kinematics are also predictive of ACL elongation during fast running and double-legged drop jump. Our first hypothesis was that knees with a steeper lateral posterior tibial slope (LPTS) would demonstrate more ACL elongation and more tibial internal rotation. The second hypothesis was that knees with a deeper medial tibial plateau (MTP) depth and a larger lateral femoral condyle anteroposterior width (LCAP)/ lateral tibial plateau anteroposterior width (TPAP) (LCAP/ TPAP) would have more ACL elongation and more tibial anterior-posterior translation.

METHODS: Written informed consent was obtained from 19 healthy collegiate athletes with no history of knee injury who were active in sports that require running, jumping, and/or cutting (11 males and 8 females). Both knees were imaged within a biplane radiography imaging system (150 images/sec, 90kV, 160mA, 1ms exposure) for three trials per knee during fast running (5.0m/s on an instrumented treadmill) and double-legged drop jump off a 60cm platform. Tibiofemoral motion was tracked using a previously validated volumetric model-based tracking process that matched CT based subject-specific 3D bone models to the synchronized biplane radiographs [7]. Knee kinematics were calculated following standard conventions [11]. ACL elongation was measured as the distance between the femoral and tibial ACL attachment points, identified on magnetic resonance imaging (MRI) [8] and registered to the CT based subject-specific 3D bone model. Bony morphological features of LPTS, MTP depth, and LCAP/ TPAP were measured on MRI using Mimics version 24.0 (Materialise, Leuven, Belgium) [6, 9, 10] and input to a multiple linear regression model to predict knee kinematics range of motion and ACL elongation at 3 instants during each activity (0%, 30%, and 60% of the stance phase in fast running and 0%, 50%, and 100% of the stance phase in double-legged drop jump).

RESULTS: Participant's average age was 20.1±1.3 years and the mean BMI was 24.0±2.8 kg/m^2. The mean LPTS was 4.7±1.8°, the mean MTP depth was 1.8±0.5 mm, and the mean LCAP/TPAP was 1.5±0.1. None of the bony morphology features predicted ACL elongation or knee kinematics during fast running (Tables 1, 2). During double-legged drop jump, deeper MTP predicted greater ACL elongation at toe off of the drop jump (β= 0.456, p= 0.006) (Table 1). Additionally, steeper LPTS and a deeper MTP depth predicted a greater range of tibiofemoral internal/external rotation (β= 0.382, p= 0.012 and β= 0.331, p= 0.028, respectively) and shallower MTP depth and a larger LCAP/TPAP predicted a greater range of anterior tibial translation (β= -0.352, p= 0.018 and β= 0.441, p= 0.005, respectively) (Table 2).

DISCUSSION: As in previous reports, bony morphology predicted knee kinematics, but only during the double-legged drop jump activity. However, contrary to our hypothesis, only MTP depth predicted ACL elongation and only at toe off of the drop jump. These findings suggest that bone morphology features that are associated with kinematics that in isolation increase ACL elongation (*e.g.*, anterior tibial translation) may not predict ACL elongation during high demand activities. These results are limited to healthy athletes performing fast running and drop jump activities in a controlled laboratory setting, and to knees with relatively normal bony morphology.

SIGNIFICANCE: Previously reported relationships between bony morphology and kinematics or ACL injury risk should not be extrapolated to suggest that those bone morphology features are also associated with ACL elongation during high demand activities.

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***Table 1**: Multiple linear regression analysis identifying bony morphological parameters associated with ACL relative elongation.*

	% of the stance phase	Regression model fit (R2; p-value)	Factors included in regression model (β; p-value)
Fast running	0%	0.089; 0.358	none; NA
	30%	0.126; 0.200	none; NA
	60%	0.063; 0.520	none; NA
Drop jump	0%	0.036; 0.790	none; NA
	50%	0.129; 0.190	none; NA
	100%	0.213; 0.043	MTP depth: 0.456; 0.006

***Table 2**: Multiple linear regression analysis identifying bony morphological parameters associated with knee kinematics.*

	Knee kinematics	Regression model fit (R2; p-value)	Factors included in regression model (β; p-value)
Fast running	The range of tibial internal-external rotation	0.196; 0.057	none; NA
	The range of tibial anterior-posterior translation	0.105; 0.280	none; NA
Drop jump	The range of tibial internal-external rotation	0.323; 0.004	LPTS: 0.382; 0.012 MTP depth: 0.331; 0.028
	The range of tibial anterior-posterior translation	0.281; 0.010	MTP depth: -0.352; 0.024 LCAP/ TPAP: 0.441; 0.005