COMBINED VALGUS AND INTERNAL ROTATION MOMENTS STRAIN THE ACL MORE THAN EITHER ALONE: IMPLICATIONS FOR NON-CONTACT ACL INJURIES

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INTRODUCTION

Video observations of non-contact injuries to the anterior cruciate ligament (ACL) suggest that the injury occurs during the deceleration phase of landing on a single limb with a combination of valgus and internal or external rotation [1]. A cadaveric study supports the conclusion that combined internal torque and valgus moment increase forces in ACL [2]. However, the dynamic effect of combined loading at physiologic levels on ACL strain during landing has not been studied. This study tested the hypothesis that the strain in the ACL is higher under combined valgus and internal rotational moments during landing than with either applied individually. The study was conducted by applying actual *in vivo* loading data to a validated simulation model of the knee to predict ACL strains.

METHODS

A combination of valgus moments, internal rotation moments, and vertical landing forces were used to drive dynamic simulations of a previously validated knee model constructed from MRI of the distal femur, proximal tibia, patella, and cartilage of a cadaveric knee (Figure 1) [3]. Peak valgus moments for valgus landers and neutral landers were obtained from the results of a previous study on sidestep cutting [4] and normalized to an average-size person (height=1.75m, weight=750N) to choose 4 physiologic levels of valgus moment for the simulations (Table 1). Four physiological levels of peak internal rotational moments were obtained from another single limb landing experiment using 30 subjects (21 female, 9 male) with no history of musculoskeletal injury (Table 1). The vertical impact force used had a peak of 1400N. Other values of valgus and internal rotation moment were also tested to illustrate the shape of the response surface. The valgus and internal rotational moments were applied at the midpoint of the trans-tibial line, while the impact force was applied at the top of femoral axis of the upper limb. The strains in both bundles of ACL were calculated, but only the anteromedial bundle strain is presented since it was the higher of the two.

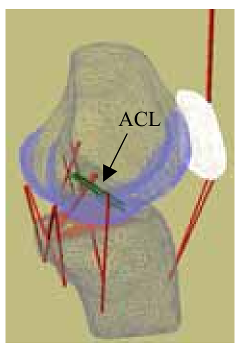

Figure 1. Knee model showing ligaments.

Table 1. Physiologic levels of valgus and internal rotational moments applied to the simulation model.

Valgus moment	Minimum	Average Neutral	Average Valgus	Maximum Valgus
	0 Nm	8 Nm	24 Nm	51 Nm
Int. Rot. moment	**Null**	**Minimum**	**Average**	**Maximum**
	0 Nm	3.6 Nm	11.5 Nm	25.9 Nm

RESULTS AND DISCUSSION

The strain in the ACL due to combined physiological maximum valgus (51 Nm) and internal rotational moment (25.9 Nm) was 10.5%, which is in the reported range for ACL rupture of 9-15% [5,6]. When applied individually, neither of the two rotational moments caused ACL strain higher than 7.7%, and the effect of each moment reached a plateau at or near the maximum level observed *in vivo.* However, when applied in combination the two rotational moments had a much larger effect, and the sensitivity of ACL strain to increases in either quantity was much higher when the other was held at a high level (Fig. 1).

Moreover, subjects whose typical valgus and internal rotation moments are high may be at greater risk because ACL strain is most sensitive to perturbations in the applied moments at those levels, as shown by the steepest slope of the surface when valgus moment is between 24 and 51 Nm, and internal rotation moment is between 11.5 and 25.9 Nm (Figure 1).

This work has shown that the combination of valgus and internal rotation moments that occur *in* vivo during simple cutting and landing maneuvers can cause ACL strains that may be high enough to cause injury, even in the absence of an anterior shear force.

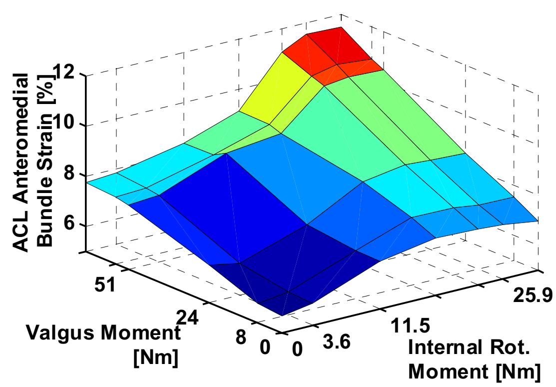

Figure 1. Response of ACL anteromedial bundle strain to applied valgus, internal rotation, and combined moments.

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ACKNOWLEDGEMENTS

Partial funding from NIH Grant No. R01-AR39212.