SEX BASED DIFFERENCES IN TENSILE PROPERTIES OF HUMAN ANTERIOR CRUCIATE LIGAMENT

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INTRODUCTION

Females participating in athletic events injure their ACL more frequently than males [1]. The disparity may be due to a smaller ACL size or inferior ACL tensile properties in females among other cited reasons. Any sex differences in the mechanical properties of the ACL might reflect a difference in the internal ACL structure. Therefore it is important to investigate how the tensile properties of ACL vary by sex. We hypothesize that male ACLs have superior structural properties than female ACL even after considering the size of the ACL as a covariant indicating a sex-based difference in the mechanical properties.

METHODS

Seventeen fresh-frozen unpaired knees (8 male and 9 female) were thawed and dissected. The average length of the ACL was measured using a vernier caliper and the minimum cross-sectional area and volume of the ACL were measured using a 3D Scanner[2]. The femur and tibia were tested in tension at 100%/s along the ligamental axis. The structural properties* were calculated and multivariate regression analysis, with age and body mass index (BMI) as covariants, was performed. To test for existence of a sex difference in mechanical properties** of the ACL, the size variables of the ACL were added as covariants and the regression analysis was repeated.

RESULTS AND DISCUSSION

As shown in Table 1, the structural properties of the male ACL are superior to those of the female ACL when age and donor body mass index (BMI) were considered as covariants. The male ACL showed a significantly higher load at failure, stiffness and absorbed energy before failure. This was expected as the female ACL (minimum area =57.32 ± 15.7, volume = 1996 ± 530) was significantly smaller than the male ACL (minimum area =72.9 ± 18.9, volume = 2772 ± 706) [3]. In order to test if any sex based differences in mechanical properties of the ACL existed, the size of the ACL was added as a covariant and the regression analysis was performed again. ACL length, cross-sectional area, area per unit length, and volume of the ACL were added as a covariate for regression analysis with displacement, load, stiffness and energy absorbed, respectively. Still, the male ACL was found to have superior tensile properties. This indicates that the female ACL is not weaker just because it is smaller [3] but also of lower mechanical quality. This might significantly contribute towards greater incidence in ACL tear rate in females. A lower torsional stiffness of female knees has also been cited as a potential reason for this disparity [5]. In our study, we found the female ACL to have lower stiffness and elastic modulus when compared to male ACL. Since ACL is the primary restraint for the internal rotation of the knee, decreased stiffness of the ACL might be a major contributor for lesser rotational knee stiffness in females. Though the reason for inferior mechanical properties of the female ACL is unclear, the influence of sex hormones can be one of the possibilities. For instance, estrogen is known to lower the failure of rabbit ACL [6] but this could be species dependant and tissue specific. Ultrastructural studies are needed to support such theories. This study also emphasizes the need for considering sex as a variable while testing mechanical properties of human ACL. One limitation of this study is that the activity levels of the donors were unknown and therefore its impact on the results could not be assessed.

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Table 1. Tensile properties of the ACL (Mean ± SD) and *P*-values of difference between the sexes.

Sex (age in years)	Elonga-tion at failure, mm	Load at Failure, N	Stiffn -ess, N/mm	Energy absorbed, N-mm
Male (36.6 ± 10.1)	8.95 ± 1.95	1810 ± 292	308 ± 87	7280 ± 3605
Female (36.8 ± 11.4)	7.48 ± 1.77	1272 ± 234	199 ± 63	4691 ± 1956
P-value (Age & BMI as covariate)	0.09	0.002	0.009	0.033
P-Value (Age, BMI and size as covariates)	0.16	0.008	0.02	0.027

* Structural properties are not normalized to geometrical variables of the tissue and include load at failure, linear stiffness, energy at failure, and elongation at failure.

** Mechanical properties are structural properties normalized based on the corresponding geometrical variables of the tissue and include Failure strength, modulus of elasticity, strain energy density, and strain at failure.