Evaluation of a Multivariate Risk Model for ACL Injury

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Introduction: Anterior cruciate ligament injury is immediately disabling7, and it is associated with the early onset and progression of osteoarthritis regardless of whether surgical or nonsurgical treatment is chosen2,6. Consequently, it is important to understand the risk factors for this injury to allow those at increased risk to be identified so an intervention can be targeted at them and to inform the development of prevention programs. ACL injury has been associated biomechanical, hormonal, and neuromuscular influences4 and current work has focused on the anatomic variables associated with risk of ACL injury. This has revealed different risk factors for ACL injury for women in comparison to men2,5,8,10.

A recently completed multivariate analysis performed by Sturnick et al investigated a wide selection of features of knee joint geometry in male and female high school and college athletes and analyzed their association with risk of ACL injury in order to develop sex-specific multivariate risk models. This study found that in women, for every millimeter decrease in femoral notch width there was a 50% increase in risk of ACL injury and for every degree increase in the middle cartilage slope of the lateral tibial plateau there was a 32% increase in risk of injury. For the men, a hundred cubic millimeter decrease in ACL volume and a degree decrease in the lateral compartment posterior meniscus-bone wedge angle were associated with a 43% and a 23% increase in risk of injury, respectively8. The hypothesis of this study is that the multivariate, MRI-based model of knee joint geometry that has been established for high school and college athletes can be applied to a more general population (in terms of age, BMI, and activity level) and demonstrate similar associations with risk for noncontact ACL injury.

Methods: This study was approved by the IRB. This data were obtained from a prior publication that focused on a cohort that represents the general population at risk for noncontact ACL injury9. Subjects that participated in the ACL-injured group had an age range between 18 and 57 years, BMI between 18.2 and 35.2 and pre-injury Tegner activity level between 5 and 10. These subjects were matched to a control group with age range between 18 and 49, BMI from 19.5 to 48.9, and Tegner activity level between 4 and 9 9. T1 weighted MRIs were collected from 15 women and 17 men that were in the ACL-injured group and 13 women and 13 men that had normal knees and no history of knee trauma using an 8 channel SENSE coil Phillips Achievia 3.0T MRI (Fletcher Allen Healthcare, Burlington, VT). Since it has been proven that there is side to side symmetry between knees, the MRI of the contralateral knee in the ACL injured subjects was used to obtain the four following measurements: femoral notch width at its outlet (NW_O), the middle articular cartilage slope (Lat_MCS) of the lateral tibial plateau, ACL volume (ACL_Vol), and the posterior meniscus-bone wedge angle (Lat_MBA) of the lateral compartment of the tibia8 (Figure 1). These were segmented using a Cintiq 21 UK Digitizing tablet (Wacom Tech Crop, Vancouver, WA, USA) and Osirix Software (Pixmeo, version 3.6.1., open source) as described by Sturnick et al. Univariate and multivariate conditional logistic regression were performed using the SAS sytem to...
assess the association between the risk of suffering an ACL injury and the specific anatomic risk factors described for each sex (Male model: Lat_MBA and ACL_Vol; Female model: Lat_MCS and NW_O). Odds ratios and associated confidence intervals were calculated separately for males and females to quantify the risk associated with measurements of ACL_Vol and Lat_MBA in males and the measurements of NW_O and Lat_MCS in females.

**Results:** Univariate analysis of data obtained from the male participants, revealed that an increased Lat_MBA was associated with a significant decrease in risk of ACL injury (OR: 0.794 per degree increase, p = 0.038) among males, whereas there was a strong trend for a decrease of ACL_Vol to be associated with an increased risk of ACL injury (OR = 0.765, p = 0.11). Univariate analysis of the data obtained from the females demonstrated that NW_O (OR = 1.168, p = .28) and the Lat_MCS (OR = 1.01, p = 0.93) were not associated with ACL injury. The multivariate analysis produced similar Odds ratios in comparison with the univariate analysis; however, statistical significance was not reached (Table 1).

**Discussion:** For males this study found similar odds ratios in the multivariate analysis for the Lat_MBA on the tibia (OR = .798 per degree increase) and ACL_Vol (OR = .794 per 0.1 cm³ increase) in comparison to the previously completed study by Sturnick et al. which reported odds ratios of 0.811 and 0.697, respectively. The univariate analysis was performed to show the individual association of each measurement with risk. The results of the previous study by Sturnick for the female population were not replicated in either our univariate or multivariate analysis. The NW_O (OR = 1.168) and Lat_MCS (OR = 0.983) were not associated with risk of ACL injury. This may have been produced by the fact that aging has a correlation (R² = 0.23) with increased stenosis of the femoral notch3. When considering the more advanced age of this general population in comparison to the high school and college athletes of the previous study, it is not surprising that there were no significant differences in notch width outlet in our female ACL injured subjects when compared to the controls because both groups would exhibit more stenosis and osteophytes.

In conclusion, the model for ACL injury that was developed on the population of high school and college athletes shows some relevance to the males, but not the females in this older cohort. There are changes in morphology that occur along with age could have obscured the results for these findings. In addition, the original multivariate analysis by Sturnick was performed on 88 ACL-injured subjects that were matched with 88 control subjects based on age, sex, and participation on the same sports team, whereas the current study had a smaller size of 31 subjects that suffered ACL injury and 26 subjects with normal knees. Therefore, the lack of statistical significance for this analysis could be attributed to the smaller sample size. This study also had a much older population; the mean age was 33, with standard deviation of 12 years, whereas the previous study was comprised of subjects that ranged between 14-23 years of age. It is possible that this population was less active than the population of high school and college athletes, and this may have had an effect on knee geometry. The differences in sample size and demographics between these two studies most likely contribute to fact that the results, although similar for the male population, were not an exact replication of the findings in the previous model.

**Significance:** Different ACL injury risk models may needed for groups with different demographic characteristics.
Figure 1. Upper Left: Notch Width Outlet, coronal view. Upper Right: Middle Cartilage Slope, sagittal plane. Lower Left: ACL Volume, sagittal plane. Lower Right: Meniscus Bone Angle, sagittal view 8.

Table 1. Univariate and Multivariate analysis of risk associated with ACL_Vol and Lat_MBA in males and NW_O and Lat_MCS for females.

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<thead>
<tr>
<th></th>
<th>Male Univariate Analysis</th>
<th>Male Multivariate Analysis</th>
<th>Female Univariate Analysis</th>
<th>Female Multivariate Analysis</th>
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<tr>
<td></td>
<td>OR</td>
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<td>P-value</td>
<td>OR</td>
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<td>Lat_MBA</td>
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<tr>
<td>ACL_VOL</td>
<td>0.765</td>
<td>(0.55-1.06)</td>
<td>0.11</td>
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