Anatomical Risk Factors Associated With Recurrent ACL Injury Risk: A Case-control Study

James Levens, Daniel Robert Sturnick, Pamela Vacek, PhD, James Slauderbeck, MD, Mack Gardner-Morse, M.S., Timothy Tourville, MEd, ATC, Michael Desarno, MS, Robert J. Johnson, MD, Bruce Beynnon, PhD.
University of Vermont College of Medicine, Burlington, VT, USA.

Disclosures:

Introduction: Noncontact anterior cruciate ligament injuries occur frequently in athletics. After reconstruction, a second injury to the ACL graft occurs at an even higher rate ranging from 3% two years post-surgery[6] to 7.7% six years post-surgery[5]. Repeated injury comes with added psychological burden and often requires additional surgery and rehabilitation, further delaying return to an active lifestyle and increasing the risk of post-traumatic osteoarthritis. Reconstruction has not improved rates of post-traumatic osteoarthritis in comparison to non-operative treatment[3], thus research has focused on identifying risk factors for injury to attempt to reduce its incidence and identify those at increased risk of suffering this injury. The geometries of the tibial plateau and femoral intercondylar notch have been implicated as risk factors for initial injury[7,8]; however, no previous study has examined these factors for risk of recurrent injury to an ACL graft. The objective of this study was to identify geometrical risk factors for recurrent ipsilateral ACL injury by comparing subjects that have suffered a repeated injury to an ACL graft with matched subjects that have suffered their first ACL injury. We hypothesize that the risk factors for repeated injury to an ACL graft will reflect those previously identified in the literature for first time injury to the ACL.

Methods: Approval was granted by the Institutional Review board at the University of Vermont, and all subjects provided signed informed consent. Bilateral knee MRI scans were obtained on 6 repeated-ACL graft injury case subjects and 36 matched first time ACL injured control subjects. Control subjects were matched in a 6:1 ratio for age and sex, and all subjects participated in organized collegiate or high school athletics. Subjects had suffered a grade III, non-contact ACL (or ACL graft) tear, as diagnosed and confirmed arthroscopically by an orthopaedic surgeon. All images were obtained using the Phillips Achieva 3.0T MRI with subjects positioned supine. DICOM images were viewed and digitized using Osirix Software (Pixmeo, version 3.6.1) and manual segmentation was completed using a Cintiq 21UK digitizing tablet (Wacom Tech Corp). Segmented data were interpolated to a coordinate system that was located in the bony tibia using custom Matlab code.

Tibial subchondral bone: The subchondral bone of the tibia in the medial and lateral compartments was digitized in the sagittal plane. The posterior-directed slopes of the plateau were measured as the slopes of a line between the anterior and posterior rims of the mid plateau relative to the AP axis of the coordinate system. The maximum depth of concavity was calculated in the medial compartment (MTD). The medial and lateral tibial spines were characterized by measuring the volume, and its center of gravity location. The medial-lateral distances from the peak of the spine to the point of maximum concavity for the medial (MLD) and lateral (LLD) compartments were measured (Figure 2).

Cartilage/Meniscus: For each compartment, all measurements were made at the sagittal slice of maximum concavity of the cartilage surface. The cartilage surface was separated into middle and posterior sections, with the middle area defined as the region where the femoral and tibial articular surfaces were in contact when at extension and posterior region defined as the portion under the posterior meniscus. Slope of the middle (MCS) and posterior (PCS) cartilage, posterior meniscus height, subchondral bone slope, posterior meniscus-bone angle and posterior cartilage-meniscus angle were measured.

Femoral Notch: Measurements were made in an oblique coronal plane oriented parallel to the ACL. The notch width was measured at the origin of the ACL, the ACL anterior attachment, the midpoint between the inlet and anterior attachment, and the outlet of the notch. The bony ridge prominence (Ridge) of the medial femoral condyle was measured as the sum of two perpendicular displacements from a line fit to the medial notch wall; the extrusion of the peak and the intrusion of the notch wall (Figure 1).

All comparisons were made using the contralateral uninjured leg; this approach has been shown to provide symmetrical measurements within subjects with normal knees and allows characterization of the knee as it was prior to injury[1]. In addition, this approach was used because the injury produced changes to the knee. Logistic regression analysis was used to test the associations of subchondral bone, articular cartilage, meniscus geometry and notch dimensions with recurrent ACL graft injury risk.

Results: Logistic regression analysis revealed the medial femoral condyle ridge prominence (Ridge) (OR=2.65, p=0.03) and lateral distance from the peak of the medial tibial spine to the point of greatest concavity of the medial compartment (MLD) (OR=1.75, p=0.04) were significant independent predictors of repeated ACL injury (Table 1). An increase of each measure was associated with an increased risk or re-injury to the ACL graft. There was also evidence that an increase in the middle cartilage...
slope of the lateral compartment of the tibia (LatMCS) (OR=1.48, p=0.06), and a decrease of the maximum depth of the medial tibial compartment (MTD) (OR= 0.086, p=0.053) may be associated with an increased risk of suffering repeated injury to the ACL graft. No other measurements appeared to be associated with risk of re-injury.

**Discussion:** This study demonstrated that the bony ridge height of the medial femoral condyle and an increased distance between the point of maximum concavity of the medial compartment of the tibia and peak of the tibial spine were independent risk factors associated with increased risk of suffering repeated ipsilateral ACL injury. A 1mm increased Ridge height was associated with a 165% increase in risk of repeated ACL graft injury. This relationship was consistent with previous reports for first-time ACL injuries[2]. Interestingly, MLD has not been cited as a risk factor associated with first time ACL injury. There was also some evidence that increased Lateral MCS and decreased MTD may be associated with an increased risk of recurrent ACL injury. This is important because MTD has been associated with risk of suffering an index ACL injury[4]. Possibly a greater sample size could have established significant relationships. The ACL graft injuries occurred between 7 months and 5 years (average 11mo) following reconstruction, and all subjects successfully returned to sport post-reconstruction prior to suffering a re-injury.

**Significance:** This study is unique in that anatomical risk factors for repeated injury to an ACL graft have been identified for the first time. It reaffirms previous work related to first time injury, and encourages further investigation of the role of the femoral notch ridge in ACL injury and re-injury. Clinically, this could generate hypotheses exploring reduction of the ridge as an effort to reduce the risk of reinjury. Additionally, identification of individuals at increased anatomical risk after primary injury may help reduce the incidence of graft injuries by improving counseling of injured athletes.

**Acknowledgments:** NIAMS- 5R01-AR05, Department of Energy SC 00017


![Figure 1. Ridge prominence measured as the sum of the two maximum displacements (green) from a line fit to medial notch wall (dashed).](image)
Figure 2. MLD measurement from medial tibial spine peak to the point of maximum concavity of subchondral bone in the medial compartment.

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR (CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ridge</td>
<td>2.65 (1.13-6.25)</td>
<td>0.03</td>
</tr>
<tr>
<td>MLD</td>
<td>1.80 (1.02-3.17)</td>
<td>0.04</td>
</tr>
<tr>
<td>LatMCS</td>
<td>1.48 (0.98-2.24)</td>
<td>0.06</td>
</tr>
<tr>
<td>MTD</td>
<td>0.086 (0.007-1.04)</td>
<td>0.053</td>
</tr>
</tbody>
</table>

Table 1. Results of univariate analysis by logistic regression.

ORS 2014 Annual Meeting
Poster No: 1962