INTRODUCTION
The geometry of the knee joint, in particular the tibia plateau, as characterized by subchondral bone features such as decreased depth of the concave medial tibial plateau as well as increased posterior directed slopes of the medial and lateral plateaus, has been identified as risk factors for anterior cruciate ligament (ACL) injury. Recent interests have shifted to exploring the articular cartilage geometry of the tibial plateau and its relationship to ACL injury risk. Due to the dramatic difference in profile between articular cartilage and its underlying subchondral bone, it is essential to characterize and investigate its role in the biomechanics of the knee. Though articular cartilage, a soft tissue, is known to deform under loads, the change in profile is minimal at a 7% volume decrease after high-impact loading. Local surface curvature measurements of shape index and curvedness, primarily applied to the study of fluid dynamics, are introduced as new measures to characterize joint geometry. The shift from two-dimensional measurements to three-dimensional characterization is vital to capturing the complexity of the knee and how load is transmitted across this joint during normal function and injury. It is hypothesized that shape index and curvedness measurements yielding a less congruent joint will characterize individuals at increased risk of non-contact ACL injury.

METHODS
The study design consisted of a matched case-control study approved by our institutional committee on human research. All participants provided written consent prior to participation. T1-weighted sagittal knee MR images of 25 ACL injured subjects and 25 controls matched for sex, age, sports team and exposure were obtained using the Phillips Achieva 3.0 T MRI system. The images in DICOM format were uploaded into a viewer program (Osirix, Pixmea, version 3.9.3, open-source). With the use of the Cintiq digitizing tablet (Wacom, 2010), the articular cartilage measurements of the medial and lateral tibial compartments were manually segmented. Segmentations were done in both sagittal and coronal orientations and bounded by the outer circumference of the menisci. Data points of the surfaces were analyzed using custom MATLAB (MathWorks, Natick, MA) code. Regions of ±20% of the digitized surfaces, centered at the minimum of the concave region of each tibial plateau compartment (where tibiofemoral contact is thought to be maximum) were reconstructed into continuous biarc surfaces. For each point of the triangular meshed surface, two principal curvatures \( K_1 \) and \( K_2 \) were calculated. Principle curvatures are local measurements of the directions and magnitudes of surface curvatures. These are used to calculate the shape index (S) and the curvedness (C):
\[
S = \frac{2}{\pi} \tan^{-1} \frac{K_1 + K_2}{K_2^2 - K_1^2} \quad C = 2 \ln \sqrt{\frac{K_1^2 + K_2^2}{K_2^2 - K_1^2}}
\]
The shape index is a scale-independent measure of the local topology of the surface.

DISCUSSION
Using local curvature measurements of shape index and curvedness, no clear case-control difference was observed. A significant within subject difference was observed between cases injured and uninjured knee, however similar limb-to-limb differences were not found within control subjects. This suggests that a change in tibial articular cartilage profile may have occurred as a result of the injury. Whether this change is created at the time of injury or during ACL insufficiency is unknown. The hypothesis of curvature measurements characterizing an increased risk of ACL injury was not supported.

The three dimensional observation of the tibial plateau provides a viable characterization of knee joint geometry. The exact change in topography after injury is uniquely described. A study designed to track the change in geometry overtime after injury could prove to be insightful in the study of post-traumatic osteoarthritis. Compared to previous two-dimensional measurement approaches, the local surface measurements presented are independent of an established coordinate system, removing one source of error.

SIGNIFICANCE
The change in articular cartilage described by the presented method of differential geometry provides insight on the effects of an ACL injury.

REFERENCES

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