

TITLE: *In vivo* Evidence of a Shift in Tibiofemoral Contact in ACL-Reconstructed Knees During Dynamic Motion

AUTHORS: Kaiser, Jarred¹; Kijowski, Richard²; Baer, Geoffrey³; Thelen, Darryl^{1,3,4}

INSTITUTIONS: 1. Dept. of Mechanical Engineering, University of Wisconsin, Madison, WI

2. Dept. of Radiology, University of Wisconsin, Madison, WI

3. Dept. of Orthopedics and Rehabilitation, University of Wisconsin, Madison, WI

4. Dept. of Biomedical Engineering, University of Wisconsin, Madison, WI

CURRENT PRIMARY CATEGORY: Knee - Kinematics and Gait

AWARDS:

KEYWORDS: ACL, Cartilage Contact, Dynamic Imaging

Introduction: It has been theorized that abnormal tibiofemoral motion following ACL reconstruction (4-6) may shift contact to infrequently loaded regions of the cartilage, thereby inducing cartilage breakdown and the development of osteoarthritis (OA) (1). MRI is well suited for studying this potential link due to its ability to resolve soft tissues, measure dynamic motion (2) and identify early biomarkers of OA (3). The objective of this study was to test the hypothesis that ACL-reconstructed knees would exhibit altered cartilage contact patterns relative to the contralateral limb during passive knee flexion-extension, and that active quadriceps loading would induce even greater bilateral asymmetries in cartilage contact.

Methods: The healthy and ACL-reconstructed knees of five subjects were tested after obtaining informed consent according to an IRB-approved protocol (3 M, 24.7 ± 5.5 yrs, 84.5 ± 16.0 kg, 1.73 ± 0.09 m, 1.8 ± 0.8 yrs post-surgery, 2 patellar tendon grafts, 3 hamstring grafts, 1 subject with partial lateral meniscectomy). Subjects had no history of inflammatory or crystalline induced arthritis, no additional ligament injury, no post-operative complications, and no history of pain, injury, or surgery to the contralateral knee. Subjects underwent a static MRI protocol of a fat-suppressed 3D SPGR sequence (0.37x0.37x0.90 mm resolution) and a 3D FSE Cube sequence (0.31 mm isotropic resolution) in a 3T MR scanner. For the dynamic tasks, subjects laid supine with their lower leg secured to a MR-compatible loading device and a 16-channel flex coil fixed about the knee. A spoiled gradient-echo sequence with vastly under-sampled isotropic projects (SPGR-VIPR, 1.5 mm isotropic cubic resolution) sequence continuously acquired 3D volumetric image data during dynamic tasks. In the first task, a researcher passively moved the subject's knee through flexion and extension at 0.5 Hz. In the second task, the subjects were asked to actively flex and extend at a rate of 0.5 Hz, while an inertial load induced eccentric quadriceps contraction with peak knee flexion (avg. range of motion = 35.6 +/- 6.1 deg). Dynamic images were retrospectively sorted based on knee flexion to create 60 frames over a 2 s cycle. High resolution models of both femur and tibia bone segments were segmented from the SPGR sequence. The bone segments were then optimally registered to each dynamic image frame to reconstruct the six degree-of-freedom *in vivo* tibiofemoral kinematics.

Cartilage models were manually segmented from the FSE Cube images, passed through a Laplacian smoothing function, and meshed with an average density of 3.33 triangles per 1 mm². Femoral and tibial cartilage were assumed to be rigidly attached to the bones at each frame. A ray was cast normal to each tibial plateau triangle to determine the distance to the femoral cartilage surface. This distance is considered cartilage proximity, with positive numbers indicating overlap of the cartilage surfaces. The maximum proximity of each tibial triangular mesh through the flexion-extension cycle was then calculated. Medial and lateral tibial cartilage surfaces were divided into a five-by-four rectangular grid and the maximum proximities were then averaged within these areas. A three-way repeated measure analysis of variance (ANOVA, p<0.05) was used to assess the effects of limb (reconstructed, contralateral), load (passive, active), and location on average cartilage proximity. If a significant difference was detected with the ANOVA, a post-hoc Tukey HSD test was used to find location-dependent differences.

Results: Greater contact occurred in the medial compartment in both tasks, with an average proximity increase of 0.25 mm compared to the lateral compartment. As expected, active loading produced a significant increase in proximity of 0.35 mm and 0.25 mm for the medial and lateral compartments of both knees. The leg effect was greater in the medial compartment, though neither compartments reached significance ($p=0.18$ for medial, $p=0.41$ for lateral). The contact pattern on the medial plateau changed more with ACL-reconstruction, with a lateral and posterior shift, than the lateral plateau. This shift was more evident in the active case. The lateral plateau displayed a decrease in anterior contact with ACL-reconstruction and an increase in posterior contact, though both of these changes were restricted to a single area.

Discussion: It has been hypothesized that abnormal knee kinematics in ACL-reconstructed may induce abnormal cartilage contact patterns. We are testing this hypothesis by measuring *in vivo* cartilage contact patterns during both passive and active loading conditions. Our current data indicates that ACL reconstructed knees do exhibit a difference in cartilage loading relative to the uninjured contralateral knee. Specifically, we found a posteriolateral shift in the medial compartment of the tibia plateau and a posterior shift in the lateral plateau. These shifts would be consistent with the increase in external tibia rotation and anterior tibia translation that has been previously observed following ACL-reconstructive surgery (5). Future studies will investigate if these altered contact patterns correspond to the cartilage regions exhibiting signs of early onset OA, as evidenced by quantitative MRI approaches (3).

Significance: Spatial shifts in tibial cartilage contact patterns were measured *in vivo* following ACL-reconstruction surgery, which could potentially contribute to the increased risk for early onset osteoarthritis.

Acknowledgements: NIH AR062733, EB015410

References:

1. Andriacchi, TP, Mundermann, A, Smith, RL, et al. 2004. A framework for the *in vivo* pathomechanics of osteoarthritis at the knee. *Ann Biomed Eng* 32: 11.

2. Kaiser, J, Bradford, R, Johnson, K, et al. 2013. Measurement of Tibiofemoral Kinematics Using Highly Accelerated 3D Radial Sampling. Magnetic Resonance in Medicine Wiley Subscription Services, Inc., A Wiley Company: 7.
3. Li, X, Kuo, D, Theologis, A, et al. 2011. Cartilage in anterior cruciate ligament-reconstructed knees: MR T1rho and T2-initial experience with 1-year follow-up. Radiology 258: 10.
4. Scanlan, SF, Chaudhari, AM, Dyrby, CO, Andriacchi, TP. 2010. Differences in tibial rotation during walking in ACL reconstructed and healthy contralateral knees. J Biomech 43: 1817-1822.
5. Tashman, S, Kolowich, P, Collon, D, et al. 2007. Dynamic function of the ACL-reconstructed knee during running. Clin Orthop Relat Res 454: 66-73.
6. Webster, KE, Feller, JA, Wittwer, JE. 2012. Longitudinal changes in knee joint biomechanics during level walking following anterior cruciate ligament reconstruction surgery. Gait & Posture.

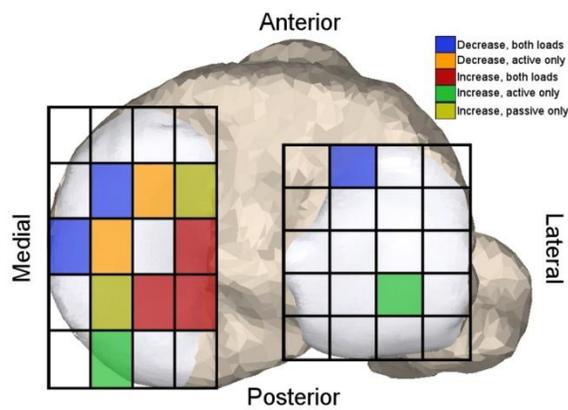


Figure 1. Medial and lateral tibial plateaus were broken into four medial-lateral and five anterior-posterior areas. Colors indicate significant increases and decreases in maximum proximity with ACL-reconstruction for the two loading conditions. Contact shifts posterior on both the medial and lateral plateau, with the greatest change in the medial plateau during active loading.