Evaluation of Medial Meniscus Strain in Anatomic Versus Non-Anatomic ACL Reconstruction


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Introduction: It is widely recognized that current methods of ACL reconstruction do not completely restore the native stability of the knee, especially in response to rotatory loading. If the reconstructed ligament supports less load under these conditions, it is hypothesized that more load must be placed on the secondary structures of the knee, primarily the medial meniscus, leading to increased risk of meniscal degeneration and early onset of osteoarthritis. Recent work has indicated that graft orientation has a significant effect on the loading of ACL grafts. This study was undertaken to test the hypothesis that non-anatomic graft placement increases loading of the medial meniscus following anterior cruciate ligament reconstruction when compared to both the intact knee and reconstruction performed with anatomic graft placement.

Methods: Seven fresh-frozen cadaveric knees (38.9±9.7 years; range 30-53 years) were harvested from male donors. Any knee was excluded if there was evidence of ligament deficiency, degenerative joint disease, or prior knee surgery. A medial parapatellar arthrotomy was performed on each knee to facilitate implantation of twelve metallic beads into the medial meniscus for radio-stereometric analysis (RSA). The specimens were prepared and mounted in a provocative pivot simulator. Two orthogonal radiographs were taken with the knee unloaded and positioned at full extension. Subsequently, loads of 7Nm valgus and 2Nm internal rotation were applied under nominal muscle forces to simulate the loads applied during a clinical non-weight bearing pivot shift exam. The knee was then positioned at 15°, 30°, and 45° of flexion and the orthogonal radiographs were taken with fiducial makers allowing calculation of a common coordinate system for analysis. The anterior cruciate ligament was then resected from each specimen and tested in the same manner.

The ACL was then reconstructed using bone-tendon-bone allografts harvested from donor specimens using interference screws as fixation with a post used for backup fixation and all testing was repeated. Two reconstruction methods were performed: (i) Anatomic ACL reconstruction: the center of the tibial tunnel was located on the native ACL footprint, with the posterior edge of the tunnel located on the posterior edge of the anterior horn of the lateral meniscus. The femoral tunnel was located at the center of the native ACL footprint between the anteromedial and posterolateral bundles. (ii) Non-anatomic ACL reconstruction was performed after the anatomic tunnels were filled with bone plugs. A 7mm PCL referencing guide was used to locate the tibial tunnel and a 10mm tunnel was drilled. A 3D computer model was generated from CT scans and native ACL footprints on the femur were located using a digitizing stylus. Standardization of the nonanatomic femoral tunnel was accomplished following the methods of Kopf et al. who identified the most common location of tunnel placement following transtibial ACL reconstructions. Using the quadrant method of Bernard and Hertel, femoral tunnels created in a transtibial fashion were positioned 37.2% of Blumensaat’s line from the posterior cortex of the femoral condyle and 11.2% of the height of the lateral condyle from the articular surface.

Each radiograph was scanned and digitally stored. An imaging program (ImageJ) was used to determine the two-dimensional coordinates of each bead on each radiograph. The three-dimensional positions of the beads were then calculated using custom RSA software.

To quantify internal strains within the meniscus, an anatomically representative computer model of the meniscus was created and discretized using four-noded quadrilateral shell elements (2606 elements) using Hypermesh. A viscoelastic material model governed the meniscal loading response (E=150MPa, η=60,000PaS, μ=0.44). The model was kinematically constrained, i.e. displacements of nodes corresponding to location of the beads were prescribed, and the FE model was solved using a non-linear static solver in LS Dyna. Maximum principal strains were calculated for each nodal point within the FEA mesh. Additionally, gross meniscal movement measured by meniscal rotation about the tibial shaft and meniscal displacement along the tibial surface was observed throughout each flexion angle and ACL state. All repeated measure analysis of variance combined with a Fisher’s least significant difference post-hoc test was used to determine significance between groups.

Results: The posterior translation of the intact meniscus averaged 2.12±0.58mm at 15° of flexion, 2.38±0.70mm at 30°, and 2.23±0.54mm at 45°. There was no significant difference in overall meniscal translation between states (at 30°: ACL Deficient 2.26±0.93mm; Anatomic ACL 2.52±1.36mm; Non-Anatomic ACL 2.27±1.04mm). For meniscal rotation, a significant difference...
observed was between ACL deficient and anatomic reconstruction at both 15° and 30° of flexion (15°: 4.61°±2.3° vs. 0.93°±4.62°; 30°: 4.81°±3.43° vs. 1.75°±4.91°).

The maximum principal strains measured within the intact meniscus averaged 39.0±25.5% at 15° of flexion. There was no significant difference in strain at higher flexion angles (30°: 38.63%±18.94%; 45°: 38.66%±13.61%). There was no significant difference in strain seen in deficient cases. ACL reconstruction was associated with almost double the maximum strain within the medial meniscus, independent of graft placement (i.e. anatomic vs. non-anatomic). In the case of anatomic reconstruction, the contrast with respect to the intact state was greatest at 30° (38.6±18.9% vs. 70.0±45.2%, p=0.039). Similar differences were seen with the non-anatomic reconstructions at 45° (38.7±13.6% vs. 73.2±44.7%, p=0.034). There were no significant differences between anatomic and non-anatomic grafts in terms of meniscal strains.

Discussion: There was minimum transfer of load to the medial meniscus following ACL injury. Reconstruction of the ACL using either anatomic or non-anatomic ACL placement did not show differences in the strain of the meniscus. Gross translations and rotations of the medial meniscus were similar in all tested states. The results suggest a load transfer in the knee to a structure other than the medial meniscus when loaded with valgus and internal rotation moments. This static loading condition may shift the load from the injured ACL to the lateral meniscus instead of the medial and further investigation is needed to ascertain the load shift following ACL injury.

Significance: Reconstruction of the ACL using either anatomic or non-anatomic ACL placement did not show differences in the strain of the meniscus. The results suggest a load transfer in the knee to a structure other than the medial meniscus when loaded with valgus and internal rotation moments.

Acknowledgments:

References:
Gross Meniscal Displacement

Displacement (mm)

Flexion Angle

15 30 45

Intact  Deficient  Anatomic  Non-Anatomic
Non-Anatomic 30