ACL Fibers Inserting on the Lateral Intercondylar Ridge Carry the Greatest Loads - Are Modern Anatomic Femoral Tunnel Positions Too Low?

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Disclosures:

Introduction: In contrast to macroscopic studies of the ACL reporting the presence of two distinct ACL bundles, recent histological studies have shown that the ACL consists of two different structures: the direct and indirect insertions. The direct insertion has a zonal architecture whereas the indirect insertion comprises collagen fibers directly anchoring ligament to bone. The direct insertion is located along the lateral intercondylar ridge and the indirect insertion is ‘lower’ on the lateral wall of the notch, adjacent to the posterior articular cartilage. The ‘lower’ position has become more popular for locating the femoral tunnel, as surgeons switch to the anteromedial (AM) portal drilling technique in order to place the graft in the native footprint. Further, load transfer across the substance of the ACL is not well understood even though this may help inform new methods of ACL reconstruction. The purpose of this study was, 1) to compare the load characteristics of the native ACL between the direct and indirect insertions and, 2) to determine if there is load-sharing between the direct and indirect components of the ACL, or do they behave independently?

Methods: Thirteen fresh-frozen cadaveric knees (mean age, 52.5 years; range, 29-65) were mounted to a six degree of freedom (DOF) robot equipped with a universal force-moment sensor. We simulated the Lachman and anterior drawer tests at 0, 15, 30, 45, 60 and 90° of flexion by applying a 134N anterior load and the pivot shift at 5, 15, 30, and 45° flexion by applying combined valgus (8Nm) and internal (4Nm) rotational moments. The five DOF kinematics that satisfy these loading conditions were recorded. Subsequently, the medial femoral condyle was removed to visualize the femoral insertion of the ACL. Fibers located in the high position near the intercondylar ridge were sectioned off of the femoral footprint (direct fibers). Similarly, fibers in the low position close to the posterior articular cartilage (indirect fibers) were also removed. Sectioning order was alternated from specimen to specimen. Sectioning was performed by identifying the lateral intercondylar ridge and posterior articular margin. By drawing a tangent to the articular cartilage, parallel with the posterior femoral cortex, the maximum perpendicular distance between the ridge and tangent was measured. The 50% mark along this line was used to delineate the regions of the direct and indirect insertions (Fig. 1). The regions were delineated macroscopically using digital calipers as previously defined [1,2]. The borders of the sectioned areas were digitized after sectioning and mapped onto a CT scan of each knee (Fig. 2). The sectioning method was assessed under a blinded validation by 2 experienced observers who excluded 3 specimens that did not conform to the sectioning method. The kinematics of the intact knee were replayed after each stage of sectioning and the principle of superposition was employed to determine the loads transferred across the direct and indirect fibers of the femoral footprint, by calculating the loads for the ACL intact, ACL partially sectioned, and ACL completely sectioned states. If load sharing did not occur, the load measured across the direct fibers and indirect fibers would be the same regardless of sectioning order. Loads transferred across the direct and indirect fibers were expressed as a percentage of the total load borne by the ACL. This yielded 5 samples with direct fibers sectioned first, and five samples with the indirect fibers sectioned first. To test for the differences in load of direct versus indirect insertion across increasing flexion angles, we used a repeated measures general linear model with Tukey post-hoc adjustment. Interaction effects of insertion and component loading were also analyzed in the model with statistical significance set to alpha less than or equal to 0.05. A post-hoc power analysis found that a sample size of six specimens achieves 98% power to detect a difference of 10% between direct and indirect ACL insertions with a standard deviation of ± 4%.

Results: Under an anterior tibial load, at 30° flexion the direct insertion carried 83.9% (±7.2%) of the total ACL load compared to 16.1% (±7.2%) in the indirect insertion (p<0.001). The direct insertion also carried more load at 90° flexion (95.2% vs 4.8%; p<0.001). Further, the direct fibers carried greater loads when they were sectioned last compared to when they were sectioned first at 0, 15, 30 and 45° flexion by 44, 41, 30 and 17%, respectively. Under a combined rotatory load, at 15° flexion the direct insertion carried 84.2% (±4.2%) of the total ACL load compared to 15.8% (±4.2%) in the indirect insertion (p<0.001). Further, the direct fibers carried greater loads when they were sectioned last compared to when they were sectioned first at 5 and 15° flexion by 27 and 18%, respectively. Since loads in the direct and indirect fibers were expressed as a percentage of the total load, results for the indirect fibers were the compliment of those measured across the direct fibers.

Discussion: The fibers in the direct insertion of the ACL carry more load than fibers in the indirect insertion when subject to both an anterior load and a combined rotatory load. Load sharing across the substance of the ACL resulted in section-order dependency of the loads borne by the direct and indirect fibers of the ACL. The level of load sharing was highest at full extension, and decreased with knee flexion in response to anterior forces and to combined moments. Although further work is
required in determining graft behaviour at the insertion sites described in this study, our findings suggest that placing a graft in the native ACL footprint as close as possible to the lateral intercondylar ridge may be an important consideration when performing anatomic ACL reconstruction. Further, since functional activities such as gait occur primarily within 20° of full extension, the load sharing phenomenon found in this study may be an important factor enabling daily activities. However, the ability of graft tissue to recapitulate load sharing exhibited by the native ACL is not well understood, and may be an important criterion when designing improved methods of ACL reconstruction. This characteristic is likely related to the interaction of its constituent ground substance and fibers, as well as the complex spatial relationship of the tibial and femoral footprints as the knee is loaded through a range of flexion angles.

Significance: Direct ACL fibers at the lateral intercondylar ridge carry greater loads than indirect fibers located lower on the wall adjacent to the posterior articular cartilage. With the current shift in emphasis towards anatomic ACL reconstruction, it may be beneficial to create the femoral tunnel within the direct insertion rather than ‘lower’ down the wall.

Acknowledgments:

Figure 1: Sagittal Section of Lateral Wall Intercondylar Notch of Femur

Shaded = Direct
Dotted = Indirect

50% line
Ridge Line
Tangent
Figure 2: Sagittal CT scan of Lateral Wall of intercondylar Notch with digitized footprint