A COMPUTATIONAL SIMULATION OF THE EFFECT OF GRAFT STIFFNESS ON ANTERIOR CRUCIATE RECONSTRUCTION

Introduction
Bone-patella tendon-bone (BPTB) grafts are widely used for anterior cruciate ligament (ACL) reconstruction. Experimental data have demonstrated that these grafts are almost 3 times stiffer than the ACL. While many in-vivo and in-vitro data have shown that the ACL reconstruction is efficient in restoring anterior stability using anterior drawer tests, recent in-vitro measurement on ACL reconstructed patients showed that the initial graft stiffness is overcorrected after ACL reconstruction indicating an over-constrained knee. Many factors, such as graft fixation and orientation, initial graft tension, and stiffness of the graft material influence the post-operative stability of the knee. However, few data are available describing the effect of these variables on knee joint function under physiological loading conditions. This study investigated the effect of graft stiffness and initial graft tension on knee joint kinematics under simulated anterior and muscle loading using a validated, 3D finite element knee joint model.

Methods
A 3D computational knee joint model was constructed from MR images of a cadaver knee. The bone and cartilage contours were digitally traced and imported into MSC/Patran where the bone and cartilage geometry were recreated. The model included bone geometry, cartilage, ligaments and meniscus elements. The model was validated by comparing predictions of the model to results obtained experimentally from testing of other cadaver knees.

To simulate ACL reconstruction using single bundle grafts, the ACL in the model was replaced with a graft modeled with a single nonlinear spring element. Grafts with three different axial moduli were used in this study. Graft 1 had a modulus similar to the intact ACL, and Grafts 2 and 3 had moduli similar to 10mm and 14mm wide BPTB grafts, respectively. The ACL deficient case was analyzed by using a graft with zero axial modulus. The initial graft tension was set to 0 N or 40 N with the knee at 30° of flexion by adjusting the resting length of the graft. The graft tunnels were modeled according to a current ACL reconstruction technique first described by Clancy et al. (4) (Figure 1) The graft was assumed to be rigidly fixed to the bone at the midpoint of the length of each tunnel.

Results
After ACL reconstruction, the ATT, ITR, and graft tension under the anterior drawer load followed the same trends with respect to flexion angle as in the intact knee. When the initial graft tension was set to 0 N, ACL reconstruction using Graft 1 allowed a peak ATT, which occurred at 30° of flexion, that was 8% greater than that of the intact knee. (Figure 2) Reconstruction using Grafts 2 and 3 restricted the peak ATT to 3% and 10% less than the ATT of the intact knee, respectively. The ITR at 30° of flexion when using Graft 1 was 10% greater than the intact ITR. The ITR when using Grafts 2 and 3 were 4% and 13% less than the intact ITR, respectively. Peak graft tension was also observed at 30° of flexion in all three grafts. When Graft 1 was used, the peak tension was 21% less than in the intact ACL. Grafts 2 and 3 had a peak tension that was 8% and 24% greater than in the intact ACL.

Discussion
This computer simulation demonstrated that the stiffness of the graft has a considerable effect on the kinematics and graft force of the ACL reconstructed knee. When the initial graft tension was set to 0 N, both Grafts 2 and 3 overcorrected the knee kinematics, and the graft tensions were higher than that of the intact ACL. Initial graft tension also plays a significant role in ACL reconstruction. When the initial graft tension was set to 40 N, all three grafts over-constrained the knee by more than 15%, and the corresponding graft tensions were more than 35% greater than the tension in the intact ACL. These results are supported by a study that found knees reconstructed with a 10mm BPTB graft to have 2 mm less anterior laxity than intact knees under a 90 N anterior tibial load immediately after reconstruction in living patients. (5) Over-constrained knee kinematics may result in increased joint contact forces, which may lead to early joint degeneration.

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References

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