KNEE FLEXION ANGLES ASSOCIATED WITH PEAK ACL BUNDLE LENGTHS DURING RUNNING

Scott Tashman1, William Anderst1, Eric Thorhauer1, Jennifer Bishop2, Freddie Fu1, Patricia Kolowich2
1Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA; 2Orthopaedic Surgery, Henry Ford Health System, Detroit, MI
tashman@pitt.edu

Introduction: Recent anatomic studies have shown that the ACL has two functional bundles (1,2). Single-bundle ACL reconstructions cannot restore this complex anatomy or reproduce kinematics of the uninjured knee (3), prompting the development of anatomic double-bundle ACL reconstruction. The anterior-medial (AM) and posterio-lateral (PL) bundles of the ACL are thought to reach peak tension at different flexion angles (PL: tightest in extension; AM: tightest in flexion). However, the optimal knee flexion angles for tensioning each bundle are controversial. The purpose of this study was to determine the flexion angles at which maximum lengths of the AM and PL bundles of the intact ACL occurred during in vivo, dynamic, functional loading.

Materials and Methods: 9 subjects undergoing anatomical ACL reconstruction who were free of injury or disease in their contralateral limb and provided informed consent participated in this IRB-approved study. Femoral tunnels were placed at the insertion points of the residual ligament bundles. 1.6 mm tantalum beads (minimum of 3 markers per bone) were implanted in both tibias and femurs of all subjects at the time of their surgery to enable 3D tracking. Knee motion was assessed 5 months after surgery during downhill treadmill running (10% slope, 2.5m/s). Kinematic data (3 trials per leg) was collected using a stereo-radiographic system capable of tracking 3D joint kinematics from the implanted markers at 250 frames/s with a dynamic accuracy of ±0.1mm or better, as previously described (3). Bone geometry was determined from 3D bone surface models derived from subject-specific CT scans. The centers of the graft tunnel entrances were identified on the model using 3D visualization software. CT models were “mirror imaged” to define origin/insertion points for the contralateral (ACL-intact) limb. Functional ligament length (defined as the 3D distance between ligament bundle origin and insertion) was calculated for the AM and PL bundles of the uninjured knee for the bundle tension at much higher flexion angles than the PL bundle.

Results: Maximum stance-phase bundle lengths for all subjects averaged 30.2±5.7 mm for AM and 27.3±6.0 for PL. Peak length occurred at 27±12 degrees of flexion for AM, and 7.7±10.9 degrees of flexion for PL (significantly different; p=0.008). However, there were two distinctly different patterns of length vs. flexion. Six subjects had bundle length curves that clearly peaked at different flexion angles for the two bundles, with the AM bundle reaching peak tension at much higher flexion angles than the PL (11 degrees or greater; mean difference 9.3 degrees; Figure 1). In the other 3 subjects, peak length occurred at the same flexion angles for both AM and PL (mean difference 0.2±0.3 degrees; Figure 2). For all subjects, the pattern of ACL length vs. flexion angle was significantly different during stance phase (high loads) than during swing phase (low loads).

Discussion: On average, in vivo, dynamic length behavior of the ACL bundles was as previously described from cadaver studies. The PL bundle reached maximum tension near full extension (immediately after footstrike) and shortened with flexion. The AM bundle did not reach peak length until later in early stance, at about 30 degrees of knee flexion. This pattern was clearly observed in 6 of the 9 subjects. However, the other 3 subjects exhibited a nearly isometric length pattern, with little change in ligament length throughout the peak loading period of running. It is possible that these differences between subjects are due to errors in the estimation of the bundle insertion locations on the femur (which were based on anatomically placed tunnels during reconstruction of the contralateral limb; a limitation of the study). However, a review of 3D tunnel locations found no clear differences between the two subject groups. Because graft length was estimated during a dynamic, functional activity with high loads and the knee under active muscular control, differences in neuromuscular function between subjects could have affected ligament length patterns. Alternatively, subject-specific differences in joint

Figure 1: Stance-phase bundle lengths vs. knee flexion, for 6 subjects that reached peak AM bundle tension at much higher flexion angles than the PL bundle.

Figure 2: Stance-phase bundle lengths vs. knee flexion, for the 3 subjects that reached peak tension for the AM and PL bundles at the same flexion angle.

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References: