How Does Resection of the Anterior Cruciate Ligament Change the Envelopes of Passive Motion of the Normal Tibiofemoral Joint?

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Disclosures: J.D. Roth: None. M.L. Hull: 5; Stryker Orthopaedics, DePuy Orthopaedics. 6; Stryker Orthopaedics, DePuy Orthopaedics. S.M. Howell: 1; Biomet Sports Medicine. 2; Biomet Sports Medicine. 3B; Biomet Sports Medicine. 7; Saunders/Mosby-Elsevier.

Introduction: Both the articular surfaces and soft tissues of the tibiofemoral joint determine tibiofemoral kinematics (i.e. passive motions) [1]. Tibiofemoral kinematics may be characterized by measuring the envelopes of passive motion that are described, for each degree of freedom (DOF) over a range of flexion, by the positive and negative limits of displacement about a neutral position, under an applied load. Therefore, either damage or removal of soft tissues will change the envelopes of passive motion.

There is no consensus about which DOFs are affected by either damage or removal of the anterior cruciate ligament (ACL). Prior studies agree that loss of the ACL leads to an increase in the anterior limit [2-4], but there is debate about whether the loss of the ACL also affects other DOFs [2-7]. Discrepancies between the results of previous studies may be due to limitations including investigating a limited range of flexion [2-6], imposing constraints to coupled motions [2-4, 6], and not including all DOFs [5, 7]. Accordingly, the objective of the present study was to determine how the resection of the ACL changes the internal-external (I-E), varus-valgus (V-V), anterior-posterior (A-P), and compression-distraction (C-D) envelopes of passive motion from normal over a large range of flexion angles without constraining coupled motions.

Methods: Seven fresh-frozen, cadaveric knees were included (average age: 72 years, range: 57 to 91 years). Specimens were free from degenerative arthritis, chondrocalcinosis, osteophytes, soft tissue damage, and evidence of previous surgery to the knee.

Each knee was prepared for testing by dissecting and then aligning the specimen in a six DOF load application system (LAS). First, all tissues more than 15 cm proximal and 12 cm distal to the joint line were removed and then all remaining subcutaneous fat was removed. Second, the fibula was fixed to the tibia using a transverse screw. Third, each knee was aligned in the LAS [8] so that the flexion-extension (F-E) and I-E rotation axes of the LAS were coincident with the F-E and longitudinal rotation axes of the tibiofemoral joint respectively.

Following dissection and alignment, each knee specimen was subjected to a standard preconditioning protocol. First each knee was cycled five times between ± 2.5 N-m in F-E and then extended under 2.5 N-m to define 0° flexion [9]. Next, the knee was cycled five times between ± 3 N-m in I-E rotation [1], ± 5 N-m in V-V rotation [6], ± 45 N in A-P translation [10], and ± 100 N in C-D translation [11], at 0°, 60°, and 120° flexion.

Following preconditioning, the envelopes of passive motion in I-E, V-V, A-P, and C-D were measured over a range of flexion angles from 0° to 120° in 15° increments using the loads listed above. During both preconditioning and testing, a 45 N compressive tare load was applied to the tibia using an air spring as a replacement for the passive compression created by the soft tissues that were transected during the dissection. For all randomly-ordered combinations of flexion angle and DOF, the loading sequence to measure the envelopes of passive motion was as follows: apply positive load, apply negative load, unload, apply negative load, apply positive load, and unload; the position at each of the six loading conditions was recorded. The neutral position was defined as the average of the two positions of the unloaded knee. The positive limit was defined as the difference between the average of the two positions of the knee under the applied positive load and the neutral position. The negative limit was defined as the difference between the average of the two positions of the knee under the applied negative load and the neutral position.

After testing the normal knee had been completed, the knee was removed from the LAS and the ACL was resected through an arthrotomy created using the transpatellar approach [12]. The arthrotomy was closed using two transverse screws through the patella and sutures for the patellar tendon and joint capsule. Next, the knee was reinserted into the LAS. The new extension position was found by extending the knee under 2.5 N-m. The four envelopes of passive motion were measured for the ACL-deficient (ACL-d) knee at the same nine flexion angles using the same procedure as described for the normal knee.

The limits of each envelope of passive motion before and after ACL resection were each analyzed using a two-factor repeated measures analysis of variance. A post hoc Tukey’s test was used to identify at which flexion angles there were significant changes in the limit between normal and ACL-d knee. A 95% confidence interval was computed for the change in full extension position after ACL resection to determine whether ACL resection changed the position of full extension.

Results: The internal, external, valgus, and posterior limits were not changed after ACL resection (Figure 1). There were
increases, after ACL resection, in the varus limits at 90° flexion (0.8° ± 0.8°) (p < 0.03), the anterior limit throughout flexion (range: 2.0 ± 1.1 mm at 90° flexion to 5.6 ± 2.6 mm at 15° flexion) (p < 0.02), the compression limit at 90° and 105° flexion (0.3 ± 0.4 mm at 90° and 105° flexion) (p < 0.04), and the distraction limits between 75° and 120° flexion (range: -0.9 ± 1.1 mm at 90° flexion to -0.7 ± 0.6 mm at 120° flexion) (p < 0.04). The position of full extension increased by 1.6° ± 1.3° (95% confidence interval: 2.9° to 0.4°) after ACL resection.

Discussion: This study quantified the change in the envelopes of passive motion from normal in four DOFs (I-E, V-V, A-P, and C-D) after ACL resection. These results agree with prior studies [2-4] that determined the anterior limit increases after ACL resection. In contrast to some prior studies [2-4, 6, 7], the present study did not find differences in the I-E limits, and found that the distraction limit increases in flexion rather than extension. One explanation for these differences is that the present study used of a six DOF LAS which did not constrain coupled motions as the apparatuses used in prior studies did. The finding that the anterior limit is the only large change from normal in the ACL-deficient knee is important for two reasons. First, it helps guide both the rehabilitation of patients following ACL rupture who choose not to have a reconstruction and the design of supportive braces to compensate for a damaged ACL. Second, it directs the development of implants and surgical techniques for total knee arthroplasty (TKA) because currently nearly all surgeons resect the ACL whether or not it is still functioning. Hence, it is critical to understand what changes in knee kinematics in the various DOFs are created by resecting the ACL so that both implant designs and surgical techniques can be developed to minimize the changes to the kinematics. For example, a recent study found that increases in anterior laxity as small as 1.8 mm increase the wear rate of the tibial liner by 40% [13]. Therefore, restoration of normal A-P laxity is a critical step to minimize the wear rate to improve long-term implant survival after TKA.

Significance: A thorough understanding of the effect of loss of the ACL is important to both understand the consequences of ACL rupture on tibiofemoral kinematics and guide the development of both innovative components and surgical techniques for TKA to help restore normal tibiofemoral kinematics.

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References:

ORS 2014 Annual Meeting
Poster No: 0808