Static and Dynamic Constraint in ACL-Reconstructed Patients at 10-15 Year Follow-Up

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INTRODUCTION: The goal of anterior cruciate ligament reconstruction (ACLR) is to restore knee stability and reduce the risk of secondary damage to menisci and posttraumatic osteoarthritis (PTOA). Static laxity can be measured relatively easily and relates directly to the passive constraint conferred by ligaments (or grafts) and menisci. Conversely, dynamic kinematic outcomes are a combination of both passive constraint and the active constraint modulated by the neuromuscular system to provide joint stability. In both instances, the contralateral limb is almost always used as an internal control to represent baseline. In our work describing long-term joint function and the neuromuscular contributions to PTOA risk following ACLR,[1] we sought to explore the relationship between static and dynamic constraint in a subset of ACLR patients and control subjects who have been followed over a decade. The objective of the present work was to quantify bilateral static and dynamic tibiofemoral positions in ACLR patients and healthy controls. We hypothesized that anterior tibial position would be greater in the surgical compared to the contralateral knee and knees of control subjects, and that surgical limb differences in anterior tibial position would be greater in the dynamic state during a hop landing that challenges the ACL graft.

METHODS: Twenty-one subjects were recruited from the ongoing parent study [NCT00434837] and they provided written informed consent to participate in this IRB-approved ancillary study. Ten subjects (5 females/5 males; mean age=33.8±10.0 years; BMI = 26.9±4.2; 12.1±1.2 years follow-up) had undergone ACLR surgery 10-15 years prior to participation. Eleven control subjects (5 females/6 males, mean age=38.1±7.5 years; BMI = 24.3±3.2; 11.9±3.8 years post initial parent trial enrollment) were additionally recruited from the parent study. Femur and tibia bone models were segmented from computed tomography (CT) images that were obtained bilaterally, and local coordinate systems were generated automatically from the bone geometry.[2] The static 3D tibiofemoral position was extracted from the orientations of the bones in each subject's CT and described by 6-degree-of-freedom position to constitute our measure of "static constraint". Dynamic knee kinematics were recorded bilaterally at a frame rate of 250Hz using biplane videoradiography during a 1-leg hop landing that spanned ground contact to 0.2 seconds after. Side-to-side differences were used as a measure of "dynamic constraint". Peak anterior tibial position was the primary outcome measure for both static and dynamic conditions, and anterior tibial position as a function of dynamic flexion angle was the secondary outcome measure. Generalized estimating equations were used to test for differences between ACLR surgical and contralateral limbs, and between ACLR and controls. Pairwise comparisons between groups were tested within the models via orthogonal contrasts. The Holm test was used to adjust for multiple comparisons while maintaining a two-tailed alpha of 0.05. All analyses were conducted in SAS version 9.4 (SAS Institute Inc).

RESULTS: Whereas static flexion angles were consistent bilaterally in ACLR patients (p=0.82) and between ACLR patients and controls (p=0.20), static ACLR tibial position was significantly more anterior compared to uninjured controls (7.5±2.3mm; 95% CI [2.6-12.4mm], p=0.02) and the contralateral limb (3.1±1.1mm; 95% CI [0.77-5.4mm], p=0.04)(Fig. A, C). Knee flexion angle at peak anterior tibial position during the hop landing was also consistent bilaterally in ACLR patients (p=0.38) and between ACLR surgical knees and controls (p=0.90). Contrary to static position, the peak dynamic anterior position during the hop landing was not statistically different between surgical and contralateral limbs in ACLR patients (0.44±2.1mm; 95% CI [-4.0-4.9mm], p=0.83), but tended to be more anterior compared to controls (5.0±3.1mm, 95% CI [-1.44-11.5mm], p=0.12) (Fig. B). Dynamic anterior tibial position as a function of flexion angle (i.e., regression model slope) was similar between ACLR surgical limbs and controls (p=0.16), but the model intercept was 10.3mm greater in the ACLR surgical (95% CI [1.7-19.0mm]; p=0.01) and 7.5mm contralateral limbs (95% CI [1.8-13.2mm]; p=0.001) compared to controls.

DISCUSSION: Our hypothesis was supported whereby the tibia was significantly more anteriorly translated in ACLR patients in a static position which was maintained during dynamic function as demonstrated by the significant bias in anterior position despite a similar magnitude of anterior tibial translation with flexion as controls; however, we did not anticipate that the bias in ACLR anterior tibial position would be present bilaterally in the dynamic, but not static condition. The results suggest that ACLR patients have greater surgical limb static laxity, which aligns with conventional arthrometer measures in this population.[3] Conversely, dynamic stability was restored with no side-to-side differences. Nevertheless, the magnitude of both static and dynamic anterior tibial position bias compared to healthy controls was 5-7x greater than previously reported side-to-side differences within ACLR patients.[4] It is unknown whether the presence of dynamic bilateral symmetry represents "normal" function and could explain why these patients were at higher risk of injury, or whether the contralateral limb function changed due to central nervous system adaptations to restore stability and symmetry.[5] Future longitudinal studies would be needed to answer this question.

SIGNIFICANCE/CLINICAL RELEVANCE: Static laxity is present long after ACLR, whereas dynamic side-to-side stability is restored but with a persistent bias towards greater anterior tibial position that is present bilaterally. The stark contrast between static and dynamic constraint was detectible only in the context of healthy control data, emphasizing the caution needed in treating the contralateral limb as "normal" in ACLR patients.

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IMAGES AND TABLES:

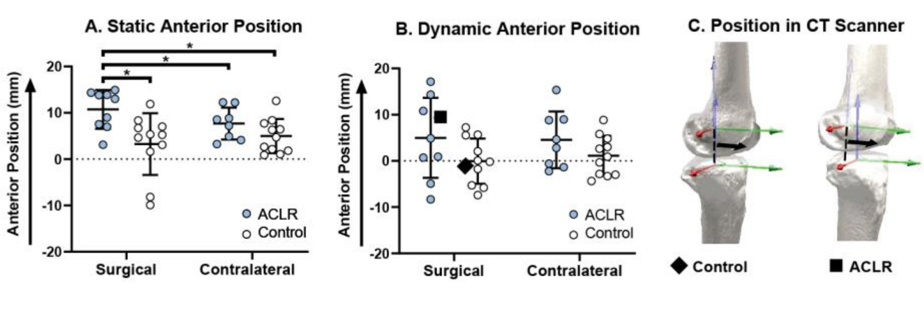

*Figure. **A.** Static anterior tibial position. "*" denotes statistically significant. **B.** Peak anterior tibial position during hop landing. The square and diamond correspond to the individual subjects shown in (C). **C.** Visualization of anterior tibial position for examplar subjects; local coordinate system axis orientations are displayed by red (medial-lateral), green (anterior-posterior), and blue (inferior-superior) arrows.*