

# Anterior Cruciate Ligament Graft Strain Rate, but Not Magnitude, is Increased During a Hop Landing

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**INTRODUCTION:** Anterior cruciate ligament (ACL) injuries continue to present a higher risk for post-traumatic osteoarthritis (PTOA), regardless of surgery.<sup>1</sup> The mechanisms behind this association remain not fully understood, but there is convincing evidence that altered contact mechanics contribute in some way.<sup>2,3</sup> The primary role of the ACL is to constrain knee motion, therefore when graft function is diminished, factors such as increased elongation could enable changes in contact mechanics after ACL reconstruction (ACLR). Existing work suggests that kinematic abnormalities within the first two years of surgery are small,<sup>4,5</sup> but little is known regarding long-term graft function at a time when PTOA emerges. Using a unique cohort of ACLR and healthy control subjects that have been followed for over a decade (NCT00434837),<sup>6</sup> we quantified in vivo ACL strain during a challenging hop landing task and tested three hypotheses: H1. ACLR grafts would exhibit higher peak strain than native ACLs; H2. Graft strain rate would be greater for ACLR patients; and H3. Differences in strain would be amplified under load at, or near, peak ground reaction force (pGRF).

**METHODS:** Previously recorded data from an IRB-approved study were analyzed: 8 ACLR subjects, 10-15 years after surgery, (5 females, 3 males; age =  $35.1 \pm 10.8$  years) and 12 healthy control subjects (6 females, 6 males; age =  $37.8 \pm 7.4$  years).<sup>7,8</sup> ACLR subjects received either a bone-patellar tendon-bone autograft (n=5) or hamstring autograft (n=3). All subjects underwent a clinical exam and magnetic resonance imaging (MRI) to assess ACL/graft status.<sup>9</sup> Bi-plane videoradiography (BVR) was used to record three-dimensional knee kinematics of the landing phase of a single leg hop - an activity used to gauge ACLR recovery.<sup>10</sup> Subject-specific knee models were created from computed tomography (CT) images and co-registered to BVR images to reconstruct the 3-dimensional kinematics. ACL insertions were identified in the knee MRIs<sup>11</sup> and mapped to the patient's corresponding CT models for each BVR frame. The instantaneous ACL length was calculated as the vector between insertion centroids. After confirming normality, we found that baseline ACL/graft resting lengths were similar between groups ( $p = 0.61$ ). Figure 1.A), ACL strain was calculated as the change in length relative to the resting length during MRI acquisition for every BVR frame.<sup>12</sup> This approach revealed a bi-modal distribution in strain patterns whereby strain increased after ground contact in 17/20 subjects and decreased in the remaining subjects (2 ACLR; 1 control). For the 17 subjects with a positive strain rate after ground contact, i.e., those that experienced ACL/graft elongation, a linear regression was calculated from all data points spanning ground contact to peak strain to determine strain rate. Generalized linear models with a Gaussian distribution and an identity link function were used to compare peak strain (H1) and strain rate (H2) between ACLR patients and healthy control subjects. Statistical parametric mapping was used to test for difference in average strain over time (H3).

**RESULTS:** All grafts were intact at the time of follow-up. Peak ACL graft strain was not significantly different from native ACL ( $p=0.50$ ; Figure 1.B). ACLR grafts experienced an 82% greater graft strain rate than native ACLs ( $p = 0.04$ ; Figure 1.C). Temporal differences in ACL/graft strain during the single leg hop landing emerged only after pGRF ( $p < 0.05$ ).

**DISCUSSION:** Our major finding was that ACLR grafts elongate at a significantly higher rate than healthy ACLs and that the grafts continue to elongate after pGRF in 75% (6/8) of ACLR subjects versus only 1 control subject. Control subjects had an average peak strain value of  $6\% \pm 5\%$ , which aligns with previous work that estimated native ACL strains of  $7\% \pm 6\%$  at peak extension just prior to landing during a single leg hop.<sup>13</sup> Our existing work has identified delayed hamstring activation within the current ACLR cohort,<sup>7</sup> which may have contributed to the greater strain rate due to the role of hamstring activation in constraining anterior tibial translation. Further, the increased graft strain rate seen in these ACLR subjects may have implications for long-term cartilage health, whereby a more compliant ACL graft would allow tibiofemoral surfaces to move faster relative to each other for longer durations, a phenomenon shown to correlate with more severe cartilage damage in ACL-deficient animal models.<sup>2,14</sup> The current work would benefit from a larger sample size, as there was notable variation in ACLR graft strain rate; however, the variable response to injury and surgery in this longitudinal cohort dovetails heterogeneous ACLR patient outcomes and allows us to investigate underlying relationships between knee function and long-term joint health.<sup>9</sup>

**SIGNIFICANCE/CLINICAL RELEVANCE:** The observation that ACLs/grafts continue to lengthen for a longer time after pGRF in most ACLR patients but only in a few control subjects at a time when joint degeneration emerges presents a plausible mechanical mechanism that could help explain the variable severity and rate of PTOA onset after ACL injury.

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## IMAGES AND TABLES:

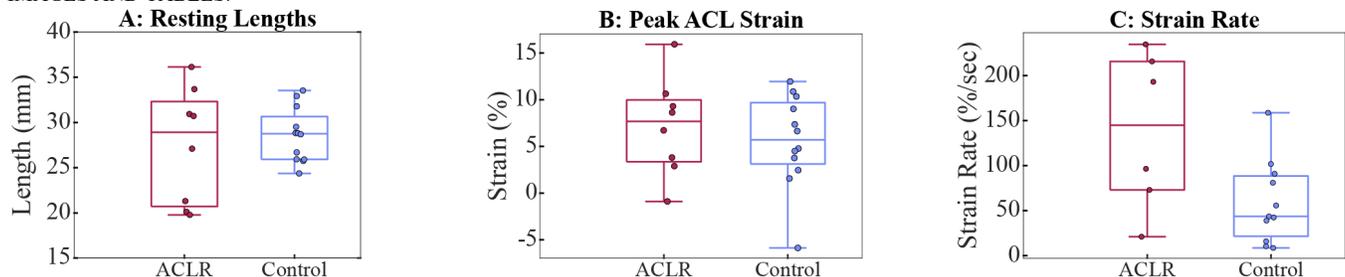


Figure 1. Boxplots of (A) Resting ACL/graft length during the MRI; (B) Peak ACL/graft strain during the landing phase of the hop; (C) ACL/graft strain rate for subjects who demonstrated peak ACL strain after ground contact.