Effects of Quadriceps Strength Recovery in the First Year Following Anterior Cruciate Ligament Reconstruction on Gait Biomechanics.

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INTRODUCTION: Aberrant gait biomechanics are commonly observed after anterior cruciate ligament reconstruction (ACLR) and may contribute to the elevated risk of developing posttraumatic knee osteoarthritis (KOA). While quadriceps weakness is a well-documented impairment following ACLR, the extent to which strength recovery trajectories impact gait biomechanics during the first year postoperatively remains unclear. Although cross-sectional studies have identified associations between quadriceps weakness and aberrant gait biomechanics, they do not capture the longitudinal variability in gait biomechanics across the stance phase from the preoperative period through 12 months post-ACLR. Understanding these relationships is essential to identifying rehabilitation targets that promote long-term joint health.

METHODS: We conducted a prospective cohort study of 59 participants (25 males, 34 females; aged 16–35 years) with unilateral primary ACLR. Eligible participants underwent primary unilateral arthroscopic ACLR using a bone-patellar tendon-bone (PT), quadriceps (Q), or hamstring (H) autograft (Table 1). All procedures were approved by the Institutional Review Board and informed consent was obtained. Quadriceps strength was measured preoperatively and at 4, 6, and 12 months post-ACLR using maximal voluntary isometric contractions normalized to body mass. Gait biomechanics—including vertical ground reaction force (vGRF), knee flexion angle (KFA), knee extension moment (KEM), and knee adduction moment (KAM)—were collected at 4, 6, and 12 months during overground walking at habitual speeds. Group-based trajectory modeling identified strength recovery profiles, and functional mixed effects modeling was used to compare stance-phase gait waveforms from the involved limb between strength trajectory groups and sex-, age-, and BMI-matched uninjured controls. Statistically significant regions of difference were defined as areas where the 95% confidence interval of the group mean difference did not include zero. Gait speed was included as a covariate in secondary sensitivity analyses.

RESULTS: Two distinct strength trajectories were identified (Figure 1). Participants in the trajectory group with higher strength values (N = 28) were classified as the stronger group, while those in the lower trajectory (N = 31) were classified as the weaker group. The weaker group exhibited less dynamic vGRF during early stance, with peak differences relative to controls of –0.15 bodyweight (BW) (95% CI [–0.21, –0.09]) at 4 months, –0.13 BW (95% CI [–0.19, –0.06]) at 6 months, and –0.10 BW (95% CI [–0.16, –0.04]) at 12 months (Figure 2). Compared with the stronger group, the weaker group also showed reduced KFA (–1.85°; 95% CI [–3.42, –0.27] at 6 months; –2.18°; 95% CI [–3.78, –0.56] at 12 months) and KEM (0.006 BW·height; 95% CI [0.006, 0.011] at 4 months; 0.006 BW·height; 95% CI [0.001, 0.012] at 6 months) during early stance. Only the weaker group had significantly lower KAM relative to controls (0.007 BW·height; 95% CI [0.004, 0.011] at 4 months; 0.007 BW·height; 95% CI [0.002, 0.009] at 6 months; 0.007 BW·height; 95% CI [0.002, 0.010] at 12 months) during early stance. Gait speed sensitivity analyses attenuated some findings but did not fully account for observed differences.

DISCUSSION: While the group exhibiting greater strength recovery demonstrated gait biomechanics that more closely resembled uninjured controls, neither group fully normalized gait biomechanics. The group demonstrating persistent quadriceps weakness over time consistently exhibited less dynamic waveforms suggesting altered loading during early stance. These aberrant gait biomechanics, particularly during early stance when the limb experiences peak loading, may reflect compensatory motor control strategies and contribute to abnormal joint loading over time. Notably, both groups failed to reach a previously published strength sufficiency threshold (≥3.0 Nm/kg), and average strength did not return to preoperative levels despite most participants having completed formal rehabilitation. These findings suggest that quadriceps strengthening, while essential, may not be sufficient for restoring normal gait biomechanics. Persistent aberrant biomechanics, even among those with better strength recovery, underscore the need for complementary movement control interventions. Real-time gait biofeedback may help correct abnormal loading patterns and reduce the risk for long-term joint degeneration after ACLR.

SIGNIFICANCE/CLINICAL RELEVANCE: Quadriceps strength recovery alone does not normalize gait biomechanics after ACL reconstruction, highlighting a critical barrier to joint health. Integrating gait retraining interventions may improve clinical outcomes and reduce long-term KOA risk.

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IMAGES AND TABLES: Table 1. Participant characteristics.

Characteristics	Time point	Weaker Group	Stronger Group	Controls	*p*-value
Sex (M/F)		11/20	14/14	26/33	
Age (years)		22.42 ± 4.76	21.33 ± 4.63	19.43 ± 3.46	0.451
BMI (kg/m^2)		24.48 ± 3.53	23.94 ± 2.90	22.06 ± 3.41	0.440
Gait Speed (m/s)	4 months	1.21 ± 0.16 [b]	1.26 ± 0.10 [b]	1.36 ± 0.14 [a]	< 0.001
	6 months	1.22 ± 0.14 [b]	1.28 ± 0.10 [b]	1.36 ± 0.14 [a]	< 0.001
	12 months	1.26 ± 0.11 [b]	1.28 ± 0.11 [b]	1.36 ± 0.14 [a]	0.001
Graft type (PT/Q/H)		29/0/2	26/1/1		

Figure 1. Quadriceps strength recovery trajectories from the involved limb.

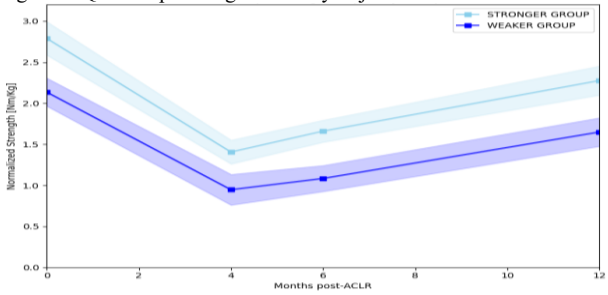

Figure 2. Comparisons of stance-phase gait biomechanics waveforms.