Effusion Persists at 6 Months After Anterior Cruciate Ligament Reconstruction Without Impacting Gait Biomechanics or Quadriceps Strength

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INTRODUCTION: Knee effusion is common after anterior cruciate ligament reconstruction (ACLR) and is associated with poor outcomes such as knee osteoarthritis. However, its persistence and clinical significance at 6 months post-operatively remain poorly defined. Prior studies analyzing the prevalence of effusion after ACLR and its independent associations with gait biomechanics and quadriceps strength are limited by semi-quantitative or region-specific methods of measuring effusion. We aimed to determine (1) the prevalence of persistent effusion at 6 months after ACLR using a quantitative volumetric analysis, and (2) whether persistent effusion is associated with gait biomechanics and isometric quadriceps strength. We hypothesized that effusion would persist at 6 months following ACLR and would be associated with worse gait biomechanics and quadriceps strength.

METHODS: Sixty-three participants between the ages of 13 and 35 years underwent axial T2-weighted MRI of the injured knee, gait biomechanical analysis, and quadriceps strength testing at 6 months following ACLR. Effusion volume was quantified using a quantitative protocol. The volume of effusion (mL) was quantified using Otsu's method of thresholding to classify the highest intensity pixels as fluid within custom MATLAB software. A subgroup of 35 participants underwent MRI of the uninjured knee, and a non-parametric approach using the 97.5th percentile was used to define persistent effusion as ≥6mL. Gait biomechanics were evaluated using a 3D motion capture system with embedded force plates and a passive, retroreflective marker set placed on segments and bony landmarks of each participant to assess kinetic and kinematic parameters. Participants completed 5 valid gait trials in each limb at a self-selected speed that was maintained ±5% throughout testing. Using a subject-specific model, an inverse dynamics approach was used to calculate external joint moments, which were normalized to body mass and height. Variables of interest during stance phase of gait included the first peak of the vertical ground reaction force (PvGRF) and the average rate to reach PvGRF (PvGRF Rate), peak knee flexion angle (PKFA) and moment (PKFM), and first peak of the knee adduction moment (PKAM). Knee moments and forces were expressed as interlimb ratios (injured / uninjured). Peak knee flexion angle was expressed as an interlimb difference (injured – uninjured). Isometric quadriceps strength was measured using an electromechanical dynamometer in 90° of knee flexion. Outcomes of interest included peak isometric quadriceps torque (Max Torque) and the rate of torque development during the initial 200 milliseconds of the isometric contraction ($RTD_{0\text{-}200}$), with quadriceps variables expressed as a limb symmetry index (injured / uninjured × 100%). Two-way mixed analyses of variance (ANOVAs) were used to assess the effects of limb (injured vs uninjured) and effusion status (Persistent Effusion [≥6mL] vs No Persistent Effusion [<6mL]) on biomechanical and strength outcomes. Confirmatory analyses using one-way ANOVAs were performed comparing biomechanical and strength outcomes across quartiles of effusion. An *a-priori* p-value was set at 0.05.

RESULTS: Participants were 19.9±5.1 years old and 55.6% were female. Persistent effusion was present in 65.1% of participants at 6 months after ACLR. The average volume in injured knees with persistent effusion was 10.0±3.7mL. There were no significant interaction effects between limb and effusion status for any biomechanical or strength outcomes (all $p>0.05$) (Table 1). A significant main effect of limb was observed for all variables (all $p < 0.05$), as joint moments and angles during gait and quadriceps strength were lower in the injured compared to uninjured limb. There were no significant main effects of effusion group for any variable (all $p>0.05$). These findings remained unchanged in confirmatory analyses comparing biomechanical and strength outcomes across effusion volume quartiles (all $p>0.05$), supporting the use of 6mL as the threshold to define persistent effusion.

DISCUSSION: Persistent effusion is highly prevalent at 6 months following ACLR. The lack of association between effusion with gait biomechanics and quadriceps strength suggests a biological, rather than functional, impact of effusion on the knee. Adaptation of mechanoreceptors in response to chronic effusion within the knee joint could cause mechanoreceptors to increase their activation thresholds over time, diminishing their responsiveness and thereby reducing the likelihood of strength or gait disturbances.

SIGNIFICANCE/CLINICAL RELEVANCE: This study is the first to quantitatively determine the persistence of effusion at 6 months after ACLR. While not associated with gait biomechanics or quadriceps strength impairments, persistent effusion may reflect ongoing intra-articular pathology and warrants closer clinical attention.

Table 1. Two-way mixed analyses of variance (ANOVAs) comparing limb (injured vs uninjured) and effusion status (No Persistent Effusion <6mL vs Persistent Effusion ≥6mL) at 6 months after anterior cruciate ligament reconstruction.

	No Persistent Effusion (<6mL) Mean±SD		Persistent Effusion (≥6mL) Mean±SD		p-value		
	INJ	UN	INJ	UN	Limb	Group	Interaction
PvGRF (BW)	1.10±0.09	1.14±0.08	1.09±0.10	1.13±0.12	<0.001*	0.675	0.804
PvGRF Rate (BW/s)	1.07±0.09	1.11±0.08	1.06±0.10	1.10±0.12	<0.001*	0.709	0.822
PKFA (°)	13.02±7.61	16.43±5.25	13.91±6.36	15.22±7.92	0.002*	0.925	0.163
PKFM (N·m/kg·m)	0.20±0.15	0.34±0.13	0.25±0.14	0.34±0.20	<0.001*	0.529	0.127
PKAM (N·m/kg·m)	0.20±0.08	0.25±0.09	0.22±0.10	0.23±0.10	0.049*	0.971	0.322
Max Torque (N·m/kg)	1.98±1.00	3.14±0.59	2.32±0.74	3.35±0.69	<0.001*	0.136	0.399
$RTD_{0\text{-}200}$ (N·m/kg·s)	7.13±4.24	12.28±2.33	7.26±2.73	12.50±3.16	<0.001*	0.811	0.901

*Represents $p<0.05$.
Abbreviations: INJ, injured knee; UN, uninjured knee; PvGRF, first peak of vertical ground reaction force; BW, bodyweight; PvGRF Rate, mean rate from initial contact to PvGRF; s, second; PKFA, peak knee flexion angle; °, degree; PKFM, peak knee flexion moment; N, newton; m, meter; kg, kilogram; PKAM, first peak of knee adduction moment; Max Torque, maximum quadriceps torque; $RTD_{0\text{-}200}$, rate of torque development from 0-200 milliseconds.