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Quadriceps Strength and Knee-Related Symptom State 6 Months After Anterior Cruciate Ligament Reconstruction

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Context: Isometric quadriceps strength metrics and patient-reported outcomes are commonly used in return-to-sport assessments in those with anterior cruciate ligament reconstruction (ACLR). Patients may experience clinical knee-related symptoms aggravating enough to seek additional medical care after ACLR. In addition to seeking additional medical care, these patient-reported clinical knee-related symptoms may also influence function after ACLR. However, whether an association exists between these common quadriceps metrics and the patient-reported clinical knee-related symptom state is unknown.

Objective: To determine if meeting isometric quadriceps strength and symmetry criteria is associated with acceptable clinical knee-related symptoms at 5 to 7 months post–ACLR.

Design: Cross-sectional study.

Setting: Laboratories.

Patients or Other Participants: We classified individuals at 5 to 7 months post–ACLR based on their isometric ACLR and uninvolved-limb quadriceps strength or quadriceps strength symmetry. We also dichotomized participants based on the Englund et al criteria for unacceptable clinical knee-related symptoms.

Main Outcome Measure(s): Quadriceps strength variables were compared between groups using analysis of covariance, and the relative risk of a participant in each quadriceps strength group reporting acceptable clinical knee-related symptoms was determined using binary logistic regression.

Results: A total of 173 individuals participated. The isometric quadriceps strength and limb symmetry index were different ($P < .001$) between quadriceps strength groups. Those categorized as both strong and symmetric had a 1.28 (95% CI = 0.94, 1.74) and individuals categorized as symmetric only had a 1.29 (95% CI = 0.97, 1.73) times greater relative risk of reporting acceptable clinical knee-related symptoms compared with the neither strong nor symmetric group.

Conclusions: The majority of individuals (85%) recovering from ACLR failed to meet either the clinical quadriceps strength or symmetry criteria at 5 to 7 months post–ACLR. Quadriceps strength and quadriceps strength symmetry are clinically important but may not be primary determinants of the clinical knee-related symptom state within the first 6 months post–ACLR.

Key Words: limb symmetry index, knee-related quality of life, patient-reported outcome measures

Key Points

- At 5 to 7 months post–anterior cruciate ligament reconstruction, 85% of individuals did not meet clinical quadriceps strength (≥3.0 Nm/kg) or quadriceps strength symmetry (limb symmetry index ≥90%) criteria.
- More than one-third of individuals (39.9%) reported clinically unacceptable knee-related symptoms for which they might seek additional medical treatment at 5 to 7 months post–anterior cruciate ligament reconstruction.
- Quadriceps strength and quadriceps strength symmetry may not influence the clinical knee-related symptom state despite being important for functional performance and progression through rehabilitation and return to sport.

Adequate quadriceps strength is necessary to stabilize the knee joint during high-level athletic tasks, such as running, cutting, and jumping after anterior cruciate ligament (ACL) injury and ACL reconstruction (ACLR).[1] However, the clinical criterion for acceptable involved-limb isometric quadriceps strength (≥3.0 Nm/kg) is the most commonly unmet criterion at 6 to 9 months post–ACLR.[2] On average, at 6 to 12 months post-ACLR, patients demonstrated a 24% ACLR-limb deficit in isometric quadriceps strength compared with their uninvolved limb.[3] In further support, the authors[4] of a recent systematic review and meta-analysis of 28 studies reported that the average ACLR-limb isometric quadriceps strength fell below the clinical criterion for ideal quadriceps strength (<3.0 Nm/kg) in all but 3 studies. Interestingly, in this same analysis, Lisee et al[4] indicated that, on average, the patients also failed to achieve clinical criteria for quadriceps strength in the uninvolved limb in all but 4 of these studies as well.

In addition to individual-limb quadriceps strength, quadriceps strength symmetry (limb symmetry index [LSI] ≥90%) is often used as a clinical indicator of physical readiness for return to unrestricted physical activity as part of a comprehensive battery of return-to-sport tests after ACLR.[5,6] Yet quadriceps strength symmetry does not provide a complete depiction of adequate quadriceps function post–ACLR, as bilateral quadriceps strength deficits were shown to be underreported.[5] Deficits in quadriceps strength and quadriceps strength symmetry were present at 6 months[2–5,7] and persisted for up to 1 year[3,4,7] post–ACLR. As a result, the objective assessment of isometric quadriceps strength relatively early in the ACLR rehabilitative process to identify individuals experiencing meaningful quadriceps weakness with the goal of providing aggressive, evidence-based strengthening interventions during formal rehabilitation would offer a clear benefit in improving clinical outcomes.

Independently, adequate ACLR-limb isometric quadriceps strength (3.0 Nm/kg)[3] and quadriceps strength symmetry (LSI ≥90%) have been associated with acceptable patient-reported function at 6 months to 13 years after ACLR.[8,9] Individuals with ACLR who demonstrated strong quadriceps muscles (ie, ≥3.0 Nm/kg) in their ACLR limb reported better function than those with weak quadriceps muscles.[8] Also, those who displayed symmetric quadriceps strength (ie, LSI ≥90%) had a reduced risk of reinjury on return to sport versus those with clinically relevant quadriceps strength asymmetry.[10] Englund et al[11] developed a composite score from the Knee injury and Osteoarthritis Outcome Score (KOOS) subscales to identify individuals who describe their reconstructed knee as symptomatic enough to seek medical care. Using the Englund criteria rather than an outcome measure, such as the International Knee Documentation Committee (IKDC) form or the recently established Patient Acceptable Symptom State (PASS), offers the advantage of a valid and reliable patient-reported outcome measure (KOOS) in the ACLR population to identify individuals experiencing knee-related symptoms severe enough to affect function that might be clinically modifiable via additional medical care. Thus, the Englund et al criteria provide clinicians with valuable information for developing patient-centered care that addresses functional and patient-reported deficits. In a recent study,[12] at 5 to 7 months after ACLR, 42% of individuals described unacceptable clinical knee-related symptoms as measured by the KOOS. If patients are detailing unacceptable clinical knee-related symptoms severe enough to cause them to seek medical care when they are still pursuing organized rehabilitation, their rehabilitation specialist would be appropriately positioned to address these inadequacies. Although the researchers[12] noted the high prevalence of patients who were experiencing meaningful clinical knee-related symptoms after surgery, it is unclear if quadriceps weakness, relative to clinical threshold values (<3.0 Nm/kg) and the uninvolved limb (LSI), was associated with patient-reported clinical knee-related symptoms after ACLR.

After ACLR, quadriceps strength metrics are commonly used in clinical assessments to monitor recovery and patient-reported outcomes are associated with quadriceps strength metrics, yet evidence for the relationship between quadriceps dysfunction and knee-related symptoms (a patient-centered metric) is lacking. Therefore, the purpose of our study was to determine if categorization of isometric quadriceps strength and quadriceps strength symmetry in patients after ACLR was associated with acceptable clinical knee-related symptoms at 6 months. We hypothesized that individuals who displayed adequate ACLR-limb isometric quadriceps strength (3.0 Nm/kg) and quadriceps strength symmetry (LSI ≥90%) would report acceptable clinical knee-related symptoms compared with those who exhibited quadriceps weakness, asymmetry, or both. Understanding the relationship between commonly used, objectively measured quadriceps strength metrics and patient-reported knee-related symptoms would provide valuable information for clinicians to guide lower extremity strengthening and patient-centered care at a critical time during the ACLR rehabilitation process.

METHODS

This was a multisite, cross-sectional study in which bilateral quadriceps strength and patient-reported outcomes were collected during a single visit.

Participants

We recruited 173 participants across 3 institutions. Participants were included if they were between 13 and 30 years old and 5 to 7 months post–primary, unilateral ACLR. Volunteers were excluded if they had a multiligament reconstruction involving the posterior cruciate ligament or a history of cardiovascular, neurologic, or another medical condition that prohibited them from being tested safely. All participants who were less than 19 years old provided informed and written assent, and their legal guardian provided written consent. Adult participants supplied informed written consent. All experimental procedures were approved by each institution's institutional review board.

Patient-Reported Outcome Measures

Participants completed the Tegner Activity Scale to describe their preinjury and current levels of physical activity.[13] They also completed the KOOS, which is a valid and reliable patient-reported outcome measure that can be used to identify individuals experiencing clinical knee-related symptoms severe enough to warrant seeking medical care.[11] The KOOS consists of 5 subscales (with 4 to 17 questions each): quality of life (QOL); symptoms; pain; activities of daily living (ADLs); and function, sports, and recreational activities (Sports).[14] Each question is scored on a 0 to 4 scale; subscale scores are normalized and reported on a 0 to 100 scale, where higher scores indicate better patient-reported function.[15,16] Based on established threshold criteria, participants were categorized as exhibiting unacceptable clinical knee-related symptoms if they scored ≤87.5 on the KOOS QOL subscale and met ≥2 of the following subscale cutoff scores: KOOS symptoms ≤85.7; KOOS pain ≤86.1; KOOS ADLs ≤86.8; or KOOS sports and recreation ≤85.0.[11,17] Those who did not meet both criteria were considered to have acceptable clinical knee-related symptoms.

Assessment of Quadriceps Strength

Participants underwent isometric knee-extension (quadriceps) strength testing on their ACLR and uninvolved limbs.

Knee-extension maximal voluntary isometric contractions (MVICs) were performed on a multimodal dynamometer (model 4 Pro; Biodex Medical Systems, Inc) with individuals seated and secured with padded straps, the hips flexed to 85°, and the test knee flexed to 90° with the arms folded across the chest. After a submaximal warm-up, they completed 2- to 5-second holds for each MVIC and 2 to 3 maximal trials with real-time visual feedback and loud oral encouragement from the tester.[18] Assessment of isometric knee-extension strength (quadriceps peak torque) has been shown to be reliable and valid across multiple research sites.[19] For all protocols, quadriceps strength was normalized to body mass (Nm/kg).

Quadriceps Strength and Quadriceps Strength Symmetry Classification

Participants were classified according to whether the isometric quadriceps strength of the ACLR limb normalized to body weight and quadriceps strength symmetry criteria were met or not (Table 1). Quadriceps strength symmetry was calculated as follows: LSI = ACLR-limb isometric quadriceps strength (Nm/kg)/uninvolved-limb isometric quadriceps strength (Nm/kg) × 100%. Those who demonstrated ≥3.0 Nm/kg and ≥90% quadriceps LSI were categorized as both strong and symmetric. This cutoff for quadriceps strength (≥3.0 Nm/kg) has been associated with positive patient-reported functional outcomes[8] and was used previously[4] as a threshold value for return-to-sport testing. Additionally, quadriceps strength symmetry (LSI ≥90%) has been used as the common cutoff score in the ACLR population for return to unrestricted physical activity and associated with favorable patient-reported outcomes.[5,20,21] If participants displayed quadriceps strength symmetry LSI ≥90% but quadriceps strength <3.0 Nm/kg, they were classified as *symmetric only*. If they exhibited isometric quadriceps strength ≥3.0 Nm/kg but quadriceps strength symmetry LSI ≤90%, they were categorized as *strong only*. Anyone who demonstrated isometric quadriceps strength of the ACLR limb <3.0 Nm/kg and quadriceps strength symmetry LSI <90% was classified as *neither strong nor symmetric*.

Statistical Analysis

We calculated means and SDs for all demographic descriptors, patient-reported outcome measure scores, and quadriceps strength variables. We also computed the prevalence with which individuals were classified as having acceptable or unacceptable clinical knee-related symptoms and the frequencies with which they were classified by the composite isometric quadriceps strength or quadriceps strength symmetry criteria or both (Table 2). Demographics were then compared among quadriceps strength classification groups using analyses of covariance (ANCOVAs), with the data-collection site as the covariate. The distributions of participant sexes, meniscal surgery at the time of ACLR, and graft sources were compared among groups using a chi squared test. Tegner activity levels were evaluated among groups using a Kruskal-Wallis test. Quadriceps strength variables were compared among groups using ANCOVAs with enrollment site as a covariate. We adjusted our a priori α for multiple comparisons among the quadriceps strength variables ($\alpha < .05/8 = .006$). Finally, we applied binary logistic regression to calculate relative risk ratios (RRRs) and 95% CIs to describe the relative risk of a participant reporting acceptable clinical knee-related symptoms between the strong and symmetric group or symmetric-only groups when compared with the neither strong nor symmetric group. All statistical analyses were performed via an open-source statistical package (version 1.2.27; jamovi).

Table 1. Quadriceps Classification Groups

Group	Quadriceps Strength Criteria
Both strong and symmetric	ACLR-limb quadriceps strength ≥3.0 Nm/kg and quadriceps strength LSI ≥90.0%
Symmetric only	ACLR-limb quadriceps strength LSI ≥90.0%
Strong only	ACLR-limb quadriceps strength ≥3.0 Nm/kg
Neither strong nor symmetric	ACLR-limb quadriceps strength <3.0 Nm/kg and quadriceps strength LSI <90.0%

Abbreviations: ACLR, anterior cruciate ligament reconstruction; LSI, limb symmetry index.

Sample Size Estimation

We estimated the sample size a priori. Our estimation was based on the ability to detect a 10% increase in the relative risk of meeting the Englund et al[11] criteria for acceptable knee function among individuals who were classified as strong and symmetric versus the relative risk (RR = 1.39) for all patients with ACLR in a recent paper by Harkey et al.[12] Accordingly, 149 participants were needed for the current study to be powered appropriately.

RESULTS

Participant demographics, patient-reported outcomes, and quadriceps variables are summarized by quadriceps classification group in Table 3. Meniscal repair and meniscectomy were combined and reported as *meniscal surgery* at the time of ACLR (Table 3). Fifteen percent of individuals were classified as both strong and symmetric (≥3.0 Nm/kg and ≥90% LSI), 2.3% as strong only (≥3.0 Nm/kg but <90% LSI), 17.3% as symmetric only (<3.0 Nm/kg but ≥90% LSI), and 65.4% as neither strong nor symmetric (<3.0 Nm/kg and <90% LSI). Quadriceps strength classification groups did not differ based on demographics, but the preinjury Tegner activity level ($P = .003$), current Tegner activity level ($P = .002$), and all quadriceps strength variables (P values < .001) were different among quadriceps classification groups. One person's graft source was listed as *unknown* because the individual did not provide this information at the time of study enrollment and medical records were not accessible (Table 3). The neither strong nor symmetric group demonstrated the weakest isometric quadriceps strength for the ACLR limb (2.13 ± 0.49 Nm/kg), whereas the symmetric-only group displayed the

Table 2. Summary of Quadriceps Strength and Clinical Knee-Related Symptom Classification Groups

Group	Symptoms, No. (%)		Relative Risk Ratio (95% CI)
	Acceptable	Unacceptable	
Both strong and symmetric	18 (69.2)	8 (30.8)	1.28 (0.94, 1.74)
Symmetric only	21 (70.0)	9 (30.0)	1.30 (0.97, 1.73)
Neither strong nor symmetric	61 (54.0)	52 (46.0)	

The neither strong nor symmetric group was the reference group in our analysis.

Table 3. Participant Demographics, Patient-Reported Function, and Quadriceps Strength

Demographic	Group (No. [%])				*P* Value
	Both Strong and Symmetric (26 [15.0])	Strong Only (4 [2.3])	Symmetric Only (30 [17.3])	Neither Strong Nor Symmetric (113 [65.4])	
Sex, No., males/females	18/8	3/1	11./19	41/72	.09
Age, mean ± SD, y	18.5 ± 3.3	20.2 ± 1.9	18.0 ± 3.5	19.0 ± 3.6	.44
Body mass index, mean ± SD, kg/m^2	23.2 ± 3.3	21.9 ± 2.7	25.0 ± 5.0	25.0 ± 4.7	.22
Time since surgery, mean ± SD, mo	6.2 ± 0.55	5.8 ± 0.75	6.1 ± 0.55	6.0 ± 0.54	.46
Graft source, No.					.008
Bone-patellar tendon-bone	2	0	1	35	
Hamstrings autograft	22	2	28	67	
Quadriceps tendon autograft	0	1	0	8	
Allograft	2	1	1	2	
Unknown	0	0	0	1	
Meniscal surgery at time of ACLR, %	46.2	25.0	50.0	55.8	.53
Tegner Activity Score, median [interquartile range]					
Preinjury	10 [1]	10 [0.25]	9 [2]	9 [2]	.003[a]
Current	7.5 [3]	6.5 [1.75]	6 [2]	6 [2]	.002[a]
Quadriceps strength, mean ± SD, Nm/kg					
ACLR limb	3.61 ± 0.44	3.74 ± 0.66	2.41 ± 0.41	2.13 ± 0.49	<.001[a]
Uninvolved limb	3.59 ± 0.49	4.33 ± 0.73	2.45 ± 0.43	3.06 ± 0.59	<.001[a]
Quadriceps strength limb symmetry index, mean ± SD, %	101.0 ± 7.2	86.4 ± 0.88	98.7 ± 6.6	70.8 ± 14.2	<.001[a]

Abbreviation: ACLR, anterior cruciate ligament reconstruction.

[a] Indicates a significant difference.

weakest isometric quadriceps strength for the uninvolved limb (2.45 ± 0.43 Nm/kg). The strong-only group exhibited the greatest isometric quadriceps strength in both the ACLR (3.74 ± 0.66 Nm/kg) and uninvolved (4.33 ± 0.73 Nm/kg) limbs.

The prevalence of clinical knee-related symptom classifications in each quadriceps strength group is summarized in Table 2. Four participants were categorized as strong only (3 males, 1 female; age = 20.2 ± 1.9 years) and were therefore excluded from further analysis. Nearly 40% of participants demonstrated unacceptable clinical knee-related symptoms, regardless of quadriceps strength classification group, at 6 months post–ACLR. The relative risk of a participant in the strong and symmetric group being categorized as having acceptable clinical knee-related symptoms was not greater than that of a participant in the neither strong nor symmetric group (RRR = 1.28; 95% CI = 0.94, 1.74). Similarly, the relative risk of a participant in the symmetric-only group being classified as having acceptable clinical knee-related symptoms was not greater (RRR = 1.30; 95% CI = 0.97, 1.73) than in the neither strong nor symmetric group.

DISCUSSION

At 6 months after ACLR, quadriceps weakness is experienced by 82.7% of patients, quadriceps strength asymmetry by 67.6%, and unacceptable clinical knee-related symptoms by 39.9%. The primary purpose of our study was to determine if patients with ACLR who met isometric quadriceps strength and quadriceps strength symmetry criteria experienced acceptable clinical knee-related symptoms at 5 to 7 months post–ACLR versus those who met the criteria for only quadriceps strength symmetry or neither quadriceps strength nor symmetry. Previous researchers established that quadriceps strength symmetry was positively associated with patient-reported function after ACLR,[3,9,22] and greater isometric quadriceps strength in both the ACLR and uninvolved limbs was associated with adequate knee function and lower levels of knee-joint pain.[23] We found that 40% of individuals at 5 to 7 months post–ACLR reported unacceptable clinical knee-related symptoms. This result is concerning; however, meeting common thresholds for quadriceps strength or quadriceps strength symmetry (or both) was not associated with the knee-related symptom status at this early and well-defined time point after surgery. The ACLR recovery process is extensive, and because these data are only a snapshot of the quadriceps function and patient-reported clinical knee-related symptom status at 5 to 7 months post–ACLR, our investigation may not provide information regarding changes in quadriceps strength metrics and their effect on clinical knee-related symptom status throughout the latter stages of the rehabilitation process.

We used established criteria to classify participants as experiencing unacceptable clinical knee-related symptoms that may warrant seeking additional medical care.[11] Although the KOOS subscales are valid and reliable as standalone measures in the ACLR population,[24] this simple additional step creates a composite score across all the individual KOOS subscale scores to indicate whether patients demonstrate unacceptable clinical knee-related symptoms at a given time point after knee surgery. It is concerning that 40% (n = 69) of individuals in our study described unacceptable clinical knee-related symptoms, which indicates a persistent limitation when they were transitioning to more sport-specific and high-intensity physical activity or their formal rehabilitative care had ceased or both.[25,26] Our findings are consistent with those of recent researchers[12] who observed that 42% of individuals at 5 to 7 months post–ACLR noted unacceptable clinical knee-related symptoms. Among individuals with ACLR, unacceptable clinical knee-related symptoms have also been linked to negative physiological long-term conse-

quences, including the development of knee osteoarthritis.[11] Of those who reported unacceptable clinical knee-related symptoms, 30.8% were classified as both strong and symmetric, 30% as symmetric only, and 46% as neither strong nor symmetric; however, the relative risk of experiencing acceptable compared with unacceptable symptom states was not different among groups.

Earlier authors indicated that more than 55% of individuals with ACLR had a quadriceps strength LSI $\geq$90% at 6 months post-ACLR,[5] yet only 32.4% of our participants met this criterion. The lack of quadriceps strength symmetry may reflect reliance on the uninvolved limb for strength and stability during high-level activities, either consciously or unconsciously.[27] In addition, isometric quadriceps strength deficits up to 40% in the ACLR limb versus the uninvolved limb, resulting in inadequate quadriceps strength symmetry (<90% LSI), were seen at 6 months post–ACLR[3] and some persisted for 2 years.[4] Among our participants, 82.7% did not meet ACLR-limb quadriceps strength ($\geq$3.0 Nm/kg) recommendations at 5 to 7 months post–ACLR. This lack of adequate quadriceps strength and quadriceps strength symmetry is concerning, considering that many individuals are transitioning to higher-level, late-stage rehabilitation (eg, sport-specific activities) or are cleared to return to unrestricted physical activity as early as 6 months post–ACLR.[3,25] In the current study, the symmetric-only group displayed inadequate uninvolved-limb quadriceps strength (2.45 $\pm$ 0.43 Nm/kg) and ACLR-limb weakness. This finding is consistent with previous literature[5] in showing that despite its common clinical application, quadriceps strength symmetry may overestimate quadriceps function in this population due to bilateral weakness. As the prevalence of individuals in our study who met established involved-limb quadriceps strength and quadriceps strength symmetry metrics was so low, 6 months post–ACR may not provide enough time for adequate quadriceps function recovery. Our findings add to the growing clinical recommendations to delay return to sport beyond 6 months post–ACLR because patients do not demonstrate adequate involved-limb quadriceps strength or quadriceps strength symmetry before then.[2,5]

A unilateral isometric quadriceps strength cutoff score of 3.0 Nm/kg was established in an adult population (age = 22.5 $\pm$ 5.0 years),[8] whereas our study population encompassed adolescents. For certain individuals, such as adolescent females, 3.0 Nm/kg may be a physiologically unattainable unilateral isometric quadriceps strength output. Future researchers should better determine both sex- and age-specific thresholds for objective clinical measures (eg, quadriceps strength, single-legged hop testing). Our results add to the growing evidence that more than 50% of patients who returned to sport between 6 and 12 months post–ACLR did not meet quadriceps strength symmetry or quadriceps strength metrics[2] and highlight the need for focused rehabilitation efforts to address persistent quadriceps strength impairments, which are known to negatively affect patient functional outcomes.

Several limitations should be considered when evaluating our findings. The majority of participants did not meet either the quadriceps strength ($\geq$3.0 Nm/kg) or quadriceps strength symmetry ($\geq$90% LSI) threshold, which led to unbalanced group memberships and small sample sizes in our symmetric-only (n = 30; 17.3%) and both strong and symmetric (n = 26; 15%) groups. Additionally, just 4 participants (0.02%) fit the strength-only group criterion, so we eliminated this group from the analyses due to the small sample size. Future authors should explore this quadriceps strength phenomenon to better explain the mechanisms that may be causing these unique quadriceps strength outcomes after ACLR. Despite our unbalanced group memberships, we were able to determine the prevalence of quadriceps strength metrics and clinical knee-related symptoms at this critical point in the ACLR recovery process. Although quadriceps strength has been associated with patient-reported outcomes,[9] we did not control other possible factors, such as psychological readiness for return to sport, graft source, and concomitant injuries. Also, we did not analyze rehabilitation status or return-to-sport status. As 5 to 7 months post–ACLR is often a time of transition from the mid to late stage of rehabilitation, including progression to sport-specific activities, or a time when individuals may be returning to unrestricted sport participation, these high-level activities influence quadriceps strength and function, as well as patient-reported function.

CONCLUSIONS

At 6 months post–ACLR, 85% of individuals did not meet clinical recommendations for quadriceps strength or symmetry and nearly 40% reported clinically unacceptable clinical knee-related symptoms. Based on our findings, it does not appear that individuals who met previously described criteria for ACLR-limb isometric quadriceps strength or quadriceps strength symmetry (or both) were less likely to report unacceptable clinical knee-related symptoms compared with individuals who did not meet both quadriceps strength criteria. At 6 months post–ACLR, 85% of patients failed to meet 1 or both of the commonly used isometric quadriceps strength metrics. This is especially concerning because this is a time of transition to higher-level activities or clearance for return to sport, which requires adequate quadriceps strength and function. Formal ACLR rehabilitation efforts should incorporate bilateral quadriceps strengthening as early as possible to promote adequate quadriceps strength and strength symmetry to improve knee-related symptoms for short- and long-term knee-joint health and patient satisfaction.

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