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Predicting Anterior Cruciate Ligament Reinjury From Return-to-Activity Assessments at 6 Months Postsurgery: A Prospective Cohort Study

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Context: Return-to-activity (RTA) assessments are commonly administered after anterior cruciate ligament reconstruction (ACLR) to manage the patient's postoperative progressions back to activity. To date, few data are available on the clinical utility of these assessments to predict patient outcomes such as secondary anterior cruciate ligament (ACL) injury once the athlete has returned to activity.

Objective: To identify the measures of patient function at 6 months post-ACLR that best predict RTA and second ACL injury at a minimum of 2 years after ACLR.

Design: Prospective cohort study.

Setting: Laboratory.

Patients or Other Participants: A total of 234 patients with primary, unilateral ACLR completed functional assessments at approximately 6 months post-ACLR. Of these, 192 (82.1%) completed follow-up at ≥2 years post-ACLR.

Main Outcome Measure(s): The 6-month functional assessments consisted of patient-reported outcomes, isokinetic knee-flexor and -extensor strength, and single-legged hopping. We collected RTA and secondary ACL injury data at ≥2 years after ACLR.

Results: Of the patients who were able to RTA (n = 155), 44 (28.4%) had a subsequent ACL injury, 24 (15.5%) to the ipsilateral graft ACL and 20 (12.9%) to the contralateral ACL. A greater proportion of females had a secondary injury to the contralateral ACL (15/24, 62.5%), whereas a greater proportion of males reinjured the ipsilateral ACL graft (15/20, 75.0%; $P =$ .017). Greater knee-extension symmetry at 6 months increased the probability of reinjury (B = 0.016, $P =$ .048). Among patients with RTA at <8 months, every 1% increase in quadriceps strength symmetry at 6 months increased the risk of reinjury by 2.1% (B = 0.021, $P =$ .05). Among patients with RTA at >8 months, every month that RTA was delayed reduced the risk of reinjury by 28.4% (B = –0.284, $P =$ .042). Descriptive statistics of patient function stratified between the early and delayed RTA groups can be found in the Supplemental Table (available online at http://dx.doi.org/10.4085/1062-6050-0407.20.S1).

Conclusions: Patients with more symmetric quadriceps strength at 6 months post-ACLR were more likely to experience another ACL rupture, especially those who returned to sport at <8 months after the index surgery. Clinicians should be cognizant that returning high-functioning patients to activity at <8 months post-ACLR may place them at an increased risk for reinjury.

Key Words: return to sport, return to play, knee, quadriceps muscle, limb symmetry

Key Points

- In isolation, quadriceps limb symmetry should not be used to accelerate return-to-activity clearance after anterior cruciate ligament reconstruction (ACLR).
- Among patients who returned to activity at >8 months after ACLR, every month that return to activity was delayed decreased the probability of subsequent injury by 28%.
- Functional assessments at 6 months should not be administered with the goal of releasing patients to activity at <8 months after ACLR.

Reinjury rates up to 28% after primary anterior cruciate ligament reconstruction (ACLR) have been reported for individuals who returned to high levels of physical activity and sports.[1,2] In addition to high reinjury rates, decreased physical activity,[3] worse subjective function,[4] and early-onset posttraumatic osteoarthritis[5,6] have challenged contemporary management strategies for patients rehabilitating after ACLR. To effectively manage health care decisions after anterior cruciate ligament (ACL) injury, we need functional measures that best identify patients at risk for secondary ACL injury. Currently, patients commonly complete performance assessments that guide the progression to unrestricted activities at approximately 6 months after ACLR.[7] Conventional practice is to use postoperative strength and jumping symmetry tests to inform the timing of return to activity (RTA) and sport with the ultimate goal of promoting greater strength and symmetry as benchmarks for successful progress through rehabilitation.

The goal of safely returning patients to high levels of physical activity requires clinicians and researchers alike to determine appropriate timepoints throughout the recovery process for identifying and treating functional impairments. Functional assessments used to guide RTA are typically administered around 6 months.[8–10] These assessments do not often result in immediate activity clearance but provide objective measures to better inform clinicians about deficits that may need to be addressed throughout the RTA progression.[11–13] Laboratory measurement techniques allow the collection of precise and objective data regarding muscle and patient function. The clinical challenge is to compile a battery of assessments that are clinically feasible and time sensitive and best describe the measures of patient function that predict outcomes. The most frequently used assessments for managing RTA decision making are the time since surgery, subjective function quantified via patient questionnaires, quadriceps and hamstrings strength assessed through isometric and isokinetic tests, and single-legged hopping.[8,14,15] To date, limited information is available about the ability of these assessments at 6 months to predict an effective RTA without a secondary ACL injury.

The use of objective measures to manage activity clearance has risen dramatically in the past decades.[8] Time since surgery is the most commonly used metric when managing clearance for sport activity, and many clinicians rely on it as the only measure.[8] In assessments of quadriceps strength, the typical target for patients and clinicians is a limb symmetry index (LSI) of 90%, using the contralateral limb as an objective comparison.[16] However, an LSI of 90% is often not attained after ACLR.[11] The ability to predict subsequent outcomes, such as reinjury, before release for unrestricted activity could empower clinicians with information for treating patients after ACLR while they are still under the supervision of health care providers.

The identification of typical components of RTA assessments, such as quadriceps strength and single-legged hopping distance, that predict patients who will sustain a secondary ACL injury can allow clinicians to more efficiently manage rehabilitation progressions and RTA decision making after ACLR. Therefore, the purposes of our study were to identify the measures of patient function at 6 months post-ACLR that best predicted RTA and secondary ACL injury at $\geq$2 years after ACLR. We hypothesized that better measures of self-reported function, strength, and functional performance at 6 months post-ACLR would increase the probability of a successful RTA. Additionally, we proposed that worse measures of self-reported function, strength, and functional performance at 6 months post-ACLR would increase the probability of secondary ACL injury.

METHODS

We conducted a prospective cohort study with $\geq$2 years of follow-up. The dependent (outcome) variables were RTA (*yes* or *no*), months between ACLR and RTA, and ACL reinjury (*yes* or *no*). An *ACL reinjury* was defined as a subsequent injury to the ACLR graft or the contralateral ACL. The independent (predictor) variables were measures of function collected during the patient's functional assessment: patient-reported outcomes, knee-extensor and -flexor strength, and single-legged hopping distance.

Participants

All patients were referred from a multisurgeon academic orthopaedic subspecialty practice to complete a battery of functional assessments in a controlled laboratory setting at approximately 6 months post-ACLR. The data in this study were collected as part of an ongoing program in which patients routinely complete postoperative assessments after lower extremity surgery.[11,14] Patients and their clinicians were provided a detailed report, including the data from the assessment, to guide rehabilitation progressions and RTA decision making. Because this study was a point-of-care research design, we did not know if or how the data were used to manage the patient's rehabilitation. Patients were included in the analyses if they had a history of primary, isolated, unilateral ACLR confirmed in their medical records. Patients were excluded from analyses if they had a history of other lower extremity surgery, concomitant ligament reconstruction, surgical complications, or any neurologic disorder. Participants followed the same postoperative rehabilitation guidelines distributed by their surgeon. This study was approved by our university's institutional review board, and all patients voluntarily provided written informed consent.

Patient-Reported Outcomes

After enrolling and providing consent, all participants completed the Knee Osteoarthritis Outcome Score (KOOS) and International Knee Documentation Committee (IKDC) subjective form to evaluate subjective knee function. These measures are valid and reliable in patients after ACLR.[17] The preinjury level of physical activity was quantified via the Tegner Activity Scale.[18] Kinesiophobia was assessed using the Tampa Scale for Kinesiophobia and global function through the Veterans Rand 12-Item Survey.

Knee-Extensor and -Flexor Strength

Isokinetic concentric peak knee-flexion and -extension torques were measured bilaterally using a dynamometer (model IV; Biodex Medical Systems) at a speed of 90°/s. All testing was performed first on the uninvolved limb and then on the involved limb. Participants completed practice trials with each limb for familiarization before testing. They were orally encouraged to provide maximal effort through their full range of motion for 8 test contractions.

Single-Legged Hopping

Single-legged hopping performance was measured bilaterally using a battery of 3 hopping tasks, as follows: the single hop for distance, the triple hop for distance, and the 6-m timed hop. The participant was given as many practice trials as needed until he or she was comfortable completing the task. Testing was performed first on the uninvolved limb, followed by the involved limb, for a total of 3 trials on each limb. All hopping tasks required the participant to maintain single-limb stability at the end of each hop. Tasks for distance were measured from the toe at the start to the heel at the landing, and the average distance across the 3 trials was used for analysis. The 6-m timed hop was instrumented with timing gates (FITLIGHT Corp) that were placed 1 m off the ground at the start and finish.

Two-Year Follow-Up

Follow-up assessments for all patients occurred at ≥2 years post-ACLR. Data were obtained via phone interview, email, or a subsequent clinic visit identified through a medical record review. Patients were assessed about the (1) ability to RTA and (2) incidence of secondary ACL injury to the primary involved or contralateral knee. The dates of RTA and ACL reinjury were collected when available.

Data Processing

Unilateral measures of peak torque were normalized to the participant's body mass (Nm/kg). Strength and hopping symmetry measures were calculated using the following equation:

$$\text{Limb Symmetry} = \left(\frac{\text{Involved Limb}}{\text{Uninvolved Limb}}\right) \times 100.$$

Statistical Analysis

Descriptive demographic statistics were collected for all patients with a 2-year follow-up and for all patients who returned to activity. Descriptive statistics were obtained for time to RTA, time from ACLR to secondary injury, and time from RTA to secondary injury.

Return to Activity. Analyses with RTA (*yes* or *no*) as the dependent variable were performed on all patients. We calculated Cox proportional survival curves while controlling for age, sex, and activity level for RTA as the dependent variable and time from ACLR to RTA (months) as the measure of time. Regression models were adjusted to control for the possible following covariates: sex, age, and preinjury activity level. A logistic regression model was computed with RTA as the outcome variable and measures of patient function as the predictor variables. Predictor variables of patient function consisted of the KOOS Sport, IKDC score, knee-extensor strength and symmetry, knee-flexor strength and symmetry, single-legged hop distance and symmetry, triple-hop distance and symmetry, and 6-m timed hop and symmetry.

Reinjury. Analyses with ACL reinjury as the dependent variable were conducted on patients who successfully returned to their prior levels of activity. Chi-square tests were performed to assess the distribution of sex, graft type, and activity level among patients who did and those who did not have a second ACL injury. Among those with a second ACL injury, chi-square tests were calculated to assess the distribution of sex and graft type on the side of ACL injury (ACLR graft or contralateral ACL).

We generated Cox proportional survival curves while controlling for age, sex, and activity level with (1) reinjury (*yes* or *no*) as the dependent variable and time from ACLR to reinjury (months) as the measure of time and (2) reinjury as the dependent variable and time from RTA to reinjury (months) as the measure of time. All regression models were adjusted to control for the following possible covariates: sex, age, and preinjury activity level. Another logistic regression analysis was performed with reinjury as the dependent variable and measures of patient function as the independent variable (KOOS Sport, IKDC score, knee-extensor strength and symmetry, knee-flexor strength and symmetry, single-legged hop for distance and symmetry, triple-legged hop for distance and symmetry, and 6-m timed hop and symmetry). For an exploratory analysis, we then stratified the study cohort by the median time of RTA (8 months). Patients with RTA at <8 months were operationally defined as *early RTA* and those with RTA at ≥8 months as *delayed RTA*. The same logistic regression models were conducted in the early RTA and delayed RTA subgroups.

Relationships Between RTA Assessments. Pearson *r* correlations were obtained between measures of quadriceps strength and symmetry to time to RTA, KOOS Sport, IKDC score, Tampa Scale for Kinesiophobia score, and Veterans Rand 12-Item questionnaire score.

A priori α was set at ≤.05 for all analyses. All statistical analyses were conducted using SPSS (version 26; IBM Corp).

RESULTS

A total of 357 consecutive patients after ACLR were evaluated between November 2013 and April 2018; 123 patients were excluded due to a history of lower extremity surgery, concomitant ligament reconstruction, surgical complication, or a neurologic disorder, leaving 234 patients (Figure 1). Confirmation of an ACL graft or contralateral ACL injury at ≥2 years post-ACLR was obtained for 192 patients (82.1%). Demographic characteristics are shown in Table 1.

Return to Activity

Of the 192 patients, 155 returned to their prior level of physical activity (80.7%). Descriptive information on the time of RTA and reinjury is provided in Figure 2, and RTA logistic regression statistics are available in Table 2. Factors that increased the probability of RTA were higher values for the KOOS Sport, IKDC score, quadriceps symmetry, and single-legged hop symmetry.

Reinjury

Of the 155 patients who returned to their prior level of physical activity, 44 (28.4%) had a secondary ACL injury (Figure 1). The overall proportion of reinjury between males and females did not differ ($\chi^2 = 0.13$, $P = .86$). Among patients who incurred a secondary ACL injury, a greater proportion of females reinjured the contralateral ACL (15/24, 62.5%) and a greater proportion of males reinjured the ipsilateral ACL graft (15/20, 75.0%; $\chi^2 = 6.18$, $P = .017$). Of the 155 patients who returned to activity, the graft type distribution was patellar tendon = 95 (61.3%); hamstrings = 58 (37.4%); and quadriceps tendon = 2 (1.3%). For all analyses of graft type, those with quadriceps tendon grafts were removed due to the small sample size. No differences were present between patellar tendon and hamstrings grafts in the proportion ($\chi^2 = 0.24$, $P = .71$) or side ($\chi^2 = 1.81$, $P = .23$) of reinjury.

Logistic regression statistics for reinjury can be found in Table 3. Factors that increased the probability of reinjury

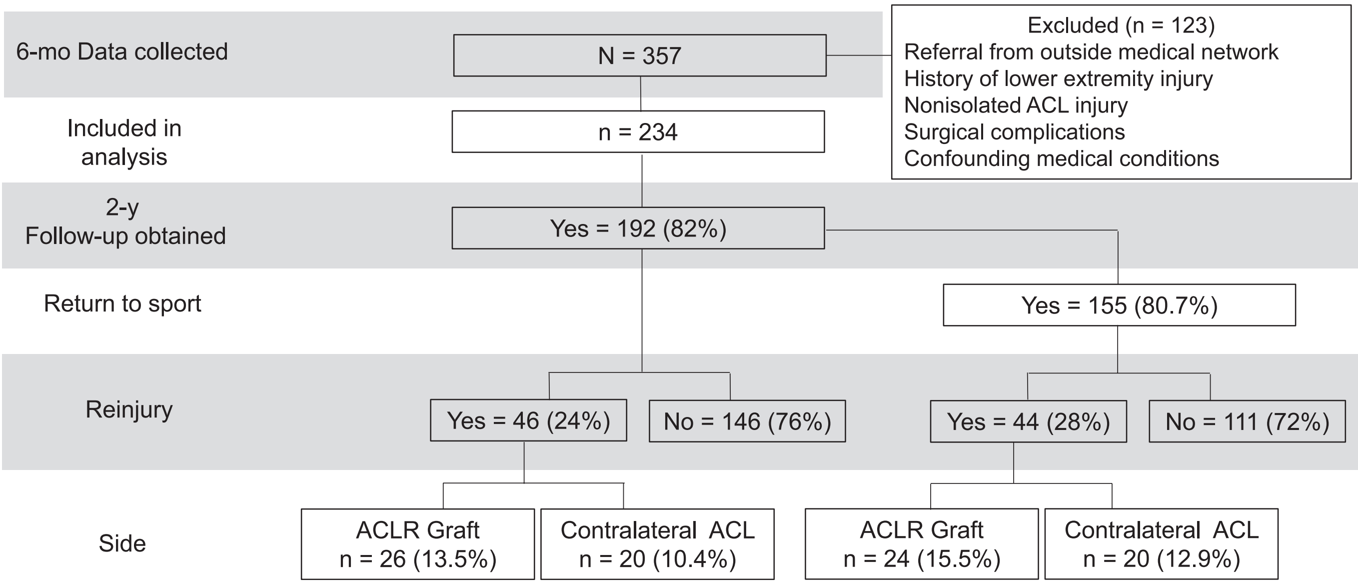


Figure 1. Flow chart of study participants. Abbreviations: ACL, anterior cruciate ligament; ACLR, ACL reconstruction.

were higher values for the KOOS Sport, knee-extensor symmetry, and triple-hop symmetry.

A total of 78 patients (50.3%) returned to activity at <8 months after ACLR. Among patients with early RTA (<8 months), neither quadriceps strength (B = 0.80, P = .20, odds ratio [OR] = 2.22 [95% CI = 0.67, 3.74]) nor time to RTA (B = 0.495, P = .10, OR = 1.64 [95% CI = 0.92, 2.94]) predicted reinjury, but quadriceps strength symmetry predicted secondary ACL injury (B = 0.021, P = .05, OR = 1.02 [95% CI = 1.00, 1.04]). Every 1% increase in quadriceps strength symmetry at 6 months increased the risk of reinjury by 2.1%.

A total of 77 patients (49.7%) retuned to activity at >8 months post-ACLR. Among patients with delayed RTA (>8 months), quadriceps strength (B = 0.817, P = .22, OR = 2.26 [95% CI = 0.62, 8.30]) and symmetry (B = 0.014, P = .41, OR = 1.01 [95% CI = 0.98, 1.05]) at 6 months did not predict reinjury; however, the time to RTA did predict secondary ACL injury (B = –0.284, P = .042, OR = 0.75 [95% CI = 0.58, 0.98]). Among patients with RTA at >8 months, every month that RTA was delayed resulted in a reduced risk of reinjury by 28.4%.

Table 1. Patient Demographics

Characteristic	Patients With Follow-Up	Patients Who Returned to Activity
	No.	
Patients	192	155
Sex (females/males)	104/88	81/74
	Mean ± SD	
Age, y	21.2 ± 9.2	20.1 ± 8.3
Height, cm	172.0 ± 17.8	172.1 ± 9.8
Mass, kg	73.7 ± 17.8	73.4 ± 17.9
Time since surgery, mo	6.73 ± 1.4	6.68 ± 1.4
Preinjury Tegner Activity Scale score (range = 0–10)	8.55 ± 1.3	8.66 ± 1.3

Relationships Between RTA Assessments

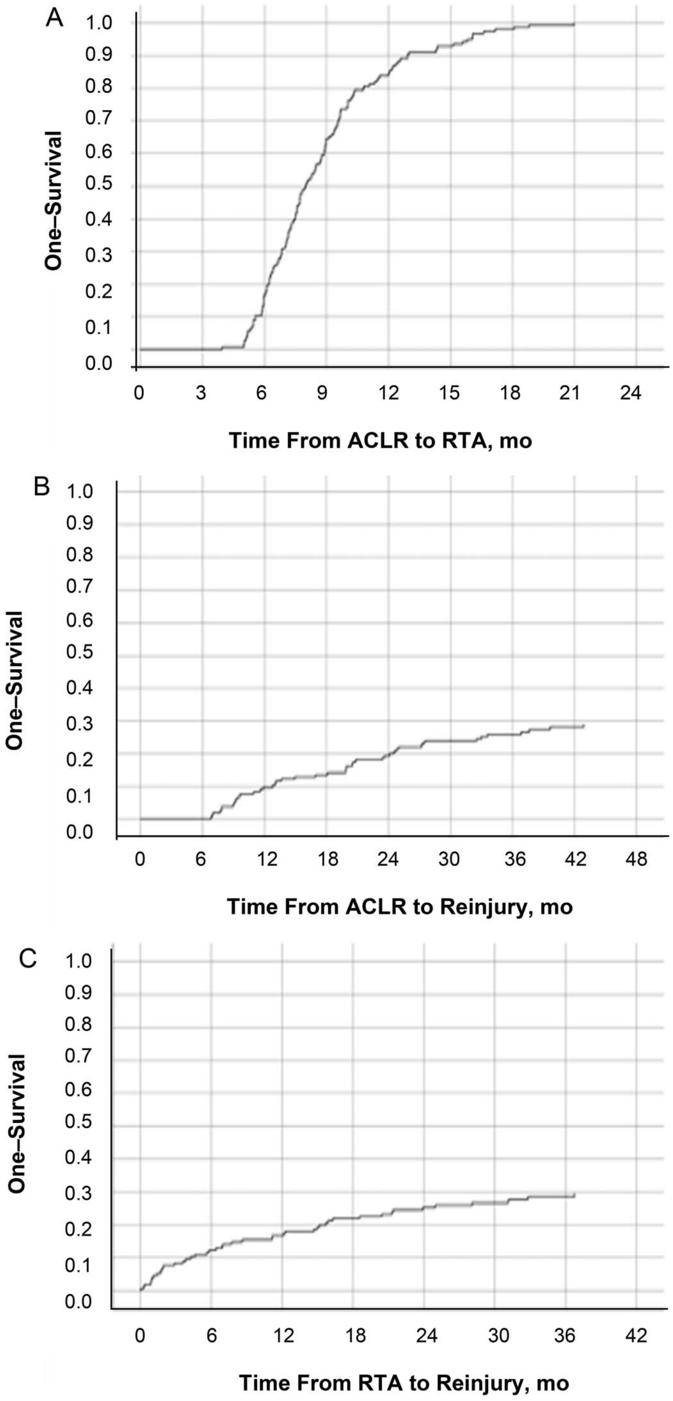
Weak, positive, statistically significant relationships were noted between measures of quadriceps strength at 6 months and all the KOOS subscales, Tampa Scale for Kinesiophobia score, and Veterans Rand 12-Item questionnaire score (Table 4). We also observed weak, positive, statistically significant relationships between measures of quadriceps symmetry at 6 months and the KOOS subscales for Pain, Sport, Activities of Daily Living, and Quality of Life (Table 4).

DISCUSSION

Physical performance assessments administered during postoperative recovery can yield insight into persistent functional deficits before a patient is released to unrestricted activity. Our purpose was to identify the measures of patient function at 6 months post-ACLR that best predicted RTA and second ACL injury at ≥2 years after ACLR. Among the total cohort included in the final analyses, the reinjury rate was 24%: 14% of patients reinjured the ACLR graft and 10% injured the contralateral ACLR. In patients who returned to activity, greater quadriceps symmetry at 6 months postsurgery increased the probability of a second ACL injury. In individuals who returned to activity at <8 months, greater quadriceps symmetry remained a predictor for reinjury. In patients who returned to activity at >8 months, quadriceps strength and symmetry at 6 months did not predict reinjury; however, every month that RTA was delayed decreased the probability of subsequent injury by 28%.

Return to Activity

The average time of RTA was 8.8 months post-ACLR, with 65% of patients returning to unrestricted physical activity in <9 months and 84% in <12 months (Figure 2). Patients with greater quadriceps symmetry at 6 months had a greater probability of returning to their prior level of



Time Frame, mo	Mean ± SD	Median (Interquartile Range)
A. ACLR to RTA	8.81 ± 3.16	7.99 (6.40, 9.36)
B. ACLR to reinjury	19.13 ± 10.10	18.99 (9.58, 24.93)
C. RTA to reinjury	10.89 ± 9.90	7.35 (1.91,16.78)

Figure 2. Survival curves of participants who successfully returned to activity (n = 155) after ACLR. Abbreviations: ACLR, anterior cruciate ligament reconstruction; RTA, return to activity.

physical activity. Younger age has been reported to predict RTA status,[1] perhaps due to increased exposure to activity and sport.[19] Quadriceps strength symmetry also increased the probability of the cohort returning to the preinjury level of activity. This finding supports the current clinical practice of health care providers (including the attending surgeons involved in this study) using quadriceps strength symmetry as a primary measure to manage RTA decisions.[8,20]

Table 2. Logistic Regression to Identify Factors Associated With Return to Activity Controlled for Age, Sex, and Preinjury Activity Level (n = 192)

Independent Variable	β Value	Odds Ratio[a] (95% CI)	*P* Value
Subjective function			
Knee Injury and Osteoarthritis Outcome–Sport	0.028	1.03 (1.01, 1.05)[b]	.009
International Knee Documentation Committee questionnaire score	0.039	1.04 (1.01, 1.07)[b]	.005
Knee			
Extensor strength, Nm/kg	0.823	2.28 (0.88, 5.86)	.088
Extensor symmetry, %	0.034	1.04 (1.01, 1.06)[b]	.004
Flexor strength, Nm/kg	0.231	1.26 (0.27, 5.85)	.768
Flexor symmetry, %	0.008	1.01 (0.99, 1.03)	.443
Single-legged hop			
Normalized, m/m	2.19	8.95 (0.80, 100.5)	.076
Symmetry, %	0.047	1.05 (1.02, 1.08)[b]	.002
Triple hop			
Normalized, m/m	0.51	1.67 (0.76, 3.64)	.200
Symmetry, %	0.018	1.02 (0.987, 1.05)	.249
6-m Timed hop, s	−0.22	0.80 (0.52, 1.24)	.317
Symmetry, %	−0.013	0.987 (0.964, 1.01)	.268

[a] Odds ratios should be interpreted as the relative increase in the odds of returning to activity for a 1-unit increase in the independent variable.
[b] $P < .05$.

Table 3. Logistic Regression to Identify Factors Associated With Reinjury Controlled for Age, Sex, and Preinjury Activity Level in Participants Who Returned to Sport (n = 155)

Independent Variable	β Value	Odds Ratio[a] (95% CI)	*P* Value
Subjective function			
Time from anterior cruciate ligament reconstruction to return to activity	−0.093	0.912 (0.81, 1.03)	.143
Knee Injury and Osteoarthritis Outcome–Sport score	0.038	1.04 (1.01, 1.07)[b]	.023
International Knee Documentation Committee questionnaire score	0.016	1.02 (0.99, 1.05)	.314
Knee			
Extensor strength, Nm/kg	0.825	1.58 (0.70, 3.56)	.065
Extensor symmetry, %	0.022	1.02 (1.01, 1.04)[b]	.045
Flexor strength, Nm/kg	0.761	2.14 (0.54, 8.43)	.276
Flexor symmetry, %	0.009	1.01 (0.99, 1.03)	.284
Single-legged hop			
Normalized, m/m	2.31	10.12 (0.96, 106.1)	.054
Symmetry, %	0.027	1.03 (0.99, 1.06)	.149
Triple hop			
Normalized, m/m	0.592	1.81 (0.81, 4.05)	.150
Symmetry, %	0.046	1.05 (1.01, 1.10)[b]	.046
6-m Timed hop, s	−0.437	0.65 (0.31, 1.36)	.252
6-m Timed symmetry, %	−0.032	0.97 (0.93, 1.01)	.116

[a] Odds ratios should be interpreted as the relative increase in the odds of subsequent anterior cruciate ligament injury for a 1-unit increase in the independent variable.
[b] $P < .05$.

Table 4. Relationships Between Quadriceps Strength and Symmetry and Other Variables at 6 Mo After Anterior Cruciate Ligament Reconstruction in Patients Who Successfully Returned to Activity[a]

		Score							
		Knee Injury and Osteoarthritis Outcome							
Variable and Value	Time From Surgery to Return to Activity	Symptoms	Pain	Activities of Daily Living	Sport	Quality of Life	International Knee Documentation Committee Questionnaire	Tampa Scale for Kinesiophobia	Veterans Rand 12-Item Survey
Strength									
r	−0.061	0.206[b]	0.249[b]	0.275[b]	0.359[b]	0.223[b]	0.218[b]	0.192[b]	0.277[b]
P	.452	.011[c]	.002[c]	.001[c]	.001[c]	.006[c]	.007[c]	.022[c]	.001[c]
Symmetry									
r	−0.133	0.129	**0.197**[b]	**0.161**[b]	**0.31**[b]	**0.181**[b]	0.142	0.021	0.069
P	.099	.114	.015[c]	.048[c]	<.001[c]	.026[c]	.081	.804	.412

[a] Bold values represent statistically significant correlation coefficients ($P < .05$).
[b] Significant *R* value.
[c] $P < .05$.

Reinjury

In the patients who returned to their previous levels of physical activity (n = 155), the reinjury rate increased from 24% to 28% (n = 44/155). This injury rate is consistent with prior reinjury rates (graft or contralateral ACL) after primary ACLR between 10% and 28%.[1,2,10,21,22] The average time from ACLR to reinjury was 19.3 months (range = 6.84–42.9 months), and 68% (n = 30/44) sustained the reinjury in <24 months post-ACLR. Furthermore, the average time from RTA to reinjury was 10.9 months (range = 1 day to 36.8 months), and the median was 7.35 months, indicating that 50% of reinjuries occurred within 7.35 months of RTA. This result is consistent with earlier reports that after ACLR, individuals are at a high risk of reinjury in the first 2 years when returning to sport.[19,23,24] Sport and activity clearance from health care professionals may be perceived by patients as an unrestricted release to the preinjury functional status. However, biological and functional adaptations have been observed up to 5 years after ACLR,[25–27] so patients should be aware of the predictors of reinjury and counseled appropriately up to and beyond the RTA progression.

Compared with researchers[28] who found a difference in reinjury rates depending on the type of graft type used, we demonstrated no differences in the proportions of reinjury between patellar tendon and hamstrings grafts. Graft decisions are commonly based on patient and surgeon preference and often on the age and activity level of the patient, thereby biasing observational studies such as ours. In randomized controlled trials with 2-year outcomes, no influence of graft type on ACLR graft or contralateral ACL reinjury rates was seen.[29] In regard to patient sex, no reinjury differences occurred in the overall proportions of males and females, but females had a greater proportion of contralateral ACL injuries, whereas males had a greater proportion of ACLR graft reinjuries. Similar findings were evident in earlier studies,[22,30–32] with greater proportions of ACL graft injuries in males and greater proportions of contralateral ACL injuries in females. Whether the greater incidence of contralateral ACL injuries in females is due to biomechanical adaptations that occur after the initial ACLR or to preexisting conditions that elevate the risk of ACL injury is unknown. This is an area for future research.

Our results support clinicians' current use of clinical assessments to guide RTA decisions.[8] Better measures for patient subjective function, quadriceps strength, and single-legged hopping performance predicted those who successfully returned to activity (Table 2). Yet, for predicting secondary ACL injury, our research challenges the way these 6-month assessments should be used (Table 3). Patients who demonstrated greater subjective function (KOOS Sport), higher measures of quadriceps symmetry, and more symmetric single-legged hopping (triple hop) at 6 months had a greater probability of reinjury. Our 6-month data were available to the surgeons and other members of the health care team so that they could provide feedback to patients regarding their rehabilitation progress. Objective feedback may influence decisions about RTA progression and clearance. Patients with better measures of subjective function and quadriceps symmetry were more likely to RTA (Table 2). It is possible that individuals with high-level functional outcomes from RTA assessments had increased exposure to subsequent injury via earlier RTA. Prior authors[33] described lower reinjury rates when RTA was later. Traditionally, clinicians base RTA timing on a patient's achievement of optimal strength and symmetry (>90% LSI).[16] Our work suggests that the "reward" of early RTA may increase the risk of secondary injury. Clinicians should discuss this risk-reward paradox with their patients when counseling them about RTA.

To further analyze the clinical utility of these assessments in a similar way as earlier investigators,[33] we stratified the cohort into those who returned to their prior level of activity before versus after 8 months (a previously reported time for release to sport[34]) and placed nearly equal numbers of patients in each group (early RTA = 78, delayed RTA = 77). For patients with early RTA, these results held true. Greater measures of quadriceps limb symmetry at 6 months increased the odds of reinjury. In patients with delayed RTA, quadriceps strength and symmetry at 6 months did not predict reinjury. Still, for every month that RTA was delayed after 8 months, the probability was reduced by 28%. In patients with early RTA, these findings contradict the current thinking about frequently administered RTA testing.[9] The common clinical goal is to maximize quadriceps strength and symmetry to reduce the likelihood of reinjury. Qualitative studies have identified patients' perceptions of the need to attain high measures of strength and symmetry to receive clearance for RTA[35] and perceived pressures from parents and coaches to do so.[36]

These beliefs regarding 6-month assessments were not supported by our data; instead, the opposite occurred, such that greater quadriceps symmetry at 6 months actually increased the probability of a second ACL injury. It is important to note that we do not endorse the clinical pursuit of quadriceps weakness or asymmetry to reduce the likelihood of reinjury. Early quadriceps strengthening post-ACLR should be a clinical priority, as it is related to greater subjective function and force attenuation during gait.[37,38] Better quadriceps strength has also been associated with more psychological readiness to RTA, which may enhance the rehabilitation progression.[39] In the patients with delayed RTA, 6-month quadriceps strength and symmetry measures did not predict reinjury. This finding is not unexpected because 6-month performance assessments may not accurately represent how the patient is functioning on RTA more than 2 months later. Nonetheless, earlier researchers[1] failed to identify quadriceps strength as an important predictor of reinjury, leading to questions about the utility of this measure.

Our finding of a 28% reduced injury probability per month after 8 months post-ACLR differed from the results of a study[21] of 69 athletes in which the investigators demonstrated that a delay in return to unrestricted sport did not reduce the probability of knee reinjury after 9 months. They classified *knee reinjury* as any subsequent injury to either knee, such as meniscal injury, patellar subluxation, or secondary ACL graft rupture, which varied from our metric of an isolated secondary ACL injury. Delaying RTA to reduce ACL reinjury after 8 months may address the importance of allowing sufficient time after ACLR for proper recovery. Even in patients who score well on subjective and objective measures of function, healing may continue during this time. A proposal[40] to delay RTA to 2 years after ACLR was based on the biological healing process of the ACLR graft. Ultimately, clinicians who are determining the safest time for return to unrestricted physical activity after ACLR should consider many factors, including subjective readiness, objective function, time since surgery, and exposure to high-risk environments.[41,42] These factors should also be serially measured so that both patients and clinicians are aware of any deteriorating function in advance of reinjury.[11]

The use of objective data to track outcomes during postoperative rehabilitation through RTA is a vital aspect of patient care. However, the traditional use of strength and hopping data at 6 months after ACLR for RTA decisions, especially less than 8 months after surgery, should be approached with caution based on our results. Quadriceps strength and symmetry data are still clinically valuable because these measures are related to knee function, global function, and patient fear of movement (Table 4).[38,43] With the optimal goal of increasing patient function, commonly evaluated via patient-reported outcomes, 6-month assessments may continue to guide clinicians in identifying functional deficits. Serial assessments after 6 months may offer greater clinical value for assessing patient progression and capturing a more accurate description of function before RTA. Functional assessments at 6 months should guide postoperative treatments and dictate the RTA progression but should be used cautiously for releasing patients to unrestricted activity before 8 months post-ACLR.

Our assessments provide objective measures of function to the patient and clinician to inform decisions that may influence patient outcomes. As with all long-term follow-up studies, our results are limited to the objective measures of patient function that were obtained at the time, although more granular measures of muscular function have since been established. This point-of-care research design represented the actual clinical use of RTA testing and patient outcomes. Also, the outcomes of RTA and reinjury were self-reported. Monitoring and quantifying patient exposures after RTA would strengthen clinical recommendations post-ACLR. The timing of RTA is a controversial topic. Future researchers should focus on the best way to identify the combination of metrics that is most useful in guiding decision making for rehabilitation progression and return to unrestricted physical activity after ACLR. Neither postoperative physical activity nor exposure were tightly controlled or objectively quantified in our work, and these should be areas for future research. Additionally, a larger sample would allow separate prediction models for sex and the side of reinjury.

CONCLUSIONS

Patients with higher levels of subjective function and quadriceps symmetry had a greater probability of returning to activity. Yet, among patients who returned to activity before 8 months, better measures of quadriceps symmetry at 6 months increased the probability of reinjury. In patients who returned to activity at later than 8 months, every month that RTA was delayed reduced the probability of reinjury by 28%. Functional assessments administered with the intention of releasing the patient to activity before 8 months should be used with caution. Clinicians should discuss this risk-reward paradox with high-functioning patients seeking an early RTA.

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