Predicting ACL Reinjury from Return to Activity Assessments at 6-months Post-Surgery: A Prospective Cohort Study

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Predicting ACL Reinjury from Return to Activity Assessments at 6-months Post-Surgery: A Prospective Cohort Study

Context: Return to activity (RTA) assessments are commonly administered following ACL-Reconstruction (ACLR) to manage post-operative progressions back to activity. To date, there is little knowledge on the clinical utility of these assessments to predict patient outcomes such as secondary ACL injury once returned to activity.

Objective: To identify what measures of patient function at 6-months post-ACLR best predict return to activity and second ACL injury at a minimum of 2-years following ACLR.

Design: Prospective-cohort

Setting: Laboratory

Patients: A total of 234 patients with primary, unilateral ACLR completed functional assessments at approximately 6-months post-ACLR. A total of 192 (82%) completed follow-up ≥ 2-years post ACLR.

Main Outcome Measures: Six-month functional assessments consisted of patient reported outcomes, isokinetic knee flexor and extensor strength, and single-leg hopping. The ability to return to activity and secondary ACL injury were collected at a minimum of two-years following ACLR.

Results: In patients who did RTA (n=155), a total of 44 (28%) individuals had a subsequent ACL injury; graft n=24 (15.5%), contralateral ACL n=20 (13%). A greater proportion of females had a secondary injury to the contralateral ACL (15/24, 63%) whereas a greater proportion of males reinjured the ipsilateral ACL graft (15/20, 75%, P=.017) Greater knee extension symmetry at 6-
months increased the probability of reinjury ($B=.016, P=.048$). In patients who RTA before 8-months, every 1% increase in quadriceps strength symmetry at 6-months increased the risk of reinjury by 2.1% ($B=.021, P=.05$). In patients who RTA after 8-months, every month that RTA was delayed reduced the risk of reinjury by 28.4% ($B=-.284, P=.042$).

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

**Key Words:** Return to Sport, Return to Play, Quadriceps, Symmetry

**Key Points:**

- Quadriceps limb symmetry should not be an isolated metric used to accelerate return to activity clearance.
- In patients who returned to activity after 8-months, 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 intention to release patients to activity prior to 8-month following ACLR.
Introduction

Reinjury rates after primary ACL reconstruction (ACLR) have been reported up to 28% for individuals who return to high levels of physical activity and sports. In addition to high reinjury rates, decreased physical activity, lower subjective function, and early onset post-traumatic osteoarthritis have challenged contemporary management strategies for patients rehabilitating after ACLR. To effectively manage healthcare decisions following ACL injury, measures of patient function that best identify patients at risk for secondary ACL injury are needed. Currently, patients are commonly referred to complete performance assessments that guide the progression to unrestricted activities at approximately 6-months following ACLR.

Conventional practice is to use post-operative strength and jumping symmetry tests to inform the timing of return to activity 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 challenges clinicians and researchers alike to identify appropriate timepoints throughout the recovery process to identify and treat functional impairments. Functional assessments used to guide RTA are commonly administered around 6-months. These assessments do not often cause immediate activity clearance, but provide objective measures to better inform clinicians on deficits that may need to be addressed throughout the RTA progression. Laboratory measurement techniques administered throughout these assessments allow precise and objective data of muscle and patient function to be collected. The clinical challenge is to compile a battery of assessments that are clinically feasible, time-sensitive, and best describe measures of patient function that predict outcomes. The most commonly used assessments used for managing return to sport decision making are the time since surgery, subjective function quantified through...
patient questionnaires, quadriceps and hamstring strength assessed through isometric and isokinetic tests, and single-leg hopping.\textsuperscript{8, 14, 15} To date, there is limited information about the ability of these assessments at 6-months to predict an effective return to sport without a secondary ACL injury.

The use of objective measures to manage activity clearance has risen dramatically in the past decades.\textsuperscript{8} Time since surgery is the most commonly used metric when managing clearance for sport activity, with many clinicians using it as the only measure.\textsuperscript{8} In assessing quadriceps strength, the most common target for patients and clinicians is a limb symmetry index (LSI) of 90%, using the contralateral limb as an objective comparison.\textsuperscript{16} Low rates of passing return to activity assessments (>90% LSI) are commonly reported following ACLR.\textsuperscript{11} The ability to predict subsequent outcomes, such as reinjury, prior to release for unrestricted activity could empower clinicians with the knowledge to how to treat patients following ACLR while they are still under the supervision of healthcare providers.

The ability to identify common components of return to activity assessments, such as quadriceps strength and single leg hop distance, that predict patients who sustain secondary ACL injury can allow clinicians to more efficiently manage rehabilitation progressions and return to activity decision making following ACLR. Therefore, the purposes of this study were to identify what measures of patient function at 6-months post-ACLR best predicts return to activity and secondary ACL injury at a minimum of 2-years following ACLR. We hypothesize that better measures of self-reported function, strength, and functional performance at 6-months post ACLR will increase the probability of a return to activity. Additionally, we hypothesize that lower measures of self-reported function, strength, and functional performance at 6-months post ACLR will increase the probability of secondary ACL injury.
Methods

This was a prospective cohort study with minimum of 2-years follow up. The dependent (outcome) variables for the study was return to activity (RTA) (Yes/No), months between ACLR to RTA, and ACL Reinjury (Yes/No). ACL Reinjury was defined as a subsequent injury to the ACLR graft or the contralateral ACL. Independent (predictor) variables were measures of patient function collected during the patient’s functional assessment: patient reported outcomes (PROs), knee extensor and flexor strength, and single-leg hopping distance.

Participants

All patients were referred from a multi-surgeon academic orthopaedic subspecialty practice to complete a battery of functional assessments in a controlled laboratory setting approximately 6-months post-ACLR. Data used in this study were collected as a part of an ongoing program where patients routinely complete post-operative assessments following a lower extremity surgery. Patients and their clinicians were provided a detailed report including the data from the assessment to guide rehabilitation progressions and return to activity decision making. As a point of care research design, it is unknown how this data was utilized to manage the patient’s rehabilitation. Patients were included in the analyses if they had a history of primary, isolated, unilateral ACLR confirmed through their medical records. Patients were excluded from analyses if they had a history of other lower extremity surgery, concomitant ligament reconstructions, surgical complications, or any neurological disorders. Participants followed the same post-operative 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

Following enrollment and consent, all participants completed the Knee Osteoarthritis Outcome Score (KOOS) and the International Knee Documentation Committee (IKDC) subjective form to evaluate subjective knee function. These measures have been shown to be valid and reliable within patients following ACLR. Pre-injury level of physical activity was quantified through the Tegner Activity Scale. Kinesiophobia was assessed through the Tampa Scale for Kinesiophobia and global function through the Veterans Rand-12.

Knee Extensor and Flexor Strength

Isokinetic, concentric peak knee flexion and extension torque was measured bilaterally using a Biodex Systems IV dynamometer (Biodex Medical Systems, Inc. Shirley, NY) at a speed of 90 deg/sec. All testing was performed on the uninvolved limb, followed by testing of the involved limb. Participants completed practice trials on each limb for familiarization before testing. The participants were verbally encouraged to provide maximal effort through their full range of motion for 8 test contraction repetitions.

Single-Leg Hopping

Single-leg hopping performance was measured bilaterally using a battery of three hopping tasks: the single hop for distance, the triple hop for distance, and the 6-meter timed hop. The participant was given as many practice trials until they were comfortable completing the task. All testing was performed on the uninvolved limb, followed by testing of the involved limb for a total of three trials on each limb. All hopping tasks required the participant to maintain single-limb stability at the conclusion of each hop. All tasks for distance were measured from the toe at start to the heel at landing. The average distance across the three trials were used for
analysis. The 6-meter timed hop was instrumented with timing gates (Fitlight Corp. Aurora, ON, Canada) that were placed 1-meter of the ground at the start and finish.

**Two-Year Follow-Up**

Follow-up assessment for all patients occurred at minimum of 2-years post-ACLR. Patient follow-up data were obtained via phone interview, email, or subsequent clinic visit identified through medical records review. Patients were assessed on the 1) the ability to return to their pre-injury level of activity (RTA) and 2) incidence of secondary ACL injury on the primary involved or contralateral knee. The date of RTA and ACL Reinjury were collected if applicable.

**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: 

\[
\text{Limb Symmetry} = \left( \frac{\text{involved limb}}{\text{uninvolved limb}} \right) \times 100.
\]

Limb symmetry for the 6-meter timed hop was calculated through:

\[
\text{Limb Symmetry} = \left( \frac{\text{uninvolved limb}}{\text{involved limb}} \right) \times 100.
\]

**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 collected for time to RTA, time from ACLR to secondary injury, and time from RTA to secondary injury.

**Return to Activity**

Analyses with RTA (Yes/No) as the dependent variable were performed on all patients. Cox proportional survival curves were performed controlling for age, sex, and activity level for RTA (Yes/No) as the dependent variable and time from ACLR to RTA (months) as the measure
of time. Regression models were all adjusted to control for the potential covariates: sex, age, and pre-injury activity level. A logistic regression model was performed with RTA (Yes/No) as the outcome variable and measures of patient function as the predictor variables. Predictor variables of patient function consisted of the IKDC, KOOS Sport, knee extensor strength and symmetry, knee flexor strength and symmetry, single hop distance and symmetry, triple hop distance and symmetry, and the 6-meter timed hop and symmetry.

Reinjury

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

Cox proportional survival curves were performed controlling for age, sex, and activity level for 1) Reinjury (Yes/No) as the dependent variable and time from ACLR to Reinjury (months) as the measures of time and 2) Reinjury (Yes/No) as the dependent variable and time from RTA to Reinjury (months) as the measures of time. Regression models were all adjusted to control for the potential covariates: sex, age, and pre-injury activity level. Another logistic regression analysis was performed with Reinjury (Yes/No) as the dependent variable and measures of patient function as the independent variable (IKDC, KOOS Sport, knee extensor strength and symmetry, knee flexor strength and symmetry, single hop distance and symmetry, triple hop distance and symmetry, and the 6-meter timed hop and symmetry). For an exploratory analysis, the study cohort was then stratified by the median time of RTA (8-months).
Patients with RTA < 8-months were operationally defined as “Early RTA” and those with RTA \( \geq 8 \) months as “Delayed RTA”. The same logistic regression models were performed within the Early RTA and Delayed RTA sub-groups.

*Relationships between RTA Assessments*

Pearson’s \( r \) correlations were performed between measures of quadriceps strength and symmetry to time to RTA, IKDC, KOOS Sport, Tampa Scale for Kinesiophobia, and the Veterans Rand-12 questionnaire.

An *a priori* alpha was set \( \leq .05 \) for all analyses. All statistical analyses were conducted through SPSS (Version 26; IBM Inc., Chicago, IL).

**Results**

A total of 357 consecutive patients following ACLR were enrolled and evaluated between November, 2013 and April, 2018, 122 patients were excluded from analyses due to prior history of lower extremity surgery, concomitant ligament reconstructions, surgical complications, or a neurological disorder (Figure 1). The remaining 235 patients were included in the analyses (Figure 1). Confirmation of an ACL graft or contralateral ACL injury at a minimum of 2-years post-ACLR were collected for 192 patients (82%). Demographics can be found in Table 1.

**Return to Activity**

Of the 192 patients, 155 returned to prior levels of physical activity (80%). Study descriptives on time of RTA and reinjury can be found in Figure 2. Logistic regression statistics for RTA can be found in Table 2. Factors that significantly increased the probability of RTA
were higher measures of IKDC, KOOS-Sport, quadriceps symmetry, and single hop symmetry (Table 2).

**Reinjury**

Of the 155 patients who returned to prior levels of physical activity, 44 (28%) had a secondary ACL injury (Figure 1). There were no significant differences in the overall proportion of reinjury between males and females (chi = 0.13, *P* = 0.86). In patients who had 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%; \( \chi^2 = 6.18, P = 0.017 \)).

Of the 155 patients who returned to activity, graft type distribution was Patellar Tendon: n=95 (61.3%), Hamstring: n=58 (37.4%), and Quadriceps Tendon: n=2 (1.3%). For all analyses of graft type, those with Quadriceps Tendon Graft were removed due to low sample. There were no differences between patellar tendon and hamstring grafts in the proportion of reinjury (\( \chi^2 = 0.24, P = 0.71 \)) or the side of reinjury (\( \chi^2 = 1.81, P = 0.23 \)).

Logistic regression statistics for reinjury can be found in Table 3. Factors that significantly increased the probability for reinjury were higher measures of KOOS-Sport, knee extensor symmetry, and triple-hop symmetry (Table 3).

A total of 78 patients (50.3%) returned to activity prior 8-months post-ACLR. In patients with Early RTA (<8 months) neither quadriceps strength (B=.80, *P* = .20, OR=2.22[0.67, 3.74]) nor time to RTA (B=.495, *P* = .10, OR=1.64[0.92, 2.94]) predicted reinjury. However, in patients with Early RTA, quadriceps strength symmetry predicted secondary ACL injury (B=.021, *P* = .05, OR=1.02[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%) returned to activity later than 8-months post-ACLR. In patients with Delayed RTA (>8-months), quadriceps strength (B=.817, P=.22, OR=2.26[0.62, 8.30]) and symmetry (B=.014, P=.41, OR=1.01[0.98, 1.05]) at 6-months did not predict reinjury. In those with Delayed RTA, the time to RTA did predict secondary ACL injury (B=-.284, P=.042, OR=0.75[0.58,0.98]). In patients who RTA after 8-months, every month that RTA was delayed resulted in reduced risk of reinjury by 28.4%.

**Relationships between RTA Assessments**

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

**Discussion**

Physical performance assessments administered throughout the post-operative recovery can yield insight into functional deficits that may persist prior to release to unrestricted activity. The purpose of this study was to identify what measures of patient function at 6-months post-ACLR best predict return to activity and second ACL injury at a minimum of 2-years following ACLR. Of the total cohort included in final analyses, there was a reinjury rate of 24%, with 14% of patients reinjuring the ACLR graft and 10% injuring the contralateral ACLR. In patients who returned to activity, greater quadriceps symmetry at 6-months post-surgery increased the probability of a second ACL injury. In individuals who returned to activity prior to 8-months, greater quadriceps symmetry remained a predictor for reinjury. In patients who returned to
activity after 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

In the current cohort, the average time of return to activity was 8.8-months post-ACLR, with 65% of the patients returning to unrestricted physical activity prior to 9-months, and 84% prior to 12-months (Figure 2). In the current study, patients with a greater quadriceps’ symmetry at 6-month testing had a greater probability of returning to prior levels of physical activity. A lower age has been previously reported to predict return to activity status,^1^ and is thought to be due to an increased exposure of activity and sport.^19^ Quadriceps strength symmetry was also found to increase probability of returning to pre-injury levels of activity within this cohort. This supports current practice of health care providers, including the attending surgeons involved with this study, that use quadriceps strength symmetry as primary measures to manage return to activity decisions.^8,^20

Reinjury

In the patients who returned to 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 reported reinjury rates (Graft or Contralateral ACL) following primary ACLR between 10% and 28%^1,^2,^10,^21,^22^ in the current cohort, the average time from ACLR to reinjury was 19.3 months (Range: 6.84, 42.9 months) with 68% (n=30/44) sustaining the reinjury in less than 24-months post-ACLR. Further, the average time from RTA to reinjury was 10.9-months (Range: 1 day, 36.8 months) and the median being 7.35-months, indicating that 50% of reinjuries occurred within 7.35 months from RTA. This is in agreement with prior literature reporting individuals following
ACLR are at a high reinjury risk within the first 2-years from surgery and returning to sport.\textsuperscript{19, 23, 24} Sport and activity clearance from health care professionals may be perceived by patients as an unrestricted release to pre-injury functional status. However, with biological and functional adaptations observed up to 2- to 5-years following ACLR,\textsuperscript{25-27} patients should be aware of the predictors of re-injury and counseled appropriately up to and beyond the return to activity progression. 

Compared to prior studies that found a difference in reinjury rates depending on the type of graft type used,\textsuperscript{28} the current study found no differences in the proportions of reinjury between patellar tendon and hamstring grafts. Graft type decisions are commonly based on patient and surgeon preference and often based on the age and activity levels of the patients, thus biasing observational studies such as this. In randomized controlled trials with two-year outcomes, there has been found to be no influence from graft type on ACLR graft or contralateral ACL reinjury rates.\textsuperscript{29} In regards to patient sex, no difference in reinjury were observed within the overall proportions of between males and females; however, when looking at the side of reinjury, females had a significantly greater proportion of contralateral ACL injuries where males had a greater proportion of ACLR graft reinjuries. Studies have observed similar findings, with males demonstrating greater proportions of ACL graft injuries while females demonstrate greater proportions of contralateral ACL injuries.\textsuperscript{22, 30-32} It is unknown if a greater incidence of contralateral ACL injuries are observed in females due to biomechanical adaptations that occur following the initial ACLR or due to pre-existing conditions elevating the risk of ACL injury. This is an area for future research.

When assessing the ability of clinical assessments to predict returning to activity, this study’s findings supports how clinicians currently use these assessments to guide return to
activity decisions. Higher measures of patient subjective function, quadriceps strength, and single leg hopping performance were found to significantly predict those that successfully returned to activity (Table 2). However, when we look at the ability of these tests to predict secondary ACL injury, we see that the results challenge the way in which the data from these assessments performed at 6-months should be used (Table 3). In the current study, patients who demonstrate greater subjective function (KOOS Sport), higher measures of quadriceps symmetry, and more symmetrical single-leg hopping (Triple hop) at 6-month testing were found to have a greater probability for reinjury. In the current study, data collected at the 6-month assessment were available to surgeons and other members of the healthcare team to provide feedback to the patients regarding rehabilitation progress. Patients receiving objective feedback may influence decisions for RTA progression and clearance. In the current study, patients with greater measures of quadriceps symmetry and subjective function were more likely to RTA (Table 2). It is possible that individuals with high functional outcomes from RTA assessments experienced increased exposure for subsequent injury through earlier RTA. Prior literature has reported lower reinjury rates with later timepoints of RTA. Traditionally, clinicians will base return to activity timing on the ability for patients to achieve optimal strength and symmetry (over 90% LSI). However, findings from the current study may suggest that the “reward” of early RTA may increase the “risk” of secondary injury. Clinicians should discuss this risk-reward paradox with their patients when counselling them about RTA.

To further analyze the clinical utility of these assessments similarly to prior research, the study cohort was stratified between those who returned to prior levels of activity before and after 8-months as this is a previously reported time to release to sports, as well as providing an equal number of patients within each cohort (Early RTA: n=78, Delayed RTA: n=77). In 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 measured at 6-months did not predict reinjury. However, based on the findings of this study, every month that return to activity was delayed after 8-months reduced the probability by 28%. In patients with Early RTA, these findings contradict current thought around the use of commonly administered return to activity testing. The common clinical goal is to maximize quadriceps strength and symmetry to reduce the likelihood of reinjury. Qualitative studies have identified patient perceptions of achieving high measures of strength and symmetry in order to receive clearance for returning to sport, and perceived pressures from parents and coaches to do so. These notions for 6-month assessments are not supported with the current study; rather the opposite, with greater quadriceps symmetry at 6-months actually increasing the probability of a second ACL injury. It is important to note that the authors do not support the clinical pursuit of quadriceps strength weakness or asymmetry to reduce the likelihood of reinjury. Early quadriceps strengthening post-ACLR should be clinical priority as it has been shown to relate to greater subjective function and greater force attenuation throughout gait. Greater quadriceps strength has also been related to greater psychological readiness to return to sport which may enhance the rehabilitation progression prior to returning to activity. In the patients with Delayed RTA, 6-month quadriceps strength and symmetry measures did not predict reinjury. This may be expected because 6-month performance assessments may not accurately represent how the patient is functioning at the time they return to activity over two-months later. However, prior literature assessing quadriceps strength following the release to prior levels of activity by their treating surgeon and rehabilitation clinicians failed to identify quadriceps strength as an important predictor for reinjury, questioning the utility of this measure to effectively do so.
Findings of reduced injury probability by 28% per month after 8-months post-ACLR differ from a previous study of 69 athletes who demonstrated delayed time to unrestricted sport did not reduce the probability of knee reinjury after 9-months. The prior study classified knee reinjury as any subsequent injury to either knee, such as meniscal injuries, patellar subluxations, and secondary ACL graft ruptures that may differ when comparing predictors for isolated secondary ACL injuries. The finding of delaying RTA to reduce ACL reinjury in those after 8-months may support the importance of time following ACLR for proper recovery. Even in patients who score high on subjective and objective measures of function, there may be a healing processes occurring throughout this time. Recent proposals of delaying RTA to 2-years following ACLR have been made due to biological healing processes of the ACLR graft. Ultimately, the decision regarding the safest time for return to unrestricted physical activity following ACLR should take into consideration many factors including subjective readiness, objective function, time from surgery and exposure to high risk environments. These factors should also be serially measured so patients and clinicians both are aware of potential deteriorating function in advance of reinjury. The use of objective data to track outcomes over the course of post-operative rehabilitation through return to activity is an important aspect of patient care. However, the traditional approach of using strength and hopping data at a 6-month time point after ACLR for RTA decisions, especially earlier than 8 months after surgery, should be approached with caution based on the findings of this current study. Quadriceps strength and symmetry data still hold clinical value because relationships exist with measures of knee function, global function, and patient fear of movement (Table 4). These relationships between strength and function to subjective outcomes have been previously reported. With the optimal goal of increasing
patient function, commonly assessed through PROs, 6-month assessments may still guide clinicians to identify functional deficits to achieve this. Serial assessments following 6-months may hold greater clinical value to assess patient progression and capture a more accurate description of patient function prior to returning to activity. Functional assessments administered at 6-months should be used to guide post-operative treatments and dictate the RTA progression but should be utilized with caution if used to release patients to unrestricted activity prior to 8-months post-ACLR.

The assessments administered in the current study provides objective measures of function to the patient and clinician to inform decisions that may influence patient outcomes. As a limitation to all long-term follow up studies, this current study is limited to the objective measures of patient function that was utilized at that time, though further granular measures of muscular function have since then been established. This is a point of care research design that is representative of actual clinical use of return to activity testing and resulting patient outcomes.

Patient outcomes of RTA and reinjury were also self-reported. The ability to monitor and quantify patient exposures following the RTA would strengthen clinical recommendations following ACLR. The decision about timing for RTS is currently a controversial topic and future cohort studies should focus on the best way to determine the combination of metrics that is most useful in guiding the decision-making for rehabilitation progression and return to unrestricted physical activity following ACLR. Neither post-operative physical activity nor exposure were tightly controlled and objectively quantified within the current study and should be an area for future research. Additionally, a larger sample would allow separate prediction models to be investigated between sex and the side of reinjury.
In conclusion, patients with higher levels of subjective function and quadriceps symmetry had a greater probability of returning to activity. However, in patients who returned to activity earlier than 8-months, higher measures of quadriceps symmetry at 6-months increased the probability of reinjury. In patients who returned to activity later than 8-months, every month return to activity was delayed reduced the probability of reinjury by 28%. Functional assessments administered with the intention to release to activity prior to 8-months should be used with caution. Clinicians should discuss this risk-reward paradox with high functioning patients seeking early return to activity.
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Figure Legends

Figure 1: Flow chart of study participants.

Figure 2: Survival curves of study participants that successfully returned to activity (n=155) following ACLR. RTA: Return to Activity.
Table 1: Patient Demographics

|                        | Patients with Follow-up | Patients that Returned to Activity |
|------------------------|-------------------------|------------------------------------|
| Patients (n)           | 192                     | 155                                |
| Age (years)            | 21.2±9.2                | 20.1±8.3                           |
| Sex (Female:Male)      | 104:88                  | 81:74                              |
| Mass (kg)              | 73.7±17.8               | 73.4±17.9                          |
| Height (cm)            | 172.0±17.8              | 172.1±9.8                          |
| Time Since Surgery     | 6.73±1.4                | 6.68±1.4                           |
| (Months)               |                         |                                    |
| Pre-Injury Activity Level (Tegner [0-10]) | 8.55±1.3 | 8.66±1.3 |
Table 2: Logistic Regression to Identify Factors Associated with return to activity controlled for age, sex, and pre-injury activity level. (n=192) 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.

| Independent Variables                     | Beta | Odds Ratio [95% CI] | P-Value |
|-------------------------------------------|------|---------------------|---------|
| IKDC                                      | .039 | 1.04 [1.01, 1.07]*  | .005    |
| KOOS-Sport                                | .028 | 1.03 [1.01, 1.05]*  | .009    |
| Knee Extensor Strength (Nm/kg)            | .823 | 2.28 [0.88, 5.86]   | .088    |
| Knee Extensor Symmetry (%)                | .034 | 1.04 [1.01, 1.06]*  | .004    |
| Knee Flexor Strength (Nm/kg)              | .231 | 1.26 [0.27, 5.85]   | .768    |
| Knee Flexor Symmetry (%)                  | .008 | 1.01 [0.99, 1.03]   | .443    |
| Normalized Single Hop (m/m)               | 2.19 | 8.95 [0.80, 100.5]  | .076    |
| Single Hop Symmetry (%)                   | .047 | 1.05 [1.02, 1.08]*  | .002    |
| Normalized Triple Hop (m/m)               | .51  | 1.67 [0.76, 3.64]   | .200    |
| Triple Hop Symmetry (%)                   | .018 | 1.02 [.987, 1.05]   | .249    |
| 6-m Timed Hop (seconds)                   | -.22 | 0.80 [0.52, 1.24]   | .317    |
| 6-m Timed Hop Symmetry (%)                | -.013| .987 [.964, 1.01]   | .268    |

Abbreviations. IKDC: International Knee Documentation Committee, KOOS: Knee Osteoarthritis Outcome Score. * P-value <.05
Table 3: Logistic Regression to Identify Factors Associated with Reinjury controlled for Age, Sex, and Pre-Injury Activity Level In participants that returned to sport. (n=155) Odds ratios should be interpreted as the relative increase in the odds of subsequent ACL injury for a 1-unit increase in the independent variable.

| Independent Variables                  | Beta  | Odds Ratio [95% CI] | P-Value |
|----------------------------------------|-------|---------------------|---------|
| Time from ACLR to RTA                  | -.093 | 0.912 [0.81, 1.03]  | .143    |
| IKDC                                   | .016  | 1.02 [0.99, 1.05]   | .314    |
| KOOS-Sport                             | .038  | 1.04 [1.01, 1.07]*  | .023    |
| Knee Extensor Strength (Nm/kg)         | .825  | 1.58 [0.70, 3.56]   | .065    |
| Knee Extensor Symmetry (%)             | .022  | 1.02 [1.01, 1.04]*  | .045    |
| Knee Flexor Strength (Nm/kg)           | .761  | 2.14 [0.54, 8.43]   | .276    |
| Knee Flexor Symmetry (%)               | .009  | 1.01 [0.99, 1.03]   | .284    |
| Normalized Single Hop (m/m)            | 2.31  | 10.12 [9.6, 106.1]  | .054    |
| Single Hop Symmetry (%)                | .027  | 1.03 [0.99, 1.06]   | .149    |
| Normalized Triple Hop (m/m)            | .592  | 1.81 [0.81, 4.05]   | .150    |
| Triple Hop Symmetry (%)                | .046  | 1.05 [1.01, 1.10]*  | .046    |
| 6-m Timed Hop (seconds)                | -.437 | 0.65 [0.31, 1.36]   | .252    |
| 6-m Timed Hop Symmetry (%)             | -.032 | 0.97 [0.93, 1.01]   | .116    |

Abbreviations. IKDC: International Knee Documentation Committee, KOOS: Knee Osteoarthritis Outcome Score. * P-value <.05
Table 4: Relationships between measures of quadriceps strength and symmetry at 6-months post-ACLR to time to RTA and measures of subjective function in patients that successfully returned to activity. Significant $r$ values are bolded.

| Correlations | Time from ACLR to RTA | IKDC | KOOS Symptoms | KOOS Pain | KOOS ADL | KOOS Sport | KOO QoL | Tampa | VR12 |
|--------------|-----------------------|------|---------------|-----------|-----------|------------|---------|-------|------|
| Quadriceps Strength | $r$ | -0.061 | **.218** | **0.206** | **0.249** | **0.275** | **0.359** | **0.223** | **0.192** | **0.277** |
| | $P$ | 0.452 | .007* | 0.011* | 0.002* | 0.001* | 0.006* | 0.022* | 0.001* |
| Quadriceps Symmetry | $r$ | -0.133 | .142 | 0.129 | **0.197** | **0.161** | **0.31** | **0.181** | 0.021 | 0.069 |
| | $P$ | 0.099 | .081 | 0.114 | 0.015* | 0.048* | <.001* | 0.026* | 0.804 | 0.412 |
Six-Month Data Collected

n=357

Included for Analysis

n=234

Excluded (n=123)
Referral from outside medical Network
Prior history of LE injury
Non-isolated ACL injury
Surgical Complications
Confounding medical conditions

Two-Year Follow-Up Obtained

Yes: n=192 (82%)

Return to Sport

Yes: n=155 (80.7%)

Reinjury

Yes: n=46 (24%)
No: n=146 (76%)

Yes: n=44 (28%)
No: n=111 (72%)

Side

ACLR Graft: n=26 (13.5%)
Contralateral ACL: n=20 (10.4%)
ACLR Graft: n=24 (15.5%)
Contralateral ACL: n=20 (12.9%)
Supplemental Table: Descriptive statistics for all independent variables utilized in the regression analyses. All data are presented as Mean±SD. All unilateral measures are presented for the involved (ACLR) limb.

| Variables                                      | All patients (n=155) | RTA < 8-months (n=78) | RTA > 8-months (n=77) |
|------------------------------------------------|----------------------|-----------------------|-----------------------|
| IKDC                                           | 83.4±12.4            | 84.09±12.32           | 82.65±12.59           |
| KOOS-Sport                                      | 85.0±15.4            | 86.54±14.49           | 83.31±16.22           |
| Tampa Scale for Kinesiophobia                  | 33.20±5.4            | 33.23±5.8             | 33.15±5.1             |
| Veterans Rand-12                                | 78.75±9.07           | 79.75±8.0             | 77.74±10.0            |
| Knee Extensor Strength (Nm/kg)                 | 1.61±.46             | 1.61±.48              | 1.61±.45              |
| Knee Extensor Symmetry (%)                     | 73.04±17.94          | 75.18±18.78           | 70.86±16.90           |
| Knee Flexor Strength (Nm/kg)                   | 0.92±.29             | 0.89±.29              | 0.95±.29              |
| Knee Flexor Symmetry (%)                       | 95.04±21.53          | 97.32±24.45           | 92.72±18.0            |
| Normalized Single Hop (m/m)                    | 0.67±0.27            | 0.66±.20              | 0.69±.34              |
| Single Hop Symmetry (%)                        | 90.5±11.3            | 90.54±11.97           | 90.55±10.58           |
| Normalized Triple Hop (m/m)                    | 2.34±.57             | 2.34±.62              | 2.33±0.51             |
| Triple Hop Symmetry (%)                        | 91.91±10.48          | 91.48±12.14           | 92.36±8.44            |
| 6-m Timed Hop (seconds)                        | 2.47±.65             | 2.52±.67              | 2.42±.63              |
| 6-m Timed Hop Symmetry (%)                     | 94.87±9.1            | 95.07±9.9             | 94.66±8.2             |

Abbreviations. IKDC: International Knee Documentation Committee, KOOS: Knee Osteoarthritis Outcome Score. * P-value <.05