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Effect of Time and Sex on Post–Anterior Cruciate Ligament Reconstruction Psychological Patient-Reported Outcome Measure Scores

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Context: Low scores on psychological patient-reported outcomes measures, including the Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI) and Injury-Psychological Readiness to Return to Sport (I-PRRS), after anterior cruciate ligament reconstruction (ACLR) have been associated with a maladaptive psychological response to injury and poor prognosis.

Objective: To assess the effect of time post-ACLR and sex on ACL-RSI and I-PRRS scores and generate normative reference curves.

Design: Case series.

Setting: Outpatient sports medicine and orthopaedic clinic.

Patients or Other Participants: A total of 507 patients (age at ACLR, 17.9 ± 3.0 years) who had undergone primary ACLR and completed ACL-RSI or I-PRRS assessments ≥1 times (n = 796) between 0 and 1 year post-ACLR.

Main Outcome Measure(s): An honest broker provided anonymous data from our institution's knee-injury clinical database. Generalized additive models for location, scale, and shape and generalized least-squares analyses were used to assess the effect of time post-ACLR and sex on ACL-RSI and I-PRRS scores.

Results: The ACL-RSI and I-PRRS scores increased over time post-ACLR. Males had higher scores than females until approximately 5 months post-ACLR, with scores converging thereafter.

Conclusions: Males reported higher ACL-RSI and I-PRRS scores than females in the initial stages of rehabilitation, but scores converged between sexes at times associated with return to play post-ACLR. Normative reference curves can be used to objectively appraise ACL-RSI and I-PRRS scores at any time post-ACLR. This may lead to timely recognition of patients with a maladaptive psychological response to injury and a higher likelihood of a poor prognosis, optimizing ACLR outcomes.

Key Words: ACL-RSI, I-PRRS, ACLR, return to play, confidence

Key Points

- Males displayed higher Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI) and Injury-Psychological Readiness to Return to Sport (I-PRRS) scores than females until approximately 5 months after anterior cruciate ligament reconstruction.
- Normative reference values improved the ability to identify patients with ACL-RSI or I-PRRS scores associated with maladaptive psychological responses to injury.
- Normative reference curves as a function of time after anterior cruciate ligament reconstruction improved the ability to interpret ACL-RSI and I-PRRS scores over time and determine if patients are "on track" to meet certain clinical criteria.

Approximately 35% of patients after primary anterior cruciate ligament (ACL) reconstruction (ACLR) do not return to sport (RTS) at their preinjury level, and 25% of young patients post-ACLR injure their ACLR graft or contralateral native ACL.[1,2] After ACLR, providers administer a variety of assessments to appraise the current status of patients to forecast outcomes and augment clinical decision-making.[3] Maladaptive psychological responses and behaviors are prevalent after ACL injury and ACLR.[4,5] Thus, psychological readiness to RTS, which encompasses constructs including but not limited to injury-related fear, performance confidence, risk evaluation, self-efficacy, locus of control, motivation, and self-esteem, has emerged as an essential component of the post-ACLR assessment.[6–11]

The psychological effect of ACL injury and ACLR and the importance of providing holistic physical and psychological rehabilitation post-ACLR is well established.[4,5,12,13] Although authors of some studies have demonstrated a relationship between passing physically based criteria on post-ACLR assessments, such as symmetrical strength or function between limbs, and a greater likelihood of RTS, others have not.[14,15] This is not surprising, as fear of reinjury is consistently self-reported

as the greatest reason why an athlete did not RTS.[16] Conversely, patients with high motivation, self-esteem, and self-efficacy; an internal locus of control; and a low level of fear have better adherence to rehabilitation programs and higher odds of returning to sport.[10,11] Despite mounting evidence of the importance of psychological readiness to RTS post-ACLR, Burgi et al, in a recent review, found that only 12% of studies used psychologically based patient-reported outcome measures (PROMs) as part of the RTS assessment process.[3] This may in part be because clinicians primarily responsible for post-ACLR rehabilitation often find they lack the knowledge of how to identify and address maladaptive psychological responses to injury.[17]

The development of psychologically based PROMs has improved the ability to quantify the psychological response to injury and readiness to RTS, with low scores suggesting a maladaptive psychological response and a poor prognosis.[9,18–20] A commonly used psychological PROM is the Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI), which is used to assess emotions, performance confidence, and risk appraisal.[6] Patients with lower ACL-RSI scores (<56%) 4 months post-ACLR tend to have lower odds of RTS at 1 year post-ACLR.[18] Furthermore, patients who demonstrate smaller improvements in ACL-RSI scores from pre-ACLR to 1 year post-ACLR and young patients with lower ACL-RSI scores (<77%) 1 year post-ACLR have higher odds of sustaining a second ACL injury within 2 to 4 years.[9,19]

The Injury-Psychological Readiness to Return to Sport (I-PRRS) is another psychologically based PROM used to assess similar psychological constructs, which include confidence and self-efficacy within a sport-specific situation after injury. The I-PRRS is a general psychologically based PROM that has been applied over a wide variety of musculoskeletal injuries but is not specific to ACL injury; therefore, less is known about the association between the I-PRRS score and ACLR outcomes. The relationship between the ACL-RSI and I-PRRS is also unclear. Although including both PROMs simultaneously in post-ACLR assessments likely has no added benefit and using just 1 is sufficient, additional research is needed to confirm this. Still, both the ACL-RSI and I-PRRS could be and are used either separately or simultaneously.

Using patient-specific reference values to characterize scores may improve the ability to monitor, progress, and intervene effectively throughout rehabilitation and RTS.[21] In this context, authors of several studies have presented simple descriptive statistics, such as the mean ± SD, for the ACL-RSI and I-PRRS or provided dashboards to aid in the characterization of a single observation of ACL-RSI.[9,14,18,21–25] Although useful, the applicability of this information in most post-ACLR workflows is limited for several reasons. First, assessments may not occur at the standardized times post-ACLR (eg, 4, 6, or 12 months post-ACLR) often reported in the literature.[18,22–24] Second, the literature often aggregates data from large timespans post-ACLR (eg, 5 to 7 months post-ACLR).[21,26–28] Third, based on the aggregation of ACL-RSI and I-PRRS at regularly spaced and standardized times post-ACLR, the population-level improvement over time post-ACLR is nonlinear, with the largest degree of improvement occurring earlier post-ACLR.[9,14,18,22–25] Finally, scores are likely not normally distributed and skewed toward 100%, particularly at later times post-ACLR. These issues make it challenging to characterize patient scores, which should be unique to each patient's present time post-ACLR, using patient-specific reference values. A continuous reference distribution as a function of time post-ACLR that considers the nonlinearity and nonnormal distribution of scores over time would be highly beneficial. Commonly referred to as *normative reference curves* or *growth curves*, these curves enhance the ability to characterize a single score at a given time post-ACLR as a percentile as well as monitor score progression from repeated assessments over time post-ACLR against the reference values. This allows for timely recognition of patients who have scores in an exceptionally low or high percentile for their unique time post-ACLR as well as patients who have scores that are not progressing as expected or "on track" to meet later clinical thresholds, with repeated assessments over time post-ACLR.

Sex influences outcomes post-ACLR. Compared with females, males report higher subjective knee function, greater physical activity levels, and, although the evidence is mixed, a higher risk for ACLR graft reinjury.[29–32] These findings could be related to RTS rates, as males have greater odds of returning to sport than females.[1,29,31] These disparities may be, in part, linked to differences in the psychological response to injury and readiness to RTS. Males tend to report greater self-efficacy, a loss of overall self-worth, and distress regarding poor physical performance and speed of recovery, whereas females report greater external locus of control and anxiety about the effect of injury on their lives and a loss of physical self-worth post-ACLR.[33,34] Thus, males tend to report higher scores than females up to 1 year post-ACLR, but longer term, scores between the sexes may begin to converge.[8,26–28,35–37] Therefore, males and females likely present with unique trajectories and distributions of ACL-RSI and I-PRRS scores over time post-ACLR, necessitating sex-specific normative reference curves.

Accordingly, the primary purpose of our retrospective study was to assess the effect of time post-ACLR on the ACL-RSI and I-PRRS to develop normative reference curves, using a novel statistical approach including general additive models for location, scale, and shape (GAMLSS) that can be used to appraise scores over the first year post-ACLR. The secondary purpose was to assess the effect of sex on the ACL-RSI and I-PRRS over time post-ACLR. We hypothesized that males would demonstrate higher ACL-RSI and I-PRRS scores than females in the first year post-ACLR.

METHODS

Participants

The Sanford Health Institutional Review Board granted the retrospective analysis an exemption (review number: 2390). Beginning in 2012, postinjury assessment data from patients who completed assessments at 1 of 2 sports physical therapy clinics were added to our institution's postinjury RTS assessment clinical data repository. Anonymous data from this repository were provided by an honest broker (not an author) on September 19, 2022. At this time, the full database contained data from 897 patients. Patients who underwent primary ACLR; were aged between 12 and 30 years at the time of ACLR; and received a bone-patellar tendon-bone, hamstrings, or quadriceps autograft were included if they had at least 1 assessment between 0 and 1 year post-ACLR. They were included regardless of articular cartilage or menisci pathologies treated at the time of ACLR. Patients were excluded from the analysis if they had a history of substantial lower extremity injury before the present ACL injury including a previous ACLR, had an ACLR using allograft, had

Table 1. Patient Characteristics (N = 507)

Characteristic	Mean ± SD
Age at injury, y	17.8 ± 3.0
Age at surgery, y	17.9 ± 3.0
	No. (%)
Sex	
Male	254 (50)
Female	253 (50)
Mechanism of injury	
Noncontact	352 (69)
Contact	113 (22)
Combination or unknown	21 (4)
Sports participation preinjury	
Basketball	203 (40)
Football	152 (30)
Track and field	81 (16)
Volleyball	76 (15)
Baseball or softball	66 (13)
Soccer	56 (11)
Wrestling	20 (4)
Gymnastics	10 (2)
Autograft	
Hamstring	366 (72)
Bone-patella tendon-bone	126 (25)
Quadriceps	15 (3)
Medial compartment	
Meniscus repair	127 (25)
Meniscectomy	25 (5)
Chondroplasty	5 (1)
Lateral compartment	
Meniscectomy	117 (23)
Meniscus repair	112 (22)
Chondroplasty	10 (2)

post-ACLR complications that required secondary surgery for the present ACL injury, had an ACL injury but did not have an ACLR, had other ligaments reconstructed in addition to the ACL, or waited >1 year between injury and ACLR. After exclusion criteria were applied, 507 ACLR patients with 796 post-ACLR assessments were included in this retrospective analysis (Table 1).

Procedures

Between 2012 and 2022, our health care institution performed approximately 400 primary ACLR cases annually. Approximately 25% of these patients were referred to 1 of 2 of our health care institution's sports physical therapy facilities for rehabilitation and ≥1 post-ACLR assessments. In addition, patients who had their ACLR performed at other health care institutions may have been referred to our facility for physical rehabilitation and post-ACLR assessments. Patients may have completed ≥1 post-ACLR assessments, with most completing their first between 3 and 5 months post-ACLR and the second between 5 and 8 months post-ACLR, corresponding with the conclusion of traditional post-ACLR physical therapy and immediately before RTS, respectively. Additional post-ACLR assessments may have been completed depending on patient desire and provider discretion. Assessments administered during post-ACLR assessments included a variety of PROMs including but not limited to the ACL-RSI and I-PRRS as well as physical tests such as lower extremity strength, single-legged hopping, and movement quality.

The ACL-RSI and I-PRRS were completed before performing other tests. The ACL-RSI is considered unidimensional, and the mean score, presented as proportional data on a scale from 0% (*maladaptive emotions, performance confidence, and risk appraisal*) to 100% (*adaptive emotions, performance confidence, and risk appraisal*), for its 12 questions is reported most frequently.[6,8] The English version of the ACL-RSI is valid and reliable for both adult and pediatric populations and has subsequently been adapted into several languages. For our study, the full 12-question version of the ACL-RSI was used.[6,38] Patients responded to the questions by circling a number on a scale from 0 to 100 points provided in 10-point increments using prompts associated with each end of the scale's continuum.

Like the ACL-RSI, the I-PRRS is considered unidimensional. The mean score, presented as proportional data on a scale from 0 (0%; *maladaptive confidence and self-efficacy*) to 60 (100%; *adaptive confidence and self-efficacy*), for its 6 questions is reported most frequently.[39] The English version of the I-PRRS is valid and reliable and has subsequently been adapted into several languages.[39] For our study, the 6-question version of the I-PRRS was used.[39] Patients responded to the questions by writing any number between 0 and 100 using prompts associated with each end of the scale's continuum. Patients initially completed the ACL-RSI and I-PRRS on paper, and the data were subsequently transferred to a digital clinical repository managed using REDCap (Vanderbilt University).[40]

Statistical Analysis

The primary continuous dependent variables were the mean ACL-RSI and I-PRRS scores represented as proportional data on a scale from 0% to 100%. The independent continuous variable was time post-ACLR in months, and the independent categorical variable was sex.

To develop the normative reference curves for the ACL-RSI and I-PRRS over time post-ACLR, we used GAMLSS to model the dependent, or response, variables as smooth functions over time post-ACLR separately for males and females.[41,42] A more in-depth primer is provided by Stasinopoulos et al; briefly, GAMLSS are single response variable distributional regression models in which all the parameters of the assumed distribution for the response variable, including the location (eg, mean or median), scale (eg, variance), and shape (eg, kurtosis and skewness), are modeled as additive functions of the explanatory variable(s).[43] The GAMLSS allow one to fit a wide variety of nonexponential family distributions to the response variable, including highly skewed and kurtotic continuous distributions. An inflated β distribution at 1 for proportional data (eg, bound from >0 to ≤1) was used to model the presented data, as 100% was observed in our dataset for both the ACL-RSI and I-PRRS. Parameters included in this GAMLSS distribution include μ (location or mean or median), σ (scale or variance), and ν (skewness). Penalized splines (P-splines) with 3 knots were used to smooth the 3 distribution parameters over time post-ACLR. Data were treated in a cross-sectional fashion, in which each observation was considered independent. We took this approach, as opposed to other statistical methods that incorporate hierarchical or within-patient correlation structures, because of the small number of observations per patient, irregularly spaced and unbalanced observations, and the proportional nature of the dependent variables. Similar approaches have been applied to construct various growth

charts, with P-splines and random effects demonstrating similar smoothing properties.[41–43] Curves for the 10th, 25th, 50th (median), 75th, and 90th percentiles were computed from approximately 2.5 to 11.5 months post-ACLR, represented as 101 equally spaced points. To generate confidence bands for the point estimates of the curves, we used a Monte Carlo cross-validation procedure, in which 1000 resamples were generated by randomly selecting 75% of the observations in the original data without replacement. The GAMLSS were fit to each resample, and the corresponding percentile curves were computed as described. Confidence bands were produced by aggregating the curves generated by each resample analysis and computing the middle 95%, in which the lower and upper bounds were represented as the 2.5th and 97.5th percentile, respectively, pointwise for each of the 101 points.

To assess the mean response over time post-ACLR, we used generalized least squares (GLS) to model the dependent, or response, variables as smooth functions over time post-ACLR. Given the proportional nature of the ACL-RSI and I-PRRS, the dependent variables were transformed using an empirical logit transformation, in which ε was set to 1×10^{-3}. Effects in the model included time post-ACLR, which was modeled using a restricted cubic spline with 3 knots and an autoregressive within-subjects correlation structure, and sex. Variance was modeled as a function of time post-ACLR and sex. Predicted values on the proportional scale were then computed from approximately 2.5 to 11.5 months post-ACLR, represented as 101 equally spaced points (eg, 0%–100%). Again, to generate confidence bands for the predicted values, we used grouped Monte Carlo cross-validation to create 1000 resamples composed of approximately 75% of the observations in the original data. To do this, we randomly selected patients such that, if a patient was randomly selected, all their observations were included in the resample. The GLS model was fit to each resample, and the predicted values on the proportional scale were computed. Confidence bands were produced by aggregating the predicted values generated by each resample analysis and computing the middle 95%, in which the lower and upper bounds were represented as the 2.5th and 97.5th percentile, respectively, pointwise fashion for each of the 101 points. We conducted GLS analysis of variance to evaluate the effect of time post-ACLR and sex on ACL-RSI and I-PRRS scores. Contrasts for the difference between sexes were then computed for each of the 101 points. Significance was set to $P < .05$. Data were analyzed using R (version 4.2.2; The R Foundation) and the packages GAMLSS (version 5.4-12) and RMS (version 6.6-0).

RESULTS

Anterior Cruciate Ligament—Return to Sport After Injury

The final data analyzed for the ACL-RSI consisted of 129 males and 130 females with a combined 387 observations (Figures 1 and 2; Table 2). We observed effects of time post-ACLR ($\chi^2_4 = 74.99$, $P < .001$) and sex ($\chi^2_3 = 15.27$, $P = .002$) but no interaction effect ($\chi^2_2 = 3.60$, $P = .17$). Contrasts revealed evidence of a difference in ACL-RSI scores between males and females from approximately 2.5 to 5 months post-ACLR ($P < .05$) but no evidence of a difference thereafter ($P > .05$).

Injury-Psychological Readiness to Return to Sport

The final data analyzed for the I-PRRS consisted of 112 males and 106 females with a combined 315 observations (Figures 3 and 4; Table 2). We observed effects of time post-ACLR ($\chi^2_4 = 28.93$, $P < .001$) and sex ($\chi^2_3 = 11.74$, $P = .008$) but no interaction effect ($\chi^2_2 = 0.48$, $P = .79$). Contrasts revealed evidence of a difference in I-PRRS scores between males and females from approximately 2.5 to 4.7 months post-ACLR ($P < .05$) but no evidence of a difference thereafter ($P > .05$).

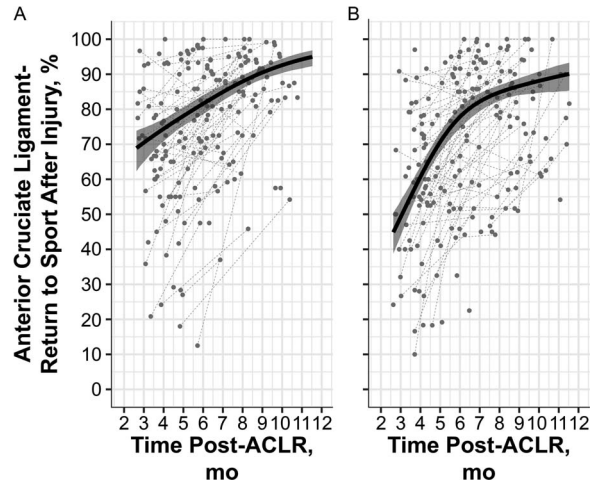

Figure 1. Mean response on the Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI) as a function of time after anterior cruciate ligament reconstruction (ACLR) for A, males and B, females. Circles and thin dashed lines indicate individual patients with ACLR, the line indicates the mean predicted value, and the ribbon indicates the 95% CI for the mean predicted value from cross-validation.

DISCUSSION

The importance of psychological readiness to RTS in the assessment of patients post-ACLR is unequivocally vital in the pursuit of optimized outcomes.[6–11] The normative reference curves presented here offer tremendous value because they enhance the ability to characterize a single score at a unique time post-ACLR as well as monitor score progression from repeated assessments over time post-ACLR against the reference values. To this end, printable versions of the normative reference curves presented here can be found in the Supplemental Material (see Supplemental Figures 1 and 2, available online at https://dx.doi.org/10.4085/1062-6050-0189.23.S1). In addition, our results partially support the hypothesis that males would exhibit higher ACL-RSI and I-PRRS scores than females.

Compared with other research in which scores were reported for the ACL-RSI at standardized times post-ACLR irrespective of sex, a longitudinal study of patients postprimary and postrevision ACLR (mean age = 30.2 ± 9.5 years) revealed that the mean (median) score for the ACL-RSI pre-ACLR and at 4, 6, 12, and 24 months post-ACLR was approximately 41% (40%), 55% (58%), 58% (60%), 65% (68%), and 65% (70%), respectively.[24] However, the mean age of the sample was approximately 12 years older than that in our study and included patients with revision ACLR.[24] In another repeated-measures study, Langford et al demonstrated mean ACL-RSI scores at 3 and 6 months post-ACLR of 56% and 58%, respectively, although the mean age of the sample was approximately 8 years older than that in our study.[22] Authors of several studies have also captured the mean ACL-RSI score at a single standardized time post-ACLR, such as 45% at 4 months

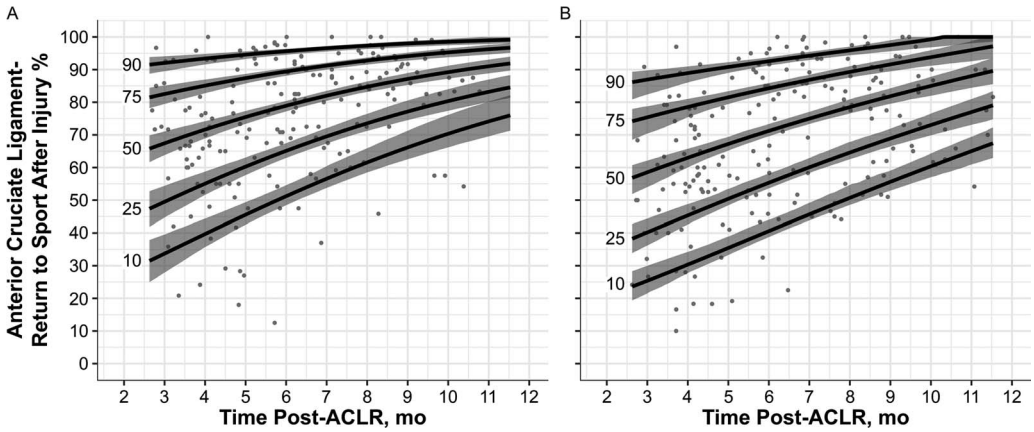

Figure 2. Distribution of the Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI) as a function of time after anterior cruciate ligament reconstruction (ACLR) for A, males and B, females. Circles indicate individual ACLR patients; lines indicate the 10th, 25th, 50th, 75th, and 90th percentiles; and the ribbon indicates the 95% CI for the associated percentile from cross-validation.

post-ACLR and 64% at 6 months post-ACLR.[18,23] Regarding the effect of sex, males and females have been reported to have different psychological responses to injury, and males tend to report higher scores than females up to 1 year post-ACLR.[8,26–28,33–36] In a repeated-measures study, Kostyun et al demonstrated that males and females have mean ACL-RSI scores of approximately 64% and 54%, respectively, at 3.1 months (range, 2.5–4.2 months) post-ACLR and 74% and 73%, respectively, at 6.6 months (range, 5.0–11.2 months) post-ACLR.[28] Researchers have demonstrated a mean I-PRRS of 80% in males at 7.1 months (range, 3–12 months) post-ACLR and 80% in females at 7.1 months (range, 3–12 months) post-ACLR.[26,27] In both studies, researchers aggregated scores from a large timespan post-ACLR, potentially masking important effects of time on scores.[26,27] Nevertheless, the mean scores that we identified appear to be slightly higher than those reported in the literature. This could be related to our sample having a younger mean age than that frequently reported in other literature, as increasing age appears to be associated with decreasing scores; the inclusion of only patients with primary ACLR, as patients with revision tend to report lower scores; and other undocumented factors.[21,44]

A commonality among many RTS clinical decision-making workflows is that they rely on 1 final battery of tests around the time of RTS. Earlier objective and more frequent assessments at multiple rehabilitation milestones would allow the provider to assess the "recovery trajectory" (slope) and potentially forecast future ACL-RSI or I-PRRS scores. This approach would enable the clinician to determine if a patient is on track to meet later clinical thresholds and, if they are not on track, offers time to provide psychological intervention well before the conclusion of rehabilitation and typical RTS, potentially enhancing ACLR outcomes. This is particularly relevant given that patients with decreasing scores or minimally improving scores over time post-ACLR are at an increased risk for ACL reinjury.[19] In addition to the normative reference curves presented here, a clinician may also find value in using normative reference values obtained from healthy, uninjured individuals to characterize patients' scores.[45,46] Another commonality among many studies is the establishment of a "passing" score.[9,18] The passing score is the threshold associated with better odds of a positive outcome, although the passing score can be variable between the different target outcomes such as ACL reinjury or failure to RTS, which is a potential barrier to clinical implementation as the target outcome is not necessarily clear. Furthermore, passing scores are typically developed using data collected from a cohort

Table 2. Number of Patients by Number of Observations for the ACL-RSI and I-PRRS After Anterior Cruciate Ligament Reconstruction

	No. of Patients	
Measure and No. of Observations	Male	Female
ACL-RSI		
1	129	130
2	52	59
3	7	9
4		1
I-PRRS		
1	112	106
2	40	45
3	6	6

Abbreviations: ACL-RSI, Anterior Cruciate Ligament—Return to Sport After Injury; I-PRRS, Injury-Psychological Readiness to Return to Sport.

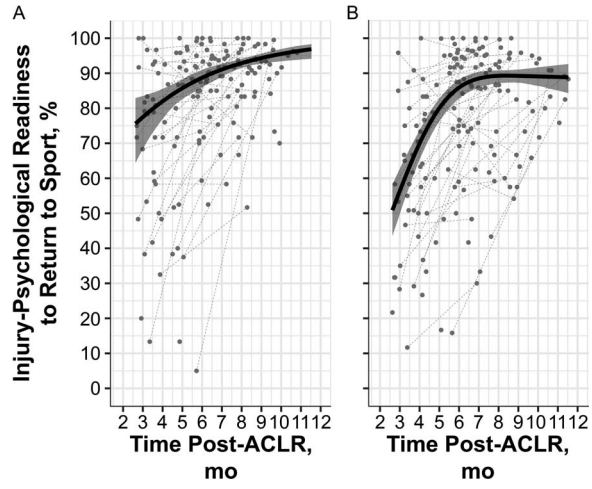

Figure 3. Mean response on the Injury-Psychological Readiness to Return to Sport (I-PRRS) as a function of time after anterior cruciate ligament reconstruction (ACLR) for A, males and B, females. Circles and thin dashed lines indicate individual patients with ACLR, lines indicate the mean predicted value, and the ribbon indicates the 95% CI for the mean predicted value from cross-validation.

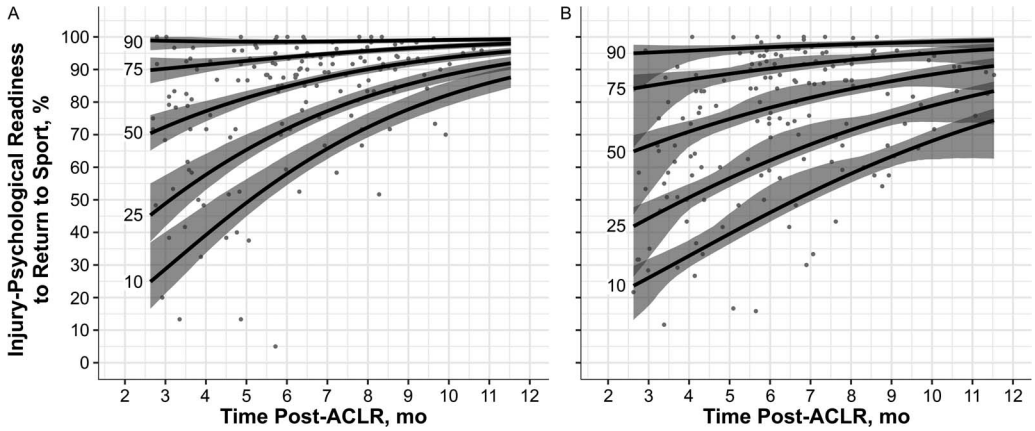

Figure 4. Distribution of the Injury-Psychological Readiness to Return to Sport (I-PRRS) as a function of time after anterior cruciate ligament reconstruction (ACLR) for A, males and B, females. Circles indicate individual patients with ACLR; lines indicate the 10th, 25th, 50th, 75th, and 90th percentiles; and the ribbon indicates the 95% CI for the associated percentile from cross-validation.

at a standardized time post-ACLR. Given the nonlinear nature of patients' psychological status as demonstrated in our study, applying a passing score developed at a given time post-ACLR that differs from patients' current time post-ACLR could lead to erroneous assessments of patients' current score and weaken clinical decision-making.

The literature typically relates a low score to having a maladaptive psychological response to injury and a higher likelihood for a poor prognosis. Alternatively, patients who report exceptionally high scores, particularly in the early stages of rehabilitation, may also have a maladaptive psychological response to injury and a greater likelihood of a poor prognosis. For example, whereas an exceptionally low score may indicate poor risk appraisal, an exceptionally high score may indicate a lack of risk appraisal altogether. This could correspond to a cavalier outlook that potentially increases the risk of a poor ACLR outcome, such as ACL reinjury, as patients may be more likely to engage in activities that place the still maturing ACLR graft at risk. This raises an issue with normative reference curves because these curves reflect the distribution of scores over time and are not necessarily associated with the risk for a poor outcome over time. It also calls into question the use of passing scores, as simply scoring above the identified cutoff by a wide margin, especially early on post-ACLR, could also signal a maladaptive psychological response to injury.[9,18] A band (range) of ACL-RSI or I-PRRS scores is likely associated with the lowest risk for poor outcomes. For example, it is possible that an ACL-RSI or I-PRRS score from 50% to 70% at 3 months post-ACLR is associated with the lowest odds of ACL reinjury and that this band increases to 70% to 90% at 6 months post-ACLR and 80% to 100% at 1 year post-ACLR, although these time points and values are fictitious for the sake of this illustration. Nevertheless, several contextual factors are important to consider when evaluating the association between these PROMs and clinical outcomes. For example, patients who RTS demonstrate higher scores than those who do not RTS, yet returning to sport itself increases the risk for reinjury compared with not returning to sport.[2,18] In addition, younger patients demonstrate higher scores than older patients, yet younger age has been independently associated with a higher risk for reinjury.[2,21]

In our study, motivations for RTS and RTS status at the time of the assessment and eventual RTS status were not documented. Motivation underlying the desire to RTS may influence scores, as researchers have demonstrated that intrinsic motivations for RTS are associated with a positive renewed perspective on sport participation.[47,48] Conversely, extrinsic motivations for RTS are associated with increased worry and concern, although the definition of when RTS occurs is equivocal.[47,48] For example, some researchers define RTS as full resumption of competitive sport without restrictions, whereas others may define it as the initiation of sport-specific drills.[49] This ambiguity suggests that RTS lies on a continuum and does not necessarily occur at an identifiable instance in time. Nevertheless, characterizing patients' scores with respect to their motivational sources and where they are on the RTS continuum may provide additional insights.

Our study had some additional limitations. Data for this retrospective study were collected as part of routine clinical practice. This led to data that were irregularly spaced, meaning patients had different numbers of assessments and times between assessments; had a nonuniform distribution of assessments over time post-ACLR, meaning that the density of assessments was greater from 4 to 8 months post-ACLR than between 2 to 4 and 8 to 12 months post-ACLR; and were sparse, meaning that most patients had $\leq$2 assessments. Although the statistical analyses that we used are robust, a more preferred methodology would have been to standardize and collect the ACL-RSI and I-PRRS at several regularly spaced and standardized times post-ACLR, such as 3, 6, 9, and 12 months post-ACLR, which would lead to a more uniform distribution of observations over time post-ACLR and a denser number of observations per patient. The effect of categorical variables, such as the mechanism of ACL injury or other pathologies treated at the time of ACLR, were not considered, but these groups could exhibit distinct response patterns. Our sample included only patients with ACLR aged between 12 and 30 years and did not include age as a covariate, so results cannot be generalized across patients of all ages, although most ACL injuries occur in the 12- to 30-year age group. Furthermore, numerous researchers have applied the ACL-RSI and I-PRRS to pediatric (age $<$ 18 years) and adult (age $\geq$ 18 years) patients and pooled these data; it is possible that the psychological response to injury and readiness to RTS may be better represented by separate PROMs specifically developed for pediatric and adult patients, although the ACL-RSI is valid to use with pediatric and adolescent patients.[38,50] The ACL-RSI and I-PRRS were only

recorded up to 1 year post-ACLR, so longer-term psychological readiness is unknown. All patients included in the study participated in a recreational activity or sport; however, their preinjury physical activity levels, frequency of athletic participation, and level of competition were not quantified, which may influence RTS aspirations. Finally, although self-reporting is necessary for PROMs such as the ACL-RSI and I-PRRS, the nature of self-report measures is a limitation because individuals are often biased when they report on their own experiences and expectations.

CONCLUSIONS

Assessment of psychological readiness to RTS after ACLR is critical because it is associated with poor outcomes post-ACLR, including failure to RTS and ACL reinjury. The normative reference curves provided here enable a provider to objectively appraise ACL-RSI and I-PRRS scores at any time post-ACLR using unique curves for both males and females. This may lead to timely recognition of patients with maladaptive psychological responses to injury and a higher likelihood of a poor prognosis, optimizing ACLR outcomes.

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SUPPLEMENTAL MATERIAL

Supplemental Figure 1. The 10th, 25th, 50th, 75th, and 90th percentile for A, males and B, females over time post–anterior cruciate ligament reconstruction (ACLR) in months for the Anterior Cruciate Ligament—Return to Sport After Injury (ACL-RSI) scale.

Supplemental Figure 2. The 10th, 25th, 50th, 75th, and 90th percentile for A, males and B, females over time post–anterior cruciate ligament reconstruction (ACLR) in months for the Injury-Psychological Readiness to Return to Sport (I-PRRS) scale.

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