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Published in:
Journal of athletic training

DOI:
10.4085/1062-6050-0407.21

Journal of Athletic Training 2022;57(6):540–546
doi: 10.4085/1062-6050-0407.21

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Reintroduction of Running After Anterior Cruciate Ligament Reconstruction With a Hamstrings Graft: Can We Predict Short-Term Success?

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Context: Return to running (RTR) after anterior cruciate ligament reconstruction (ACLR) is a crucial milestone. However, how and when to start a running program are uncertain.

Objective: To explore the feasibility of a structured program to reintroduce running after ACLR and evaluate the predictive value of potential predictors of short-term success.

Design: Longitudinal cohort study.

Setting: Local research center and participants' homes.

Patients or Other Participants: Thirty-five participants were recruited after ACLR.

Intervention(s): Program with a progression algorithm to reintroduce running (10 running sessions in 14 days).

Main Outcome Measure(s): The criterion for short-term success was no exacerbation of symptoms. Potential predictors were (1) the International Knee Documentation Committee (IKDC) subjective knee form score, (2) ACL Return to Sport after Injury questionnaire score, (3) quadriceps and hamstrings strength, (4) step-down endurance test, and (5) modified Star Excursion Balance test. Descriptive statistics were performed to study the feasibility of the RTR program, and Poisson regression analysis was used to evaluate predictors of success.

Results: Of the 34 participants, 33 completed the RTR program. Sixteen participants experienced some temporary exacerbation of symptoms, but only 1 had to stop the program. The initial IKDC score was the only significant predictor of a successful RTR, with an area under the receiver operating characteristic curve of 80.4%. An IKDC cut-off of 63.7/100 differentiated responders and nonresponders with the highest sensitivity and specificity (77.8% and 75.0%, respectively). A participant with an IKDC score above this threshold had a 3-fold greater chance of success.

Conclusions: Our results confirm the feasibility of our RTR program and progression algorithm after ACLR. Clinicians should use an IKDC score of >64 as a criterion to reintroduce running after ACLR to increase the likelihood of short-term success.

Key Words: prediction rules, guidelines, International Knee Documentation Committee subjective knee form

Key Points

- Our program with a progression algorithm to reintroduce running after anterior cruciate ligament reconstruction based on symptom exacerbation was well tolerated by patients.
- The International Knee Documentation Committee subjective knee form score was the only significant predictor of the likelihood that a patient could return to running without short-term symptom exacerbation.

The reintroduction of running after anterior cruciate ligament reconstruction (ACLR) is a crucial milestone for the patient and clinician. Clinicians often consider it the first major step in the return-to-sport continuum.[1] Yet only a few researchers[2–5] have examined reintroducing running after ACLR, leaving clinicians uncertain as to how and when to start a return to running (RTR) program.

Dauty et al[3,4] published 2 studies evaluating the feasibility of 2 RTR programs after ACLR. The progression of the RTR programs was predetermined and not individualized to each participant. However, current recommendations encourage clinicians to individualize the progression of rehabilitation after ACLR to optimize outcomes.[6]

In a recent scoping review by Rambaud et al,[5] researchers of 198 of the 201 studies reported a time-based criterion for RTR after ACLR, starting at a median time of 12 weeks postsurgery. Authors of only 36 studies used additional criteria for RTR, such as clinical and questionnaire evaluation and strength and functional testing. Unfortunately, all of these criteria relied solely on the opinions of experts, and scientific validation and determination of cut-off values, which would help clinicians in their decision to

Table 1. Characteristics of the Study Population at Baseline (N = 35)

Characteristic	Value
Sex	
Females	15
Males	20
	Mean ± SD[a]
Age, y	28.5 ± 7.5
Minimum–maximum	19.4–47.5
Height, cm	173.0 ± 9.3
Weight, kg	73.2 ± 13.1
Body mass index, kg/m^2	24.3 ± 2.7
Minimum–maximum	19.9–33.6
Preinjury Tegner Activity Scale score	6.9 ± 1.4
Minimum–maximum	5–9
Time postsurgery, mo	3.8 ± 0.7
Minimum–maximum	2.8–5.4

[a] Except where indicated otherwise.

clear a patient for an RTR program after ACLR, were lacking. Many physical tests have been reported by investigators,[5] including the evaluation of strength, endurance and balance, and limb symmetry.

Running is a cyclical task with a series of single-legged stance phases that are likely to require sufficient balance, muscular strength, and endurance to tolerate knee loading. Greater recovery of these characteristics may positively influence RTR. Besides the physical factors, the psychological state of the patient has been known to influence both function and recovery after ACLR[7] and may predict the capacity to RTR. Questionnaires on symptoms and functional limitations are used to evaluate a patient's disability or ability to perform activities of daily life and sport. It could be meaningful to evaluate both functional limitations and the psychological effects of injury before RTR.

When returning athletes to running after ACLR, clinicians should differentiate between short- and long-term goals. The long-term goal could be RTR performance without biomechanical alterations, whereas a short-term goal could be to start running without exacerbating symptoms.

In this study, we focused on the early time frame of an RTR (ie, when to reintroduce running after ACLR), and we considered an absence of symptom exacerbation, such as pain and knee swelling, as a criterion of success. Five categories were evaluated: (1) questionnaire on symptom and functional limitations, (2) questionnaire on psychological state, (3) strength, (4) functional endurance, and (5) balance. The first aim of our study was to explore the feasibility of a new structured running program with a progression algorithm after ACLR. The second aim was to evaluate the predictive values of potential predictors in the short-term success of an RTR program.

METHODS

Study Population

Thirty-five participants were recruited through the electronic mailing list of employees and students at our local university (Table 1). Inclusion criteria were >18 and <60 years of age, <6 months after ACLR, primary and unilateral ACLR with a hamstrings graft, and clearance by their physiotherapist or surgeon for RTR. Clearance was based on the time since surgery (mostly 3 or 4 months after ACLR) and the absence of contraindications (obvious gait asymmetry, pain at rest, significant knee swelling). Participants were excluded if they had pain at rest, knee swelling, or both; if they answered *yes* to the question, "Have you returned to running since surgery?"; or if they had >1 injured ligament. Ethical approval for the study was granted by the local ethics committees (2017-564, NCT04130308). Written informed consent was obtained from all participants before inclusion in the study.

Study Design

This longitudinal cohort study consisted of 2 evaluation sessions (baseline and follow-up 14 days after baseline). At the baseline evaluation, the characteristics of the study population and data from the surgical report (eg, meniscal and cartilage lesions) were collected. The International Knee Documentation Committee (IKDC) subjective knee form, ACL Return to Sport after Injury (ACL-RSI) scale, strength and functional endurance tests, and balance test (modified Star Excursion Balance test [mSEBT]) were administered using standardized procedures. Thereafter, during the same baseline session, all participants took part in the first running session of their RTR program on a treadmill. They then performed the 2-week RTR program at home without supervision. Each person was required to fill out daily log sheets to document compliance, including the date of completion; number of training sessions; and symptoms during, 1 hour after, and the morning after the training session. At follow-up, the logbooks were collected, and the data were checked before analysis.

Return-to-Running Program

Program Description. Derived from the study of Dauty et al[3,4] and guidelines suggested by Adams et al,[2] we developed an RTR program to reintroduce running after ACLR. This version was presented to clinical experts (n = 4) on ACL rehabilitation and running-related injuries. After discussion with these experts, we reached consensus on the final design of a structured program to reintroduce running after ACLR with a progression algorithm based on symptom exacerbation. Participants performed the program at home except for the first session at baseline. It consisted of 5 running sessions per week and lasted 2 weeks. Each running session started and ended with 5 minutes of walking, and 1-minute running and walking periods were performed (Table 2). The number of running periods was increased progressively, and the participants were encouraged to run at their self-preferred jogging speed between 8 and 10 km/h.

Progression Algorithm for the RTR Program

A graduated algorithm was designed by clinical experts based on the soreness rules of Fees et al[8] to individualize progression through the RTR program. The main guideline was that participants could progress through the RTR program if they experienced a pain score of ≤2 on a numeric scale of 0 to 10 during running and no pain 1 hour after running. This was defined as *minimal symptoms* and considered acceptable for promoting adaptations. More

Table 2. Return-to-Running Program

Running Session	Program
Wk 1	
1	5-min W + 3*[1-min R + 1-min W] + 5-min W
2	5-min W + 4*[1-min R + 1-min W] + 5-min W
3	5-min W + 5*[1-min R + 1-min W] + 5-min W
4	5-min W + 6*[1-min R + 1-min W] + 5-min W
5	5-min W + 7*[1-min R + 1-min W] + 5-min W
Wk 2	
6	5-min W + 8*[1-min R + 1-min W] + 5-min W
7	5-min W + 9*[1-min R + 1-min W] + 5-min W
8	5-min W + 10*[1-min R + 1-min W] + 5-min W
9	5-min W + 11*[1-min R + 1-min W] + 5-min W
10	5-min W + 12*[1-min R + 1-min W] + 5-min W

Abbreviations: R, run; W, walk.

severe symptoms (*symptom exacerbation*) indicated that the load tolerance was exceeded, which was detrimental for recovery. If the pain was >2/10 during running or occurred 1 hour after running, the individual was asked to assess knee swelling the next morning. If no knee swelling was present, he or she was asked to repeat the training session. Otherwise, 1 day of rest was implemented and training was stepped back 1 session (Figure 1). If symptoms did not decrease when stepping back 1 training session after 1 day of rest, the participant was asked to stop the RTR program and contact the research team. A meeting of the participant, physiotherapist, and a member of the research team was organized to determine the best management.

To monitor swelling, the examiner used a measuring tape to assess the above-knee girth during the baseline evaluation (mean of 3 measurements). Participants were instructed on how to evaluate knee joint swelling the next morning after a running session (inexperienced testers displayed excellent intra- and intertester reliability[9]). A fabric strip 1-cm longer than the above-knee girth was given to the participant. If the 2 ends of the fabric strip did not meet, then the swelling was considered clinically significant.[9]

Criteria for a Successful Reintroduction of Running

Reintroduction of running was considered *successful* when the participant completed the RTR program (10 running sessions in 14 days) without any exacerbation of symptoms (according to the progression algorithm). This meant that symptoms remained minimal (as defined in the previous section) and that the training load did not exceed load tolerance. Participants were then classified as responders or nonresponders.

Potential Predictors of the Successful Reintroduction of Running

Questionnaires. ***The IKDC Subjective Knee Form.*** The IKDC subjective knee form is a valid and reliable self-administered questionnaire that evaluates the severity of symptoms and functional limitations in patients after knee injury.[10]

The ACL-RSI Scale. The ACL-RSI scale is a valid and reliable self-administered questionnaire evaluating the psychological state of patients after ACL injury.[11]

Physical Tests. ***Isometric Quadriceps and Hamstrings Strength.*** Isometric quadriceps and hamstrings strength were measured bilaterally using a belt-stabilized handheld dynamometer (Nicholas handheld dynamometer; Lafayette Instruments)[12,13] that was shown to be reliable (intraclass correlation coefficient = 0.98).[13] Briefly, participants were seated on a table with the knees flexed to 90° and grabbed the table edge with both hands. The same examiner performed this test for all participants. The distance between the knee joint line and the point of application of the dynamometer was measured. Strength values were normalized to each participant's mass and distance of application and expressed as Nm/kg.

Step-Down Endurance Test. This procedure was described by Kline et al.[14] In short, participants stood on a 20-cm step, performed a single-limb stance, and attempted to touch a scale with the heel of their free limb without transferring more than 10% of their body weight. Participants completed as many step-downs as possible in 60 seconds. Step-downs were not counted if the participant

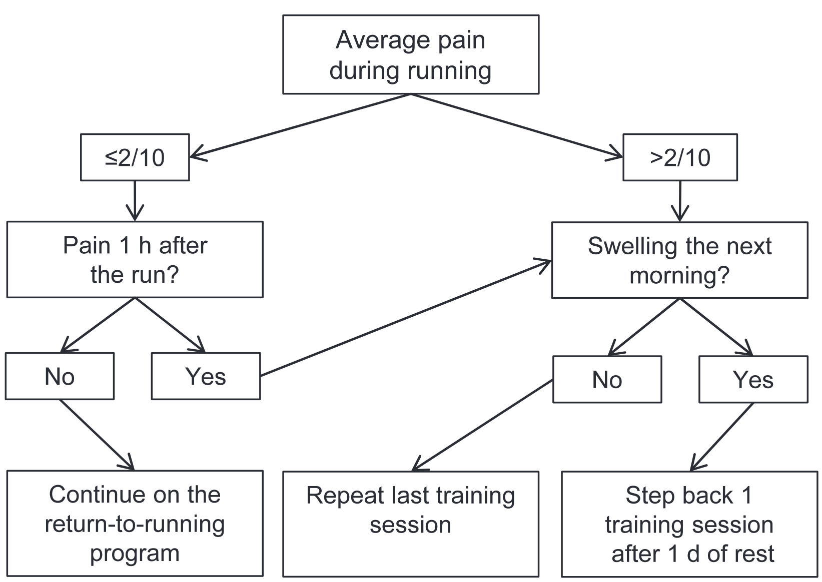

Figure 1. Return-to-running progression algorithm. Progression was based on the pain and swelling experienced by the patient.

Table 3. Symptom Exacerbation By the Number of Sessions in the Return-to-Running Program

	Session(s)		
Symptom	1st	2nd to 5th	6th to 10th
Patients (n = 34), No. (%)	9 (26.5)	6 (17.6)	1 (2.9)
Pain >2 during running, No. (mean score/10)	7 (3.1)	6 (4.7)	1 (3.5)
Pain 1 h after running, No. (mean score/10)	2 (2.0)	2 (2.0)	0
Knee swelling, No.	0	0	0

Table 4. Characteristics of Responders and Nonresponders

Characteristic	Responders	Nonresponders
Sex, females/males	9/9	6/10
Age, y	27.5 ± 8.0	28.9 ± 6.9
Height, cm	171.1 ± 8.0	174.2 ± 10.3
Weight, kg	70.1 ± 10.5	76.0 ± 15.1
Body mass index, kg/m^2	23.8 ± 2.3	24.9 ± 2.9
Minimum–maximum	20.9–33.6	19.9–27.6
Tegner Activity Scale score		
Baseline	3.1 ± 0.8	3.1 ± 0.6
Preinjury	6.9 ± 1.2	7.0 ± 1.6
Minimum–maximum	5–9	5–9
Time postsurgery, mo	3.9 ± 0.7	3.6 ± 0.6
Minimum–maximum	2.8–4.4	2.9–5.4
Lesions, No.		
Meniscal	8	7
Cartilage	3	3

did not contact the scale, transferred >10% of body weight, or did not fully return to the initial position. The test assesses the balance and endurance of the operated limb.[14]

The mSEBT. The mSEBT is a valid and reliable test used to evaluate dynamic balance.[15] A full description of the mSEBT has been published previously.[15] Balance was evaluated in the anterior, posterolateral, and posteromedial planes. Direction scores were normalized to the participant's height. The composite scores (sum of the 3 direction scores) of the mSEBT were used as an index of dynamic balance.

Statistics

Data from participants who completed the RTR program with or without symptom exacerbation or had to stop the RTR program were reported as a number and percentage. The percentages of participants who experienced symptom exacerbation at the first training session, between the second and fifth sessions, and between the sixth and tenth sessions were also provided. The relationship between outcome (responder versus nonresponder) and potential predictors was determined by Poisson regression analysis. The 6 potential predictive factors (IKDC score, ACL-RSI score, isometric quadriceps strength, isometric hamstrings strength, endurance, and mSEBT) were entered into the Poisson regression. For each predictive factor revealed by Poisson regression analysis ($P < .05$), we computed a receiver operating characteristic (ROC) curve. According to the cut-off value with the optimal sensitivity and specificity (closest point to the top left corner), the predictive continuous variable was transformed into a binary variable. Poisson regression was performed again with the binary variables (responder versus nonresponder and below versus above the cut-off value of the predictive variable) to determine the significance of the predictive model. If the Poisson regression analysis reached statistical significance, we calculated the relative risk (RR).

RESULTS

Study Population

Of the 35 participants, 2 withdrew from the study because of pain. The first participant experienced hamstrings pain during a running session, and the second participant experienced knee pain after a home move. The first participant was considered a nonresponder and was included in the analysis; the second participant was excluded from the analysis.

Feasibility of the RTR Program

Of the 34 patients, 18 were considered responders. Fifteen participants had to slow down the progression of the program because of symptoms (but still managed to perform 10 running sessions in 14 days), and 1 participant had to stop the program due to hamstrings pain. The characteristics of the responders and nonresponders are shown in Table 2. One participant (3%) had to stop the RTR program, and 33 (97%) were able to complete the 10 running sessions. The details on symptom exacerbation are reported in Table 3, but among the 33 participants, only 1 reported symptom exacerbation after the first week of the program. No differences in terms of meniscal or cartilage lesions or time after surgery occurred between the responders and nonresponders (Table 4).

Evaluation of Potential Predictors

Poisson regression revealed that the IKDC score was the only predictive factor for the short-term success of the RTR ($P = .0018$; Table 5). The ROC curve indicated a cut-off value of 63.7 points for the IKDC score (sensitivity = 77.8%, specificity = 75.0%; area under the curve = 80.4% [95% CI = 62.5, 95.5]; Figure 2).

A Poisson regression analysis with IKDC as a continuous variable transformed into a binary variable according to the optimal cut-off value (63.7 points) reached statistical significance ($P < .001$) with an RR = 3.11 (95% CI = 1.29, 7.53). Participants with an IKDC score >63.7/100 had a 3.11 times greater chance of a successful reintroduction of running than participants with an IKDC score below this cut-off.

DISCUSSION

The aims of our study were to explore the feasibility of a structured program to reintroduce running after ACLR and to evaluate the predictive value of potential predictors of short-term success. The most important finding was that 97% of all patients (n = 33) completed 10 running sessions in 14 days. By session 5 and beyond, all but 1 of the participants were tolerating our RTR program (ie, no symptom exacerbation). Based on these results, our study confirms the feasibility of this new structured RTR program

Table 5. Baseline Differences Between Responders and Nonresponders and Poisson Regression Analysis of Potential Predictors for Successful Return to Running

Variable	Mean ± SD		*P* Value (Poison Regression Analysis)
	Responders	Nonresponders	
International Knee Documentation Committee subjective knee form score	67.1 ± 6.7[a]	59.3 ± 7.82	.0018[b]
Anterior Cruciate Ligament Return to Sport After Injury score	56.5 ± 19.9	48.8 ± 19.3	.800
Isometric quadriceps strength, Nm/kg	1.8 ± 0.6[c]	1.5 ± 0.5	.274
Isometric hamstring strength, Nm/kg	0.9 ± 0.3	0.8 ± 0.3	.771
Step-down endurance, No. repetitions	39.3 ± 9.1[c]	33.5 ± 7.8	.183
Modified Star Excursion Balance Test score, height	1.2 ± 0.1	1.2 ± 0.1	.474

[a] $P < .01$.
[b] $P < .001$, intergroup difference.
[c] $P < .05$.

and progression algorithm to reintroduce running in patients after ACLR.

We found no difference in meniscal or cartilage lesions reported at the time of surgery and time of RTR after surgery (2.8 to 5.4 months after ACLR) between responders and nonresponders. Although meniscal and cartilage lesions may affect long-term outcomes after ACLR,[16] they do not seem to influence the short-term success of the RTR program.

A greater IKDC score predicted the successful reintroduction of running after ACLR. An IKDC score of >64/100 increased the chance of completing the RTR program without symptom exacerbation by 3.11 times. High IKDC scores are associated with jumping performance[17] and return to sport.[18] A higher score may reflect a greater global ability (mix of psychological, physical, and social factors) to tolerate load in daily activities, rehabilitation, and high-level functional tasks.

Another major finding was that the isolated assessments of psychological effects, strength, functional endurance, and balance did not predict the short-term success of the RTR program. Ardern et al[7] demonstrated that psychological factors, such as fear of reinjury, negatively affected the return to sport after ACLR. However, as running is an in-line activity, participants have a very

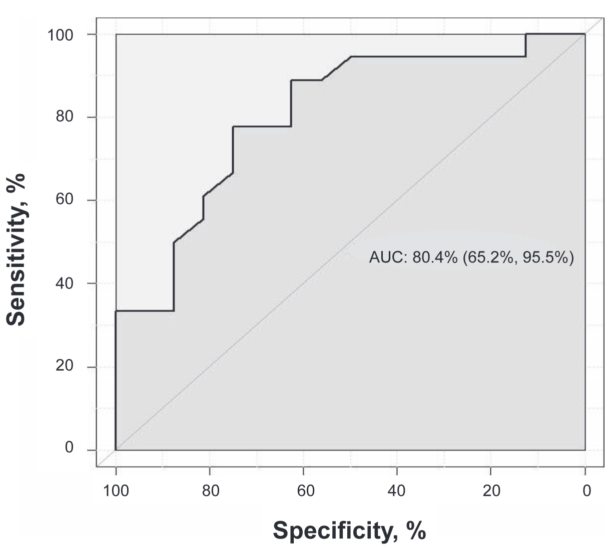

Figure 2. Receiver operating curve for discriminating responders and nonresponders based on the International Knee Documentation Committee subjective knee form score. AUC = area under the curve (95% CI).

limited risk of a knee sprain,[19] which could explain why the psychological state did not affect the short-term success of the RTR program.

In terms of muscular strength, quadriceps and hamstrings symmetry is essential for recovery after ACLR, as it is associated with greater function,[20] and weakness of these muscles has been associated with biomechanical alterations during running after ACLR.[21] Experts recommend a minimal limb symmetry index of 60% to 80% for isometric strength[2] before returning to running. However, the limb symmetry index is not a true measure of strength and, therefore, we used unilateral measures of quadriceps and hamstrings strength in our study. Taken in isolation, quadriceps and hamstrings strength do not seem to influence symptom exacerbation when reintroducing running after ACLR. Moreover, a large amount of variability was present in quadriceps and hamstrings strength among participants, and responders and nonresponders overlapped completely. Notably, participants were encouraged to run at their self-preferred speed, which does not require maximal activation of the quadriceps and hamstrings muscles.[22,23]

Among the other criteria evaluated, we observed that better performance in the step-down endurance test was not related to symptom exacerbation. In contrast, Kline et al[14] noted that a greater number of repetitions 3 months after ACLR predicted better running biomechanics at 6 months after ACLR. Biomechanical alterations and symptoms are not likely to be related and should thus reflect different aims (short- and mid- or long-term) of the RTR phase. Finally, the mSEBT composite scores did not differ between responders and nonresponders. A ceiling effect might have affected the potential predictive value of balance. Furthermore, as running is an in-line activity, multiplanar knee joint control does not seem to be meaningful in predicting the short-term success of the RTR program after ACLR.

Our study had several strengths and limitations. It adds to the body of knowledge on RTR programs, with progression based on symptom exacerbation. Our relatively small sample size could be considered a limitation. However, we focused on the homogeneity of our sample by defining specific inclusion and exclusion criteria. Only participants with primary, unilateral ACLR with a hamstrings graft were recruited, and none of the patients returned to running before enrollment, increasing the internal validity of our research. Moreover, only the IKDC score was strongly significant, whereas the other variables were far from the significance threshold. Hence, we are confident that increasing the sample size would not have significantly altered our results. A limitation of our RTR program was that it was home based; even though participants were encouraged to run at their self-preferred jogging speed between 8 and 10 km/h, we did not monitor running pace during the follow-up.

Defining a successful reintroduction of running after ACLR is challenging. Different criteria could have been chosen and led to different results. We could have considered biomechanical alterations as criteria of success. However, these alterations during running last for at least 5 years after ACLR[24] and were therefore expected when reintroducing running. As clinicians, we think that symptom exacerbation is the most meaningful way to delineate between responders and nonresponders int the short term. We think that having minimal symptoms ($\leq$2/10 during running, no pain 1 hour after running) is acceptable for promoting adaptations, but worse symptoms ($>$2/10 during running, pain 1 hour after running, knee joint swelling) may be detrimental. As a result, we considered participants who had to slow down the running progression to be nonresponders.

As this investigation is the first in which researchers have evaluated the predictive value of potential predictors, further work is required to make definitive recommendations on RTR criteria.

These findings should help clinicians determine how and when to reintroduce running after ACLR. We encourage clinicians to use our RTR program after AC-R and base progression on the algorithm developed in this study. Also, clinicians should be confident that patients who score $>$64/100 on the IKDC are likely to tolerate running loads without symptom exacerbation when reintroducing running after ACLR.

Once this 14-day RTR program is completed, clinicians are advised to recommend continuing the running program while respecting our progression algorithm and the patient's goals. We also suggest evaluating biomechanical alterations during running and implementing targeted rehabilitation to improve long-term outcomes after ACLR.[24]

Our results should not discourage clinicians from assessing the patient's psychological state, strength, balance, and endurance through the rehabilitation process, as these factors have implications for global outcomes after ACLR (eg, function, return to the preinjury sport level, risk of reinjury, and knee osteoarthrosis[7,25–27]) and help clinicians individualize their rehabilitation protocols.

CONCLUSIONS

Our study supports the feasibility of a structured program for reintroducing running after ACLR with a progression algorithm based on symptom exacerbation. Most participants (97%) were able to complete 10 running sessions in 14 days. Moreover, the IKDC score was the only significant predictor of short-term success. Patients who scored $>$64/100 on the IKDC were 3 times more likely to tolerate the reintroduction of running without adverse reactions. Thus, clinicians should use the IKDC score to individualize clinical decision making regarding RTR after ACLR.

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