

## ORIGINAL ARTICLE OPEN ACCESS

# Functional Asymmetries After 6 Months of ACL Reconstruction: A Cross-Sectional Study

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**Received:** 29 November 2024 | **Revised:** 26 May 2025 | **Accepted:** 16 June 2025

**Funding:** The authors received no specific funding for this work.

**Keywords:** anterior cruciate ligament reconstruction | athletic performance | knee injury | rehabilitation | sports injury

## ABSTRACT

Functional tests commonly assess athletes' readiness to return to sports after knee surgery. Despite this, there are still more studies on clinical and patient-reported outcomes. The purpose of this study was to determine differences and combinations of various functional performances within and between athletes 6 months after anterior cruciate ligament (ACL)-reconstruction (ACLR) for the first time (ACLR-I group) versus second ACL injury on the same knee (ACLR-II group) versus ACLR procedures on both legs (ACLR-III group). A total of 88 patients with ACLR performed single-leg hop (maximum forward distance hop, SLH; side hop > 40 cm in 30 s, SH), Functional Movement Screen (FMS) and dynamic postural balance (Y Balance Test – YBT). Data were recorded during return-to-sport testing (6 months post-surgery). For each variable, a mixed-model analysis of variance, with a between-subjects factor of group (primary ACL injury, recurrent ACL injury and bilateral ACL injury) and a within-subjects factor of limb (involved, uninvolved), were conducted. Differences between the groups were found in different degrees of inter-limb asymmetry in the single-leg hop ( $p < 0.001$ ) and side hop test ( $p < 0.02$ ). There was a main effect of limb for the anterior and posteromedial YBT distances, and the single-leg hop and side hop test distances ( $p \leq 0.04$ ). For each variable, performance was worse for the involved limb compared to the uninvolved limb. Individuals after recurrent ACLR showed greater functional asymmetries at 6 months of treatment. Jumping tests detected greater performance deficits compared to YBT and FMS.

## 1 | Introduction

In the last decades research regarding anterior cruciate ligament (ACL) injuries in athletes has increased exponentially; despite this and an increased threshold in return to play criteria, there

is still a high rate of injury recurrence [1–6]. Besides this issue, in some cases, many individuals undergo ACL reconstruction (ACLR) but do not return to play, suffer recurrent injury and osteoarthritis. Outcome studies show that after ACLR, 81% of individuals return to sports, 65% return to their pre-injury level

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## Summary

- We have evaluated functional performances within and between athletes 6 months after ACL reconstruction.
- Individuals after recurrent ACLR showed greater functional asymmetries at 6 months of treatment.
- Jumping tests detected greater performance deficits compared to YBT and FMS.

and 55% return to competitive sports. Multiple factors classified as modifiable and non-modifiable are thought to influence ACL injuries [7–9]. Some of the most common modifiable factors are neuromuscular control and landing biomechanics. Failure to correct these factors increases the risk of injury and recurrence [9, 10].

Athletic performance amongst elite athletes who have returned to sport after ACLR often deteriorated compared to pre-injury levels, and they returned to level I sports and experienced a four-fold increase in the re-injury risk compared to athletes from lower levels [11–13]. Currently, patients commonly complete performance assessments that guide the progression to unrestricted activities at approximately 6 months after ACLR [14]. ACLR causes various impairments, such as mechanical instability, pain, kinesiophobia, and muscle inhibition. These impairments, together with the behavioural changes resulting from rehabilitation and movement compensations, cause neural and orthopaedic adaptations [14–17].

The return criteria have changed over time, sometimes tending towards an earlier return, sometimes towards a later one. Understanding the changes that have taken place in recent years is fundamental to assimilating what we do today and avoiding the same mistakes of the past [18–20]. To manage health care decisions after ACL injury, there is a need to identify residual movement impairments following ACLR that are apparent during an array of functional tasks after ACLR, which has been prospectively linked with another ligament injury [12, 21–25]. Furthermore, symmetry levels were important for a complete recovery of knee joint functionality [10, 13, 26–28]. To quantify the symmetry level as a measure of knee joint functionality, the leg symmetry index (LSI) is a recognised method [29–31].

Functional assessment is inexpensive and easy to use at any time of clinical intervention. Y Balance Test (YBT) may be applied for injury risk assessment-based asymmetry and dynamic balance [30, 32–34]. The Functional Movement Screen (FMS) is used to assess functional movement patterns, which require both mobility and stability [34, 35]. Hop tests hold potential as predictive factors of self-reported knee function in individuals after ACLR [36, 37].

To date, there is a lack of data on dynamic functional testing in patients with a previous history of knee compared to the timings of a first recovery. Objective measures of dynamic control of the knee joint are needed, which can be related to the condition of the ACLR, with a previous injury for two different reasons at

least – to add data points for epidemiology data and to monitor progress and divergences from the non-injured knee, which can potentially help prevent injury. These high-functioning ACLR must be able to complete tasks with dynamic control like the contralateral leg. The hypothesis of this study is that patients with a previous ACL injury will demonstrate different functional clinical outcomes – specifically in dynamic control – compared to those recovering from a first-time ACL reconstruction, and that the involved leg will show measurable differences from the uninvolved leg 6 months post-surgery. The purpose of the present study was to compare functional clinical outcomes in different groups 6 months after ACLR and between the involved and the uninvolved leg.

## 2 | Methods

### 2.1 | Participants

A total of 88 recreational athletes (mean age,  $27.3 \pm 7.6$  years) who underwent primary single-bundle ACLR using the autogenous semitendinosus-gracilis (STG) tendon graft performed by an experienced team of surgeons (all over 20 years of experience in ACLR) were evaluated in this study. The ACLR was performed on the dominant ( $n = 35$ ) and the non-dominant ( $n = 53$ ) lower extremity. A sample of 88 young athletes were recruited from a hospital setting and divided into three groups. They were screened according to our inclusion and exclusion criteria for eligible patients after ACL rupture.

The ACL-I group ( $25.8 \pm 9.1$  years) of both sexes (15 females and 29 males) corresponds to the group of individuals who suffered an ACL injury for the first time and are undergoing the entire rehabilitation process for the first time. The ACL-II group includes athletes who have re-injured their ACL in the same knee ( $27.1 \pm 7.5$  years) of both sexes (9 females and 16 males). In this clinical criterion, the injury to the same knee occurred after at least 1 year. The ACL-III group includes individuals who had a bilateral ACL injury ( $30.4 \pm 6.8$  years) of both sexes (5 females and 14 males), considering the current injury for the study, but the contralateral leg in the past had undergone the same rehabilitation.

**Inclusion Criteria:** Participants were normotensive, with normal body mass index (BMI); began physiotherapy in the pre-operative context and continuation of recovery up to 2 weeks after surgery; age equal to or greater than 18 years; be able to correctly fill in the assessment instruments and complete the informed consent form. Participants with previous severe chondral defects were not included in the study, but meniscus repair or meniscectomy performed at the time of ACL reconstruction was tolerated.

**Exclusion Criteria:** Concomitant bilateral injury with several chondral defects/history of surgery or contralateral dysfunction; meniscal suture; cartilaginous injury; injury to the medial collateral ligament (MCL), lateral collateral ligament (LCL) and posterior cruciate ligament (PCL); concomitant intra- and extra-articular plastic surgery; complex injury from any accident; complex tibial condyle fracture; rheumatoid arthritis; individuals with recent heart disease, intermittent claudication, neuropathies, and cognitive alterations.

Participants' information is described in Table 1. For ACLR, a maximum of 4 months between index injury and surgery was accepted to reduce the influence of manifested deficits in functional performance. Each patient received precise guidelines for ACL in the early postoperative phase, focusing on the knee range of motion, edema management, muscle strength as well as the progression of the exercise phase. All procedures followed the principles of the Helsinki Declaration for good clinical practice and were previously approved by the Institutional Ethics Committee (Process CE.CSJD/P1.23). The Ethics Committee for Health gave a favourable opinion to the implementation of the doctoral project and showed itself available to provide support to achieve the proposed research objectives.

## 2.2 | Study Procedures

Anthropometric and clinical parameters were recorded. Control subjects were asked to indicate their dominant leg, if possible; otherwise, they were asked about their preferred kicking leg. Participants provided informed consent and completed various self-report scales: Knee Injury and Osteoarthritis Outcome Score (KOOS), Lysholm Rating Scale, International Knee Documentation Committee (IKDC), Lower Extremity Functional Scale (LEFS) and Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI).

Participants completed a 15-min warm-up walk on a treadmill at 4 km/h walking speed. They completed single-leg hop (SLH) and side hop (SH, both hop performance) tests with both legs, YBT and FMS. The starting leg was randomised for each task, and legs were alternated for the trials of YBT, SLH, and SH.

## 2.3 | Hop Performance

Participants completed a pre-test for SLH and SH with each leg, which was a submaximal jump forward and laterally over 40 cm with hands placed on the hip and controlled landing of one leg with sufficient movement quality and stability. After a successful pre-test, participants performed four forward SLHs for maximum distance per leg with unrestricted arm movement [38]. LSI for both tests was calculated in the same manner. Excellent reliability (ICC = 0.88–0.92) and precision (SEM = 3.49%–4.32% of the maximum distance) were reported [39].

## 2.4 | YBT Performance

The participants, whilst standing on one leg (barefoot) in a central location on the YBT instrument with their hands placed on the wings of their ilium, were asked to move the pointer (the central plastic plate) as far as possible in three different directions (anterior, posteromedial, and posterolateral) using the lower limb opposite to their support limb. Each movement was demonstrated, and then standardised practice trials were completed in each direction [40, 41].

## 2.5 | FMS Test

Participants performed the seven movements: 1. Deep squat (DS); 2. Hurdle step (HS); 3. In-line lunge (IL); 4. Rotary stability (RS); 5. Active straight leg raise (ASLR); 6. Trunk stability push-up (TSP); and 7. Shoulder mobility (SM). A demonstration was provided before each movement test. Scores ranged from 0 to 3, with zero points awarded to participants who felt any pain whilst performing any of the movements and 3 points awarded

**TABLE 1** | Mean and standard deviations (SD) of groups' demographic characteristics.

Parameter	ACL-I	ACL-II	ACL-III	<i>p</i> <sup>a</sup>
Anthropometrics				
Sex, <i>n</i> (male/female)	29/15	16/9	14/5	—
Age (years), mean (SD)	25.8 (9.1)	27.1 (7.5)	30.4 (6.9)	0.273
Body mass (kg), mean (SD)	67.5 (12.1)	66.7 (14.5)	70.7 (15.4)	0.655
Body height (cm), mean (SD)	174.2 (9.8)	171.5 (8.4)	173.0 (10.1)	0.720
Body mass index (kg/m <sup>2</sup> ), mean [minimum; maximum]	22.6 [21.4; 27.0]	22.0 [20.4; 25.2]	23.8 [21.9; 26.6]	0.242
Clinical parameters				
Time from injury to surgery (days) [minimum; maximum]	30 [25; 35]	42 [18; 64]	35 [25; 48]	0.192
Follow-up (months)	6	6	6	—
Dominance of ACLR				
Dominant, <i>n</i> (%)	19 (43%)	9 (36%)	11 (58%)	—
Non-dominant, <i>n</i> (%)	25 (57%)	16 (64%)	8 (42%)	—

Note: Bold *p* values indicate a statistically significant difference between groups ( $p < 0.05$ ). *n* (%) means the percentage of ACL injuries within the group occurring in the leg considered dominant or non-dominant (contralateral).

Abbreviations: cm: centimetre; kg: kilogram; m: metre.

<sup>a</sup>One-way analysis of variance significance.

to participants who were able to perform the movements according to the FMS guide. In asymmetric tests, both the right and left sides were assessed, and the lower result was considered for the final score. A level 3 score is expected for a person without any musculoskeletal problems. Subsequently, the rater tested the opposite side. Scoring at level 1 or 2 is described as a “weak link” (e.g., biomechanical and/or neuromuscular dysfunction). A movement in compliance with a standard could receive a total score of between 0 and 21 points [42, 43].

## 2.6 | Data Analysis

Statistical analysis was performed in SPSS Version 27.0.1.0 (IBM Corporation, Armonk, NY, USA). The dependent variables of interest were the reach distance for the YBT (anterior, posteromedial and posterolateral directions) and hop performances hop distances for the SLH and SH. Group demographics were compared using a one-way analysis of variance (ANOVA). For each variable, a two-way mixed-model analysis of variance was conducted between the subjects' factor of group (ACLR-I, ACLR-II and ACLR-III groups) and the within-subjects factor of limb (involved and uninvolved).

An alpha level of 0.05 was used for each test of statistical significance. A LSI was also generated for each variable by dividing the distance for the involved limb by the distance for the uninvolved limb. An LSI equal to 100% reflects perfect inter-limb symmetry, an LSI less than 100% reflects poorer performance for the involved limb, and an LSI greater than 100% reflects poorer performance for the uninvolved limb. Values considered as clinically relevant for comparisons I and II: LSI of  $\geq 90\%$  is considered normal. We calculated a LSI where  $LSI = (1 + [SSD - \text{side-to-side difference}/\text{higher leg value}]) \times 100$ , where values below/above 100% indicate a deficit of the involved leg. According to the literature, an LSI below 90% was used as a clinical threshold and considered a positive result [44–46]. Leg differences  $\leq 10\%$  within a person were clinically considered as physiological. The difference between the involved and uninvolved legs of ACLR-I, ACLR-II, and ACLR-III groups was also calculated.

## 3 | Results

Table 1 describes the characteristics of the athletes whose data were analysed as part of this study.

**Demographic and Health Data:** There were no significant differences ( $p > 0.05$ ) in demographic data amongst the three groups (age [ $p = 0.273$ ], mass [ $p = 0.655$ ], height [ $p = 0.720$ ], BMI [ $p = 0.242$ ], time since surgery [ $p = 0.192$ ]). The same was valid between the groups at baseline for any of the dependent variables of interest ( $p \geq 0.100$ ), indicating that the groups were comparable in terms of initial anthropometry and injury history.

No ACL injuries occurred during the study period. IKDC scores were significantly lower in the ACL-II and ACL-III groups 6 months after surgery than in the group with primary injury. The Lysholm scale and the KOOS subscales showed the same trend again, except for the KOOS-ADL, which was very similar between ACL-I and ACL-III. There were also differences in the ACL-RSI scale.

There was a significant difference in KOOS-Sport, IKDC and ACL-RSI scores between the groups ( $p < 0.001$ ). The ACL-I group reported significantly higher KOOS-Sport, IKDC and ACL-RSI scores. There were significant differences in KOOS-QOL and Lysholm scores between the groups ( $p = 0.02$ ;  $p = 0.022$ , respectively) (Table 2).

On average, YBT reach distances were 1.4 cm less in the anterior direction; 3.3 cm less in the posteromedial direction and 0.4 cm for the involved limb in the posterolateral direction, compared to the uninvolved limb for the ACLR-I group. For the ACLR-II group, 4.3 cm less in the anterior direction, 8.6 cm less in the posterior direction and 1.1 cm less in the posterolateral direction. Comparing again the involved limb with the uninvolved limb for the ACLR-III groups, the involved limb was 2.7 cm less in the posteromedial direction, 0.1 cm less in the posteromedial direction and 1.7 cm less in the posterolateral direction. There was also a main effect of limb for the SLH test [ $F = 24.11$ ;  $p < 0.001$ ]. SLH test distances were 9.4 cm less for the involved limb for the ACLR-I group, 9.6 cm less for the involved limb for the ACLR-II group and 5.2 cm less for the involved limb, compared to the uninvolved limb (Table 3).

There was an group-by-limb interaction effect for the anterior [ $F = 12.26$ ;  $p = 0.02$ ] and posteromedial [ $F = 8.40$ ;  $p = 0.04$ ] YBT reach distances. There was no effect of group-by-limb interaction for the posterolateral distance [ $F = 1.81$ ;  $p = 0.27$ ]. The SLH test [ $F = 12.04$ ;  $p = 0.001$ ] and SH test [ $F = 9.03$ ;  $p = 0.02$ ] indicate that the groups exhibited different degrees of inter-limb asymmetry in performance tests.

**TABLE 2** | Patient demographics and functional outcomes following ACL reconstruction.

Reported patient outcomes and FMS	ACLR-I	ACLR-II	ACLR-III	$p^a$
KOOS-Sport	93.7 (5.7)	80.2 (15.1)	82.2 (9.8)	<b>&lt;0.001</b>
KOOS-QOL	75.0 (20.5)	65.8 (15.1)	62.7 (13.8)	<b>0.02</b>
KOOS-ADL	94.5 (2.9)	90.6 (5.8)	94.2 (4.8)	0.226
KOOS-Symptoms	86.5 (10.1)	80.8 (11.4)	81.0 (13.0)	0.110
KOOS-Pain	96.6 (3.0)	89.8 (8.2)	87.5 (12.2)	0.054
Lysholm	93.5 (5.4)	80.2 (15.5)	82.0 (14.0)	<b>0.022</b>
IKDC	91.5 (6.6)	88.8 (8.1)	80.1 (9.4)	<b>&lt;0.001</b>
ACL-RSI	76.2 (17.5)	68.4 (19.5)	60.2 (22.7)	<b>&lt;0.001</b>
FMS (total score)	16.6 (2.2)	15.3 (1.8)	16.5 (2.4)	0.31

Note: Values other than the number of participants (N) are given as mean (standard deviation). Bold  $p$  values indicate a statistically significant difference between groups ( $p < 0.05$ ).

Abbreviations: ACL-RSI, Anterior Cruciate Ligament-Return to Sport after Injury Scale; ADL, activities of daily living; IKDC International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life.

<sup>a</sup>One-way analysis of variance significance (based on the analysis of variance  $F$  tests).

There was a main effect of limb for the anterior [ $F=24.02$ ;  $p<0.001$ ] and posteromedial [ $F=8.7$ ;  $p=0.014$ ] YBT reach distances; however, there was not a main effect of limb for the posterolateral direction [ $F=2.36$ ;  $p=0.12$ ].

Unilateral injury may also affect the function of the uninvolved leg, using the healthy contralateral leg as sole reference in participants which may lead to overestimation of the performance of the involved leg. We calculated the relative number of patients who achieved leg symmetry (defined as  $LSI \geq 90\%$ ) and a performance of healthy controls (defined as  $\geq 90\%$  of the average performance of the non-dominant leg of controls) in SLH and postural dynamic control with the involved leg (ACLR) or the non-dominant leg (control). All patients completed the hop performance and YB tests. Within- and between-group differences are presented in Table 4. The LSIs of these scores were well above 90.

## 4 | Discussion

We aimed to determine differences in functional leg ACLR in hops and dynamic postural control (I) between the legs of patients 6 months after ACLR, the legs of patients 6 months after ACLR and the legs of ACL-I, and (II) between the involved leg of patients and uninvolved leg using statistical and clinical thresholds. The commonly used criteria for return to sports release in clinical practice are time after surgery, which is derived from biological healing time and ranges from a few months to 2 years [34, 47, 48]. The rehabilitation process is long and multifactorial. Although the length of time since surgery has traditionally been used as the main criterion for establishing whether an athlete is ready for a return to activity, a shift towards comprehensive functional testing has dominated in recent years but has not been explored in a population with

**TABLE 3** | Summary of patient data and functional recovery measures after ACL reconstruction.

Parameter	ACL-I		ACL-II		ACL-III	
	Involved	Uninvolved	Involved	Uninvolved	Involved	Uninvolved
Functional parameters						
SLH distance	149.7 (19.8)	159.1 (16.9)	142.9 (17.1)	152.5 (18.9)	141.2 (22.5)	146.4 (20.9)
SH (n)	39.4 (6.0)	43.2 (5.2)	37.0 (5.3)	42.2 (4.6)	35.0 (6.6)	39.6 (6.7)
Y Balance Test						
Anterior	64.7 (4.4)	66.1 (4.1)	63.9 (4.5)	68.2 (5.1)	66.6 (8.5)	69.3 (5.6)
Posteromedial	109.8 (6.9)	113.1 (7.4)	106.0 (7.1)	114.6 (8.1)	112.7 (12.3)	112.8 (16.3)
Posterolateral	106.9 (5.6)	107.3 (6.3)	110.6 (5.7)	111.7 (6.3)	115.1 (9.3)	116.8 (6.2)

Note: Values other than the number of participants (N) are given as mean (standard deviation). Abbreviations: ACL, Anterior Cruciate Ligament; SH, side hop; SLH, single-leg hop.

**TABLE 4** | Within groups and between legs in functional performance tests.

Clinical threshold	(i) SSD within groups			(ii) involved leg vs. uninvolved leg		
	ACL-I, involved vs. uninvolved	ACL-II, involved vs. uninvolved	ACL-III, involved vs. uninvolved	ACL-I	ACL-II	ACL-III
	LSI > 90%			Absolute leg difference performance of the involved leg > 10%		
	Mean (SD)					
Hop performance						
SLH distance (%)	94.1 (17.1)	93.7 (18.0)	96.4 (21.2)	5.8 (28.1)	7.7 (21.8)	3.8 (29.8)
SH (%)	91.2 (5.5)	87.6 (4.9)	88.3 (6.7)	11.8 (31.9)	9.3 (42.8)	4.9 (30.2)
Y Balance Test						
Anterior (%)	97.9 (4.3)	93.7 (6.4)	96.1 (5.7)	4.8 (10.2)	5.5 (11.3)	1.9 (4.8)
Posteromedial (%)	97.1 (4.8)	92.5 (5.5)	101.4 (6.0)	1.8 (10.1)	0.9 (6.8)	1.3 (7.2)
Posterolateral (%)	99.6 (3.9)	99.0 (5.1)	98.5 (7.1)	2.0 (11.8)	1.4 (8.8)	1.9 (5.2)

injury recurrence. This study demonstrates that even with the same follow-up, there are different functional indicators.

The YBT is a functional test that requires strength, flexibility, neuromuscular control, stability and range. This is concerning since deficits in postural stability and dynamic balance are associated with an increased risk for ACL injury/re-injury [33, 38]. The existence of limb-to-limb asymmetries following ACLR has been shown to predict re-injury in patients returning to sports after ACLR [3, 49, 50]; 6–9 months following ACLR, patients continue to demonstrate functional hop, as well as kinematic differences, during the propulsion and landing phases of the hop tests [50, 51].

The FMS is a non-specific movement pattern assessment to identify dysfunctional movement patterns by analysing mobility and stability during prescribed movements. Prior research has demonstrated that higher levels of exercise participation were associated with higher FMS scores. The results of this research highlight that not only does the level of activity influence functional movement [52]. The total FMS score was greater than 14 in all groups, with the lowest value being found in ACL-II. It has been demonstrated that low FMS composite scores ( $\leq 14$ ) may be associated with increased risk of injury whilst also predicting trauma [52].

An increasing number of studies underscore the importance of psychological condition (e.g., motivation, confidence, no fear) and the concept of readiness to return to sports and normal performance [53–55]. A higher ACL-RSI score was related to a higher functional parameter; this was observed in the ACL-I group. This positive psychological response was also reflected in functional tests to perform at the pre-injury level, formulated at the end of rehabilitation.

When you suffer an injury, there is and must be a progressive rehabilitation process. There are established and validated premises and criteria (chronobiological, functional and psychosocial) to progress in rehabilitation and to support the decision to return to sport [56, 57]. For example, in the case of surgical ACL reconstruction, if the established criteria for returning to sport are not met, there appears to be a four-fold increased risk of re-rupture. Likewise, when an athlete is reintegrated into training and competition, extrinsic factors (along with any unachieved rehabilitation goals and criteria for return to sport), such as workload and match congestion, can particularly predispose an athlete to recurrence [3, 34, 58]. Scientific evidence seems to support that low self-esteem, poor performance in unipodal and long jump, altered motor control in the hip and knee during a dynamic ground reception task and deficits in postural stability after surgical ACLR can be managed by subgrouping individuals who may require and benefit from an extension to the rehabilitation period to reduce the risk of recurrence. Approaching neuroscience to improve rehabilitation techniques, skills and effectiveness can bring positive results in motor development, restoration and improvement of motor deficits that seem to persist even 2 years after ACL reconstruction [3, 59].

The asymmetrical loading is believed to be due to underloading of the ACLR limb during part of the treatment [60, 61]. The load asymmetry is relevant because bilateral exercises are often

performed during ACLR rehabilitation to increase the strength of the muscles around the joint to improve its stability. If athletes underload the joint, the desired effects of exercise training will not be realised, and asymmetries between the legs will be exacerbated [60–64].

Given that injuries are multifactorial in nature and that a previous injury constitutes one of the primary risk factors for re-injury, this study aimed to control the relevant variables in order to support evidence-based decision-making aimed at mitigating this risk. Future studies should build on current preliminary findings to help evaluate performance readiness following ACL surgery, considering functional ability and psychological readiness. Long-term studies are needed to investigate prognostic factors which may allow for more appropriate decision-making strategies and give a reliable prediction.

The integration of the most recent scientific evidence with direct clinical data offers a contemporary, pragmatic and clinically validated approach to rehabilitation following ACLR. This study highlights key updates to current rehabilitation protocols, notably the recommendation to delay return to sport and to implement a structured secondary injury prevention program upon resumption of athletic activity. These measures are particularly indicated in the presence of persistent functional asymmetries, with a more pronounced necessity observed in individuals with a history of multiple ACL rehabilitation episodes.

Several limitations of our study should be acknowledged. Kinetic data were not included in this study, and these could have provided important information about the forces and moments during the hop tests. All participants in our ACLR groups received an autogenous tendon graft as part of the current national standard procedure. A generalisation with other graft types is beyond the scope of this discussion, as different grafts are associated with distinct comorbidities and therefore necessitate individualised rehabilitation progressions. Additionally, strength assessment of the hip and ankle musculature might have provided additional information that could explain the performance of the hop test.

## 5 | Conclusion

Six months after ACL reconstruction, functional asymmetries remain, particularly in athletes with a history of prior ACL injuries. These deficits – especially in jump performance – highlight the need for individualised rehabilitation strategies and criteria-based return-to-sport protocols.

### Acknowledgements

The authors would like to thank all the coaches and players for their willingness to participate in this study. Funding for open access charge: Universidade da Coruña/CISUG.

### Ethics Statement

All procedures followed the principles of the Helsinki Declaration for good clinical practice and were previously approved by the Institutional Ethics Committee Clínica São João de Deus – in Lisbon, Portugal

(Process CE.CSJD/P1.23). The Ethics Committee for Health gave a favourable opinion to the implementation of the doctoral project and showed itself available to provide support to achieve the proposed research objectives.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

The dataset supporting the conclusions of this article is available in the [sergio.nuno@udc.es](mailto:sergio.nuno@udc.es) in the Research, Health and Podiatry Group, Department of Health Sciences, Faculty of Nursing and Podiatry, Industrial Campus of Ferrol, Universidade da Coruña, Spain.

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