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Original Research

Return-to-sport tests: Do they reduce risk of re-rupture after anterior cruciate ligament reconstruction?

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ABSTRACT

Introduction: Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries. Despite the effectiveness of reconstruction, re-rupture rates of up to 15 % have been reported. Static and dynamic test of strength and movement control have been used to determine when return to sports (RTS) is appropriate.
Objective: To determine whether successfully passing return to sport (RTS) tests reduces the re-rupture rate.
Methods: Retrospective cohort study. Patients who underwent ACL reconstruction (ACLR) from June 2018 to May 2023, and who performed RTS tests after rehabilitation, were analyzed. Patients who, in addition to ACLR, underwent extra-articular tenodesis, osteotomy, or multiligament injuries were excluded. RTS tests included the following: repeat sprint ability, dynamic valgus, proagility, unilateral counter movement jump (CMJ), isokinetic, triple hop test, and functional movement screen (FMS). All statistical analyses were performed with STATA version 18.0.
Results: Ninety five patients underwent RTS tests after ACLR, with a follow-up time of 27.8 months. 71.6 % of patients were men with a mean age of 25.15 $\pm$ 10.7 years. The overall re-rupture rate was 13.68 % (13 patients). When comparing patients who passed and did not pass the RTS tests, there were no differences by sex ($p = 0.06$) or age ($p = 0.11$). The only statistically significant difference between the groups was the mean risk score (passed: 11.5 $\pm$ 0.7 vs. not passed: 15.5 $\pm$ 2.1; $p < 0.001$). Patients with re-rupture were more likely to be from the non-passed group (passed: 0 % v/s not passed: 18.1 %; $p = 0.03$), with a statistical power of 0.70.
Conclusion: Our records show that passing RTS test after an ACLR could guarantee the absence of re-rupture in the medium term.
Level of evidence: Level IV.

What are the new findings?

- Passing the return-to-sport tests is a protective factor against anterior cruciate ligament re-ruptures after reconstruction.
- Of the group of patients who passed the return-to-sport tests, 91 % returned to sport.
- The time elapsed from surgery to return-to-sport may be a key factor moderating the risk of a second anterior cruciate ligament injury.

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INTRODUCTION

In the United States, the annual incidence of anterior cruciate ligament (ACL) injuries is estimated to be between 100,000 and 250,000 patients [1], with reconstruction surgery rates ranging from 60,000 to 175,000 [2]. Despite its effectiveness in restoring stability and function to the joint, the incidence of re-rupture increases over time after surgery: 3 %, 6 %, 9 % at follow-ups of 2, 5, 8 years, respectively [3,4].

The timelines for return-to-sport (RTS) after an anterior cruciate ligament reconstruction (ACLR) are variable and depend not only on time but on multiple factors [5]. According to a meta-analysis by Lai et al. the RTS time varied between 6 months and more than a year [6]. Among the risk factors for a second ACL injury, early RTS has been identified, especially in young patients [7].

RTS tests are tools designed to assess the functional capacity of the athlete, measuring both strength and movement control in dynamic situations that simulate the physical efforts of sport. These have been used individually or combined, after a rehabilitation protocol, to try to determine the best time for the patient to RTS.

Despite the implementation of these tests in many rehabilitation programs, there is no consensus on their effectiveness in predicting whether passing them decreases the risk of re-rupture [8]. The objective of this study is to determine if passing the RTS tests significantly reduces the re-rupture rate in patients undergoing ACLR.

METHODS

Retrospective cohort study was conducted at our center, Clinica Alemana Santiago, which included patients who underwent ACLR surgery between June 2018 and May 2023. Ethical review was undertaken by the Health and Disability Ethics Committee of Clinica Alemana Center. Informed consent was taken from all patients for use of data. No funding was required for this study.

Patients followed the standard rehabilitation protocol at our center and underwent RTS tests. Excluded from the study were those with neurovascular injuries, tibial plateau fractures, multiligament reconstructions, or procedures combined with osteotomy or extra-articular tenodesis.

All surgeries were performed by experienced knee surgeons (10+ years of experience), under general anesthesia with a thigh-high tourniquet. Patients typically stayed one night in the hospital and completed at least one physiotherapy session before discharge. Patients who underwent meniscal repair were immobilized with a range-of-motion (ROM) brace and had weight-bearing restrictions for six weeks, after which full ROM was allowed. The rehabilitation protocol focused on pain and edema management, joint ROM, and quadriceps activation in the early weeks. For patients unable to perform a straight leg raise without extension lag, electrostimulation and biofeedback were implemented during the initial sessions [9].

Quadriceps strengthening begins with isometric exercises and progresses to open kinetic chain (OKC) exercises in protected ranges, typically introduced between weeks 4 and 6 postoperatively, with ROM limited to 90°–45° and gradually expanded by week 12. This strategy reduces the risk of injury to semitendinosus-gracilis (ST-G) grafts, which are more prone to laxity than patellar tendon (PT) grafts. However, studies show no significant differences in outcomes like anterior tibial laxity, muscle strength, or patient-reported function, regardless of early or late OKC exercise initiation [10,11]. Additionally, a study conducted by Forelli F in 2023 demonstrated that the early incorporation of OKC exercises in patients with ST-G tendon grafts is safe, provided that loads are kept under control [12].

As rehabilitation progresses, functional exercises are incorporated [9,13,14], with impact exercises introduced no earlier than the third or fourth month, depending on the patient's condition. Core strengthening and proprioception exercises are tailored to the recovery phase, and plyometric exercises may begin from the third month [15].

Postoperative follow-ups were conducted at 2 weeks, 4 weeks, 6 weeks, 3 months, 6 months, and 1 year by the treating surgeon. After completing the rehabilitation protocol, patients underwent a magnetic resonance image to assess graft ligamentization and performed RTS tests. Those who failed the tests were advised to continue rehabilitation or attend RTS sessions.

Due to the lack of a standardized RTS battery in the literature, the test battery was designed collaboratively by the knee team's orthopedic surgeons and physiotherapists based on current evidence.

Return-to-sport tests

Repeat sprint ability (RSA): This test evaluates athletes' resistance to fatigue during high-intensity sports involving short sprints. It consists of an 8-repetition sprint over a 30-m course, with each sprint performed at maximum speed and followed by 25 s of active recovery before the next sprint [16]. The goal is to minimize the difference between the fastest and slowest sprints. Fatigue is measured using a fatigue index, and the test is considered successful if the fatigue index is <15 %.

Dynamic valgus: The patient performs a drop jump from a 30 cm high box, landing softly and immediately executing a maximum vertical jump. This is repeated three times, and the quality of execution is assessed by measuring lower limb alignment, specifically knee valgus during landing. The average valgus angle from all attempts is recorded. The test is considered successful if the valgus angle is < 16° for men and <20° for women (see Fig. 1) [17].

Proagility test: This test primarily evaluates changes in direction rather than agility. The course is 10 m long, with cones placed every 5 m. The participant starts at the center (A), moves to (B), then to (C), and returns to the starting point (A), where the test ends (see Fig. 2). The participant must touch the line they reach with the closest foot and hand, while the opposite hand must remain off the ground during direction changes. The time to complete the test is measured in seconds, with a time <5 s considered a pass [18].

Unipodal counter movement jump (CMJ): This test measures the strength and stability of the affected leg compared with the unaffected leg. The patient performs a maximum single-leg vertical jump onto a force platform. The jump starts with hands on the waist in a bipedal stance

Fig. 1. Evaluation of the degrees of dynamic valgus, from dropping off a 30 cm high box followed by a maximum vertical jump.

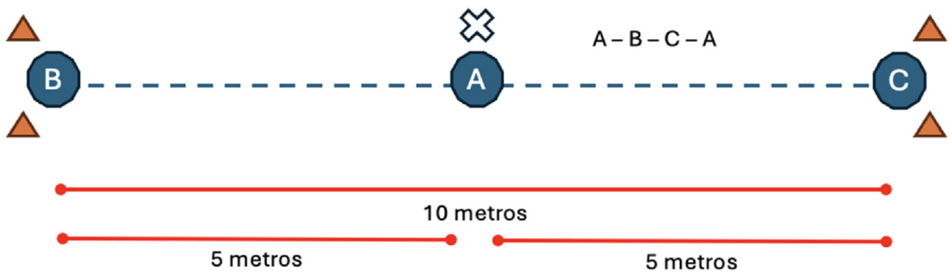
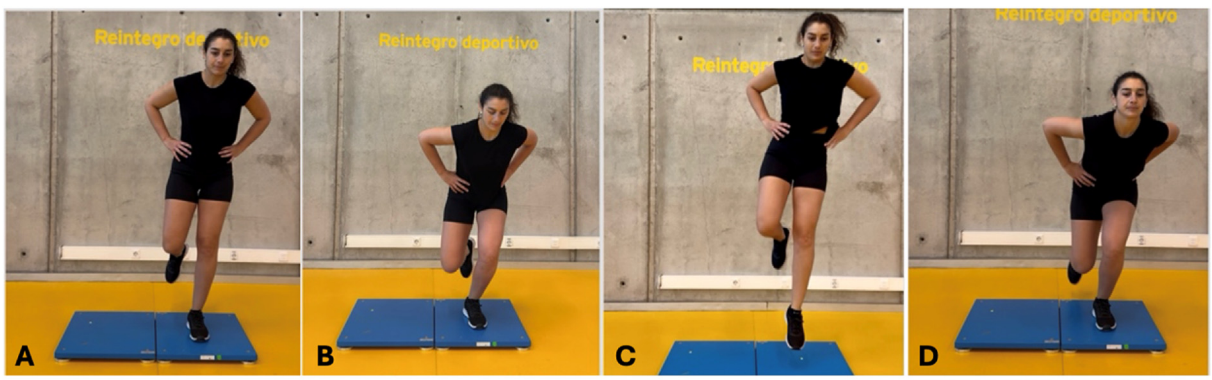


Fig. 2. The proagility test measures changes in direction over a 10-m course, with the time being recorded.



$$Symmetry\ Index = (Injured\ Leg\ Height/Healthy\ Leg\ Height)x\ 100$$

Fig. 3. Difference in unipodal jump. A. This jump is performed with hands on the waist starting from a bipedal position. B. A quick downward counter movement is made. C. Vertical jump as high as possible while keeping the leg extended. D. Finally landing in a controlled manner. E. Symmetry index formula.

(Fig. 3A), followed by a quick downward counter movement (Fig. 3B), a maximum vertical jump while keeping the jumping leg extended (Fig. 3C), and a controlled landing (Fig. 3D). The difference in maximum jump height between legs, based on three attempts, is assessed using the symmetry index (Fig. 3E). A symmetry index >90 % is required to pass the test.

Isokinetic: The muscle strength of the quadriceps and hamstrings was assessed using an isokinetic dynamometer. Patients warmed up for 5 min on a stationary bike at intensity level 5 and 80 rpm.

The participants were seated with an 85° backrest angle and a seat adjusted to thigh length. They performed 4 submaximal repetitions with a 30-s rest before test repetitions, starting with the non-operated leg, followed by the operated leg. Each leg performed 4 maximum concentric isokinetic contractions from 90° of knee flexion to 0° of extension at 60°/s and then at 180°/s. A one-min rest was taken between legs.

The hamstring-to-quadriceps ratio was calculated by dividing the peak torque of the hamstrings at 60°/s by the peak torque of the quadriceps at 60°/s and multiplying by 100. The test is considered passed if the muscle imbalance between legs for both extensors and flexors is <10 %, and the hamstring-to-quadriceps ratio is ±5 % of the ideal 66 % ratio [19–22].

Triple hop test: The patient, with the tip of their foot behind the mark and with arms always at the waist, must perform three consecutive hops on the same foot aiming for the maximum horizontal distance (see Fig. 4). The test is performed three times per leg, and the best result is considered. The distance is measured, considering the quality of execution and symmetry (>90 %) [23].

Functional movement screen (FMS): It analyzes functional movement patterns to detect limitations or asymmetries that could predispose to injuries. It is 7 tests (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up, and rotary stability). Each test is scored on a scale from 0 to 3 (3: performs pattern correctly, 2: performs pattern with compensation, 1: does not perform pattern, 0: experiences pain). The maximum score is 21 and a score of 14 or higher is considered good [24].

The association between re-rupture rate and RTS test failure was analyzed as the main outcome. The associations between the re-rupture rate and demographic, anthropometric, graft type and time between surgery and test were considered.

Categorical variables were analyzed using Pearson's chi-squared test or Fisher's exact test as appropriate. After verifying the normality of the

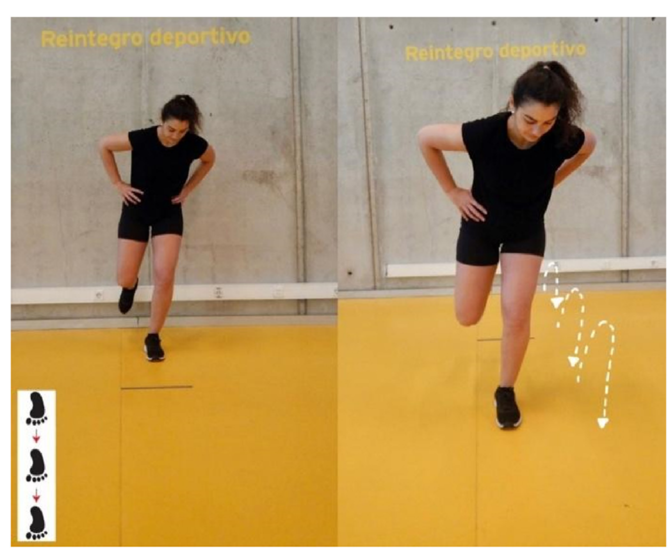


Fig. 4. Initial and final position after performing three consecutives jumps during the triple hop test. The best result obtained is recorded.

distribution with the Shapiro–Wilk test, quantitative variables were analyzed with Student's *t* test or the Mann–Whitney U test. Bivariate logistic regressions were performed to estimate effect sizes. Power analysis was conducted to ensure the representativeness of the results. Statistical analyses expressed with a 95 % confidence interval in STATA v. 18.5.

RESULTS

A total of 109 patients underwent ACLR and RTS testing between June 2018 and May 2023. All patients were contacted between July and September 2024 for a review. At follow-up, 95 patients were available, giving a follow-up rate of 87 % at a mean follow-up time of 24 months after surgery (standard deviation [SD]: 10.29, range: 12–69 months). Most patients were men (71.6 %), with a median age of 23 years (interquartile range [IQR]: 2 0–31) and median BMI of 24.2 (IQR: 22.6–26.4).

Regarding the sports practiced by patients before the injury, 43 % played soccer; 10.5 % practiced volleyball or basketball; 24.5 % played racket sports, and 7 % participated in skiing. Out of all the patients, only two were elite athletes. The choice of graft was mainly between the surgeon and the patient's own characteristics and sports activities. Sixty cases involved ST-G grafts (65.3 %), 24 PT grafts (25.3 %), and 9 peroneus longus allografts (9.5 %). All cases were primary ACLR.

The RTS test was performed at a median of 330 days after surgery (IQR: 259–411). Overall, 23 patients (24.21 %) passed the RTS test; 72 patients (75.78 %) failed the RTS tests. Thirteen graft re-ruptures were reported during follow-up, giving an overall re-rupture rate of 13.68 % (see Fig. 5).

Regarding patients with a re-rupture (see Table 1), 69.2 % were men, the median age was 21 (IQR: 21–25), and the median BMI was 25.4 (IQR: 24.1–26.3).

All patients with re-rupture had previously failed the RTS test (patients with re-rupture: RTS tests passed: 0 % vs. RTS tests failed: 100 %; p = 0.03) compared with patients without re-rupture (patients without re-rupture: Pass RTS tests: 25 % vs. 6 % vs. Fail RTS tests: 74.4 %) (p = 0.03), with those with re-rupture 2.2 times more likely to fail the test than those without re-rupture (OR: 2.2 [95 % CI: −0.6–5.1]). Although the magnitude of the association was not significant, in the *post hoc* analysis, the statistical power was found to be 0.70.

DISCUSSION

This study evaluates ACLR outcomes and re-ruptures following rehabilitation and RTS tests, aiming to determine if these tests help prevent second ACL injuries in the medium term.

The first finding was that no re-ruptures were reported up to the follow-up point in patients who passed the RTS tests. Second ACL injury occurred in the group of patients who failed these tests. Therefore, the results suggest that passing the RTS tests after an ACLR is associated with a lower rate of re-ruptures in the medium term. However, the statistical power of this study was 70 %, which limits the generalization of the results. A larger sample size and longer follow-up would be needed to confirm these findings. This finding aligns with previous studies suggesting that functional tests are effective predictors of injury risk [25]. Studies comparing groups of patients who meet test battery criteria before sports discharge versus those who do not have demonstrated up to a fourfold increase in the risk of graft rupture for the latter group [26]. Our data align with a prospective study of 106 pivoting sport athletes, assessing knee function via knee injury and osteoarthritis outcome score, global rating scale, quadriceps strength, and jump test symmetry. Among patients who did not pass the tests, 38.2 % suffered new injuries compared with only 5.6 % of those who passed. Importantly, greater quadriceps strength symmetry prior to returning to activity significantly reduced the recurrence rate of knee injuries [28].

Similarly, a 2016 study evaluated 158 professional athletes post ACLR, who returned to sports after completing a battery of tests. Among the participants, 16.5 % experienced ACL graft ruptures, with a mean of 105 days post RTS. Two factors were strongly associated with an

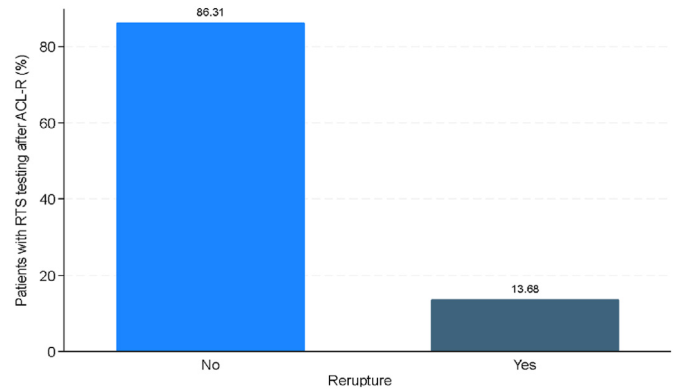


Fig. 5. The chart of patients represents the group that did not have re-ruptures (86.31 %) versus the group that did have re-ruptures (13.68 %).

increased risk of ACL graft rupture: failure to meet the six discharge criteria before returning to team training and a decreased hamstring/quadriceps ratio in the involved leg at 60°/s [26].

Recent meta-analyses on RTS tests indicated that passing the RTS tests reduces the rate of re-rupture, although this effect is not statistically significant [5,27]. Our study found a not statistically significant difference between passing the RTS tests and the risk of ACL re-rupture. These results indicate the need for further research to prospectively examine RTS decisions based on objective tests.

The second finding of our study was that, in patients who suffered re-ruptures, the average number of days after surgery until the RTS tests was performed was 357 days. Second ACL injuries typically occur within the first 6 months to 2 years after returning to sport [28,29]. Research indicates that deficits in strength, landing mechanics, proprioception, psychological readiness, and perceived knee function can persist for up to 2 years after ACL reconstruction (ACLR) and may continue for as long as 20 years post-surgery. The time between surgery and return-to-sport (RTS) appears to be a critical factor in reducing the risk of reinjury as suggested by two studies [28,30]. However, there is no consensus on the optimal timing for RTS. Grindem et al. [28] found that delaying RTS by one month (up to 9 months) reduces the risk of new knee injuries by 51 %.

The third finding of our study was that 18.18 % (10 of 55 patients) of patients aged 25 years or younger suffered a re-rupture. This concurs with the findings by Wiggins et al. that determined the incidence of a second ACL injury is 23 % in individuals under 25 years old [31]. In patients under 20 years, the incidence of a second ACL injury is about 1 in

Table 1
Baseline characteristics of patients with ACLR according to the presence of re-rupture.

	Re-rupture (n = 13; 13.7 %)	Without re-rupture (n = 82; 86.3 %)	p value
Demographic and anthropometric characteristics			
Women	4 (30.8)	23 (28.1)	0,84
Median age (IQR)	21 (21–25)	23.5 (19–32)	0,69
Median BMI (IQR)	25.4 (24.1)	24.1 (22.3–26.4)	0,27
Surgical and rehabilitation characteristics			
Type allograft			0,94
- Allograft	1 (7.7)	8 (9.8)	
- PT	3 (23.1)	21 (25.6)	
- ST-G	9 (69.2)	53 (64.6)	
Days Surgery-RTS test			0,10
- Median days (IQR)	342 (269–419)	297 (256–317)	
RTS test			0.03*
Pass	0 (0)	21 (25.6)	
Fail	13 (100)	61 (74.4)	

(*) denotes statistical significance (p < 0.05).
Abbreviations: BMI = body mass index; IQR = interquartile range; PT = patellar tendon; STG = semitendinosus and gracilis; RTS = return-to-sport.

3 patients, with similar rates for both ACL graft re-rupture and injuries to the contralateral native ACL [32].

Lastly, we found that of the group of patients who passed the RTS tests (23/95), 91 % returned to sport (21/23 patients). In contrast, only 45 % of the patients (27/59 patients) who failed the RTS tests and did not suffer a second ACL injury returned to sport. This raises the question of whether RTS tests, in addition to playing a role in reducing the risk of re-rupture, could correlate with effectively preparing the patient to RTS. This concept has not been previously addressed in the literature. This idea is highly relevant as, if proven, it would provide significant evidence in favor of RTS tests as a tool for preventing re-ruptures. Passing or failing an RTS test appears to classify individuals into a higher or lower risk group for re-ruptures, but it is difficult to determine whether this is cause or effect. Although there are no definitive answers regarding the reasons behind the high failure rate in RTS tests, several factors could explain this situation. First, one of the main issues is the lack of adherence to treatment. Since rehabilitation after an injury is a lengthy process, many patients fail to follow the plan consistently, leading to interruptions in their therapy. In fact, it has been observed that only 30 % of patients complete a plyometric program following ACLR [15].

An interesting aspect to highlight, which was not considered in our study, is that persistent psychological deficits have been reported to reduce an individual's ability to successfully return to their pre-injury competitive level [33]. Qualitative studies suggest that, following ACLR, the primary concern for patients is the fear of reinjury [34]. It is recommended to include psychological assessments as essential components of a biopsychosocial approach to RTS decision-making.

One limitation of this study was the lack of *a priori* sample size calculation for the implementation of an RTS test battery, which requires validation in a study with a larger sample size. Further research is also needed to determine whether the test battery should be sport specific. Another limitation was the absence of data on the level of sport participation and competitiveness upon return. We note that returning to sport does not necessarily equate to returning to competition.

CONCLUSION

Patients with re-ruptures were more likely to be from the group that failed the RTS tests (pass: 0 % vs. fail: 18,1 %; $p = 0.03$), with a statistical power of 0.70. Passing the RTS tests appears to be a protective factor against re-ruptures, according to the results obtained in this study. These tests allow for an objective assessment of the patient's functional capacity before returning to competition, reducing the risk of new injuries. However, more research is needed to confirm these findings and optimize rehabilitation protocols.

Author contributions

All the authors contributed to the design, analyses, and reporting for this manuscript. Both authors read and approved the final submitted manuscript.

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Declaration of competing interest

We have no conflicts of interest relevant to the content of this review.

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