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Original article

A composite test 6 months after an Anterior Cruciate Ligament Reconstruction cannot predict graft failure: A prospective analysis of 498 patients with a mean 5-year follow-up from MERIScience cohort

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ABSTRACT

Purpose: The aim of this study was to investigate a correlation between various components of the composite test and graft failure at mid-term follow up after an Anterior Cruciate Ligament (ACL) reconstruction.
Methods: This single-center study includes patients who underwent primary ACL reconstruction surgery and received an identical 6-months postoperative composite evaluation at the institution (isokinetic tests, jump tests and ACL - Return to Sport and Injury (RSI) psychological evaluation) between 2017 and 2020. To be eligible, a minimum follow-up period of 3 years was necessary, with evaluations conducted at the longest follow-up interval to assess the rates of graft failure.
Results: Overall, 498 patients were analyzed, with a mean follow-up of 4.9 ± 1.23 years. The overall ACL graft failure rate was 5.4% (27 patients). The mean ACL-RSI at 6 months was 64.9 ± 19.4% for patients without graft failure, compared to 60.8 ± 16.3% for patients who experienced graft failure. No statistically significant difference was observed between the two groups ($p > 0.05$). There was no statistically significant between-group difference for any of the other composite test items ($p > 0.05$).
Conclusion: The composite test performed 6 months after an ACL reconstruction was not predictive of the risk of graft failure. Although it can be used to guide recovery and re-athletization, other predictive factors for the risk of graft failure, or a modification of the test items, should be considered for post-operative follow-up and evaluation after ACL reconstruction. Doctors should strive to readjust patients' expectations of these composite tests, which appear to be useful only for assessing a return to sport.
Level of evidence: IV; Case-control study.

1. Introduction

Anterior Cruciate Ligament (ACL) reconstruction is a very common procedure, with 100,000–175,000 cases reported every year in the United States, out of a total of 200,000 ACL injuries [1,2].

The main advantage of this reconstruction is that it provides reproducible and reliable functional results [3,4]. On average, 81% of operated patients resume sporting activities, 65% regain their pre-injury level and 55% return to a competitive level [5]. However, postoperative complications can occur, such as stiffness, knee locking, and contralateral or iterative rupture.

ACL graft failure remains the main complication to date [6], with a rate ranging from 6% to 28.3% according to different studies [6,7].

As well as stabilizing the knee, one of the main aims of ACL reconstruction is to enable a return to sport (RTS) for patients. Recent studies on this subject have identified some variables associated with RTS after ACL reconstruction: assessment of strength, workload and muscle power in the quadriceps and hamstrings, jump tests as well as psychological

Abbreviations: ACL, Anterior Cruciate Ligament; ACL-RSI, Anterior Cruciate Ligament – Return to Sport after Injury; ALL, anterolateral ligament; DJT, Drop Jump Test; ST4, 4-strand semitendinosus graft; IKDC, the International Knee Documentation Committee; MRI, Magnetic Resonance Imaging; RTS, return to sport; SHT, Single Hop Test; SKV, Self Knee Value; Side HT, Side Hop Test; THD, Triple Hop for Distance.

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factors [5,8,9]. To study the ability to resume sporting activities and the various influencing factors, study groups [10–12] have established composite tests at 6 months [13,14] to assess patients' ability to return to sport after ACL surgery. The use of composite tests, enabling a multimodal evaluation, appears to be suitable for assessing return to sport, which depends on multiple factors. It is well-established that RTS is dependent upon multiple factors and composite tests should be multimodal, including objective and subjective physical and psychological test characteristics. However, these composite tests were developed to predict return to sport, and patients and some surgeons believe them to be predictive of graft failure. The predictivity of graft failure or contralateral rupture has already been assessed in several studies [15,16], but none of them used these tests to assess these complications.

The aim of this study was to assess whether a composite evaluation test combining jumping tests, isokinetic tests and a psychological evaluation 6 months after ACL reconstruction could predict graft failure at medium-term follow-up. Our hypothesis was that there were elements of the composite tests that could predict these complications in the medium and long term.

2. Materials and methods

2.1. Study design

This study was approval by the Vivalto-Santé Institutional Review Board (IRB: "CERC-VS-2024-10-1").

All patients who underwent ACL reconstruction at the center and who had a composite test 6 months post-operatively between 2017 and 2019 were prospectively followed up to the present day. All patients who underwent primary ACL reconstruction using the semitendinosus, for a four-strand semitendinosus graft (ST4), with a complete 6-month composite clinical and psychological evaluation, and minimum clinical and functional follow-up of at least 3 years, were eligible. Exclusion criteria included: multiligamentous injuries, use of grafts other than four-strand semitendinosus (patellar tendon, semitendinosus-gracilis, tensor fascia lata), and absence of a complete 6-month composite evaluation.

2.2. Study population and definition

All patients were reviewed, each with a minimum follow-up duration of 3 years. Use of intraoperative meniscal surgery or anterolateral ligament (ALL) procedure (ALL reconstruction or lateral extra-articular tenodesis) was recorded. Before surgery, all patients had undergone a full clinical examination of the knee, including frontal/profile X-rays and Magnetic Resonance Imaging (MRI).

All patients had a follow-up visit (including a composite test) at 1, 3, and 6 months post-operation.

All patients followed a standardized rehabilitation protocol post-operatively. The first phase (0–4 weeks) focused on pain control, achieving full extension, and quadriceps activation. Between 6 and 12 weeks, progression included strength recovery and initiation of proprioceptive training. From 3 to 6 months, patients were cleared for dynamic activities including jogging and plyometric drills. Return to pivot sports was generally allowed between 8 to 12 months based on clinical and functional recovery. Return to sport decisions were individualized based on composite test performance at 6 months.

Patients were then followed up at 1 year and at the final follow-up. All patients for whom demographic, clinical or radiological data were missing were excluded from the statistical analysis.

2.3. Surgical technique

All ACL reconstruction surgeries were performed using the same four-strand semitendinosus graft (ST4) technique by 4 different surgeons in the same hospital. Surgery [17] was performed under arthroscopy. First, the semitendinosus was harvested and folded on itself into 4 strands with the positioning of two adjustable buttons (SBM, Lourdes, France) at both ends of the graft (Pullup© and PullUp XL©). The graft was calibrated to determine its diameter.

For ACL reconstruction the femoral tunnel was created using the in-out technique, involving the formation of a blind tunnel matching the graft's diameter. It was drilled just posterior and proximal to the lateral epicondyle. Another was drilled in the tibia just posterior to the Gerdy tubercle, 7 mm below the joint-line. The tibial tunnel was then prepared and drilled to match the diameter of the full tunnel graft. ALL reconstruction using the gracilis could also be combined with ACL reconstruction on the basis of criteria of the ALL study group [18]: pivot shift $\geq$ grade 2, hyperlaxity (knee recurvatum $>10^\circ$), top-level athlete (competing at regional or national level), second fracture (bony avulsion of the tibial ALL insertion on radiograph). The gracilis was folded on itself with an ACL TighRope® (Arthrex, Naples, Florida) at one end and a suture at the other end.

For ALL graft; on the lateral aspect of the knee, 1 cm posterior and proximal to the lateral condyle of the femur, a femoral tunnel was made with a diameter of 5 mm. A tunnel was made in the tibia from lateral to medial, just below the lateral tibial plateau and exiting into the graft harvesting incision. The ALL graft was then fixed in the femur with a resorbable interference screw (Arthrex, Naples, Florida) and then fixed in the tibia with the ACL TighRope® (Arthrex, Naples, Florida), tightened in extension and neutral rotation after ACL tensioning.

The decision to perform ALL reconstruction was made based on the presence of additional risk factors, including age under 20 years, chronic instability exceeding 6 months, or participation in pivot-heavy sports. Thus, ALL was not systematic in all grade II pivot shift cases but guided by a combination of clinical criteria and patient profile.

During the surgery, meniscal sutures or meniscectomy were performed depending on the evaluation of the menisci and the type of lesions found.

2.4. Outcomes assessment

A first follow-up consultation at 1-month post-operation was conducted to check that the skin had healed, and that full extension and 90° flexion had been achieved. A consultation at 3 months post-operation was performed to confirm the completion of the first rehabilitation phase and commence the re-athletization phase, including the resumption of jumping and running activities. The 6-month post-operation consultation was accompanied by a composite test.

The composite test [13,14] included:

- Isokinetic analysis: measuring the strength, workload and muscle power of the quadriceps and hamstrings using a motorized computerized dynamometer (Cybex©) with:
  - For the quadriceps: an analysis at slow speed (60°/s) and fast speed (240°/s) of the concentric strength of the extensors
  - For the hamstrings: an analysis at slow speed (60°/s) and fast speed (240°/s) of the concentric force and an analysis of the eccentric force of the flexors
- Jump tests [13,19]:
  - Single Hop Distance (SHD): to measure the distance achieved when jumping on one foot without a run-up, with a stabilized landing and maintained position.
  - Triple Hop for Distance (THD): to measure the distance achieved during a triple hop on one foot without a run-up and assess unipodal propulsion, deceleration, and stabilization.
  - Side Hop Test (Side HT): an endurance test involving performing as many side hops as possible within a 30-s duration.
  - Drop Jump Test (DJT): A jump test involving the observation and assessment of dynamic knee valgus upon landing from a height of approximately 35 cm, followed by a subsequent jump.

- Psychological assessment using the Anterior Cruciate Ligament – Return to Sport after Injury (ACL-RSI) * French Version [8]. The ACL-RSI scale was developed and validated in 2008 by Webster et al. [20] to identify individuals at psychological risk of not returning to sport. This 12-item questionnaire assesses the psychological impact of RTS on individuals who have undergone ACL surgery by evaluating their emotions, their confidence in their performance and their apprehension of risk.

All the results of this composite test were used to adapt patients' reathletization and to assess RTS.

The patients were then followed up at 1-year post-operation and at the final follow-up, during which clinical data were collected. At the final follow-up visit, conducted by a comprehensive knee fellow (T.M-D) who was not involved in the surgical management, patients systematically completed a questionnaire. This questionnaire assessed graft failure, contralateral rupture, return to surgery, return to sport, and the level compared to that pre-operation. Evaluation at the final follow-up also included:

- The International Knee Documentation Committee (IKDC) subjective knee evaluation form [21].
- The Tegner Activity Scale: A standardized tool used to evaluate activities of daily living, leisure activities and competitive sports [22].
- The Self Knee Value (SKV), corresponding to a single question: "How much do you think your knee is worth on the day of the examination, compared with a normal knee in percentage terms?", allowing patients to self-assess their knee function [23].
- The ACL-RSI

2.5. Statistical analysis

Qualitative variables were compared using a Chi-square test or Fisher's exact test, while quantitative variables were compared using a Student *t*-test.

Linear regression was used to determine the correlation between measures. The strength of the correlation was assessed using Spearman's rho (r) correlation coefficient, which was interpreted as follows: very weak if r = 0–0.19, weak if 0.20–0.39, moderate if 0.40–0.59, strong if 0.60–0.79, and very strong if 0.80–1.00. Statistical significance was set at $p < 0.05$.

All analyses were performed using IBM SPSS (Statistical Product and Service Solutions) software for Windows (version 27).

3. Results

3.1. Study population

Over the analysis period, 504 patients were included and 498 patients were analyzed, with a mean follow-up of 4.9 ± 1.23 years (Fig. 1). 6 patients were excluded: 3 due to incomplete composite test data at 6 months, and 3 due to missing long-term clinical follow-up. No patients were lost to follow-up. The demographic characteristics of the study population are summarized in Table 1.

Table 1
Demographic, surgery and injury-related outcome data of patients.

	No (%) or Mean ± SD
Sex	
Male	306 (61.5)
Female	182 (36.5)
Missing	10 (2.0)
BMI	24.1 (2.2)
Time post surgery (years), SD	4.9 ± 1.23
Age at surgery (years)	27.6 ± 10.9
Operated knee	
Right	267 (53.6)
Left	231 (46.4)
ALL (Anterolateral ligament) reconstruction	153 (30.7)
Tegner score	
Preinjury score	7.1 ± 0.9
Current score	6 ± 2.1
ACL-RSI score (%)	
At 6 months	64.7 ± 38.6
At last follow-up	68.8 ± 25.7 (*p* < *0.001*)
IKDC score (%)	
Current score	77 ± 11.9
SKV score	
Current score	86.8% ± 14.3
Return to sport	
Return to sport at last follow up	452 (91.1)
Same sport before surgery	359 (72.1)
Return to same or higher activity level	294 (59.2)
Associated injury	
Medial Meniscus	158 (31.7)
Lateral Meniscus	143 (28.7)
ACL graft failure	27 (5.4)
Contralateral ACL injury	53 (10.6)
Cartilage treatment	NA

ACL, Anterior Cruciate Ligament; IKDC, International Knee Documentation Committee; ACL-RSI, ACL - Return to Sport and Injury; SKV, Self Knee Value.

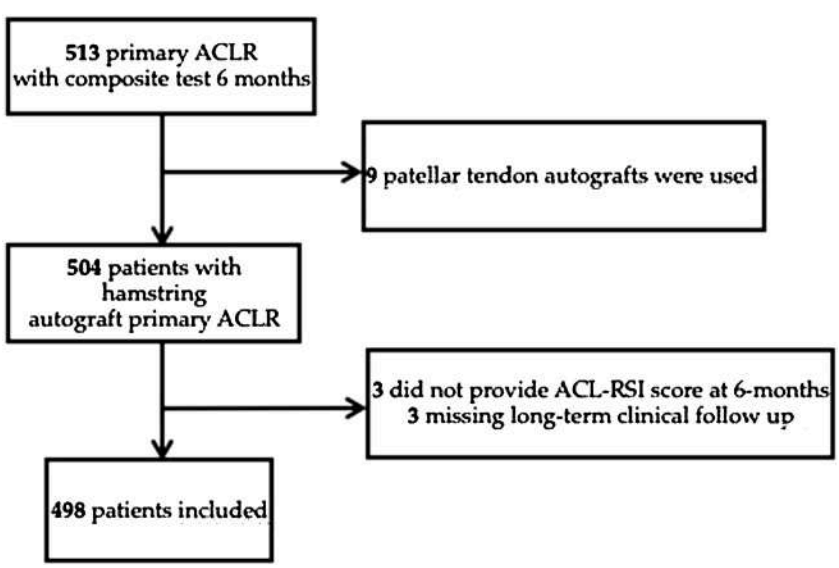

Fig. 1. Flow chart.

The pre-operative Tegner score was 7.1 ± 0.9, which corresponds to a population of competitive sportsmen and women (tennis, tracks and field, motocross, handball, basketball) and recreational sportsmen and women (football, squash, cross-country running).

3.2. *Final follow-up*

At the final follow-up, the Tegner score was 6 ± 2.1. Overall, 91.1% of patients (n = 452) returned to sport, and 72.1% of patients (n = 359) returned to the same sport as before surgery. Of these patients, 59.2% (294 patients) returned to sport at a higher or equal level (10.4% at a higher level, 48.8% at the same level).

Over the analysis period, the overall ACL graft failure rate was 5.4% (27 patients).

Patients with graft failures are comparable to patients without in terms of BMI, age at surgery and preoperative tegner ($p > 0.005$) (Table 2).

Regarding ACL graft failures, isokinetic tests and jump tests showed no statistically significant difference between groups with and without ACL graft failure ($p > 0.05$). Mean ACL-RSI at 6 months was 64.9% ± 19.4 in patients without ACL graft failure, and 60.8% ± 16.3 in patients with graft failure; without statistically significant between-group difference ($p > 0.284$) (Table 3).

There was no significant between-group difference in ACL-RSI at 6 months, with contralateral rupture (64.5%) or without contralateral rupture (64.7%) ($p = 0.9$) (Table 4).

ALL procedure was performed on 153 patients (30.7%). Tegner score was 6.4 ± 2.18 in patients with ALL procedure and 5.8 ± 1.98 in those without ($p < 0.02$). Patients who underwent ALL procedure displayed better isokinetic test results for quadriceps and hamstring concentric contraction at 60°/s on both legs ($p < 0.05$), as well as quadriceps concentric contraction at 240°/s ($p < 0.05$) (Table 5).

Among the 153 patients who underwent an ALL reconstruction, 42 had a grade II pivot shift.

Regarding jump tests, only the SJT showed a statistically significant result ($p < 0.05$) on the operated (44.9 ± 15.5 with plasty vs 39.55 ± 17.5 without) and healthy side (52.3 ± 11.88 vs 46.2 ± 14.34).

Among patients with graft failure, the presence of a lateral tenodesis (ALL) had no significant impact compared to those without graft failure ($p > 0.005$) (Table 6).

4. Discussion

The main finding of this study is the absence of correlation between the different elements of a composite test at 6 months and the risk of graft failure in the medium term.

The result was consistent for each element, and a grouping score did not reveal any difference. The mean follow-up period of this study was 4.9 years, which exceeds the 2-year follow-up period usually described in the literature as sufficient for analyzing graft failure rates, as most failures occur within the first 2 years [24,25]. This study includes patients who had undergone surgery using the same four-strand semitendinosus graft surgical technique, and the clinical and functional outcomes showed no differences compared to other ACL reconstruction techniques [26].

The composite test was performed at 6 months post-operatively during the reathletization period. In the literature, several studies have examined rehabilitation within the first 6 months after ACL reconstruction, and have developed composite tests such as the one used by our team [9,14,19], with the main objective of assessing readiness to return to sport. These tests typically include jump tests that analyze differences in muscle strength (and vertical rebound) between healthy individuals and those who have undergone ACL reconstruction [27,28]. While these composite tests are designed to evaluate the ability to return to sport, we did not find any studies examining a relationship between the test results and clinical outcome such as graft failure or contralateral ACL injury.

Isokinetic tests have also been studied [29,30]. Their reproducibility is variable in surgical patients due to the need for good motor skills and motor control [31].

Moreover, recent evidence suggests that intrinsic muscle composition does not significantly influence postoperative muscle strength recovery after hamstring tendon ACL reconstruction, reinforcing the idea that functional rehabilitation may outweigh anatomical factors [32].

Additionally, Nagai et al. demonstrated a difference in Limb Symmetry Index results between jump tests and isokinetic tests for the same patient [28], indicating these two tests are complementary. Some clinicians have added a secondary cognitive task to the exercises commonly performed during the composite test to assess its influence on both biomechanics and performance [33].

This test is complemented by the assessment of apprehension using the ACL-RSI score [20]. A study by Müller et al. [9] showed a sensitivity of 0.97 and a specificity of 0.63 for determining resumption of sport (cut-off at 51.3 points). Several studies have established critical values ranging between 51.3–65 points out of 100 for RTS [6,34,35], but no cut-off value has been set. Consequently, each team defines a "cut-off" at 6 months, based on their patients' apprehension about future activities.

Among the parameters studied, some appear to be more predictive of RTS than others, notably Single Hop Distance and ACL-RSI [9,36]. These two elements seem to be protective factors for RTS. In this study, we confirmed this point for ACL-RSI.

The Panther Symposium ACL Injury Return to Sport Consensus Group highlighted in 2020 [37] the need for further research to determine the optimal series of tests to consider for an ideal RTS.

This study found a mean ACL-RSI score at 6 months of 64.7% ± 38.6, which aligns with the literature [25,38]. At the final follow-up, with a mean follow-up of almost 4 years, the score had increased by 4 points to 68.8% ± 25.7. This increase is consistent with the data described by Sadeqi et al. in 2018 [25] for a shorter follow-up of 2 years. Although the progression of ACL-RSI was only 4 points at the final follow-up, the difference was statistically significant. There was a correlation between values at 6 months and 5 years, indicating that patients with a low ACL-RSI score at 6 months tended to have a low ACL-RSI score at 5 years. It is therefore necessary to improve the ACL-RSI score post-operatively by optimising rehabilitation and the return to sport.

The change in Tegner score between the preoperative period (7 ± 0.9) and postoperative period (6 ± 2.1) was consistent with the literature [39,40]. Using the Tegner scale, our initial population was categorized as sportsmen and sportswomen, including competitive athletes (tennis, track and fields, motocross, handball, basketball) and leisure athletes (football, squash, cross-country running) [22,41].

ACL graft failure rate in this study is 5.4%, which aligns with the literature that reports rates between 2.8% and 6%, depending on the articles [6,42,43]. The contralateral rupture rate is 10.6%, which is consistent with the literature which shows rates ranging from 5% to 24 [3,44].

There was no statistically significant difference in ACL-RSI scores between patients with graft failure and those without. This result is consistent with the study carried out by McPherson et al., which also found no significant difference, though their findings were obtained

Table 2
Comparison between patient groups in graft failure.

	Graft failure?	N	Mean Score	Standard deviation	Sig. (two-sided) (p value)
BMI	no	462	24	3.6	0.1
	yes	24	23	3.4	
Age at surgery (years)	no	471	27.6	11	0.13
	yes	27	24.6	10	
Tegner preinjury	no	471	6	2.1	0.17
	yes	27	5.4	2	

Table 3
Isokinetic tests and jump tests results for new ACL rupture.

Muscles exercises	ACL graft failure (New ACL rupture)	N	Mean scores	Standard deviation	Sig. (two-sided) (p value)	95% confidence interval	
						Lower	Upper
Healthy Quadriceps 60° (Nm)	No	478	166.7	46.45	0.324	−9	27.1
	Yes	27	157.6	50.1			
Operated Quadriceps 60° (Nm)	No	479	132.05	46.2	0.592	−13	23
	Yes	27	127.1	45.9			
Deficiency Quadriceps 60°	No	479	0.00	0.000		−0.05	0.08
	Yes	27					
Healthy Quadriceps 240° (Nm)	No	479	1239.3	414.6	0.468	−101	221.4
	Yes	27	1179.8	416.15			
Operated Quadriceps 240° (Nm)	No	479	1087.3	775.9	0.639	−226.1	368.7
	Yes	27	1016.6	367.7			
Deficiency Quadriceps 240°	No	479	0.15	0.15	0.695	−0.05	0.07
	Yes	27	0.1	0.1			
Healthy Hamstrings 60° (Nm)	No	479	101.1	115.03	0.467	−27 .6	60.2
	Yes	27	84.9	24.5			
Operated Hamstrings 60° (Nm)	No	479	88.7	98.8	0.498	−24.5	50.1
	Yes	27	75.8	23.65			
Deficiency Hamstrings 60°	No	479	0.1	0.15	0.709	−0.05	0.06
	Yes	27	0.1	0.1			
Healthy Hamstrings 240° (Nm)	No	479	780.1	366.1	0.226	−53.3	227.5
	Yes	27	693.4	263.4			
Operated Hamstrings 240° (Nm)	No	479	700.85	301.3	0.377	−62.6	167.6
	Yes	27	648.8	229.7			
Deficiency Hamstrings 240°	No	479	0.1	0.2	0.864	−0.06	0.08
	Yes	27	0.1	0.2			
Healthy. Hamstrings 30° (Nm)	No	472	141.4	50.9	0.205	−7.1	32.9
	Yes	26	128.5	41.5			
Operated Hamstrings 30° (Nm)	No	472	119.5	49.1	0.295	−8.7	29
	Yes	27	109.4	36.6			
Deficiency Hamstrings 30°	No		0.00	0.000[b]		−0.06	0.08
	Yes		0.00	0.000[b]			
Healthy Hamstrings angle peak (Nm)	No	358	13.6	10.7	0.734	−3.9	5.6
	Yes	21	12.8	9.2			
Operated Hamstrings angle peak (Nm)	No	356	13.04	10.6	0.167	−1.3	7.9
	Yes	21	9.8	5.4			
Health Ratio 60°	No	0[a]					
	Yes	0[a]					
Healthy Ratio 240°	No	478	0.7	0.2	0.986	−0.09	0.09
	Yes	27	0.7	0.3			
Healthy Ratio mixt	No	10	1.5	0.5			
	Yes	0[a]					
Operated Ratio 60°	No	1	1.00			−0.05	0.1
	Yes	0[a]					
Operated Ratio 240°	No	3	1.00	0.000		−0.1	0.2
	Yes	0[a]					
Operated Ratio mixt	No	8	1.75	0.7		−0.2	0.4
	Yes	0[a]					
Healthy Single Hop test (cm)	No	453	121.2	56.2	0.483	−15	29.8
	Yes	26	113.15	63.2			
Operated Single Hop test (cm)	No	450	106.6	54.8	0.890	−24.4	20.1
	Yes	25	108.2	62.03			
Deficiency Single Hop test	No	134	0.0	0.000[b]		−0.01	0.1
	Yes	10	0.0	0.000[b]			
Healthy Triple Hop Test (cm)	No	445	352.7	166.1	0.767	−58.4	74.4
	Yes	26	342.7	191.9			
Operated Triple Hop Test (cm)	No	441	317.8	163.3	0.832	−74.4	56.3
	Yes	26	324.9	191.3			
Deficiency Triple Hop Test (cm)	No	108	0.00	0.000[b]		−0.02	0.08
	Yes	7	0.00	0.000[b]			

(*continued on next page*)

Table 3 (*continued*)

Muscles exercises	ACL graft failure (New ACL rupture)	N	Mean scores	Standard deviation	Sig. (two-sided) (p value)	95% confidence interval	
						Lower	Upper
Healthy Side Hop Test (cm)	No	428	48.07	13.8	0.491	−7.7	3.6
	Yes	25	50.04	15.3			
Operated Side Hop Test (cm)	No	424	41.2	17.05	0.440	−9.7	4.1
	Yes	25	43.9	16.9			
Deficiency Side Hop Test	No	38	0.05	0.2	0.820	−0.4	0.5
	Yes	1	0.00				
Healthy Drop Jump Test (cm)	No	459	0.25	0.4	0.559	−0.2	0.1
	Yes	27	0.3	0.5			
Operated Drop Jump Test (cm)	No	459	0.3	0.5	0.658	−0.2	0.1
	Yes	27	0.4	0.5			
Healthy Unipodal Squat (cm)	No	465	0.3	0.5	0.227	−0.3	0.1
	Yes	26	0.4	0.5			
Operated Unipodal Squat (cm)	No	461	0.45	0.5	0.362	−0.3	0.1
	Yes	26	0.5	0.5			

ACL. Anterior cruciate ligament; Healthy. Healthy leg; Operated. Operated leg.
[a] t cannot be calculated because the standard deviation is zero. (Student *t*-test).
[b] t cannot be calculated because the standard deviations of both groups are zero. (Student *t*-test).

Table 4
Between-group analysis of ACL-RSI scores by post-surgical complication.

	N	Mean ACL-RSI at 6 months	Standard Deviation	p-Value
New ACL rupture				
No	471	64.95	19.449	p > 0.2
Yes	27	60.85	16.313	
Contralateral ACL injury				
No	445	64.75	19.364	p = 0.9
Yes	53	64.53	18.939	

from patients under 20 years old [45]. On the other hand, Zarzycki et al. found a significant difference in a population of top-level female athletes, where those with graft failure within 2 years had higher ACL-RSI scores [46], suggesting potential overconfidence.

We were therefore unable to confirm whether ACL-RSI was predictive of contralateral ACL injury. Furthermore, none of the items in the composite test, including the jump test and isokinetic tests, are predictive of these items.

The only statistically significant findings were observed in quadriceps concentric contraction at 60°/s and 240°/s in both the operated and healthy knees, for hamstring concentric contraction at 60°/s for both knees, and hamstring concentric contraction at 240°/s deficit; patients with ALL procedure had consistently better results. Among jump tests conducted, only the side hop test yielded statistically significant results for both the operated and healthy sides, with better results in patients with ALL procedure. No significant differences were observed in ACL-RSI score at either 6 months nor the final follow-up. These findings for isokinetic tests deviate from those reported in the literature [47,48], which indicated no discernible differences in isokinetic tests. Regarding jump tests, our study only found statistically significant results for the side hop test, demonstrating better results for both operated and healthy knees following ACL reconstruction. In contrast, existing literature tends to suggest either no significant differences for all jumps tests or potentially worse outcomes for patients undergoing ACL reconstruction [49].

In the literature, it has been observed that ACL-RSI scores and isokinetic performance can lead to superior laximetric and functional results at the final follow up are better for patients with ALL procedure than without [47,50,51]. However, the decision on whether to perform ALL procedure depends on the patient's level of sport.

The main strength of our study lies in its mean follow-up duration of 4.9 ± 1.23 years and the substantial number of included patients. Additionally, the uniformity of the surgical technique, along with a consistent follow-up procedure, combined with a standardized composite test, enhances the reliability of our findings. Patients with graft failures are comparable to patients without.

However, several limitations should be acknowledged. First, this was a single-center study, which may limit the generalizability of the results. Although four experienced surgeons performed the operations, slight inter-surgeon variability may have influenced outcomes. Second, despite standardized rehabilitation guidelines, individual adherence and quality of execution could not be objectively measured. The use of an identical rehabilitation protocol for each patient, regardless of their pre-operative sporting level and post-operative expectations during the initial phase, could have had an impact on the functional recovery and clinical results of the patients. Moreover, we did not perform a multivariate analysis to adjust for potential confounders such as age, chronicity, or type of associated procedures Furthermore, extrinsic factors specific to each patient, such as pregnancy or professional development, may have influenced the results at the final follow-up, with patients of different ages wishing to return to sport independently of clinical factors.

Although our study population did not differ statistically on demographic characteristics or activity level, we know that these factors and others like associated ligamentous injuries such as medial collateral ligament (MCL) damage may influence long-term outcomes. This is highlighted in recent registry-based studies [52], as well as adherence to the rehabilitation protocol, can have an impact on ACL-R failures.

5. Conclusion

In conclusion, the composite test can be used to guide recovery and reathletization for the RTS, but other evaluation elements predictive of the risk of graft failure, reoperation, or a modification of the test elements should be considered for post-operative monitoring and evaluation. The composite test needs to be made more composite, with analysis of strength, jumps, psychological assessment and analysis of the biomechanics of movement.

Table 5
Isokinetic tests and jump tests for ALL procedure.

Muscles exercises	ALL procedure	N	Mean scores	Standard deviation	Sig. (two-sided) (= p)
Healthy Quadriceps 60° (Nm)	No	345	162.6	45.1	**0.008**
	Yes	152	174.5	48.6	
Operated Quadriceps 60° (Nm)	No	345	128.3	45.6	**0.010**
	Yes	153	139.8	46.6	
Deficiency Quadriceps 60°	No	345	0.2	0.2	0.186
	Yes	153	0.2	0.2	
Healthy Quadriceps 240° (Nm)	No	345	1206.3	397.5	**0.013**
	Yes	153	1306	442.8	
Operated Quadriceps 240° (Nm)	No	345	1026.1	384.1	**0.011**
	Yes	153	1214.8	1245.3	
Deficiency Quadriceps 240°	No	345	0.2	0.2	0.819
	Yes	153	0.1	0.2	
Healthy Hamstrings 60° (Nm)	No	345	91.6	27.6	**0.010**
	Yes	153	119.9	198.5	
Operated Hamstrings 60° (Nm)	No	345	81.9	28.6	**0.028**
	Yes	153	102.6	169.1	
Deficiency Hamstrings 60°	No	345	0.1	0.2	0.068
	Yes	153	0.1	0.1	
Healthy Hamstrings 240° (Nm)	No	345	770.8	395.7	0.641
	Yes	153	787.2	268.9	
Operated Hamstrings 240° (Nm)	No	345	700.5	311.1	0.818
	Yes	153	693.8	257.3	
Deficiency Hamstrings 240°	No	345	0.1	0.2	**0.026**
	Yes	153	0.1	0.2	
Healthy. Hamstrings 30° (Nm)	No	338	138.2	51.5	0.097
	Yes	152	146.3	47.9	
Operated Hamstrings 30° (Nm)	No	338	117.7	49	0.379
	Yes	153	121.9	47.4	
Deficiency Hamstrings 30°	No	345	0.1	0.2	0.232
	Yes	153	0.2	0.2	
Healthy Hamstrings angle peak (Nm)	No	250	13.9	11.4	0.432
	Yes	122	13	9.2	
Operated Hamstrings angle peak (Nm)	No	249	13.2	10.6	0.434
	Yes	121	12.3	10.1	
Healthy Ratio 60°	No	0[a]	.	.	
	Yes	0[a]	.	.	
Healthy Ratio 240°	No	344	0.7	0.2	**0.035**
	Yes	153	0.6	0.2	
Healthy Ratio mixt	No	7	1.6	0.5	0.545
	Yes	3	1.3	0.6	
Operated Ratio 60°	No	345	0.7	0.2	0.104
	Yes	153	0.6	0.2	
Operated Ratio 240°	No	345	0.7	0.4	**0.049**
	Yes	153	0.7	0.3	
Operated Ratio mixt	No	345	0.8	0.7	0.219
	Yes	153	0.7	0.7	
Healthy Single Hop test (cm)	No	324	118.6	55.8	0.396
	Yes	149	123.4	57.9	
Operated Single Hop test (cm)	No	323	104.2	54.8	0.239
	Yes	146	110.6	55.3	
Deficiency Single Hop test	No	345	0.1	0.1	0.360
	Yes	153	0.1	0.1	
Healthy Triple Hop Test (cm)	No	319	342.6	164.1	0.145
	Yes	147	366.8	173	
Operated Triple Hop Test (cm)	No	316	308.4	163	0.127
	Yes	146	333.6	167	
Deficiency Triple Hop Test	No	345	0.1	0.1	0.781
	Yes	153	0.1	0.1	
Healthy Side Hop Test (cm)	No	307	46.1	14.3	**0.000**
	Yes	141	52.3	11.9	
Operated Side Hop Test (cm)	No	304	39.6	17.5	**0.002**
	Yes	140	44.9	15.5	
Deficiency Side Hop Test	No	23	0.1	0.3	0.252
	Yes	15	0.00000	0.000000	
Healthy Unipodal Squat	No	337	0.3	0.5	0.091
	Yes	148	0.3	0.4	
Operated Unipodal Squat	No	334	0.5	0.5	0.030
	Yes	147	0.4	0.5	

Bold values corresponds to these two parts: "Patients who underwent all procedure displayed better isokinetic test results for quadriceps and hamstring concentric contraction at 60°/second on both legs ($p < 0.05$), as well as quadriceps concentric contraction at 240°/second ($p < 0.05$)" and "Regarding jump tests, only the SJT showed a statistically significant result ($p < 0.05$) on the operated (44.9 ± 15.5 with plasty vs 39.55 ± 17.5 without) and healthy side (52.3 ± 11.88 vs 46.2 ± 14.34)."

Table 6
Comparison graft failure with or without ALL reconstruction.

		ALL reconstruction		Total
		No	Yes	
Graft failure	no	325	146	471
	yes	20	7	27
Total		345	153	498

Khi^2: $p = 0.57$.

CRediT authorship contribution statement

Thibault Marty Diloy: study design, data analysis, manuscript writing.
Clément Cazemajou: critical review of the manuscript.
Pierre Laboudie: statistical analysis, interpretation of results.
Nicolas Graveleau, Nicolas Bouguennec: scientific supervision, final revisions.
All authors read and approved the final manuscript.
Declaration of generative AI and AI-assisted technologies
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Declaration of competing interest

None.

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