

Contralateral and Ipsilateral Second Injuries of the Anterior Cruciate Ligament After Primary Reconstruction in Sport-Active Patients: A Retrospective Cohort Study

Review began 10/06/2026

Review ended 10/15/2026

Published 10/21/2026

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DOI: 10.7759/cureus.118343

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Abstract

Introduction: After anterior cruciate ligament (ACL) reconstruction, a second injury may affect either the graft or the native contralateral ACL. In this exploratory secondary analysis, we aimed to describe the cumulative incidence of contralateral ACL rupture and ipsilateral re-rupture after primary reconstruction in sport-active patients and to report these events according to surgical technique: single-bundle (SB) or double-bundle plus lateral reinforcement (DB + LR).

Materials and methods: This was a secondary analysis of a retrospective, single-center cohort of 56 patients aged 16-45 years who underwent ACL reconstruction using hamstring autografts between 2016 and 2021 (SB, n = 31; DB + LR, n = 25). Second ACL injuries documented in the center's medical records through June 2023 were analyzed (median time from surgery to data extraction, 3.3 years). Contralateral ACL rupture was not a predefined outcome of the parent study.

Results: The mean age was 25.6 ± 8.3 years; 67.9% were male, and 48.2% played rugby. At clinical discharge, 51 of 53 examined knees (96.2%) were clinically stable, and 50 of 56 patients (89.3%) had a documented return to pre-injury activity. Twelve patients (21.4%; 95% CI: 11.6-34.4) had a recorded second ACL injury: seven contralateral ACL ruptures (12.5%; 95% CI: 5.2-24.1) and five ipsilateral re-ruptures (8.9%; 95% CI: 3.0-19.6), with no significant difference between the two (exact McNemar test, $p = 0.77$). Contralateral ACL rupture occurred in 9.7% of SB and 16.0% of DB + LR patients ($p = 0.69$); this comparison was underpowered and confounded by sport.

Conclusions: Most patients achieved a clinically stable knee and had a documented return to pre-injury activity. However, about one in five had a recorded second ACL injury, and contralateral ruptures were at least as frequent as ipsilateral ruptures. The contralateral knee deserves attention during follow-up and rehabilitation; prospective studies with complete follow-up are needed to confirm these rates.

Categories: Sports Medicine, Physical Medicine & Rehabilitation, Orthopedics

Keywords: anterior cruciate ligament, anterolateral ligament, contralateral rupture, reconstruction, return to sport, second acl injury

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries in athletes, with an estimated population incidence of 68.6 per 100,000 person-years [1]. In young and active patients, surgical reconstruction is the treatment of choice to restore stability and allow a return to the pre-injury level of sport.

However, reconstruction does not eliminate the risk of a second ACL injury, which may occur in the graft (ipsilateral re-rupture) or in the native ACL of the contralateral knee. In a systematic review with at least five years of follow-up, Wright et al. reported that the risk of contralateral rupture (11.8%) was approximately twice that of graft rupture (5.8%) [2]. In young athletes returning to sport, the combined incidence of a second ACL injury is even higher: around 20% in the meta-analysis by Wiggins et al. [3], close to 30% within two years of return in the cohort of Paterno et al. [4], and up to 35% in patients younger than 20 years in the series of Webster and Feller [5].

How to cite this article

Diaz Steta R, Aramberri-Gutierrez M, Tiso-D Orazio G, et al. (October 21, 2026) Contralateral and Ipsilateral Second Injuries of the Anterior Cruciate Ligament After Primary Reconstruction in Sport-Active Patients: A Retrospective Cohort Study. Cureus 18(10): e118343. DOI 10.7759/cureus.118343

Factors associated with a second ACL injury include young age, high activity level, participation in pivoting sports, and early return to sport [3,5]. Each additional month of delayed return to sport, up to nine months, has been associated with a lower risk of a second ACL injury [6], and young athletes who return before then have a reinjury rate up to seven times higher [7]. Lateral extra-articular reinforcement has been shown to reduce graft failure [8,9], but whether it modifies the risk to the contralateral knee is unknown.

Most of these data come from North American, Australian, and Scandinavian cohorts, with limited information available on populations predominantly participating in contact sports such as rugby. In this exploratory secondary analysis of a cohort originally designed to compare rotational stability at clinical discharge between two reconstruction techniques, contralateral ACL rupture was not a predefined outcome. Our main objective was to describe the cumulative incidence of contralateral ACL rupture and ipsilateral re-rupture after primary reconstruction in sport-active patients. The secondary objectives were to descriptively compare these events between the single-bundle (SB) and double-bundle plus lateral reinforcement (DB + LR) techniques, recognizing that the study was not powered to detect differences, and to describe time to return to pre-injury activity.

Materials And Methods

Study design and ethics

This was a secondary analysis of a retrospective, observational, single-center cohort study originally designed to compare rotational stability at clinical discharge between the SB and DB + LR techniques. Contralateral ACL rupture was not a predefined outcome and was analyzed from the recorded complications. The study follows the STROBE statement [10]. The protocol was approved by the Research Ethics Committee (CEIm) of Hospital Universitario Fundación Jiménez Díaz, Madrid, on 25 October 2022 (approval number: TFG063-22_HLA), with a waiver of informed consent because of the retrospective design and the use of pseudonymized data. The study was conducted in accordance with the Declaration of Helsinki and Spanish Organic Law 3/2018 on Personal Data Protection. Data were extracted from the medical records between October 2022 and June 2023.

Patients

We reviewed the medical records of patients who underwent ACL reconstruction using hamstring autografts at Alai Sports Medicine Clinic (Madrid, Spain) between 2016 and 2021 and had complete clinical records. Patients who underwent reconstruction using other graft types were excluded; therefore, this was not a consecutive series of all ACL reconstructions performed at the center. The number of included patients per year of surgery was four in 2016, four in 2017, seven in 2018, 10 in 2019, 11 in 2020, and 20 in 2021. Patients aged 16 to 45 years with an ACL rupture confirmed by physical examination and MRI were included. Patients with previous ACL surgery on the same knee, associated multiligament injuries, or age over 45 years were excluded. The choice of technique depended on surgeon preference and the patient's sport, so the DB + LR technique was used more often in rugby players.

Surgical techniques

Three surgeons at the center performed all reconstructions using hamstring tendon autografts (semitendinosus and gracilis). In the SB technique, the anteromedial bundle was reproduced with a tibial tunnel in the posterior half of the tibial footprint and a femoral tunnel in the anteromedial footprint, with femoral and tibial cortical suspension fixation. The DB + LR technique was performed according to the procedure described by Mediavilla et al. [11]. The semitendinosus tendon was folded into four strands (8–9 mm) and used to reconstruct the anteromedial bundle through an inside-out femoral tunnel. The gracilis tendon was used to reconstruct the posterolateral bundle and, in continuity, the anterolateral ligament through an outside-in femoral tunnel, with interference screw fixation.

Rehabilitation and return to activity

Patients followed the center's rehabilitation protocol, organized in three phases. The first phase (0–8 weeks) focused on recovering range of motion and quadriceps activation; the second (three to six months) comprised progressive muscle strengthening and the introduction of low-impact activities such as running or cycling; and the third (from six months onwards) involved a gradual increase in intensity and sport-specific tasks up to the pre-injury level. Patients underwent scheduled postoperative follow-up assessments at six weeks, 3–3.5 months, and clinical discharge. After clinical discharge, patients progressively returned to sport based on clinical criteria (a stable examination, no effusion, and full range of motion) and elapsed time. Objective functional tests (hop tests and dynamometry) were not used to determine clearance for return to sport.

Variables

Age, sex, sport, pre-injury activity level on the Tegner scale [12], and surgical technique were recorded. Knee stability was assessed with the Lachman test [13] and the pivot-shift test, graded according to Jakob et al. [14], before surgery and at each review.

The main outcome was a second ACL injury, defined as rupture of the native contralateral ACL or re-rupture of the ipsilateral graft, diagnosed clinically and confirmed by MRI. All ipsilateral re-ruptures were counted together, regardless of injury mechanism. In one case, the medical record documented a direct blow to the operated knee when another player fell onto it. The injury mechanism was not otherwise recorded systematically. Second ACL injuries were identified retrospectively from the center's medical records, which included scheduled postoperative follow-up visits at six weeks, 3-3.5 months, and clinical discharge, as well as any subsequent consultations or information recorded at the center through June 2023. No routine follow-up visits were scheduled after clinical discharge; therefore, injuries treated at other centers and not reported to the clinic would not have been captured. The approximate date of the second injury was recorded for six of the 12 injured patients. Other postoperative complications were also recorded.

Time to return to pre-injury activity (TTRTP) was defined as the interval from surgery to the documented date of return to pre-injury activity or clinical clearance, as recorded in the medical records. For most patients, this corresponded to the date on which the surgeon cleared them to return to pre-injury activity, often coinciding with clinical discharge. For two patients who did not attend subsequent visits, the date of their last recorded visit was used. A return date was available for 50 of 56 patients (28 SB and 22 DB + LR). The remaining six patients either did not return to their pre-injury activity, were lost to follow-up, or sustained a second ACL injury before returning and were therefore excluded from the TTRTP analysis.

Statistical analysis

Normality of quantitative variables was assessed with the Shapiro-Wilk test [15]; they are reported as mean $\pm$ standard deviation (SD) or median and interquartile range (IQR). Categorical variables are reported as n (%). The cumulative incidence of second injuries was calculated with its exact Clopper-Pearson 95% confidence interval (95% CI) [16]. Proportions were compared between techniques with Pearson's χ^2 test or, when expected frequencies were below five, with Fisher's exact test, for which the conditional odds ratio (OR) with its 95% CI is reported as the effect measure (DB + LR vs SB). Because contralateral and ipsilateral events were counted in the same cohort, their frequencies were compared with the exact McNemar test. In a sensitivity analysis, complications that could represent unrecognized graft failure (a feeling of instability and graft resorption) were counted as possible ipsilateral graft failures. Quantitative variables were compared with Student's t-test for independent samples or the Mann-Whitney U test. The test statistic (t, χ^2 , or U) is reported with each p-value. A p-value <0.05 was considered significant. Given the number of events, no multivariable analysis was performed. Analyses were performed with the R package jamovi version 1.6.23 (The jamovi project, Sydney, Australia) [17]; exact confidence intervals, ORs, and additional exact tests were calculated with Python (Python Software Foundation, Wilmington, USA) using the SciPy library [18]. The authors used an AI-based language tool (Claude, Anthropic, San Francisco, USA) for English language editing and translation and to verify selected statistical calculations; the authors reviewed all content and take full responsibility for it.

Results

Patient characteristics

Sixty-four medical records were reviewed, and eight patients were excluded: five for age over 45 years and three for previous ACL surgery on the same knee. Fifty-six patients were included: 31 treated with the SB technique and 25 with the DB + LR technique. Figure 1 shows the patient flow. Three patients (one in the SB group and two in the DB + LR group) stopped attending scheduled postoperative follow-up visits; they were included in all analyses except the assessment of knee stability at clinical discharge. Median time to clinical discharge was 199 days (IQR: 172-243) in the SB group and 209 days (IQR: 205-270) in the DB + LR group. The median time from surgery to data extraction was 3.3 years (IQR: 2.2-4.5; range: 1.5-7.0).

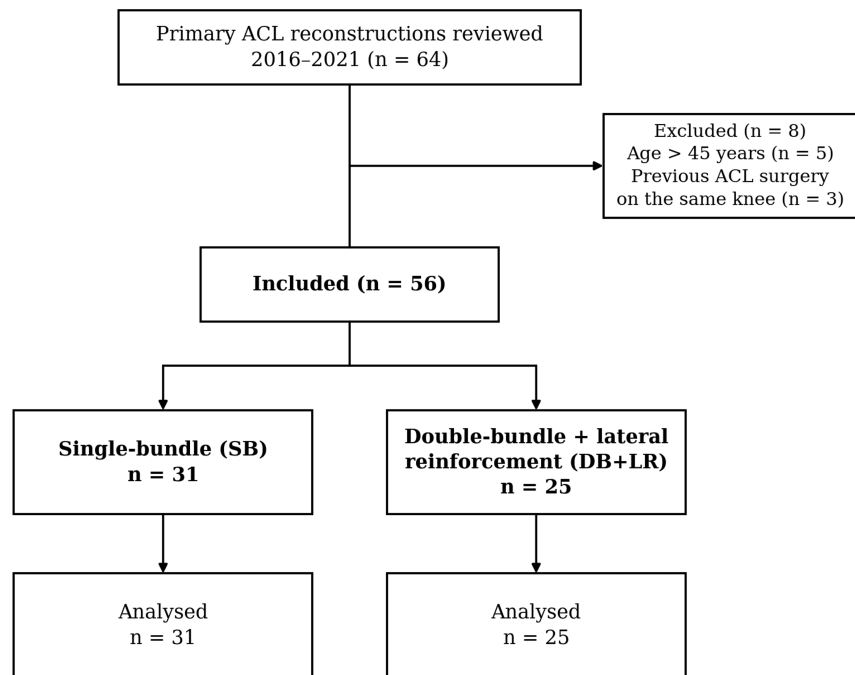


FIGURE 1: Flow diagram of patients by surgical technique

All 56 included patients were analyzed. Three patients (one in the SB group and two in the DB + LR group) missed scheduled postoperative follow-up visits; they were included in all analyses except the assessment of knee stability at clinical discharge.

ACL: anterior cruciate ligament, DB + LR: double-bundle plus lateral reinforcement, SB: single-bundle

The mean age was 25.6 ± 8.3 years; 75% of patients were aged 16-30 years, and 67.9% were male. No significant differences were observed between the surgical groups in age (Student's t-test, $t(54) = 0.04$, $p = 0.965$), age group ($\chi^2(1) = 0.02$, $p = 0.877$), sex ($\chi^2(1) = 1.37$, $p = 0.241$), or Tegner score ($t(54) = -1.26$, $p = 0.213$) (Table 1). Rugby was the most common sport (48.2%), with a significantly higher proportion in the DB + LR group (68.0% vs. 32.3%; Fisher's exact test, $p = 0.015$; OR 4.33, 95% CI 1.27-16.14). The mean Tegner score was 7.9 ± 2.7 , and 17 patients (30.4%) either participated in recreational sports or had sustained their injuries outside sporting activities.

Variable	Total (n = 56)	SB (n = 31)	DB + LR (n = 25)	Test statistic	p-value
Age (years), mean $\pm$ SD	25.6 $\pm$ 8.3	25.6 $\pm$ 9.2	25.5 $\pm$ 7.1	t(54) = 0.04	0.965
Age 16-30 years, n (%)	42 (75.0)	23 (74.2)	19 (76.0)	$\chi^2(1)$ = 0.02	0.877
Male sex, n (%)	38 (67.9)	19 (61.3)	19 (76.0)	$\chi^2(1)$ = 1.37	0.241
Tegner score, mean $\pm$ SD	7.9 $\pm$ 2.7	7.5 $\pm$ 2.7	8.4 $\pm$ 2.6	t(54) = -1.26	0.213
Sport: rugby, n (%)	27 (48.2)	10 (32.3)	17 (68.0)	Fisher; OR 4.33 (1.27-16.14)	0.015
Sport: football (soccer), n (%)	6 (10.7)	5 (16.1)	1 (4.0)	-	-
Sport: handball, n (%)	3 (5.4)	3 (9.7)	0	-	-
Sport: basketball, n (%)	3 (5.4)	2 (6.5)	1 (4.0)	-	-
Sport: amateur boxing, n (%)	3 (5.4)	3 (9.7)	0	-	-
Sport: other, n (%)	14 (25.0)	8 (25.8)	6 (24.0)	-	-
TTRTP (days), median (IQR)	-	220 (186-258), n = 28	232 (208-287), n = 22	U = 233.5	0.148

TABLE 1: Patient characteristics by surgical technique

"Other" includes bodybuilding (1), recreational sport (1), and other activities (12). Tests: Student's t-test for independent samples (age, Tegner score), Pearson's χ^2 test (age group, sex), Fisher's exact test (rugby vs. all other sports), and Mann-Whitney U test (TTRTP; available for 28 SB and 22 DB + LR patients).

DB + LR: double-bundle plus lateral reinforcement, IQR: interquartile range, OR: odds ratio (DB + LR vs SB) with 95% CI, SB: single-bundle, SD: standard deviation, TTRTP: time to return to pre-injury activity, CI: confidence interval

At clinical discharge, the pivot-shift test was negative in 28 of 30 patients (93.3%) in the SB group and in all 23 patients (100%) in the DB + LR group (Fisher's exact test, p = 0.499; OR not estimable because of a zero cell), with identical results for the Lachman test (Table 2). Thus, at clinical discharge, all operated knees in the DB + LR group and 93.3% of those in the SB group were clinically stable.

Test and grade, n (%)	SB, preoperative (n = 31)	SB, clinical discharge (n = 30)	DB + LR, preoperative (n = 25)	DB + LR, clinical discharge (n = 23)
Pivot-shift				
Grade 0 (negative)	0	28 (93.3)	0	23 (100)
Grade I (+)	22 (71.0)	2 (6.7)	22 (88.0)	0
Grade II (++)	9 (29.0)	0	3 (12.0)	0
Grade III (+++)	0	0	0	0
Lachman				
Normal	0	28 (93.3)	0	23 (100)
Nearly normal (+)	3 (9.7)	2 (6.7)	2 (8.0)	0
Abnormal (++)	26 (83.9)	0	20 (80.0)	0
Severely abnormal (+++)	2 (6.5)	0	3 (12.0)	0

TABLE 2: Stability examination before surgery and at clinical discharge

Negative pivot-shift at clinical discharge, SB vs. DB + LR: $p = 0.499$ (Fisher's exact test); identical result for the Lachman test. At the intermediate reviews (six weeks and 3-3.5 months), all examined knees were stable. Three patients did not attend all reviews.

DB + LR: double-bundle plus lateral reinforcement, SB: single-bundle

Second ACL injuries

Twelve patients (21.4%; 95% CI: 11.6-34.4) had a recorded second ACL injury (Table 3): seven contralateral ruptures (12.5%; 95% CI: 5.2-24.1) and five ipsilateral re-ruptures (8.9%; 95% CI: 3.0-19.6), one of which followed a direct blow from another player. The frequencies of contralateral and ipsilateral events did not differ significantly (seven vs. five; exact McNemar test, $p = 0.77$). In the sensitivity analysis, two patients reporting instability (one of whom underwent revision surgery with lateral reinforcement) and one patient with graft resorption were classified as possible graft failures, increasing the number of ipsilateral events to eight (14.3%; 95% CI: 6.4-26.2).

Type of injury	Total, n (%)	95% CI	SB, n (%)	DB + LR, n (%)	OR (95% CI)	p-value
Any second ACL injury	12 (21.4)	11.6-34.4	6 (19.4)	6 (24.0)	1.31 (0.30-5.78)	0.750
Contralateral ACL rupture	7 (12.5)	5.2-24.1	3 (9.7)	4 (16.0)	1.76 (0.27-13.32)	0.688
Ipsilateral re-rupture (all)	5 (8.9)	3.0-19.6	3 (9.7)	2 (8.0)	0.81 (0.06-7.76)	1.00
Without direct trauma	4 (7.1)	2.0-17.3	3 (9.7)	1 (4.0)	-	-
After direct blow	1 (1.8)	0.0-9.6	0	1 (4.0)	-	-
Sensitivity analysis: ipsilateral injuries including possible graft failures	8 (14.3)	6.4-26.2	5 (16.1)	3 (12.0)	0.71 (0.10-4.16)	0.720

TABLE 3: Second ACL injuries by surgical technique

Comparisons between techniques with Fisher's exact test; these comparisons were underpowered. Contralateral vs ipsilateral events in the whole cohort: exact McNemar test, $p = 0.77$. The sensitivity analysis counts instability ($n = 2$) and graft resorption ($n = 1$) as possible graft failures. Events were recorded through data extraction (median time from surgery to data extraction, 3.3 years).

95% CI: 95% confidence interval for the overall cumulative incidence (exact Clopper-Pearson method), ACL: anterior cruciate ligament, DB + LR: double-bundle plus lateral reinforcement, OR: odds ratio, SB: single-bundle

The approximate date of injury was available for six patients: five injuries occurred between seven and 11 months after surgery and one at about 18 months. Of these six injuries, four occurred after return to activity, whereas two occurred after clinical discharge but before the planned return to activity. Contralateral ACL rupture occurred in 3/31 SB patients (9.7%) and 4/25 DB + LR patients (16.0%) (Fisher's exact test, $p = 0.69$; OR 1.76, 95% CI 0.27-13.32), and ipsilateral re-rupture in 3/31 (9.7%) and 2/25 (8.0%), respectively ($p = 1.00$; OR 0.81, 95% CI 0.06-7.76). These comparisons were underpowered and are reported for descriptive purposes. All four ipsilateral re-ruptures not caused by direct trauma occurred in patients aged 16-30 years.

Other complications

Overall, 23 patients (41.1%) experienced a postoperative complication, with no significant differences according to surgical technique (SB, 41.9%; DB + LR, 40.0%; $\chi^2(1) = 0.02$, $p = 0.88$), age group, or sex. Eleven complications other than second ACL injuries were recorded (Table 4).

Complication, n	Total	SB	DB + LR
Superficial wound infection	1	1	0
Septic arthritis	1	1	0
Meniscal symptoms	2	1	1
Meniscal tear	1	0	1
Hamstring tear	1	0	1
Feeling of instability	2	2	0
Extension deficit	1	1	0
Cyclops lesion	1	1	0
Graft resorption	1	0	1

TABLE 4: Complications other than second ACL injuries

Each patient had a single complication. Overall complication rate, SB vs. DB + LR: Pearson's χ^2 test, $\chi^2(1) = 0.02$, $p = 0.88$. A feeling of instability and graft resorption may represent unrecognized graft failure (see sensitivity analysis in Table 3).

DB + LR: double-bundle plus lateral reinforcement, SB: single-bundle, ACL: anterior cruciate ligament

Return to activity

Median TTRTP was 220 days (IQR: 186-258) in the SB group ($n = 28$) and 232 days (IQR: 208-287) in the DB + LR group ($n = 22$) (Mann-Whitney U test, $U = 233.5$, $p = 0.148$). Thus, more than 75% of patients in the SB group and more than half of those in the DB + LR group with a recorded return date received clearance to resume their pre-injury activity before nine months (270 days). Overall, 50 of 56 patients (89.3%) had a documented return to their pre-injury activity.

Discussion

In this secondary analysis, about one in five patients had a recorded second ACL injury after primary reconstruction, and ruptures of the native contralateral ACL were at least as frequent as ipsilateral re-ruptures. The small number of events does not allow us to conclude that either injury type predominates or that surgical technique is unrelated to risk.

Our contralateral rupture rate (12.5%) over a median interval of 3.3 years from surgery to data extraction is similar to the 11.8% reported by Wright et al. after at least five years of follow-up [2], and the overall rate of second ACL injury (21.4%) lies within the range described for young athletes [3,4]. Other cohorts have also found contralateral ACL ruptures to be at least as frequent as graft re-ruptures [2,19]. Webster and Feller observed contralateral rates close to 18% in patients younger than 20 years [5]. The comparable contralateral rupture rate, despite the shorter interval from surgery to data extraction, may reflect the high-risk characteristics of our rugby-dominant cohort and the small sample size. Because the observation period varied between patients and no routine follow-up visits were scheduled after clinical discharge, these figures should be interpreted as recorded events rather than as incidences at a fixed time point.

Lateral extra-articular reinforcement reduces graft failure, as shown by the STABILITY trial and the SANTI group [8,9]. In our series, ipsilateral re-rupture rates were similar between the two techniques (8.0% vs. 9.7%), although the small sample size precludes definitive conclusions. The rate of contralateral ACL rupture was not lower in the DB + LR group (16.0% vs. 9.7%), which is consistent with the hypothesis that protecting the graft may not necessarily protect the contralateral knee. However, this comparison was underpowered (OR 1.76, 95% CI 0.27-13.32) and confounded by sport and surgeon, as the DB + LR group included a significantly higher proportion of rugby players, so no conclusion about the effect of technique on contralateral risk can be drawn.

The median time to documented return to pre-injury activity or clinical clearance was approximately seven to eight months. Most patients were cleared to resume activity before nine months based on clinical and time-based criteria, without objective functional testing. Grindem et al. found that each additional month of delayed return to sport, up to nine months, was associated with a reduced risk of a second ACL injury and that quadriceps strength symmetry below 90% increased it [6]. Beischer et al. reported a seven-fold higher rate of new injury in young athletes who returned before nine months [7], and Kyritsis et al. reported a four-fold higher risk of graft rupture in those who did not meet six clinical discharge criteria [20]. Although our

data do not allow the timing of return to pre-injury activity to be linked to the risk of injury, four of the six injuries with a known date occurred after return to activity, and the characteristics of the cohort (predominantly younger patients, participation in contact and pivoting sports, and clearance before nine months) are consistent with the high-risk profile described in the literature.

Hypothesized mechanism of contralateral overload

One proposed mechanism underlying contralateral ACL rupture is contralateral overload. After reconstruction, mechanical stability of the operated knee is restored, but deficits in neuromuscular control, proprioception, and postural stability persist in both limbs, and these deficits have been prospectively associated with a second ACL injury in either knee [21]. During rehabilitation and return to sport, patients tend to protect the operated knee and shift braking, landing, and pivoting loads to the contralateral limb, which becomes the functionally dominant side. When return occurs early and is based on elapsed time rather than objective criteria, this overloaded limb is exposed to high-risk mechanisms such as dynamic valgus and tibial rotation during deceleration and cutting. This study could not assess alternative explanations, such as intrinsic anatomical risk factors shared by both knees.

A neurocognitive component may amplify this process. ACL injury is followed by neuroplastic changes, with greater reliance on visual feedback and conscious control of movement [22], and lower baseline neurocognitive performance, including reaction time, processing speed, and visual memory, has been associated with noncontact ACL injury [23]. In real-world sporting situations, where athletes must divide their attention among the ball, opponents, and decision-making demands, they may be unable to maintain conscious control of knee position, particularly under fatigue, and unsafe landing and cutting patterns may emerge on the limb perceived as "stronger" [22,24]. Our study did not include biomechanical, functional, or neurocognitive measures, so this sequence should be regarded as a hypothesis; it is summarized in Figure 2.

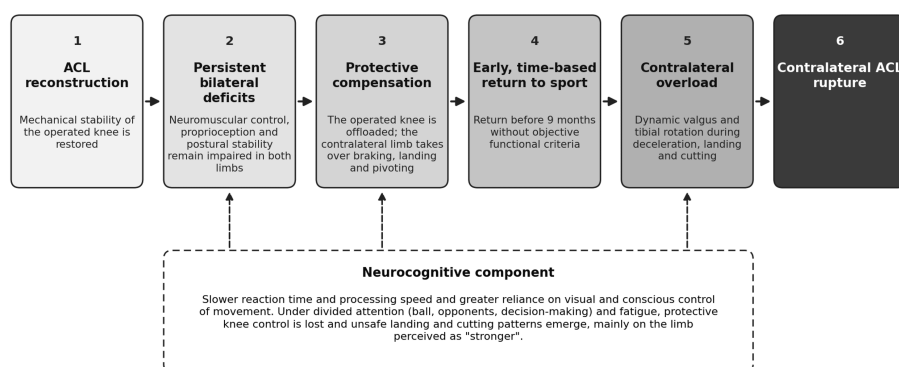


FIGURE 2: Hypothesized mechanism of contralateral ACL overload after reconstruction

The solid arrows show the proposed sequence from reconstruction to contralateral rupture; the dashed arrows show where the neurocognitive component is thought to contribute. The model is based on the literature [21-24] and on the clinical experience of the authors and was not tested in the present study.

ACL: anterior cruciate ligament

Possible bilateral prevention approach

Based on this hypothesis and our team's clinical experience, we propose a bilateral, criterion-based prevention program that treats both lower limbs as an interdependent functional unit (Table 5). The program rests on three pillars: bilateral and unilateral strength training to restore symmetry and control dynamic valgus; development of explosive strength and rate of force development (RFD), combined with progressive plyometric training to improve load absorption, landing mechanics, and deceleration; and advanced neuromuscular and neurocognitive training, including balance, change of direction, and reactive tasks under unanticipated and dual-task conditions [22,24]. These pillars are organized in five progressive phases, from early recovery to secondary prevention after return to sport. Progression between phases is based on functional criteria rather than on time alone, and return to pivoting sports is not recommended before nine months [6,7,20].

Phase	Timing	Main goals	Key content (both limbs)	Suggested criteria to progress
1. Early recovery	0-3 months	Control pain and effusion; restore range of motion; activate the quadriceps	Range-of-motion exercises, quadriceps activation, gait re-education; strength maintenance of the contralateral limb	Full extension, no effusion, straight-leg raise without extension lag
2. Strength and neuromuscular control	3-6 months	Restore strength and limb symmetry; control dynamic valgus	Bilateral and unilateral strength training, balance and proprioception, single-leg squat and step-down control	Quadriceps and hamstring strength limb symmetry indices ≥80%; controlled single-leg squat without dynamic valgus
3. Explosive strength (RFD) and plyometrics	6-9 months	Improve RFD, load absorption, and landing	Progressive plyometrics, landing technique, deceleration drills, running progression	Quadriceps symmetry ≥90%; hop test symmetry ≥90%; good landing mechanics
4. Return to sport	9-12 months	Safe return to full sport participation	Sport-specific drills, change of direction, reactive and unanticipated tasks, dual-task and visual-motor training, controlled exposure to contact	At least 9 months after surgery and all functional criteria met in both limbs
5. Secondary prevention	After return to sport	Maintain neuromuscular and neurocognitive capacities; control training load	Neuromuscular warm-up program at least twice weekly, load monitoring, periodic bilateral screening	Ongoing throughout the sporting career

TABLE 5: Proposed bilateral, criterion-based program to reduce the risk of contralateral ACL rupture

Symmetry refers to the limb symmetry index (operated limb/contralateral limb × 100). Timing is approximate; progression depends on meeting the specified criteria. Return-to-sport criteria are adapted from Grindem et al. [6] and Kyritsis et al. [20]; earlier-phase thresholds reflect the authors' clinical practice. This program is based on the literature and clinical experience and has not been evaluated in this study.

ACL: anterior cruciate ligament, RFD: rate of force development

This approach is based on the literature and clinical experience, not the data in the present study; it should be implemented through an individualized, multidisciplinary approach that considers the entire kinetic chain, and prospective studies should test its effectiveness in reducing contralateral ACL rupture.

Limitations

This study has several limitations. First, this was a retrospective, post hoc secondary analysis of a cohort designed to compare rotational stability at clinical discharge. Second ACL injuries were not predefined outcomes and were not actively sought. Second, only patients who underwent reconstruction using hamstring autografts and had complete clinical records were included, so the sample is not a consecutive series and may not be representative of all reconstructions at the center. Third, no routine follow-up visits were scheduled after clinical discharge, the observation period varied between patients, and the date of injury was available for only half of the events; injuries treated at other centers, or in the three patients who stopped attending visits, may have been missed, and time at risk after return to sport could not be calculated. Fourth, some complications, such as instability or graft resorption, may represent unrecognized graft failures, as considered in the sensitivity analysis. Fifth, the sample is small, and the comparisons between techniques are underpowered. Sixth, surgical technique was determined by the operating surgeon, and the groups differed in the proportion of rugby players. Therefore, sport and surgeon-related factors may have confounded the comparison between techniques. Seventh, nearly one-third of the patients were recreational athletes or had sustained injuries outside sport, and the small number of events precluded analyses by sport type. Eighth, return to pre-injury activity was documented retrospectively, usually using the date of clinical clearance, which was determined based on clinical and time-based criteria. Finally, no data were available on sports exposure, functional or neurocognitive measures, patient-reported outcomes, or anatomical risk factors, and the study was conducted at a single center.

Conclusions

In this secondary analysis of 56 sport-active patients undergoing primary ACL reconstruction with hamstring autograft, most patients achieved clinically stable knees and returned to pre-injury activity.

However, about one in five had a second ACL injury recorded over a median interval of 3.3 years from surgery to data extraction, and ruptures of the native contralateral ligament were at least as frequent as ipsilateral re-ruptures. The comparison between surgical techniques was underpowered and confounded by sport, so no conclusion about the influence of technique on contralateral risk can be drawn.

These findings suggest that the contralateral knee deserves attention during follow-up and rehabilitation after reconstruction. Prospective studies with complete follow-up, documented injury dates, and sport exposure data after return to sport are needed to confirm these rates, to identify modifiable risk factors, and to test whether bilateral prevention strategies reduce contralateral ACL rupture.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Research Ethics Committee (CEIm) of Hospital Universitario Fundación Jiménez Díaz issued approval TFG063-22_HLA. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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