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Predictors of Functional Recovery After ACL Reconstruction in Mid-Teen Patients: An Analysis of Clinical and Rehabilitation Factors

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Abstract

Background: ACL injuries in mid-teen athletes are increasing, and recovery after ACL reconstruction is variable despite surgery and clearance to return to sport. Functional recovery depends on both subjective function and objective performance, and may be influenced by preoperative clinical status, associated meniscal or cartilage injuries, surgical factors, and, importantly, rehabilitation dose and adherence. The study aimed to identify independent predictors of functional recovery at 12 months after primary ACL reconstruction in mid-teen patients.

Methods: This observational analytical study included mid-teen boys and girls undergoing primary unilateral ACL reconstruction at Prime Hospital, Dubai, UAE, during two years from January 2024 to December 2025, with prospective follow-up where feasible. Preoperative and intraoperative variables were recorded using a structured form. Patients were assessed at routine intervals up to 12 months. Functional recovery at 12 months was evaluated using IKDC or Pedi-IKDC and, where applicable, objective criteria such as hop-test symmetry, full ROM, and absence of clinically relevant effusion. Data were analyzed in SPSS v26 using descriptive statistics, bivariate tests, and multivariable regression to identify independent predictors, with ethical approval and de-identified data handling.

Results: Of 350 mid-teen ACL reconstruction patients, 216 (61.7%) achieved functional recovery at 12 months. Recovery was higher in males (68.5% vs 56.7%; p=0.025), those with lower BMI (23.6±3.8 vs 25.0±4.5; p=0.002), higher baseline activity (Tegner 6.4±1.3 vs 5.9±1.4; p=0.001), and greater pre-injury sports participation (90.7% vs 82.1%; p=0.017). Non-recovered patients had more swelling (72.4% vs 59.3%; p=0.014), longer injury-to-surgery delay (104 vs 72 days; p=0.001), worse pre-op pain/ROM/effusion (all p<0.001), and more cartilage and MCL injury (p≤0.045). Rehabilitation showed the biggest differences, with earlier start, supervised physiotherapy, better adherence, and higher milestone achievement all favoring recovery (all p<0.001). At 12 months, recovered patients had higher IKDC (88.7±6.8 vs 73.4±9.8) and better hop and strength symmetry (all p<0.001), and returned to sport earlier (8.7±1.9 vs 10.2±2.3 months; p<0.001). Independent predictors were lower BMI (AOR 0.93; p=0.004), shorter delay to surgery (AOR 0.89 per 30 days; p=0.016), no cartilage injury grade ≥2 (AOR 0.60; p=0.038), supervised physiotherapy (AOR 2.14; p=0.004), good-to-excellent adherence (AOR 3.21; p<0.001), and full extension by 2 weeks (AOR 2.63; p<0.001), with male sex modestly associated (AOR 1.55; p=0.045).

Conclusion: Functional recovery at 12 months was achieved in nearly two-thirds of mid-teen patients after ACL reconstruction, with substantially better patient-reported and objective function among those who recovered. Recovery was independently associated with modifiable rehabilitation factors, including supervised physiotherapy, good-to-excellent adherence, and achieving full extension by 2 weeks, while higher BMI, longer injury-to-surgery delay, and cartilage injury predicted poorer outcomes.

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Keywords: ALC reconstruction; Mid-Teen patients; Functional recovery; Rehabilitation adherence; Supervised physiotherapy; Return to sport

Introduction

Anterior cruciate ligament (ACL) rupture in adolescents has become an increasingly common sports-related injury, paralleling earlier sport specialization, higher training loads, and greater exposure to pivoting and landing tasks. Contemporary registry and population data from high-income settings show a clear upward trajectory in ACL reconstruction among younger age groups, with particular concentration in late adolescence when sport participation intensity often peaks [1,2]. Although epidemiology varies across regions, recent pediatric and adolescent data from Asia also indicate substantial cruciate ligament injury burden and frequent concomitant meniscal pathology, underscoring that this is not a purely Western problem [3].

ACL reconstruction is widely performed in mid-teen patients to restore functional stability, facilitate safe return to sport, and reduce secondary meniscal or chondral damage associated with recurrent giving-way episodes. Yet "success" after surgery is not uniform, and the adolescent profile is distinct: high performance demands, variable neuromuscular control during growth, and fluctuating psychosocial readiness can all influence recovery trajectories. Return-to-sport outcomes illustrate this tension; pooled analyses in children and adolescents suggest high rates of return to any sport, but clinically meaningful risks of graft rupture and contralateral ACL injury persist, particularly after resumption of high-risk activities [4,5].

Functional recovery is increasingly framed as a multidimensional endpoint that combines patient-reported outcomes with objective performance symmetry, strength restoration, symptom control, and effusion or motion status. Patient-reported instruments such as the IKDC family, including pediatric adaptations, remain central because they capture symptoms and perceived function that may diverge from laboratory or field tests [6]. However, even when athletes are "cleared" clinically, objective deficits often remain; prospective cohort work in young athletes has shown that only a small fraction meet combined cutoffs for subjective score, strength limb symmetry, and hop performance at return-to-sport clearance [7]. This disconnect likely contributes to the elevated reinjury rates observed in younger populations and supports a more criterion-based interpretation of recovery rather than relying on time alone [5,7].

Both clinical severity and care pathways before surgery can shape post-operative potential. Delay from injury to reconstruction has been associated with higher rates of meniscal tears in pediatric patients, plausibly through ongoing instability episodes and cumulative intra-articular insult [8]. Concomitant cartilage injury and meniscal procedures may further complicate rehabilitation due to pain, swelling, modified loading, and altered confidence in the knee. At the same time, rehabilitation exposure is not simply a background variable; it is a dose-dependent intervention. Earlier initiation of structured rehabilitation, adequate supervised physiotherapy, and adherence to progressive home programs are consistently emphasized as key determinants of strength symmetry, hop performance, and sport-specific capacity, which are themselves central to the modern definition of functional recovery [7,9].

Psychological readiness is another adolescent-sensitive dimension. Lower readiness to return to sport has been linked with higher risk of subsequent ACL injury, and adolescent-specific analyses highlight that confidence, fear, and perceived knee trustworthiness can lag behind physical milestones or, conversely, outpace them in ways that encourage premature exposure [10,11]. Meanwhile, the broader literature continues to show that determinants of return to sport are multifactorial and heterogeneous, spanning contextual, surgical, physical, and psychological domains, with substantial variability in outcome definitions between studies [12,13].

Despite this, important gaps remain. Many adolescent studies report overall outcomes or reinjury rates without integrating measurable rehabilitation dose, milestone achievement, and pre-operative clinical status into a single explanatory framework. Evidence is also dominated by well-resourced systems with mature registries; in many low- and middle-income contexts, delays to surgery, access to supervised physiotherapy, and adherence constraints may differ materially, and locally grounded predictor models are limited. Against this backdrop, identifying practical, modifiable predictors of recovery is clinically valuable because it can guide risk stratification, target rehabilitation resources, and improve shared decision-making around return to sport. Accordingly, this study aims to determine predictors of functional recovery at 12 months after primary ACL reconstruction in mid-teen patients.

Methodology and Materials

This observational, analytical study was conducted among mid-teen patients undergoing primary ACL reconstruction at the Department of Orthopedic Surgery, Prime Hospital, Dubai, UAE, with prospective follow-up where feasible. During two years from January 2024 to December 2025, a total of 350 cases were enrolled in this study. Eligible participants were boys and girls within the predefined mid-teenage range who received primary ACL reconstruction for a unilateral ACL tear, and who were complete functional testing and patient-reported outcome measures. Exclusion criteria included revision ACL reconstruction, multi-ligament knee injuries requiring staged reconstruction, major fractures around the

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knee, neuromuscular disorders affecting gait, and insufficient follow-up data at the primary endpoint.

Baseline data was recorded preoperatively using a structured case record form: sociodemographic, sport type and level, injury mechanism, time from injury to surgery, clinical status including pain score, effusion, and range of motion, and MRI-confirmed associated injuries such as meniscal tears, cartilage lesions, and collateral ligament injury. Intraoperative variables were including graft type and diameter, fixation method, tunnel technique, meniscal or cartilage procedures, operative time, and early complications. Rehabilitation exposure was captured as measurable dose and quality indicators: time to start rehabilitation, supervised physiotherapy attendance, adherence category, home program use, brace and crutch duration, and achievement of key milestones such as full extension by 2 weeks and flexion ≥120 degrees by 6 weeks.

Participants were assessed at standard intervals, for example, 6 weeks, 3 months, 6 months, 9 months, and 12 months. The primary outcome was functional recovery at 12 months, operationalized either as a continuous score using Pedi IKDC or IKDC, or as a binary recovered status defined by a composite of symptom score threshold plus objective symmetry, for example, hop test limb symmetry index ≥90%, full ROM, and absence of clinically relevant effusion. Secondary outcomes were including return to sport status and timing, psychological readiness if ACL RSI is used, and re-injury or re-operation events.

Data was analyzed using descriptive statistics (SPSS, V-26.0), then bivariate comparisons between recovered and not recovered groups using chi-square or Fisher's exact tests for categorical variables, and t-test or Mann-Whitney U tests for continuous variables. Independent predictors were evaluated using multivariable logistic regression for binary recovery, or linear regression for continuous outcomes, with assessment of multicollinearity, model fit, and discrimination where applicable; missing data was handled using predefined rules, with sensitivity analyses if needed. Ethical approval was obtained, with assent from participants and consent from guardians, and confidentiality maintained through de-identified study IDs.

Results

Among 350 mid-teen ACL reconstruction patients, 216 (61.7%) achieved functional recovery by 12 months. Mean age was similar between groups (15.3±1.2 vs 15.1±1.3 years; p=0.18). Recovery was more frequent in males (68.5% vs 56.7%; p=0.025). The recovered group had a significantly lower BMI (23.6±3.8 vs 25.0±4.5 kg/m²; p=0.002) and higher baseline activity on the Tegner scale (6.4±1.3 vs 5.9±1.4; p=0.001). Pre-injury sports participation was also higher among recovered patients (90.7% vs 82.1%; p=0.017), and sports level differed, with relatively fewer recreational athletes in the recovered group (32.7% vs 43.6%; overall p=0.031). Dominant leg and side of the injured knee were comparable (p>0.70) (Table 1).

Table 1: Baseline sociodemographic and pre injury characteristics (N = 350).

Variable	Category	Recovered (n=216) n (%)	Not recovered (n=134) n (%)	p value
Age (years)	Mean ± SD	15.3 ± 1.2	15.1 ± 1.3	0.18
Sex	Male	148 (68.5)	76 (56.7)	0.025
	Female	68 (31.5)	58 (43.3)	
BMI (kg/m²)	Mean ± SD	23.6 ± 3.8	25.0 ± 4.5	0.002
Dominant leg	Right	186 (86.1)	113 (84.3)	0.74
	Left	30 (13.9)	21 (15.7)	
Injured knee	Right	120 (55.6)	71 (53.0)	0.72
	Left	96 (44.4)	63 (47.0)	
Sports participation pre-injury	Yes	196 (90.7)	110 (82.1)	0.017
	No	20 (9.3)	24 (17.9)	
Sports level	Recreational	64 (32.7)	48 (43.6)	0.031
	School	52 (26.5)	24 (21.8)	
	Club	56 (28.6)	28 (25.5)	
	Competitive	24 (12.2)	10 (9.1)	
Baseline activity (Tegner)	Mean ± SD	6.4 ± 1.3	5.9 ± 1.4	0.001

Not recovered patients more often developed acute swelling within 24 hours (72.4% vs 59.3%; p=0.014) and had longer delays from injury to surgery (median 104 days, IQR 70-160 vs 72 days, IQR 45-110; p=0.001). Instability burden was higher in the not recovered group, with ≥3 giving-way episodes in 44.8% vs 21.3%, while zero episodes were more common among recovered (42.6% vs 20.9%; p<0.001). Pre-op physiotherapy was more frequent in recovered patients (44.0% vs 29.9%; p=0.008). Clinically, recovered patients had better pre-op status, including less extension loss (2.1±2.7 vs 3.4±3.1 degrees; p<0.001), greater flexion (128±11 vs 123±14 degrees; p<0.001), less effusion (none: 39.8% vs 23.9%; p<0.001), and lower pain (VAS 3.2±1.5 vs 4.1±1.7; p<0.001). On MRI, meniscal tears were less frequent overall in recovered patients (none: 41.2% vs 30.6%; p=0.041), cartilage injury severity was lower (no cartilage injury: 62.0% vs 49.3%; p=0.019), and MCL injury was less common (15.7% vs 23.9%; p=0.045), while bone bruise rates did not differ significantly (p=0.17) (Table 2).

Most procedures were single-bundle reconstructions in both groups (88.0% vs 85.1%; p=0.46), and graft type distribution was similar (hamstring autograft about 71% in each; p=0.8). However, recovered patients had a slightly larger mean graft diameter (8.3±0.6 vs 8.1±0.7 mm; p=0.006). Fixation choices and tunnel drilling approach were comparable (p>0.10). Meniscus procedures differed:

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Table 2: Injury profile, pre operative clinical status, and MRI findings (N = 350).

Variable	Category	Recovered (n=216)	Not recovered (n=134)	p value
		n (%)	n (%)	
Mechanism of injury	Non-contact pivot	136 (63.0)	74 (55.2)	0.09
	Contact	28 (13.0)	26 (19.4)	
	Landing	34 (15.7)	22 (16.4)	
	Other	18 (8.3)	12 (9.0)	
Acute swelling within 24 h		128 (59.3)	97 (72.4)	0.014
Time injury to surgery (days)	Median (IQR)	72 (45–110)	104 (70–160)	0.001
Giving way episodes	0	92 (42.6)	28 (20.9)	<0.001
	1–2	78 (36.1)	46 (34.3)	
	≥3	46 (21.3)	60 (44.8)	
Pre-op physiotherapy		95 (44.0)	40 (29.9)	0.008
Pre-op ROM (degrees)	Mean ± SD	2.1 ± 2.7	3.4 ± 3.1	<0.001
Pre-op knee flexion (degrees)	Mean ± SD	128 ± 11	123 ± 14	<0.001
Pre-op effusion	None	86 (39.8)	32 (23.9)	<0.001
	Mild	90 (41.7)	56 (41.8)	
	Moderate	34 (15.7)	36 (26.9)	
	Severe	6 (2.8)	10 (7.5)	
Pre-op pain (VAS 0-10)	Mean ± SD	3.2 ± 1.5	4.1 ± 1.7	<0.001
Meniscus tear on MRI	None	89 (41.2)	41 (30.6)	0.041
	Medial	54 (25.0)	40 (29.9)	
	Lateral	57 (26.4)	38 (28.4)	
	Both	16 (7.4)	15 (11.2)	
Cartilage injury grade	None	134 (62.0)	66 (49.3)	0.019
	Grade 1	25 (11.6)	13 (9.7)	
	Grade 2	32 (14.8)	26 (19.4)	
	Grade 3	19 (8.8)	20 (14.9)	
	Grade 4	6 (2.8)	9 (6.7)	
Bone bruise		116 (53.7)	82 (61.2)	0.17
MCL injury	None	182 (84.3)	102 (76.1)	0.045
	Grade I–III	34 (15.7)	32 (23.9)	

recovered patients more often had no meniscal procedure (48.6% vs 35.8%), whereas repairs were more common in the non-recovered group (43.3% vs 34.3%; p=0.021). Operative time was shorter among recovered patients (92±24 vs 101±29 minutes; p=0.002), while tourniquet time and immediate intra-op complications were not significantly different (Table 3).

Rehabilitation variables showed the strongest contrasts. Starting rehab within 1 week was much more common in recovered patients (55.1% vs 29.9%), while delayed start beyond 2 weeks was more frequent in non-recovered patients (29.9% vs 11.6%; p<0.001). Supervised physiotherapy attendance was higher in the recovered group (81.9% vs 58.2%; p<0.001), and dose-response was evident: >20 supervised sessions occurred in 31.9% of recovered vs 9.0% of not recovered, whereas zero sessions were far more common among not recovered (41.8% vs 18.1%; p<0.001). Home exercise programs were widely prescribed but still slightly higher in recovered (95.4% vs 91.0%; p=0.028). Self-reported adherence strongly separated groups: poor adherence was 8.3% in recovered versus 35.8% in not recovered, while excellent adherence was 34.7% versus 9.0% (p<0.001). Key milestones were achieved far more often in recovered patients: full extension by 2 weeks (78.2% vs 40.3%), flexion ≥120° by 6 weeks (88.0% vs 59.7%), jogging by 3 months (69.9% vs 38.1%), agility by 6 months (63.9% vs 29.9%), and sport-specific drills by 9 months (57.4% vs 23.9%), all p<0.001 (Table 4).

Baseline patient-reported scores were similar pre-operatively for IKDC (45.3±12.1 vs 44.6±12.8; p=0.58) and KOOS-Child Sport (38.9±15.2 vs 37.6±14.9; p=0.46). By 6 months, recovered patients had significantly better outcomes across measures, with IKDC 72.4±10.8 vs 63.2±11.6 and KOOS-Sport 70.6±14.0 vs 58.3±16.1 (both p<0.001), and these gaps widened at 12 months (IKDC 88.7±6.8 vs 73.4±9.8; KOOS-Sport 86.9±10.4 vs 67.5±15.2; both p<0.001).

Table 3: Intra operative and surgical characteristics (N = 350).

Variable	Category	Recovered (n=216)	Not recovered (n=134)	p value
		n (%)	n (%)	
Technique	Single bundle	190 (88.0)	114 (85.1)	0.46
	Double bundle	26 (12.0)	20 (14.9)	
Graft type	Hamstring autograft	155 (71.8)	95 (70.9)	0.8
	BPTB autograft	34 (15.7)	20 (14.9)	
	Quadriceps tendon autograft	22 (10.2)	14 (10.4)	
	Allograft	5 (2.3)	5 (3.7)	
Graft diameter (mm)	Mean ± SD	8.3 ± 0.6	8.1 ± 0.7	0.006
Femoral fixation	Endobutton	168 (77.8)	96 (71.6)	0.86
	Interference screw	36 (16.7)	28 (20.9)	
	Other	12 (5.6)	10 (7.5)	
Tibial fixation	Interference screw	156 (72.2)	92 (68.7)	0.54
	Post and washer	46 (21.3)	32 (23.9)	
	Other	14 (6.5)	10 (7.5)	
Tunnel drilling	Transportal	158 (73.1)	86 (64.2)	0.11
	Transtibial	46 (21.3)	40 (29.9)	
	Outside in	12 (5.6)	8 (6.0)	
Meniscus procedure	None	105 (48.6)	48 (35.8)	0.021
	Repair	74 (34.3)	58 (43.3)	
	Partial meniscectomy	37 (17.1)	28 (20.9)	
Concomitant LET or ALL		40 (18.5)	16 (11.9)	0.1
Tourniquet time (min)	Mean ± SD	62 ± 14	65 ± 16	0.1
Operative time (min)	Mean ± SD	92 ± 24	101 ± 29	0.002
Immediate intra-op complication		7 (3.2)	9 (6.7)	0.14

Table 4: Rehabilitation exposure, adherence, and milestone achievement (N = 350).

Variable	Category	Recovered (n=216)	Not recovered (n=134)	p value
		n (%)	n (%)	
Rehab start time	Within 1 week	119 (55.1)	40 (29.9)	<0.001
	1–2 weeks	72 (33.3)	54 (40.3)	
	>2 weeks	25 (11.6)	40 (29.9)	
Supervised physiotherapy		177 (81.9)	78 (58.2)	<0.001
Number of supervised sessions	0	39 (18.1)	56 (41.8)	<0.001
	1–5	12 (5.6)	20 (14.9)	
	6–10	34 (15.7)	22 (16.4)	
	11–20	62 (28.7)	24 (17.9)	
	>20	69 (31.9)	12 (9.0)	
Home exercise program given		206 (95.4)	122 (91.0)	0.028
Adherence (self-report)	Poor	18 (8.3)	48 (35.8)	<0.001
	Moderate	31 (14.4)	42 (31.3)	
	Good	92 (42.6)	32 (23.9)	
	Excellent	75 (34.7)	12 (9.0)	
Full extension by 2 weeks		169 (78.2)	54 (40.3)	<0.001
Flexion ≥120° by 6 weeks		190 (88.0)	80 (59.7)	<0.001
Jogging started by 3 months		151 (69.9)	51 (38.1)	<0.001
Agility drills by 6 months		138 (63.9)	40 (29.9)	<0.001
Sport-specific drills by 9 months		124 (57.4)	32 (23.9)	<0.001

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Objective function also favored recovered patients at 6 and 12 months: hop-test LSI (12 months 94.8±5.1 vs 84.2±8.7; p<0.001) and quadriceps strength LSI (12 months 93.6 ± 5.7 vs 82.1 ± 8.9; p<0.001). At 12 months, recovered patients reported less pain (VAS 1.1±1.0 vs 2.6±1.5; p<0.001), had less effusion (none 90.7% vs 68.66%; p<0.001), and demonstrated better ROM, with smaller extension deficit (0.3±0.8 vs 1.5±1.6 degrees; p<0.001) and greater flexion (136±6 vs 131±8 degrees; p<0.001) (Table 5).

Return-to-sport outcomes were substantially better in recovered patients, including return to any sport (88.0% vs 61.9%; p<0.001), return to pre-injury sport (71.8% vs 38.1%; p<0.001), and return to the same level (60.2% vs 26.1%; p<0.001). Recovered patients also returned earlier (8.7±1.9 vs 10.2±2.3 months; p<0.001). Re-injury rates were low and similar between groups (ipsilateral graft rupture 2.3% vs 3.0%; contralateral ACL 1.9% vs 2.2%; p=0.83). However, stiffness-related complications were more frequent among non-recovered patients, including arthrofibrosis (6.7% vs 1.9%; p=0.018) and cyclops lesion treatment (8.2% vs 2.8%; p=0.02), and re-operation was higher in the non-recovered group (11.2% vs 4.2%; p=0.012) (Table 6).

Table 5: Functional outcomes and clinical status at follow up.

Outcome measure	Timepoint/Category	Recovered (n=216)	Not recovered (n=134)	p value
		Mean ± SD	Mean ± SD	
Pedi IKDC or IKDC	Pre-op	45.3 ± 12.1	44.6 ± 12.8	0.58
	6 months	72.4 ± 10.8	63.2 ± 11.6	<0.001
	12 months	88.7 ± 6.8	73.4 ± 9.8	<0.001
KOOS Child Sport	Pre-op	38.9 ± 15.2	37.6 ± 14.9	0.46
	6 months	70.6 ± 14.0	58.3 ± 16.1	<0.001
	12 months	86.9 ± 10.4	67.5 ± 15.2	<0.001
Hop test LSI (%)	6 months	86.2 ± 7.8	78.4 ± 9.5	<0.001
	12 months	94.8 ± 5.1	84.2 ± 8.7	<0.001
Quadriceps strength LSI (%)	6 months	84.5 ± 8.2	76.3 ± 9.1	<0.001
	12 months	93.6 ± 5.7	82.1 ± 8.9	<0.001
Pain VAS (0–10)	12 months	1.1 ± 1.0	2.6 ± 1.5	<0.001
Effusion (12 months)	None	196 (90.7)	92 (68.66)	<0.001
	Mild	18 (8.3)	30 (22.39)	
	Mod	2 (0.93)	10 (7.46)	
	Severe	0 (0.0)	2 (1.49)	
ROM extension deficit (degrees)	12 months	0.3 ± 0.8	1.5 ± 1.6	<0.001
ROM flexion (degrees)	12 months	136 ± 6	131 ± 8	<0.001

Table 6: Return to sport, complications, and reinjury (by 12 months or last follow up).

Variable	Category	Recovered (n=216)	Not recovered (n=134)	p value
		n (%)	n (%)	
Returned to any sport		190 (88.0)	83 (61.9)	<0.001
Returned to pre-injury sport		155 (71.8)	51 (38.1)	<0.001
Returned to same level		130 (60.2)	35 (26.1)	<0.001
Return to sport (months)	Mean ± SD	8.7 ± 1.9	10.2 ± 2.3	<0.001
Re-injury during follow-up	Ipsilateral graft rupture	5 (2.3)	4 (3.0)	0.83
	Contralateral ACL	4 (1.9)	3 (2.2)	
Arthrofibrosis		4 (1.9)	9 (6.7)	0.018
Cyclops lesion treated		6 (2.8)	11 (8.2)	0.02
Re-operation		9 (4.2)	15 (11.2)	0.012

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After adjustment, modifiable clinical and rehabilitation factors remained the main independent predictors. Higher BMI reduced the odds of recovery (AOR 0.93 per 1 kg/m², 95% CI 0.89–0.98; p=0.004), and longer injury-to-surgery time was also unfavorable (AOR 0.89 per 30 days, 95% CI 0.80–0.98; p=0.016). Cartilage injury grade ≥2 predicted poorer recovery (AOR 0.60, 95% CI 0.37–0.97; p=0.038). In contrast, supervised physiotherapy doubled recovery odds (AOR 2.14, 95% CI 1.28–3.57; p=0.004), good-to-excellent adherence tripled it (AOR 3.21, 95% CI 1.96–5.25; p<0.001), and achieving full extension by 2 weeks was a strong early milestone predictor (AOR 2.63, 95% CI 1.63–4.25; p<0.001). Male sex showed a modest positive association (AOR 1.55, 95% CI 1.01–2.38; p=0.045), while age and meniscus repair (vs none) were not significant (Table 7).

Table 7: Multivariable logistic regression model for predictors of functional recovery (12 months).

Predictor	AOR	95% CI	p value
Age (years)	1.08	0.92–1.27	0.33
Male sex	1.55	1.01–2.38	0.045
BMI (per 1 kg/m²)	0.93	0.89–0.98	0.004
Injury to surgery (per 30 days)	0.89	0.80–0.98	0.016
Cartilage injury grade ≥2	0.6	0.37–0.97	0.038
Supervised physiotherapy	2.14	1.28–3.57	0.004
Adherence good to excellent	3.21	1.96–5.25	<0.001
Full extension by 2 weeks	2.63	1.63–4.25	<0.001
Meniscus repair vs none	0.76	0.49–1.18	0.22

Discussion

In this mid-teen cohort, functional recovery at 12 months was achieved by 61.7% (216 of 350), and the contrast between recovered and not recovered patients was clinically meaningful across symptoms, objective symmetry, and sport participation. Recovered participants demonstrated substantially higher 12-month IKDC scores (88.7±6.8 vs 73.4±9.8) and KOOS-Child Sport scores (86.9±10.4 vs 67.5±15.2), alongside higher hop and quadriceps strength limb symmetry indices, lower pain, less effusion, and smaller residual ROM deficits. These findings align with prognostic literature suggesting that early symptom resolution and restoration of strength and motion underpin patient-reported recovery, while concomitant intra-articular pathology can constrain longer-term outcomes. Studies from large cohorts and systematic reviews consistently report worse patient-reported trajectories when cartilage lesions and meniscal pathology are present, even when reconstruction is technically successful [14,15].

Several predictors in our multivariable model were modifiable rehabilitation or timing factors. Supervised physiotherapy (AOR 2.14) and good-to-excellent adherence (AOR 3.21) were among the strongest independent predictors, and they were mirrored by clear, dose-like gradients in the raw comparisons, including a markedly higher proportion completing >20 supervised sessions in the recovered group. This is highly consistent with evidence that adherence and participation are central determinants of ACL rehabilitation success, with scoping review data identifying motivation, therapeutic alliance, access, and clear goal setting as key drivers of adherence, and conversely, logistical barriers and low perceived benefit as common reasons for disengagement [16]. Clinically, our data reinforce that rehabilitation should be treated as an exposure with measurable intensity and fidelity, rather than a uniform post-surgical aftercare step.

Early milestone achievement also emerged as a decisive signal. Achieving full extension by two weeks independently increased the odds of recovery (AOR 2.63), and not recovered patients experienced higher arthrofibrosis and cyclops lesion treatment rates. This pattern is biologically plausible and strongly supported by prior work: early postoperative extension deficits increase the risk of cyclops syndrome in large registry analyses [17], and systematic review evidence links extension deficit to anterior knee pain after ACL reconstruction [18]. Together, these data support a pragmatic clinical implication for adolescent services: establish extension-focused early protocols, monitor extension objectively at each early visit, and trigger rapid escalation when extension is lagging, because early deficits are not benign and may become self-perpetuating through pain, guarding, and impaired quadriceps activation.

Timing of surgery also mattered in our cohort: the recovered group had a shorter median injury-to-surgery interval (72 vs 104 days), and each additional 30 days reduced the odds of recovery (AOR 0.89). This is directionally consistent with evidence that delaying reconstruction beyond clinically relevant thresholds reduces the likelihood of achieving clinically meaningful improvement [19], plausibly through prolonged instability, recurrent “giving way”, and accrual of secondary intra-articular injury. Delays may therefore act both directly, by prolonging symptomatic impairment and deconditioning, and indirectly, by increasing meniscal and chondral burden, which is repeatedly associated with worse patient-reported prognosis in cohort and systematic review evidence [14,15,19].

Cartilage injury grade ≥2 independently predicted poorer recovery (AOR 0.60), while meniscal repair was not an independent predictor after adjustment. Prior evidence generally indicates that cartilage lesions, and to a lesser extent meniscal injury, are associated with worse patient-reported outcomes over mid-term follow-up [14,15], and recent systematic review and meta-analytic evidence focusing on concomitant focal cartilage lesions similarly supports a poorer prognosis following surgical treatment [20]. The lack of an independent meniscal repair effect in our study may reflect confounding by indication, where larger tears and more symptomatic knees are preferentially repaired, while effective repair can also mitigate longer-term consequences; it may also reflect that our endpoint is 12 months, whereas meniscal and chondral sequelae may exert stronger separation later.

Body composition and sex effects were present but likely context-dependent. Higher BMI reduced odds of recovery (AOR 0.93 per kg/m²), which is consistent with plausible mechanical and behavioral pathways, including increased joint loading, slower strength normalization, and potentially lower rehabilitation tolerance or participation. However, published findings on BMI are mixed, and a recent study in a specific graft context reported no meaningful influence of BMI 15-30 on patient-reported outcomes after ACL surgery with a 10 mm BPTB graft [21]. These discrepancies may relate to age, graft selection, BMI range, rehabilitation delivery, and outcome definitions, emphasizing that BMI is best treated as a risk stratifier that should trigger enhanced rehabilitation support rather than as a deterministic barrier. Sex differences are also reported variably across studies, but systematic review and meta-analysis indicate that outcomes can differ by sex depending on the metric and follow-up window [22], and our male sex association may reflect differences in baseline sport exposure, rehabilitation dose, or psychosocial recovery factors not fully captured in our dataset.

Finally, our objective testing results fit contemporary concerns about how symmetry is interpreted. While recovered patients exceeded common RTS symmetry thresholds (for example, mean hop LSI 94.8% and quadriceps strength LSI 93.6% at 12 months), evidence shows that limb symmetry indices can overestimate true knee function because the contralateral limb may also decondition, and performance symmetry does not guarantee symmetric biomechanics [23,24]. Moreover, quadriceps strength may be more tightly linked to patient function than hop performance alone [25]. These insights support a practical refinement of adolescent follow-up, combine strength testing with movement quality assessment, symptom status, effusion, and ROM, rather than relying on a single LSI cut-off. Our reinjury rates were low and did not differ significantly by recovery status, but modern evidence in young athletes suggests that RTS criteria alone may not fully identify second-injury risk [26], while decision-rule frameworks that incorporate strength and timed RTS can reduce reinjury risk in prospective cohorts [27].

Limitations of the Study: Key limitations include the observational design, which limits causal inference and leaves potential residual confounding, despite multivariable adjustment. Rehabilitation exposure and adherence were partly self-reported, introducing recall and social desirability bias, and rehabilitation “dose” may have varied across providers and settings. Outcomes were assessed primarily at 12 months, so longer-term function, reinjury, and degenerative changes were not captured, and some clinically relevant psychosocial factors, for example, fear of re-injury or readiness, were not measured, which may influence recovery and return to sport.

Conclusion

Functional recovery at 12 months after ACL reconstruction in mid-teen patients was achieved in nearly two-thirds of cases, with markedly better patient-reported and objective functional outcomes in the recovered group. Independent predictors of recovery were predominantly modifiable, including supervised physiotherapy, good-to-excellent adherence, and early restoration of full extension, while higher BMI, longer injury-to-surgery delay, and cartilage injury were associated with poorer recovery. These findings support prioritizing timely surgery, structured and adequately supervised rehabilitation, and early motion milestone monitoring to optimize adolescent ACL outcomes and return-to-sport readiness.

Recommendations

Implement standardized, milestone-driven rehabilitation pathways that prioritize early full extension, progressive quadriceps strengthening, and objective functional testing, with guaranteed access to supervised physiotherapy and adherence-support strategies for adolescents. Reduce injury-to-surgery delays through streamlined referral and scheduling, and stratify follow-up intensity for higher-risk patients, for example, those with higher BMI, delayed presentation, or cartilage injury, to prevent stiffness, optimize return-to-sport readiness, and minimize re-operations.

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