Early vs. delayed ACL reconstruction: Comparative insight into functional recovery and complication profiles

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Abstract. The anterior cruciate ligament (ACL) is crucial for knee stability, and its injury often necessitates surgical reconstruction. However, the optimal timing of surgery remains controversial. The present study aimed to assess the effects of surgical timing on recovery and patient outcomes. The present retrospective cohort study performed at a tertiary orthopedic center, analyzed 378 patients with ACL injuries (aged 16-40 years) to compare the outcomes of early (≤12 weeks) vs. delayed (>12 weeks) reconstruction. Data were collected from patient records and validated questionnaires assessing function, complications and satisfaction. Statistical analyses adjusted for confounders. Ethical approval was obtained, and STROBE guidelines were followed throughout the study. As demonstrated by the results, as regards the sample of 378 patients, 108 (28.6%) patients underwent early ACL reconstruction and 270 (71.4%) delayed ACL reconstruction. Males were predominant (94.2%), with a median age of 29 years. Sports injuries caused 74.9% of ACL tears. Pre-operative rehabilitation was more common in delayed cases (33.3 vs. 22.2%, P=0.035). Excellent Lysholm scores were achieved by 88 (81.5%) patients who underwent early ACL reconstruction vs. 112 (41.5%) patients who underwent delayed ACL reconstruction (P<0.001). Knee stiffness (8.5 vs. 1.9%), pain (18.1 vs. 5.6%) and instability (8.1 vs. 1.9%) were significantly higher in the patients who underwent delayed ACL reconstruction. Post-operative rehabilitation was near-universal (96.8%). Re-tear and infection rates did not exhibit significant differences between the two groups. On the whole, the present study demonstrates that early ACL reconstruction (performed within 12 weeks of injury) leads to improved function, higher activity levels and fewer complications than delayed surgery. Despite longer pre-operative rehabilitation in the cases undergoing delayed ACL reconstruction, early intervention is recommended, particularly for younger, active patients, with individualized decision-making advised.

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Introduction

Anterior cruciate ligament (ACL) injuries are among the most common and economically significant musculoskeletal injuries, particularly in athletes and physically active individuals, with an estimated annual incidence of 1 in 3,500 individuals and ~400,000 ACL reconstruction (ACLR) procedures performed annually in the USA (1). These injuries frequently result in knee instability, reduced functional capacity and long-term degenerative changes (2). ACLR is the standard surgical intervention used to restore knee stability and enable a return to pre-injury activity levels, with studies demonstrating that 80% of individuals return to some form of sport and 55% return to competitive levels following reconstruction (3). While ACLR is widely accepted as effective, the optimal timing of the surgery remains a critical yet unresolved clinical question. Early reconstruction is often advocated to prevent secondary injuries, while delayed approaches aim to reduce post-operative complications, such as arthrofibrosis (2,4). This dichotomy underscores the need to balance immediate surgical intervention with pre-operative rehabilitation to optimize outcomes.

The debate surrounding early vs. delayed ACLR centers on competing biomechanical, biological and clinical considerations. Proponents of early surgery argue that prompt stabilization reduces the risk of meniscal and chondral damage caused by persistent knee instability (4,5). Conversely, delayed reconstruction allows for the resolution of acute inflammation and the restoration of pre-operative range of motion, potentially minimizing post-operative stiffness (2,4). Clinical guidelines lack consensus, with variations in recommended waiting periods ranging from weeks to several months depending on institutional protocols (2,6). This variability reflects gaps in evidence regarding how surgical timing interacts with patient-specific factors, such as age, activity level and pre-operative rehabilitation compliance.

Muscle atrophy and neuromuscular dysfunction represent significant consequences of ACL injury that influence both surgical timing and rehabilitation outcomes. Quadriceus weakness of up to 30% compared to the contralateral limb

is nearly ubiquitous following ACL injury, resulting from a combination of disuse atrophy and central activation failure. Research indicates that the optimal window for ACLR regarding muscle preservation may lie between 21-100 days post-injury, as longer delays increase the risk of progressive quadriceps atrophy and impaired early rehabilitation (7).

The existing literature on the timing of ACLR has been limited by heterogeneous study designs, inconsistent definitions of 'early' vs. 'delayed' surgery, and short follow-up durations (2,5). While recent investigations have explored objective outcomes, such as muscle strength recovery and return-to-sport rates, only a limited number of studies have comprehensively evaluated patient-reported outcomes across diverse demographic groups (6). Furthermore, previous research often focuses on isolated ACL injuries, neglecting the impact of concomitant meniscal repairs or degenerative changes that frequently accompany delayed presentations (4,5). These limitations hinder the development of standardized, evidence-based protocols tailored to individual patient needs and activity demands.

The present retrospective study aimed to address these gaps in available evidence by analyzing the association between the timing of ACLR and multidimensional patient outcomes in a large, heterogeneous cohort. Despite numerous investigations, the lack of an available consensus on optimal surgical timing persists, particularly regarding its interaction with patient age, preoperative activity level and concomitant knee pathology (3,4,6). By evaluating functional recovery, complication rates, and patient-reported outcomes across different surgical intervals, the present study aimed to provide clinicians with data-driven insights to guide shared decision-making. The primary objective of the present study was to determine whether early ACLR demonstrates superior outcomes compared to delayed reconstruction when controlling for demographic variables and injury characteristics, thereby informing personalized treatment strategies for ACL-deficient patients.

Patients and methods

Study design and setting. A retrospective cohort study was conducted at a tertiary orthopedic center to evaluate the effects of early vs. delayed ACLR on patient outcomes. The study protocol received ethical approval from the Institutional Review Board of Raparin University (Sulaymaniyah, Iraq; Reference no. 2866/28-5-2023). The dataset comprised electronic medical records covering the period between January, 2018 to December 20, 2024. The authors retrieved these records and conducted follow-up assessments using structured questionnaires between December 20, 2024 and April 10, 2025, through in-person visits and telephone interviews. This combined approach, retrospective clinical data supplemented with contemporaneous patient-reported outcomes, is consistent with current methodological standards aimed at enhancing data completeness and validity. A detailed overview of participant inclusion and analysis is illustrated in Fig. 1.

Participants and sampling. A non-probability purposive sampling strategy was employed to select participants aged 16-40 years diagnosed with partial or complete ACL tears via magnetic resonance imaging (MRI) and a clinical examination. The sample size was calculated using G*Power software (version 3.1), based on an effect size of 0.35 derived from a comparable study, with α=0.05 and 80% power, yielding a minimum required sample of 68 participants. To account for potential attrition, the target sample was increased, resulting in 378 patients. The inclusion criteria required documented ACL injury management at the study site and the completion of post-operative follow-up for a period ≥12 months. The exclusion criteria excluded individuals with multi-ligamentous injuries, prior ipsilateral ACL reconstruction, cognitive impairments affecting self-reporting, or concomitant fractures/dislocations that could confound the recovery outcomes.

The present study reviewed the outcomes of ACL injury regarding surgical timing, comparing early (within 12 weeks post-injury) and delayed (>12 weeks post-injury) interventions in a heterogeneous patient population. The objective was to identify differences in the outcome measures related to surgical timing, thereby providing insight applicable to a broad spectrum of patients.

Data collection instruments and variables. The data were extracted from electronic medical records and structured questionnaires adapted from validated tools, including the Lysholm Knee Score (LKS) (8), Knee Society Score (KSS) (9) and Tegner Activity Scale (TAS) (8). The retrieval of medical record data and the administration of questionnaires were carried out by the authors between December 20, 2024 and April 10, 2025, after obtaining ethical approval. The questionnaire was comprised of three domains: i) Socio-demographics: Age, sex, occupation, education level, residence and pre-injury activity level. ii) Clinical and surgical details: Injury mechanism, surgical timing stratified as early (≤12 weeks) or delayed (>12 weeks). iii) Rehabilitation: The duration of pre-operative and post-operative rehabilitation and participation.

The outcome measures were the following: Functional recovery (LKS and KSS), activity level (measured using the TAS), complications (infection, re-tear, stiffness, pain, instability, nerve injury) and patient satisfaction. To ensure reliability, the questionnaire underwent pilot testing with 5 patients, which was conducted by the authors between December 1, 2024, and December 15, 2024, demonstrating excellent internal consistency (Cronbach's α=0.89) and content validity, as assessed by three orthopedic surgeons independently. Final data collection was subsequently carried out by the authors via telephone or electronic communication to maximize follow-up completeness.

Ethical considerations. All data were anonymized and stored on secure, password-protected servers. Ethical approval for the full study, including pilot testing and patient follow-up, was obtained prior to data collection. The study adhered to STROBE guidelines for observational research to ensure methodological rigor and transparency.

Statistical analysis. Statistical analyses were performed using SPSS Statistics (v27.0). Descriptive statistics summarized the baseline characteristics. Continuous variables were compared

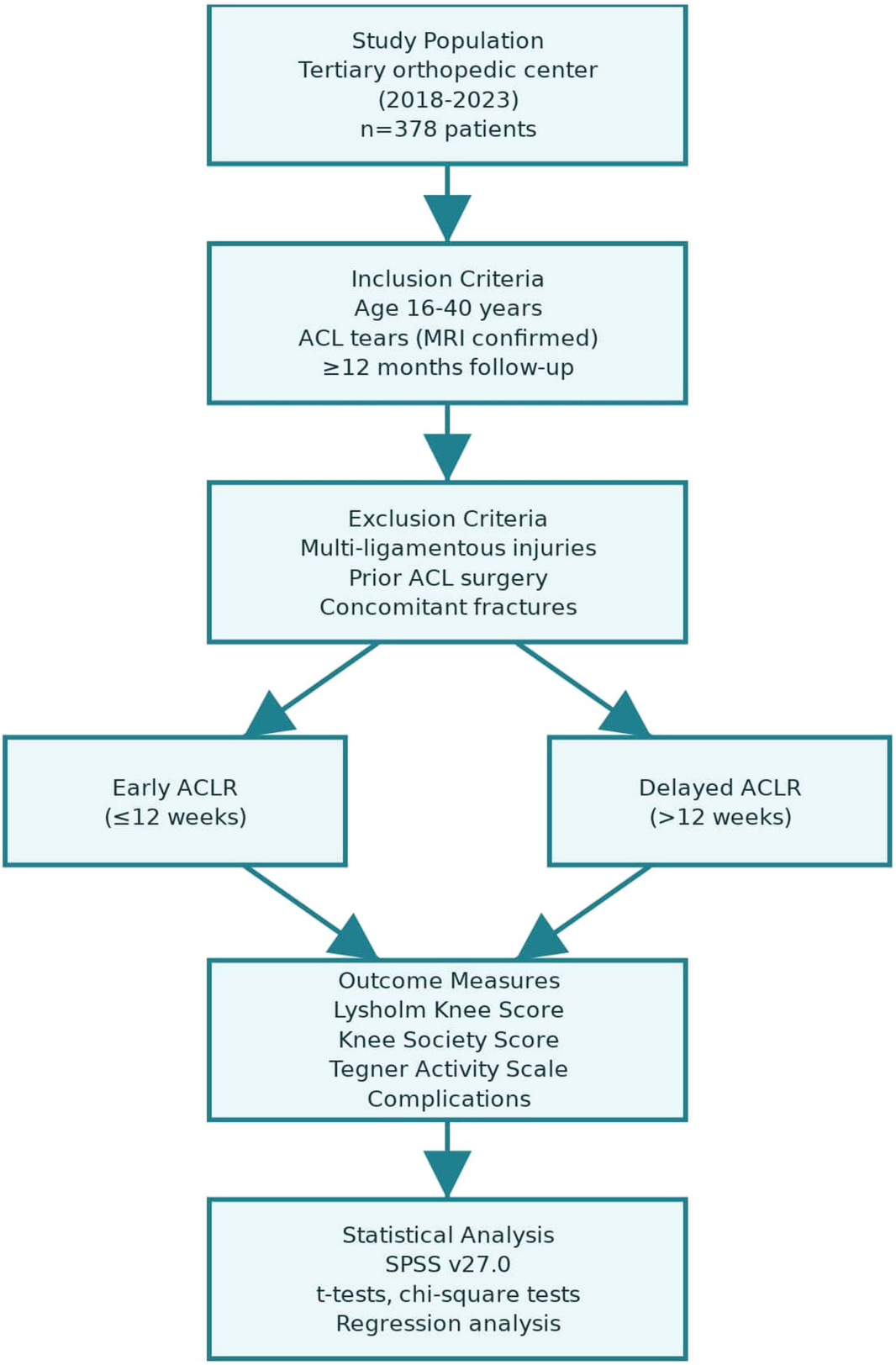

Figure 1. Flow chart illustrating the process of patient inclusion and participation in the present study. ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction.

between early and delayed groups using independent t-tests or Mann-Whitney U tests, depending on normality (assessed using Shapiro-Wilk tests). The categorical variables (e.g., complication rates) were analyzed using Chi-squared or Fisher's exact tests. Multivariable linear and logistic regression models adjusted for confounders, including age, body mass index, pre-operative activity level and meniscal/chondral injuries.

Results

The study included a total of 378 patients, with 108 (28.6%) patients in the early ACL group and 270 (71.4%) patients in the delayed ACLR group. Among these, 95 (88.0%) patients in the early ACLR group were male compared to 264 (97.8%) in the delayed ACLR group, and the difference between the groups was statistically significant (P<0.001). The median age of all the patients was 29 years [quartile range (QR), 24-35], with the early ACLR group having a younger median age of 27 years (QR, 22.5-33), compared to 30 years (QR, 25-37) in the delayed ACLR group (P=0.003). As regards occupation, heavy manual labor was the most common type of work, reported by 37 (34.3%) patients in the early group and 90 (33.3%) patients in the delayed ACLR group (P=0.096). The majority of the patients had attained a higher education, with 46 (42.6%) patients in the early ACLR group and 143 (53.0%) patients in the delayed ACLR group (P=0.138). Urban residency was reported by 58 (53.7%) of the patients in the early ACLR group and 128 (47.4%) of the patients in the delayed ACLR group (P=0.425). Sports-related injury was the leading cause of ACL rupture, accounting for 73 (67.6%) of early cases and 210 (77.8%) of delayed cases (P=0.217) (Table I).

Among the 378 patients included in the present study, 114 (30.2%) patients underwent rehabilitation prior to surgery, with a significantly higher proportion in the delayed ACLR group (n=90, 33.3%) compared to the early ACLR group (n=24, 22.2%) (P=0.035). The median duration of pre-operative rehabilitation was 4.0 weeks (QR, 2.5-8.5), with patients in the delayed ACLR group receiving longer periods of rehabilitation (median, 5.0 weeks; QR, 4.0-10.0) than those in the early ACLR group (median, 3.0 weeks; QR, 2.0-4.0) (P=0.011). Post-operative rehabilitation was almost universal, with 366 (96.8%) patients participating and no significant difference observed between the early (n=106, 98.1%) and delayed ACLR groups (n=260, 96.3%) (P=0.285). The median duration of post-operative rehabilitation was 9.0 weeks (QR, 5.0-17.0), with comparable durations between the groups (P=0.734). A history of knee popping sounds was reported in 230 (60.8%) patients, with similar rates between the early (n=63, 58.3%) and delayed (n=167, 61.9%) ACLR groups (P=0.275). The median frequency of knee popping was 30 episodes per month (QR, 15.0-75.0), consistent across both groups (P=0.606) (Table II).

The functional outcomes assessed using the LKS demonstrated that 200 (52.9%) patients achieved an excellent outcome, with a significantly higher proportion in the early ACL group (n=88, 81.5%) compared to the delayed ACLR group (n=112, 41.5%) (P<0.001). Good, fair and poor outcomes were reported in 26.5, 15.3 and 5.3% of the total cohort, respectively. The KSS for range of motion indicated that the majority of the patients attained excellent (n=286, 75.7%) or good (n=79, 20.9%) results, with no significant difference between the early and delayed ACLR groups (P=0.126). Similarly, the TAS revealed that 292 (77.2%) patients achieved excellent activity levels, with a higher percentage observed in the early ACLR group (n=93, 86.1%) compared to the delayed ACLR group (n=199, 73.7%), reaching borderline statistical significance (P=0.05) (Table III).

Complications occurred in varying frequencies among the patients. Infection was reported in 67 (17.7%) cases, with no significant difference between the early (n=21, 19.4%) and delayed ACLR groups (n=46, 17.0%) (P=0.655). Re-tear rates were low, observed in 11 (2.9%) patients overall, and tended to be higher in the delayed ACLR group (n=10, 3.7%) compared to the early ACLR group (n=1, 0.9%), although this difference was not statistically significant (P=0.190). Knee stiffness was significantly more frequent in the delayed ACLR group 23, 8.5%) than in the early ACLR group (n=2, 1.9%) (P=0.020). Nerve damage was rare, occurring in only 1 (0.3%) patient in the delayed ACLR group, with no cases reported in the early ACLR group. Persistent pain affected 55 (14.6%) patients, and was significantly more common in the delayed ACLR group (n=49, 18.1%) than the early ACLR group (n=6, 5.6%) (P=0.001). Similarly, knee instability was significantly higher in the delayed ACLR group 22(8.1%) compared to the early ACLR group (n=2, 1.9%) (P=0.020) (Table IV).

Discussion

The optimal timing for ACL reconstruction remains a topic of ongoing debate, with recent high-quality systematic reviews and meta-analyses yielding conflicting results regarding the impact of early vs. delayed intervention on comprehensive patient outcomes. In the present study, a cohort of 378 patients was analyzed, with 108 undergoing early ACLR and 270 receiving delayed surgery. Notably, the delayed group demonstrated a significantly higher proportion of male patients and an older median age, which may reflect the demographic profile commonly observed in large cohorts of ACL-deficient patients seeking care at tertiary centers (2,10). Heavy manual labor was the most common occupation in both groups, and the majority of patients had attained higher education, suggesting that socioeconomic factors did not significantly influence the timing of surgery in this population. Urban vs. rural residency also did not differ between groups, indicating that access to care may not have been a major determinant of surgical timing (11).

Herein, sports-related injury mechanisms accounted for the majority of ACL ruptures in both groups, consistent with epidemiological data identifying sports participation as the leading cause of ACL injury in young, active populations. Specifically, non-contact mechanisms account for ~70% of ACL injuries, typically occurring during pivoting, cutting, or landing maneuvers that generate combined rotational and translational forces. This injury pattern was reflected in the cohort in the present study and aligns with broader epidemiological trends demonstrating ACL injury rates of 6.5 per 100,000 athlete exposures in high school sports, with competition carrying a 7-fold higher risk than practice (12,13).

A significantly higher proportion of patients in the delayed ACLR group underwent pre-operative rehabilitation, and the duration of this rehabilitation was longer compared to the early ACLR group. This practice reflects current evidence-based recommendations to optimize knee function, reduce effusion and restore range of motion prior to surgery, although recent evidence suggests that the benefits of pre-operative rehabilitation may be limited in certain populations (2,14). A recent systematic review demonstrated that structured prehabilitation programs, incorporating quadriceps strengthening, range of motion exercises and neuromuscular training, provide

Table I. Comparison of demographic, socioeconomic and clinical characteristics between the early and delayed ACLR groups.

Variables	Total (n=378)	Early ACLR (n=108)	Delayed ACLR (n=270)	P-value
Sex, n (%)				<0.001
Male	359	95 (88.0)	264 (97.8)	
Female	19	13 (12.0)	6 (2.2)	
Age, median (QR)	29 (24-35)	27 (22.5-33)	30 (25-37)	0.003
BMI, median (QR)	26.2 (23.8-28.7)	25.9 (23.1-27.9)	26.2 (24.2-29.1)	0.547
Occupation, n (%)				0.096
Heavy manual labor	127	37 (34.3)	90 (33.3)	
Light manual labor	21	5 (4.6)	16 (5.9)	
Nonmanual (walking/standing)	71	14 (13.0)	57 (21.1)	
Non-manual (non-office)	59	24 (22.2)	35 (13.0)	
Office	92	24 (22.2)	68 (25.2)	
Domestic	8	4 (3.7)	4 (1.5)	
Educational level, n (%)				0.138
Illiterate	12	4 (3.7)	8 (3.0)	
Primary	43	10 (9.3)	33 (12.2)	
Secondary	65	26 (24.1)	39 (14.4)	
High school	69	22 (20.4)	47 (17.4)	
Higher education	189	46 (42.6)	143 (53.0)	
Time from injury to surgery, weeks, median (QR)	48.0 (12.0-144.0)	4.0 (2.0-8.0)	80.0 (36.0-208.0)	<0.001
Residence, n (%)				0.425
Urban	186	58 (53.7)	128 (47.4)	
Sub-urban	180	46 (42.6)	134 (49.6)	
Rural	12	4 (3.7)	8 (3.0)	
History of other knee injury, n (%)				0.315
Yes	72	24 (22.2)	48 (17.8)	
No	306	84 (77.8)	222 (82.2)	
Monthly income, n (%)				0.366
Sufficient	114	33 (30.6)	81 (30.0)	
Barely sufficient	243	72 (66.7)	171 (63.3)	
Insufficient	21	3 (2.8)	18 (6.7)	
Causes of ACL injury, n (%)				0.217
Sport	283	73 (67.6)	210 (77.8)	
Road traffic accident	15	7 (6.5)	8 (3.0)	
Bullet	2	0 (0.0)	2 (0.7)	
Fall from height	39	15 (13.9)	24 (8.9)	
Disease	3	1 (0.9)	2 (0.7)	
Others	36	12 (11.1)	24 (8.9)	
Return to daily activity, weeks, median (QR)	6 (4-9)	7 (2-9)	6 (2-9)	0.987

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; QR, quartile range.

measurable benefits in post-operative recovery (15). However, the optimal duration and intensity of prehabilitation remain subjects of ongoing investigation, with programs ranging from 4-6 weeks demonstrating the most consistent benefits (15). In the present study, post-operative rehabilitation was almost universal in both groups with no significant difference in participation or duration, reflecting the widespread adoption of accelerated rehabilitation protocols in modern ACLR (16).

Functional outcomes, as assessed using the LKS, revealed a marked advantage for the early ACLR group, with 81.5% achieving excellent results compared to 41.5% in the delayed ACLR group. This finding appears to be in contrast to the most recent and comprehensive meta-analysis by Shen *et al* (2), which analyzed 11 randomized controlled trials involving 972 participants and found no significant differences in the majority of functional outcomes between early and delayed

Table II. Pre-operative and post-operative rehabilitation profiles and symptomatology in early vs. delayed ACLR.

Variables	Total (n=378)	Early ACLR (n=108)	Delayed ACLR (n=270)	P-value
Rehabilitation prior to surgery, n (%)				0.035
Yes	114	24 (22.2)	90 (33.3)	
No	264	84 (77.8)	180 (66.7)	
Pre-operative rehabilitation duration, weeks, median (QR)	4.0 (2.5-8.5)	3.0 (2.0-4.0)	5.0 (4.0-10.0)	0.011
Post-operative rehabilitation, n (%)				0.285
Yes	366	106 (98.1)	260 (96.3)	
No	12	2 (1.9)	10 (3.7)	
Post-operative rehabilitation, weeks, median (QR)	9.0 (5.0-17.0)	8.0 (4.0-16.0)	9.0 (5.0-20.0)	0.734
History of knee popping sound, n (%)				0.275
Yes	230	63 (58.3)	167 (61.9)	
No	148	45 (41.6)	103 (38.1)	
Knee popping sound/month, median (QR)	30.0 (15.0-75.0)	30.0 (15.0-50.0)	30.0 (15.0-75.0)	0.606
History of knee locking, n (%)				0.415
Yes	85	21 (19.4)	64 (23.7)	
No	293	87 (80.6)	206 (76.3)	

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; QR, quartile range.

Table III. Comparison of functional outcomes, range of motion, and activity levels in early vs. delayed ACLR using LKS, KSS and TAS.

Variables	Total (n=378)	Early ACLR (n=108)	Delayed ACLR (n=270)	P-value
LKS for functional outcome, n (%)				<0.001
Excellent	200 (52.9)	88 (81.5)	112 (41.5)	
Good	100 (26.5)	8 (7.4)	92 (34.1)	
Fair	58 (15.3)	9 (8.3)	49 (18.1)	
Poor	20 (5.3)	3 (2.8)	17 (6.3)	
KSS for range of motion, n (%)				0.126
Excellent	286 (75.7)	89 (82.4)	197 (73.0)	
Good	79 (20.9)	15 (13.9)	64 (23.7)	
Fair	11 (2.9)	4 (3.7)	7 (2.6)	
Poor	2 (0.5)	0 (0.0)	2 (0.7)	
TAS for activity level, n (%)				0.05
Excellent	292 (77.2)	93 (86.1)	199 (73.7)	
Good	73 (19.3)	13 (12.0)	60 (22.2)	
Fair	9 (2.4)	2 (1.9)	7 (2.6)	
Poor	4 (1.1)	0 (0.0)	4 (1.5)	

ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; LKS, Lysholm Knee Score; KSS, Knee Society Score; TAS, Tegner Activity Scale.

ACLR. However, their analysis did identify small, yet statistically significant advantages for early reconstruction in IKDC scores (mean difference, 2.77 points) and 2-year Lysholm scores (mean difference, 2.61 points) (2). The magnitude of difference observed in the present study exceeds these meta-analytic findings, potentially reflecting the influence of confounding variables inherent in retrospective cohort designs or differences in patient populations and rehabilitation protocols. Other studies have reported that early reconstruction may be associated with improved knee function and movement ability at short-term follow-up, particularly in highly active patients (14).

Table IV. Comparison of postoperative complications in early vs. delayed ACLR.

Complications	Total (n=378)	Early ACLR (n=108)	Delayed ACLR (n=270)	P-value
Infection, n (%)	67 (17.7)	21 (19.4)	46 (17.0)	0.655
Yes	311 (82.3)	87 (80.6)	224 (83.0)	
No				
Re-tear, n (%)				0.190
Yes	11 (2.9)	1 (0.9)	10 (3.7)	
No	367 (97.1)	107 (99.1)	260 (96.3)	
Knee-stiffness, n (%)				0.020
Yes	25 (6.6)	2 (1.9)	23 (8.5)	
No	353 (93.4)	106 (98.1)	247 (91.5)	
Nerve damage, n (%)				NS
Yes	1 (0.3)	0 (0.0)	1 (0.4)	
No	377 (99.7)	108 (100.0)	269 (99.6)	
Persistent pain, n (%)				0.001
Yes	55 (14.6)	6 (5.6)	49 (18.1)	
No	323 (85.4)	102 (94.4)	221 (81.9)	
Knee instability, n (%)				0.020
Yes	24 (6.3)	2 (1.9)	22 (8.1)	
No	354 (93.7)	106 (98.1)	248 (91.9)	

NS, not significant.

Contemporary evidence regarding functional outcomes demonstrates considerable variability across studies, largely attributable to heterogeneous definitions of 'early' and 'delayed' timing, ranging from 2 days to 7 months for early reconstruction and 3 weeks to several years for delayed procedures. This definitional inconsistency complicates direct comparisons between studies and contributes to ongoing clinical uncertainty. Recent investigations have attempted to establish more precise timing thresholds, with some evidence suggesting that reconstruction performed within 3-5 months of injury may optimize outcomes while minimizing complications (17,18).

In the present study, the KSS for range of motion indicated that most patients achieved excellent or good results, with no significant difference between the groups. This is consistent with the findings of recent systematic reviews, which found no significant difference in the objective measures of knee motion or stability between early and delayed reconstruction (2,14). The TAS revealed that a higher percentage of patients in the early ACLR group achieved excellent activity levels with a borderline significant difference. This suggests that early intervention may facilitate a more rapid return to pre-injury activity, although the evidence from randomized trials remains equivocal (2,14).

Return-to-sport outcomes are critical indicators of the success of ACLR, particularly among athletic populations. Successful return to sport is influenced, not only by biomechanical recovery, but also by psychological readiness, self-efficacy and knee-related quality of life. Previous studies have demonstrated that patients who achieve a return to their pre-injury activity levels report significantly higher satisfaction rates and improved quality of life measures (19,20). In the present study, the median duration for return to daily activities was 5 weeks (QR, 4-9 weeks), with no significant difference observed between the early and delayed reconstruction groups (7.0, 2.0-9.0 weeks for the early group vs. 6.0, 2.0-9.0 weeks for the delayed group).

Complication rates were generally low in both groups, with no significant difference in infection or re-tear rates. This finding is supported by recent meta-analyses, which found no significant difference in the rates of these complications between early and delayed ACL reconstruction (2,21). However, knee stiffness and persistent pain were significantly more common in the delayed ACLR group, echoing findings from observational studies that have reported higher rates of arthrofibrosis and persistent symptoms in patients with prolonged preoperative intervals (11). In the present study, there was no significant difference in infection rates between the early and delayed ACL reconstruction groups. The initially reported infection rate of 67 out of 378 cases included all postoperative inflammatory events, such as superficial wound erythema and minor serous discharge, which were conservatively managed with oral antibiotics, rather than only confirmed deep joint infections. Upon reclassification, only 3 cases (0.8%) met the criteria for deep surgical-site infection, which is consistent with the globally reported incidence range of 0.4-1.4%, as documented in recent meta-analyses (22).

Recent studies have also highlighted the risk of secondary intra-articular pathology with delayed ACLR. For example, a previous prospective observational study found that the odds of chondral injury increased significantly with a longer time since the original injury, while meniscal injuries were less

predictable but still tended to increase over time (11). Another study reported that the risk of concomitant intra-articular pathology, particularly chondral injuries, increased linearly with a longer time to surgery (23). This suggests that while early reconstruction may not always result in improved functional outcomes, it may help to reduce the risk of additional joint damage.

The optimal window for ACLR with respect to muscle atrophy has been suggested to lie between 21 and 100 days following injury, as delaying surgery beyond this period may increase the risk of quadriceps atrophy and impair early rehabilitation (14). This is consistent with the findings of the present study, where increased stiffness and persistent pain was found in the delayed group, which may be related to prolonged immobilization or reduced muscle strength.

Several limitations should be considered in the interpretation of the present study. First, its retrospective and non-randomized nature introduces the potential for confounding variables, such as differences in surgical technique, graft selection, or associated injuries, which could influence outcomes and make it difficult to establish causality between the timing of ACLR and the clinical results. Second, all ACLRs were performed by a single surgeon, which, while ensuring procedural consistency, may limit the generalizability of the findings. The influence of the experience of the surgeon on outcomes is acknowledged as a potential source of bias and further studies are required to consider including multiple surgeons to better account for this variable. Finally, the lack of long-term follow-ups and the comprehensive assessment of secondary intra-articular pathology, such as meniscal or chondral injuries, may have resulted in an incomplete understanding of the true impact of surgical timing on knee health and function.

In conclusion, the present study demonstrates that early ACLR (performed within 12 weeks post-injury) is associated with superior functional outcomes, higher activity levels and reduced rates of knee stiffness, persistent pain, and instability compared to delayed surgery. Although delayed reconstruction allows for longer pre-operative rehabilitation, it may increase the risk of developing post-operative complications that adversely affect recovery. These findings support early surgical intervention as a strategy to optimize patient outcomes, particularly in younger, active individuals. Individualized treatment decisions should consider patient-specific factors such as age, activity demands, and concomitant knee pathology to tailor the timing of ACLR for optimal recovery.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

Both authors (BMR and YKB) contributed equally to the conception and design of the study, as well as in data collection and analysis, and in the writing of the manuscript. BMR and YKB confirm the authenticity of the raw data. Both authors have read and approved the final version of the manuscript.

Ethics approval and consent to participate

Ethical approval was obtained from the Scientific Committee of University of Raparin (Sulaymaniyah, Iraq; Reference no. 2866/28-5-2023). Written informed consent was obtained from the patients or the patients' parents (in the case of patients who were underage) for participation in the study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

References

1. Kaeding CC, Léger-St-Jean B and Magnussen RA: Epidemiology and diagnosis of anterior cruciate ligament injuries. Clin Sports Med 36: 1-8, 2017.
2. Shen X, Liu T, Xu S, Chen B, Tang X, Xiao J and Qin Y: Optimal timing of anterior cruciate ligament reconstruction in patients with anterior cruciate ligament tear: A systematic review and meta-analysis. JAMA Netw Open 5: e2242742, 2022.
3. Waldron K, Brown M, Calderon A and Feldman M: Anterior cruciate ligament rehabilitation and return to sport: How fast is too fast? Arthrosc Sports Med Rehabil 4: e175-e179, 2022.
4. Herbst E, Hoser C, Gföller P, Hepperger C, Abermann E, Neumayer K, Musahl V and Fink C: Impact of surgical timing on the outcome of anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 25: 569-577, 2017.
5. Anstey DE, Heyworth BE, Price MD and Gill TJ: Effect of timing of ACL reconstruction in surgery and development of meniscal and chondral lesions. Phys Sportsmed 40: 36-40, 2012.
6. Högberg J, Fridh E, Piussi R, Senorski RH, Cristiani R, Samuelsson K, Thomeé R and Senorski EH: Delayed anterior cruciate ligament reconstruction is associated with lower odds of returning to preinjury physical activity level at 12 months Follow-Up. Arthroscopy 41: 3401-3412.e4, 2025.
7. Thomas AC, Wojtys EM, Brandon C and Palmieri-Smith RM: Muscle atrophy contributes to quadriceps weakness after anterior cruciate ligament reconstruction. J Sci Med Sport 19: 7-11, 2016.
8. Briggs KK, Kocher MS, Rodkey WG and Steadman JR: Reliability, validity, and responsiveness of the Lysholm knee score and Tegner activity scale for patients with meniscal injury of the knee. J Bone Joint Surg Am 88: 698-705, 2006.
9. Scuderi GR, Bourne RB, Noble PC, Benjamin JB, Lonner JH and Scott W: The new knee society knee scoring system. Clin Orthop Relat Res 470: 3-19, 2011.
10. Migliorini F, Lucenti L, Mok YR, Bardazzi T, D'Ambrosi R, De Carli A, Paolicelli D and Maffulli N: Anterior cruciate ligament reconstruction using lateral Extra-articular procedures: A systematic review. Medicina (Kaunas) 61: 294, 2025.
11. Patra SK, Unnava N, Patro BP and Mohanty S: Timing of anterior cruciate ligament reconstruction and its effect on associated chondral damage and meniscal injury: A prospective observational study. Int J Res Orthop 9: 770-775, 2023.
12. Joseph AM, Collins CL, Henke NM, Yard EE, Fields SK and Comstock RD: A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics. J Athl Train 48: 810-817, 2013.

13. Montalvo AM, Schneider DK, Webster KE, Yut L, Galloway MT, Heidt RS Jr, Kaeding CC, Kremcheck TE, Magnussen RA, Parikh SN and Stanfield DT: Anterior cruciate ligament injury risk in sport: A systematic review and meta-analysis of injury incidence by sex and sport classification. J Athl Train 54: 472-482, 2019.
14. Widhalm HK, Draschl A, Horns J, Rilk S, Leitgeb J, Hajdu S and Sadoghi P: The optimal window for reconstruction of the anterior cruciate ligament (ACL) with respect to quadriceps atrophies lies within 21 to 100 days. PLoS One 19: e0296943, 2024.
15. Zakharia A, Zhang K, Al-Katanani F, Rathod P, Uddandam A, Kay J, Murphy B, Ogborn D and de SAD: Prehabilitation prior to anterior cruciate ligament reconstruction is a safe and effective intervention for short-to long-term benefits: A systematic review. Knee Surg Sports Traumatol Arthrosc 33: 4148-4166, 2025.
16. Ricupito R, Grassi A, Mourad F, Di Filippo L, Gobbo M and Maselli F: Anterior Cruciate Ligament Return to Play:'A Framework for Decision Making'. J Clin Med 14: 2146, 2025.
17. Liu AF, Guo TC, Feng HC, Yu WJ, Chen JX and Zhai JB: Efficacy and safety of early versus delayed reconstruction for anterior cruciate ligament injuries: A systematic review and meta-analysis. Knee 44: 43-58, 2023.
18. Zsidai B, Kaarre J, Narup E and Samuelsson K: Timing of anterior cruciate ligament surgery. Clin Sports Med 43: 331-341, 2024.
19. Battaglia M, Arner JW, Midtgaard KS, Haber DB, Peebles LA, Peebles AM, Ganokroj P, Whalen RJ, Provencher MT, Torre G and Ciatti R: Early versus standard return to play following ACL reconstruction: Impact on volume of play and career longevity in 180 professional European soccer players: A retrospective cohort study. J Orthop Traumatol 26: 29, 2025.
20. Piussi R, Simonson R, Zsidai B, Grassi A, Karlsson J, Della Villa F, Samuelsson K and Senorski EH: Better safe than sorry? A systematic review with meta-analysis on time to return to sport after ACL reconstruction as a risk factor for second ACL injury. J Orthop Sports Phys Ther 54: 161-175, 2024.
21. Lee YS, Lee OS, Lee SH and Hui TS: Effect of the timing of anterior cruciate ligament reconstruction on clinical and stability outcomes: A systematic review and Meta-analysis. Arthroscopy 34: 592-602, 2018.
22. Cassano GD, Moretti L, Vicenti G, Buono C, Albano F, Ladogana T, Rausa I, Notarnicola A and Solarino G: Infection after anterior cruciate ligament reconstruction: A narrative review of the literature. Healthcare (Basel) 12: 894, 2024.
23. Phillips T, Ronna B, Terner Z, Cushing T, Goldenberg N and Shybut T: After 40 days intra-articular injury, risk profile increases linearly with time to surgery in adolescent patients undergoing primary anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 33: 1192-1201, 2025.