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Early versus Delayed Rehabilitation After Anterior Cruciate Ligament Reconstruction: A Review

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Abstract :

Background: Anterior cruciate ligament (ACL) injury is a common and disabling knee condition, particularly among athletes and physically active individuals, often causing pain, instability, reduced mobility, and limited participation in sports or daily activities. Since the ACL has limited healing potential, anterior cruciate ligament reconstruction (ACLR) is commonly performed to restore knee stability. Postoperative rehabilitation is essential for successful recovery, with ongoing debate regarding whether early or delayed rehabilitation provides superior outcomes.

Objective: This review aimed to compare the effects of early versus delayed rehabilitation following ACL reconstruction on functional recovery, knee range of motion (ROM), muscle strength, pain reduction, graft integrity, and return-to-sport outcomes.

Materials and Methods: A structured literature review was conducted using PubMed/MEDLINE and Google Scholar to identify studies published between 2019 and 2025. Studies comparing early rehabilitation (within 2 weeks) and delayed rehabilitation (after 4–6 weeks) after ACLR were included. Randomized controlled trials, cohort, comparative, and cross-sectional studies assessing ROM, muscle strength, pain, functional performance, or graft integrity were selected. After screening, 10 studies involving 21,920 participants were included.

Results: Evidence showed that early rehabilitation generally produced faster improvements in knee ROM, quadriceps strength, functional performance, and earlier return to activity than delayed rehabilitation. Early weight-bearing and muscle activation reduced stiffness and muscle atrophy while improving IKDC, Lysholm, and KOOS scores. However, overly aggressive rehabilitation may increase graft stress if poorly supervised. Delayed rehabilitation may initially protect graft healing but is often associated with joint stiffness, slower muscle recovery, and delayed functional progress.

Conclusion: Early rehabilitation following ACL reconstruction generally provides superior ROM, strength, functional recovery, and earlier return to activity when guided by individualized, criterion-based progression. Although delayed rehabilitation may benefit selected high-risk patients, early rehabilitation appears more effective overall. Further high-quality trials are needed to standardize rehabilitation protocols and confirm long-term outcomes.

***Index Terms* - : Anterior cruciate ligament reconstruction, ACL rehabilitation, early rehabilitation, delayed rehabilitation, knee function, muscle strength, graft integrity.**

INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most prevalent, functionally disabling, and clinically significant musculoskeletal injuries affecting the knee joint, particularly among athletes, military personnel, and physically active individuals. The ACL is a key stabilizing structure of the knee that primarily restrains anterior tibial translation, rotational instability, and excessive valgus stress during dynamic movement. Injury to this ligament can profoundly disrupt normal biomechanics of the knee, impair athletic and occupational performance, and significantly reduce quality of life. Globally, ACL tears are increasingly common due to rising participation in high-demand sports, fitness activities, and recreational exercise. Sports such as football, basketball, handball, rugby, gymnastics, and skiing are particularly associated with a high incidence of ACL injury because they involve rapid pivoting, cutting, jumping, sudden deceleration, and awkward landing mechanics [1,2]. In addition to sports-related trauma, ACL injuries may also occur due to road traffic accidents, falls, or occupational injuries.

Epidemiological studies suggest that ACL injuries account for a substantial proportion of knee ligament injuries, with young adults between the ages of 15 and 35 years representing the highest-risk group [3]. Female athletes have also been reported to have a higher incidence of ACL tears than males participating in similar sports, potentially due to anatomical, hormonal, neuromuscular, and biomechanical differences [4]. The consequences of ACL rupture extend far beyond the immediate injury itself. Individuals frequently experience knee pain, swelling, episodes of instability or “giving way,” reduced confidence during movement, and limitations in sports participation and daily functional tasks [5]. If inadequately managed, ACL deficiency may lead to recurrent instability episodes, meniscal injury, cartilage degeneration, and an increased likelihood of developing post-traumatic osteoarthritis, even in relatively young individuals [6]. Thus, ACL injury represents not only an acute orthopedic problem but also a chronic health concern with long-term physical, psychological, and socioeconomic implications.

The intrinsic healing capacity of the ACL is poor because of its intra-articular location, synovial fluid environment, and limited vascular supply, which reduce the natural formation of stable fibrin clots necessary for healing [7]. Consequently, for young, active individuals or athletes who aim to return to pivoting sports or physically demanding activities, anterior cruciate ligament reconstruction (ACLR) has become the gold standard treatment [8]. ACLR aims to restore knee stability by replacing the torn ligament with an autograft or allograft, commonly using hamstring tendon, patellar tendon, or quadriceps tendon grafts [9]. Advances in arthroscopic surgical techniques, graft fixation devices, tunnel placement precision, and perioperative care have substantially improved the success rates of ACLR over recent decades [10]. Despite these advancements, surgery alone does not guarantee optimal recovery. Restoration of full function depends not only on successful graft placement but also on comprehensive postoperative rehabilitation.

Postoperative rehabilitation is now widely recognized as one of the most critical determinants of successful outcomes following ACL reconstruction. Rehabilitation serves multiple purposes, including pain reduction, edema control, restoration of knee ROM, prevention of arthrofibrosis, recovery of quadriceps and hamstring strength, neuromuscular re-education, proprioceptive enhancement, correction of gait abnormalities, and eventual return to pre-injury activity levels [11,12]. The rehabilitation process is often lengthy and demanding, frequently lasting 9–12 months before return to unrestricted sports is advised [13]. However, even after this period, many patients continue to exhibit persistent deficits in muscular strength, movement symmetry, and neuromuscular control. Research has consistently shown that quadriceps weakness is one of the most common and persistent impairments following ACLR, with deficits ranging from 20–30% in the early postoperative months and residual weakness of 10–15% persisting beyond six months despite structured rehabilitation [14,15].

Such deficits are not merely numerical reductions in strength but have substantial clinical significance. Persistent quadriceps weakness and limb asymmetry are associated with altered landing biomechanics, compensatory movement patterns, reduced athletic performance, increased reinjury risk, contralateral ACL injury, and the development of degenerative joint changes [16,17]. Furthermore, inadequate neuromuscular recovery may impair psychological readiness for return to sport, as fear of reinjury is a major barrier among postoperative patients [18]. Therefore, postoperative rehabilitation is not simply an adjunct to surgery but rather a cornerstone of ACLR recovery.

One of the most debated aspects of ACL rehabilitation is the optimal timing for initiation and progression of postoperative rehabilitation. Traditionally, rehabilitation protocols were conservative, emphasizing prolonged immobilization and delayed weight-bearing to protect the graft during its biological incorporation phase [19]. This delayed rehabilitation model was based on concerns that premature loading or aggressive movement might compromise graft fixation, increase laxity, or predispose the reconstructed ligament to failure [20]. Consequently, delayed rehabilitation often involved restricted ROM, bracing, and postponed strengthening for several weeks after surgery.

Over time, however, growing evidence suggested that prolonged immobilization may contribute to undesirable outcomes such as joint stiffness, arthrofibrosis, quadriceps atrophy, patellofemoral pain, and delayed functional recovery [21]. These concerns led to the emergence of early or accelerated rehabilitation protocols, which emphasize immediate or early postoperative mobilization, early ROM exercises, progressive weight-bearing, quadriceps activation, and functional strengthening within the first two weeks after surgery [22]. The rationale behind early rehabilitation is to minimize muscle wasting, promote cartilage nutrition through joint motion, reduce swelling, improve circulation, restore gait, and accelerate return to normal function [23].

Early rehabilitation has demonstrated promising benefits in improving knee extension ROM, reducing arthrofibrosis, preserving muscle activation, and facilitating earlier functional milestones [24]. Immediate weight-bearing and early closed kinetic chain exercises have also been associated with improved patient satisfaction and faster return to daily activities [25]. However, concerns remain regarding the potential risks of aggressive early rehabilitation, particularly if exercises impose excessive strain on the healing graft. Some studies have suggested that accelerated protocols may increase anterior knee laxity or graft elongation when progression is not individualized [26].

Conversely, delayed rehabilitation prioritizes graft protection by limiting early stress on the reconstructed ligament, potentially reducing the risk of mechanical overload during the vulnerable ligamentization process [27]. This approach may be particularly considered in cases involving concomitant meniscal repair, cartilage procedures, revision surgery, or specific graft types requiring cautious progression [28]. Nevertheless, delayed rehabilitation may increase the likelihood of prolonged weakness, delayed ROM restoration, reduced proprioception, and slower return to functional independence [29].

Because both rehabilitation strategies present distinct theoretical advantages and limitations, the debate surrounding early versus delayed rehabilitation continues. Modern ACL rehabilitation has increasingly shifted toward criterion-based progression rather than strictly time-based models [30]. Criterion-based rehabilitation emphasizes progression according to objective clinical milestones such as pain control, swelling reduction, quadriceps activation, limb symmetry, ROM achievement, and functional testing rather than arbitrary timelines alone [31]. This individualized approach recognizes that biological healing, psychological readiness, and functional capacity vary significantly among patients.

Rehabilitation following ACLR is commonly divided into phased progression. The maximum protection phase (day 1 to week 4) focuses on pain and swelling control, restoration of passive knee extension, early flexion, gait training, patellar mobilization, and muscle activation [32]. The moderate protection phase (weeks 4–10) emphasizes progressive strengthening, endurance, proprioception, and closed-chain kinetic exercises [33]. The minimum protection or advanced activity phase (weeks 11–24 and

beyond) incorporates plyometrics, agility drills, advanced neuromuscular control, sport-specific tasks, and return-to-sport testing [34]. Adjunctive strategies such as neuromuscular electrical stimulation, blood flow restriction training, isokinetic strengthening, and psychological readiness interventions have also gained attention in optimizing outcomes [35].

Despite substantial advancements in rehabilitation science, significant heterogeneity exists in rehabilitation protocols across institutions, clinicians, and patient populations. Differences in graft type, fixation method, concomitant injuries, patient age, baseline fitness, sport demands, and psychosocial factors further complicate standardization [36]. Moreover, while numerous studies have investigated postoperative ACL rehabilitation, findings regarding the superiority of early versus delayed rehabilitation remain inconsistent. Some evidence supports early rehabilitation for improved ROM, strength, and patient-reported outcomes without compromising graft stability [37], while other studies caution that overly aggressive rehabilitation may increase laxity or jeopardize healing in specific cases [38].

This inconsistency highlights the need for a comprehensive review of current literature examining early versus delayed rehabilitation after ACL reconstruction. Understanding the comparative effects of rehabilitation timing on muscle strength, graft integrity, knee stability, ROM, pain, and return-to-sport outcomes is essential for evidence-based clinical decision-making. Given the physical, psychological, and economic burden of ACL injuries, optimizing rehabilitation protocols is crucial not only for improving short-term postoperative outcomes but also for minimizing long-term disability and reinjury risk.

Therefore, the primary objective of this review is to critically evaluate and compare published evidence regarding early versus delayed rehabilitation protocols following ACL reconstruction. By synthesizing current research, this review aims to determine which rehabilitation approach offers the most favorable balance between accelerated functional recovery and graft protection, thereby guiding clinicians, physiotherapists, and surgeons in designing effective, individualized postoperative rehabilitation strategies.

NEED OF THE STUDY.

The growing incidence of anterior cruciate ligament (ACL) injuries, particularly among young and physically active individuals, has made anterior cruciate ligament reconstruction (ACLR) one of the most frequently performed orthopedic procedures worldwide. Despite advancements in surgical techniques, postoperative rehabilitation remains the most critical determinant of functional recovery and long-term outcomes. However, there is still a lack of consensus regarding the optimal timing of rehabilitation initiation after ACLR.

Traditionally, delayed rehabilitation protocols were recommended to protect graft integrity during the early healing phase. In contrast, contemporary approaches advocate for early rehabilitation to prevent complications such as joint stiffness, muscle atrophy, and delayed functional recovery. Although both strategies are widely used in clinical practice, existing literature presents conflicting evidence regarding their comparative effectiveness in terms of range of motion (ROM), muscle strength, graft safety, pain reduction, and return-to-sport outcomes.

Furthermore, many rehabilitation protocols are still based on time-driven progression rather than individualized, criterion-based approaches, leading to variability in patient outcomes. The absence of standardized rehabilitation guidelines and heterogeneity in clinical practice highlights a significant gap in evidence-based decision-making.

Therefore, this study is needed to systematically evaluate and compare early versus delayed rehabilitation following ACL reconstruction. By synthesizing current evidence, the study aims to identify the most effective rehabilitation approach that optimizes functional recovery while ensuring graft protection. The findings will help guide physiotherapists, clinicians, and surgeons in developing structured, evidence-based, and patient-specific rehabilitation protocols, ultimately improving clinical outcomes and quality of life for individuals undergoing ACL reconstruction.

3.1Population and Sample

The population of the present study comprised individuals diagnosed with anterior cruciate ligament (ACL) rupture who underwent anterior cruciate ligament reconstruction (ACLR), as reported in studies published between 2019 and 2025. These individuals, typically young to middle-aged and physically active, represent the broader clinical population affected by ACL injuries and therefore can be considered the universe of the study. From this population, a sample was derived by including studies that directly compared early rehabilitation (initiated within the first two weeks postoperatively) and delayed rehabilitation (initiated after 4–6 weeks). A total of 10 eligible studies involving 21,920 participants were selected based on predefined inclusion criteria such as study design, outcome measures, and relevance to rehabilitation timing. Thus, the study sample represents a subset of the overall ACLR population, selected to evaluate the comparative effectiveness of early versus delayed rehabilitation protocols.

3.2 Data and Sources of Data

The data for the present study were obtained from secondary sources through a structured and systematic literature search. Relevant studies were identified from electronic databases, primarily PubMed/MEDLINE and Google Scholar, covering publications from 2019 to 2025. Additional supporting evidence was gathered from reference lists of selected articles and standard textbooks to provide clinical context. The search strategy included a combination of keywords and Medical Subject Headings (MeSH) terms such as “anterior cruciate ligament reconstruction,” “ACL rehabilitation,” “early rehabilitation,” “delayed rehabilitation,” “accelerated rehabilitation,” “quadriceps strength,” “range of motion,” “graft integrity,” and “return to sport,” using Boolean operators (AND, OR) to refine the search. Only full-text articles published in English, including randomized controlled trials, cohort studies, comparative studies, and cross-sectional studies, were included. Data extracted from the selected studies

included author details, year of publication, study design, sample size, rehabilitation protocol, outcome measures, and key findings. Thus, the study is entirely based on secondary data sources aimed at comparing the effectiveness of early versus delayed rehabilitation following ACL reconstruction.

3.3 Theoretical framework

Anterior cruciate ligament reconstruction (ACLR) rehabilitation is based on established principles of tissue healing, biomechanics, and functional recovery. The rehabilitation process reflects the progression of graft healing through inflammatory, proliferative, and ligamentization phases, which influence the timing and intensity of therapeutic interventions. It represents the restoration of knee joint stability, range of motion, muscle strength, and neuromuscular control, which are essential indicators of patient recovery and functional performance. Early rehabilitation emphasizes controlled loading, early mobilization, and muscle activation to enhance circulation, prevent stiffness, and reduce muscle atrophy, thereby improving overall functional outcomes. In contrast, delayed rehabilitation focuses on graft protection by limiting early stress on the reconstructed ligament to avoid laxity or failure during the initial healing phase. Therefore, both approaches reflect different rehabilitation philosophies and clinical outcomes. Patients undergoing ACL reconstruction can be regarded as the universe of the study, and rehabilitation protocols (early versus delayed) are selected as key variables for comparison. Thus, this framework provides the basis for evaluating the effectiveness of rehabilitation timing in improving recovery, ensuring graft integrity, and optimizing return to activity following ACL reconstruction.

RESEARCH METHODOLOGY

The methodology section outlines the plan and methods used to conduct the study. This includes the population of the study, sample of the study, data and sources of data, study variables, and analytical framework. The details are as follows:

3.1Population and Sample

Anterior cruciate ligament (ACL) injuries are among the most common knee injuries, particularly affecting young and physically active individuals, and anterior cruciate ligament reconstruction (ACLR) is a widely accepted surgical intervention for restoring knee stability. The outcomes of ACLR largely depend on postoperative rehabilitation protocols, which vary in terms of timing and progression. Therefore, patients undergoing ACL reconstruction can be regarded as the universe of the study, as they represent the broader clinical population requiring rehabilitation. The study comprised individuals diagnosed with ACL rupture and treated with ACL reconstruction, as reported in published literature. From this population, a sample was selected based on predefined inclusion criteria, focusing on studies that compared early rehabilitation (initiated within the first two weeks postoperatively) and delayed rehabilitation (initiated after 4–6 weeks). A total of 10 relevant studies involving 21,920 participants were included in the final analysis. Thus, the selected sample represents a subset of the overall ACLR population, chosen to evaluate the effectiveness of different rehabilitation timings.

3.2 Data and Sources of Data

For this study, secondary data were collected through a systematic and structured literature search. Relevant studies were identified from electronic databases such as PubMed/MEDLINE and Google Scholar, covering publications from 2019 to 2025. Additional data were obtained from reference lists of selected articles and standard textbooks to ensure comprehensive coverage of the topic. The search strategy involved the use of keywords and Medical Subject Headings (MeSH) terms such as “anterior cruciate ligament reconstruction,” “ACL rehabilitation,” “early rehabilitation,” “delayed rehabilitation,” “range of motion,” “muscle strength,” “graft integrity,” and “return to sport,” combined using Boolean operators (AND, OR). Only full-text articles published in English, including randomized controlled trials, cohort studies, and comparative studies, were included. The data extracted included author details, year of publication, study design, sample size, rehabilitation protocol, outcome measures, and key findings. The data collection period ranged from 2019 to 2025, ensuring inclusion of recent and relevant evidence.

3.3 Theoretical framework

Variables of the study include dependent and independent variables based on rehabilitation outcomes following anterior cruciate ligament reconstruction (ACLR). The study adopts a predefined and structured approach for the selection of variables based on clinical relevance and existing literature. The primary dependent variables include pain, range of motion (ROM), muscle strength, functional outcomes (such as Lysholm score and International Knee Documentation Committee (IKDC) score), graft integrity, and return to sport. These variables collectively represent the clinical effectiveness, functional recovery, and overall success of rehabilitation protocols following ACL reconstruction.

The independent variable of the study is the timing of rehabilitation, which is categorized into early rehabilitation and delayed rehabilitation. Early rehabilitation typically begins within the first two weeks postoperatively and is based on the principle of mechanotherapy, which emphasizes the role of controlled mechanical loading in enhancing tissue healing. According to this concept, early mobilization promotes collagen alignment, increases blood circulation, reduces joint stiffness, minimizes muscle atrophy, and facilitates neuromuscular re-education. It also supports the restoration of normal movement patterns and improves proprioception, which are essential for functional recovery and return to activity.

In contrast, delayed rehabilitation is grounded in the concept of graft protection, which prioritizes the biological healing of the reconstructed ligament during the early postoperative phase. This approach limits mechanical stress on the graft to reduce the risk of elongation, laxity, or failure. It is based on the understanding that the graft undergoes a process of ligamentization, including

phases of inflammation, revascularization, and remodeling, during which excessive loading may compromise graft integrity. Therefore, delayed rehabilitation emphasizes gradual progression of exercises after an initial period of protection.

The study assumes that early rehabilitation is associated with faster improvement in pain reduction, ROM, muscle strength, and functional outcomes due to early activation and mobility, whereas delayed rehabilitation may offer advantages in terms of graft safety during the initial healing stages. However, the relationship between rehabilitation timing and outcomes is complex and influenced by multiple factors, including patient characteristics (age, activity level, compliance), surgical technique, type of graft used, and progression of rehabilitation protocols.

Furthermore, the framework incorporates a criterion-based progression model rather than a strictly time-based approach, where advancement in rehabilitation depends on achieving specific clinical milestones such as minimal pain and swelling, adequate ROM, and sufficient muscle strength. This ensures individualized rehabilitation and reduces the risk of complications.
Thus, the theoretical framework establishes a dynamic relationship between rehabilitation timing (independent variable) and clinical as well as functional outcomes (dependent variables), supported by underlying principles of tissue healing, biomechanics, and neuromuscular control. This framework provides a scientific basis for comparing the effectiveness of early versus delayed rehabilitation following ACL reconstruction and guides evidence-based clinical decision-making.

3.4 Statistical Tools and Analytical Methods

This section elaborates the statistical and analytical methods used to interpret the collected data and derive meaningful inferences. Since the present study is a systematic review based on secondary data, appropriate qualitative and quantitative synthesis techniques are applied to analyze and compare findings across the selected studies. The details of the methodology are as follows:

3.4.1 Descriptive Statistics

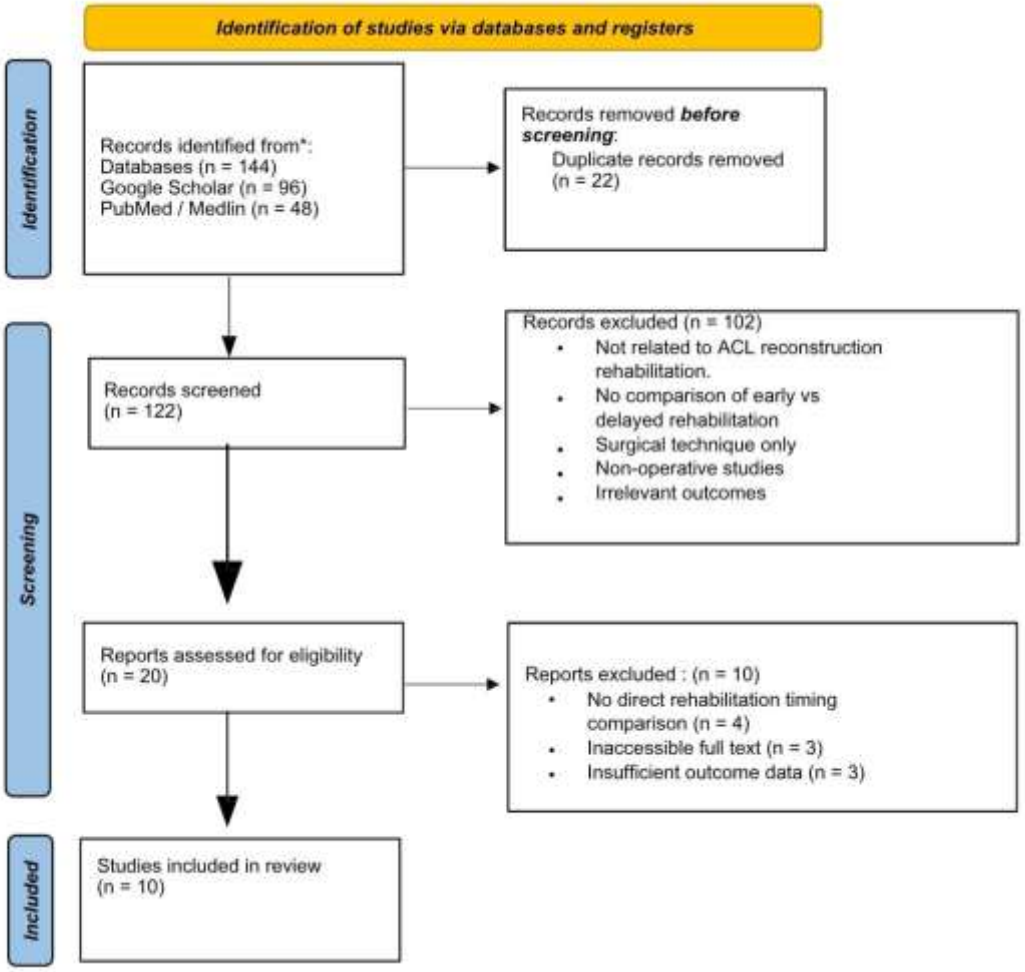
Descriptive statistics have been used to summarize and present the key characteristics of the included studies. Measures such as frequency, percentage, mean, and standard deviation (where applicable) are used to describe variables including sample size, age group, intervention type, and outcome measures. The distribution of studies based on study design (randomized controlled trials, cohort studies, etc.), year of publication, and rehabilitation protocols (early versus delayed) is also analyzed. These statistics help in understanding the general trends, variability, and patterns in the data. Tabular and graphical representations are used to enhance clarity and facilitate comparison of outcomes such as pain, range of motion (ROM), muscle strength, and functional scores across studies.

3.4.2 Comparative Analysis

A comparative analytical approach is used to evaluate the effectiveness of early versus delayed rehabilitation following ACL reconstruction. The outcomes reported in the selected studies are systematically compared based on predefined variables such as pain reduction, ROM improvement, muscle strength recovery, functional outcome scores (Lysholm, IKDC), graft integrity, and return to sport. The comparison is primarily qualitative in nature, supported by quantitative findings where available. Differences and similarities across studies are identified to determine overall trends and consistency of results. This approach helps in establishing whether early rehabilitation provides superior clinical outcomes compared to delayed rehabilitation or vice versa.

3.4.3 PRISMA Framework (Study Selection Process)

The study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a transparent and standardized study selection process. A systematic search strategy is used to identify relevant studies from electronic databases. The selection process includes identification, screening, eligibility assessment, and final inclusion of studies based on predefined inclusion and exclusion criteria. A PRISMA flow diagram is used to visually represent the number of studies identified, screened, excluded, and included at each stage. This enhances the reliability and reproducibility of the study methodology.



3.4.4 Data Extraction and Synthesis

Data from the selected studies are extracted using a standardized format, including author details, year of publication, study design, sample size, intervention details, outcome measures, and key findings. The extracted data are then synthesized to provide a comprehensive overview of the evidence. A narrative synthesis approach is used to integrate findings across studies, highlighting the effectiveness, advantages, and limitations of early and delayed rehabilitation protocols. Where possible, results are grouped and compared to identify consistent patterns and draw evidence-based conclusions.

3.4.5 Quality Assessment of Studies

To ensure the reliability and validity of the findings, the methodological quality of the included studies is assessed using standardized criteria. The assessment focuses on study design, sample size adequacy, clarity of intervention protocols, outcome measurement tools, and risk of bias. Randomized controlled trials are evaluated using tools such as the PEDro scale, while observational studies are assessed using appropriate quality appraisal checklists. Studies with higher methodological quality and lower risk of bias are given greater weight in the interpretation of results. This process helps in minimizing bias, improving the credibility of the findings, and strengthening the overall validity of the study conclusions.

3.4.2.1 Analytical Model for Rehabilitation Outcomes

In place of econometric modeling, the study adopts a clinical analytical model to evaluate rehabilitation outcomes following ACL reconstruction. The relationship between rehabilitation timing (independent variable) and clinical outcomes (dependent variables) is assessed.

Model Representation:

Rehabilitation Outcome = f (Rehabilitation Timing, Patient Factors, Intervention Protocol)

Where rehabilitation outcomes include pain, range of motion (ROM), muscle strength, functional scores (Lysholm, IKDC), graft integrity, and return to sport. Rehabilitation timing is categorized as early or delayed. Patient factors such as age, activity level, and compliance, along with intervention characteristics, influence the final outcomes. This model helps in understanding how different rehabilitation approaches impact recovery.

3.4.2.2 Outcome-Based Comparative Model

The study uses an outcome-based comparative model to analyze differences between early and delayed rehabilitation protocols. In this approach, outcomes reported in the selected studies are grouped and compared across the two rehabilitation strategies.

Model Representation:

Outcome Difference = Early Rehabilitation – Delayed Rehabilitation

Where positive differences indicate better outcomes with early rehabilitation, while negative differences indicate better outcomes with delayed rehabilitation. This model allows systematic comparison across multiple clinical parameters and helps identify which approach provides superior recovery.

3.4.3 Comparison of Rehabilitation Approaches

The next step of the study is to compare early and delayed rehabilitation protocols to evaluate which approach is more effective based on available evidence. The comparison is conducted using a narrative synthesis supported by quantitative findings where available. Outcomes such as pain reduction, ROM improvement, muscle strength recovery, functional performance, and return to sport are analyzed across studies to determine consistency of results. Greater emphasis is placed on high-quality studies to ensure accurate interpretation.

3.4.3.1 Narrative Synthesis Approach

A narrative synthesis method is used to integrate findings from different studies. Since variations exist in study design, intervention protocols, and outcome measures, a purely statistical comparison is not always feasible. Therefore, results are summarized descriptively, highlighting similarities, differences, and overall trends in findings. This approach helps in identifying whether early rehabilitation consistently demonstrates better functional outcomes compared to delayed rehabilitation.

3.4.3.2 Evidence Strength Evaluation

To strengthen the comparison, the level of evidence is evaluated based on study design and consistency of results. Studies are categorized as high, moderate, or low evidence depending on methodological quality and risk of bias. Consistent findings across multiple high-quality studies are considered strong evidence, whereas conflicting or limited data are interpreted cautiously. This approach ensures that conclusions are evidence-based and clinically relevant.

IV. RESULTS AND DISCUSSION

4.1 Results of Descriptive Statics of Study Variables

A total of 144 studies were initially identified through database searching, including 96 records from Google Scholar and 48 records from PubMed/MEDLINE. After removing 22 duplicate studies, 122 unique records remained for title and abstract screening. During this process, 102 studies were excluded for not meeting eligibility criteria, including lack of direct comparison between rehabilitation protocols, focus on surgical techniques alone, or irrelevant outcomes. The remaining 20 full-text articles were assessed for eligibility, of which 10 were excluded due to insufficient data, inaccessible full text, or absence of early versus delayed rehabilitation comparison. Ultimately, 10 studies involving 21,920 participants were included in the final review [26–33].

The included studies consistently evaluated outcomes such as knee range of motion (ROM), muscle strength, pain, graft integrity, functional scores, and return-to-sport performance. Early rehabilitation, typically initiated within the first two postoperative weeks, demonstrated superior outcomes in ROM restoration, particularly knee extension, and was associated with reduced postoperative stiffness and earlier normalization of gait [11,19]. Functional outcomes, including IKDC, Lysholm, and KOOS scores, were generally better in early rehabilitation groups, indicating improved knee function and recovery [26,28].

Early rehabilitation also showed greater improvements in quadriceps strength, reduced muscle atrophy, and better lower limb symmetry at 3- and 6-month follow-up [27,31]. However, excessively accelerated rehabilitation without proper progression occasionally increased graft laxity [30]. Delayed rehabilitation, while potentially protective for graft healing, was more commonly associated with slower ROM recovery, prolonged muscle weakness, and delayed return to activity [29,31]. Overall, criterion-based early rehabilitation appeared more effective for optimizing functional recovery without significantly compromising graft integrity [11,21,38].

S. No.	Author and publication year	Type of Study	Sample Size	Type of population	Intervention	Outcome measures	Conclusion
1	Alqahtani et al. (2025)	Cross-sectional study	132	Individuals post-ACLR	Early rehabilitation vs delayed physical therapy	IKDC score, Digital Inclinometer (ROM), Hand-held Dynamometer, Lachman and Pivot Shift tests	Early rehabilitation improved ROM, quadriceps strength, and IKDC scores with no significant compromise in graft integrity.
2	Kadivar et al. (2025)	Prospective comparative study	60	Patients with hamstring tendon autograft ACLR	Early rehabilitation vs delayed rehabilitation	Strength Symmetry Index (SSI), Isokinetic Dynamometer	Early rehabilitation demonstrated better quadriceps and hamstring strength symmetry at 3 and 6 months, with similar long-term graft outcomes.
3	Rosenberg et al. (2025)	Retrospective descriptive study	20,097	Arthroscopic ACLR patients	Supervised rehabilitation utilization timing	Rehabilitation utilization duration, Functional recovery trends	Limited prolonged rehabilitation was observed; early structured rehabilitation showed better recovery efficiency.
4	Robbertse et al. (2025)	Cross-sectional survey	120	Postoperative ACL rehabilitation practitioners/patients	Survey of rehabilitation practices	Rehabilitation protocol patterns, Functional approaches	Early rehabilitation strategies were more commonly associated with improved postoperative functional progression.
5	Högberg et al. (2025)	Retrospective cohort study	715	Patients post-ACLR	Early vs delayed ACL reconstruction rehabilitation	Isokinetic Dynamometer, Tegner Activity Scale	Delayed rehabilitation was associated with lower odds of returning to preinjury physical activity levels.
6	Yang et al. (2024)	Randomized clinical trial	90	Patients undergoing arthroscopic ACLR with hamstring graft	Early weight-bearing vs delayed weight-bearing rehabilitation	IKDC score, Lysholm score, Arthroscopic graft evaluation	Early rehabilitation improved knee function, ROM, and reduced muscle atrophy without adverse graft effects.
7	Wenning et al. (2023)	Retrospective cohort study	444	ACLR patients	Early ACL rehabilitation vs delayed/chronic rehabilitation	Isokinetic strength testing, ROM	Early rehabilitation resulted in superior muscle strength recovery and improved ROM compared with delayed protocols.
8	Elabd et al. (2023)	Randomized clinical trial	100	Amateur athletes post-ACLR	Criterion-based early rehabilitation vs conservative delayed rehabilitation	VAS, Hop Test, KOOS	Early rehabilitation improved functional performance and reduced pain more effectively than delayed rehabilitation.
9	Patra et al. (2022)	Prospective randomized trial	80	Patients after ACLR	Early accelerated rehabilitation vs delayed conservative rehabilitation	IKDC, VAS, Knee laxity, ROM	Early rehabilitation improved ROM but showed slightly higher laxity; pain and functional scores were comparable.
10	Reijman et al. (2019)	Randomized controlled trial	82	ACL rupture patients undergoing reconstruction	Early reconstruction with rehabilitation vs delayed reconstruction	IKDC score, Functional knee assessment	Early rehabilitation after reconstruction produced better strength and functional outcomes than delayed protocols.

DISCUSSION

The findings of this review suggest that early rehabilitation following anterior cruciate ligament reconstruction (ACLR) is generally more effective than delayed rehabilitation in promoting faster functional recovery, restoring knee range of motion (ROM), and improving muscle strength. Most included studies demonstrated that rehabilitation initiated within the first two postoperative weeks resulted in earlier restoration of full knee extension, reduced postoperative stiffness, and improved gait normalization compared with delayed rehabilitation protocols [11,19]. Early mobilization is particularly important because prolonged immobilization may contribute to arthrofibrosis, quadriceps atrophy, and delayed return to functional activities.

Quadriceps strength recovery was one of the most significant advantages associated with early rehabilitation. Persistent quadriceps weakness after ACLR is strongly linked to altered biomechanics, functional limitations, and increased risk of secondary injury [16]. Studies included in this review showed that early rehabilitation protocols incorporating progressive strengthening and neuromuscular re-education resulted in better quadriceps activation and improved limb symmetry at follow-up [25,31]. Improved muscle strength is essential for dynamic knee stability, return to sport, and prevention of reinjury. Functional outcome measures such as IKDC, Lysholm, and KOOS scores were also consistently higher in early rehabilitation groups, indicating superior recovery of physical performance and daily function [26,28].

Although early rehabilitation demonstrated substantial benefits, excessively accelerated progression without individualized criteria may increase graft stress or mild knee laxity [30]. Therefore, rehabilitation should not simply be aggressive but should follow a criterion-based progression model that considers pain, swelling, ROM, and muscle control [21]. Delayed rehabilitation may still be appropriate in selected cases involving concomitant meniscal repair or graft protection concerns; however, routine delay in rehabilitation appears to prolong muscle weakness and functional deficits without offering major long-term advantages [29].

Overall, the evidence supports early, supervised, and criterion-based rehabilitation as the preferred postoperative strategy after ACLR. Combining early ROM exercises, progressive strengthening, and individualized progression appears to optimize recovery while maintaining graft integrity, ultimately improving long-term functional outcomes and return-to-sport success [11,21].

GAP AND FUTURE DIRECTION:

CONCLUSION

Early rehabilitation following anterior cruciate ligament reconstruction (ACLR) appears to be a more effective approach than delayed rehabilitation for promoting overall postoperative recovery. Early initiation of rehabilitation contributes to faster restoration of knee range of motion, particularly full extension, while also reducing postoperative stiffness, muscle atrophy, and delayed functional limitations. It supports better quadriceps and hamstring strength recovery, enhances neuromuscular control, and improves functional performance, which are essential for safe return to daily activities and sports participation. Patients undergoing early rehabilitation generally demonstrate quicker improvements in mobility, gait normalization, and physical independence compared with those following delayed rehabilitation protocols.

Although delayed rehabilitation may be beneficial in selected cases where graft protection or associated tissue healing is a priority, prolonged postponement of movement and strengthening may increase the risk of persistent weakness, joint stiffness, and slower recovery. Therefore, rehabilitation should not simply be categorized as early or delayed, but rather individualized according to patient condition, surgical factors, healing progression, and functional milestones.

A criterion-based rehabilitation model that combines early mobilization, progressive strengthening, and close clinical supervision appears to provide the best balance between functional recovery and graft safety. Overall, early, structured, and personalized rehabilitation can optimize long-term outcomes, improve quality of life, and support successful return to preinjury activity levels after ACL reconstruction.

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