Closed Kinetic Chain Exercises in ACL Rehabilitation: A Systematic Review of Muscle Strength and Functional Outcomes

Latihan Closed Kinetic Chain pada Rehabilitasi ACL: Tinjauan Sistematis tentang Kekuatan Otot dan Fungsi Lutut

Review Article

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Abstract.

Background Anterior cruciate ligament (ACL) reconstruction is commonly performed to restore knee stability; however, many patients experience persistent deficits in muscle strength and functional performance, highlighting the importance of effective rehabilitation strategies. Closed kinetic chain (CKC) exercises are widely applied due to their biomechanical advantages in promoting joint stability and neuromuscular control, yet their effectiveness remains variably reported.

Objectives This study aimed to systematically review and synthesize the effects of CKC exercises on muscle strength and functional outcomes following ACL reconstruction.

Methods A systematic review design was employed using a structured search across major electronic databases for studies published between 2022 and 2026. Eligibility criteria included studies involving ACL reconstruction patients undergoing CKC-based rehabilitation with reported outcomes on muscle strength and/or functional performance. A total of six studies meeting the inclusion criteria were analyzed. Data were extracted and synthesized using a narrative approach, focusing on key outcome domains including muscle strength, functional performance, and graft stability.

Results The findings indicate that CKC exercises contribute significantly to improvements in muscle strength, joint stability, and functional performance. Greater strength gains were observed when CKC was combined with other exercise modalities, while CKC alone demonstrated consistent safety in maintaining graft integrity. Functional outcomes improved, although some deficits persisted, influenced by neuromuscular and psychological factors

Conclusion CKC exercises represent an essential component of ACL rehabilitation, with optimal outcomes achieved through integrated, individualized approaches. This study provides theoretical and practical insights for developing evidence-based rehabilitation protocols, although further high-quality research is needed to establish standardized guidelines.

Keywords: anterior cruciate ligament, closed kinetic chain exercise, rehabilitation, muscle strength, functional outcomes

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INTRODUCTION

Anterior cruciate ligament (ACL) injury remains a significant challenge in sports medicine due to its high incidence and long-term functional consequences, particularly among athletes engaged in cutting, pivoting, and landing activities. Recent epidemiological evidence indicates a rising trend of ACL injuries globally, especially in youth and female athletes, with substantial implications for healthcare systems and athletic performance [1]; [2]. Although ACL reconstruction (ACLR) is widely regarded as the gold standard intervention to restore mechanical stability, a considerable proportion of patients fail to return to their pre-injury level of sport, often due to persistent deficits in muscle strength, neuromuscular control, and psychological readiness [3]; [4]. These findings highlight the critical importance of optimizing postoperative rehabilitation strategies.

Exercise-based rehabilitation constitutes the cornerstone of ACLR recovery, with strengthening and neuromuscular training playing central roles in restoring knee function. Among various modalities, closed kinetic chain (CKC) exercises where the distal segment is fixed are frequently recommended due to their biomechanical advantages, including reduced anterior tibial translation and enhanced co-contraction of the quadriceps and hamstring muscles [5]; [6]. These characteristics are thought to promote joint stability and functional movement patterns, aligning with contemporary rehabilitation principles emphasizing task-specific and load-managed training.

Despite their widespread clinical application, the relative effectiveness of CKC exercises compared to other interventions, particularly open kinetic chain (OKC) exercises, remains a subject of ongoing debate. Some studies suggest that CKC exercises are superior in improving functional outcomes and reducing joint laxity, while others report comparable or even greater improvements in isolated muscle strength with OKC protocols [7]; [8]. Furthermore, systematic reviews have reported heterogeneous findings, largely due to differences in intervention protocols, outcome measures, and rehabilitation timelines, making it difficult to establish definitive clinical recommendations [9]; [10].

In addition to inconsistencies in comparative effectiveness, previous research has often focused on either muscle strength or functional outcomes in isolation, rather than examining both domains concurrently. This represents a critical limitation, as optimal rehabilitation should address not only isolated muscular performance but also integrated functional capacity required for return to sport. Moreover, variations in patient characteristics, such as age, activity level, and time since surgery, further complicate the generalizability of findings [4];[6].

Another notable gap in the literature is the lack of updated and focused systematic reviews that specifically synthesize the effects of CKC exercises on both muscle strength and knee functional outcomes following ACL reconstruction. While earlier reviews have contributed valuable insights, recent advances in rehabilitation science including progressive loading strategies, neuromuscular training integration, and individualized rehabilitation protocols necessitate a re-evaluation of existing evidence [8]; [11]. Therefore, a contemporary synthesis of the literature is essential to inform evidence-based clinical practice.

Accordingly, the present study aims to systematically review and critically synthesize current evidence on the effects of closed kinetic chain exercises on muscle strength and functional outcomes in individuals following ACL reconstruction. This review seeks to identify patterns of effectiveness, explore potential sources of heterogeneity, and provide a comprehensive understanding of how CKC-based interventions contribute to rehabilitation outcomes.

From a theoretical perspective, this study contributes to the integration of biomechanical and neuromuscular control frameworks within exercise-based rehabilitation. It advances the understanding of how CKC exercises influence joint loading, muscle activation patterns, and functional performance. Practically, the findings are expected to support clinicians, physiotherapists, and sports rehabilitation specialists in designing evidence-based, targeted rehabilitation programs, while also highlighting directions for future research, particularly in optimizing individualized rehabilitation strategies and long-term functional recovery.

METHOD

Research Design

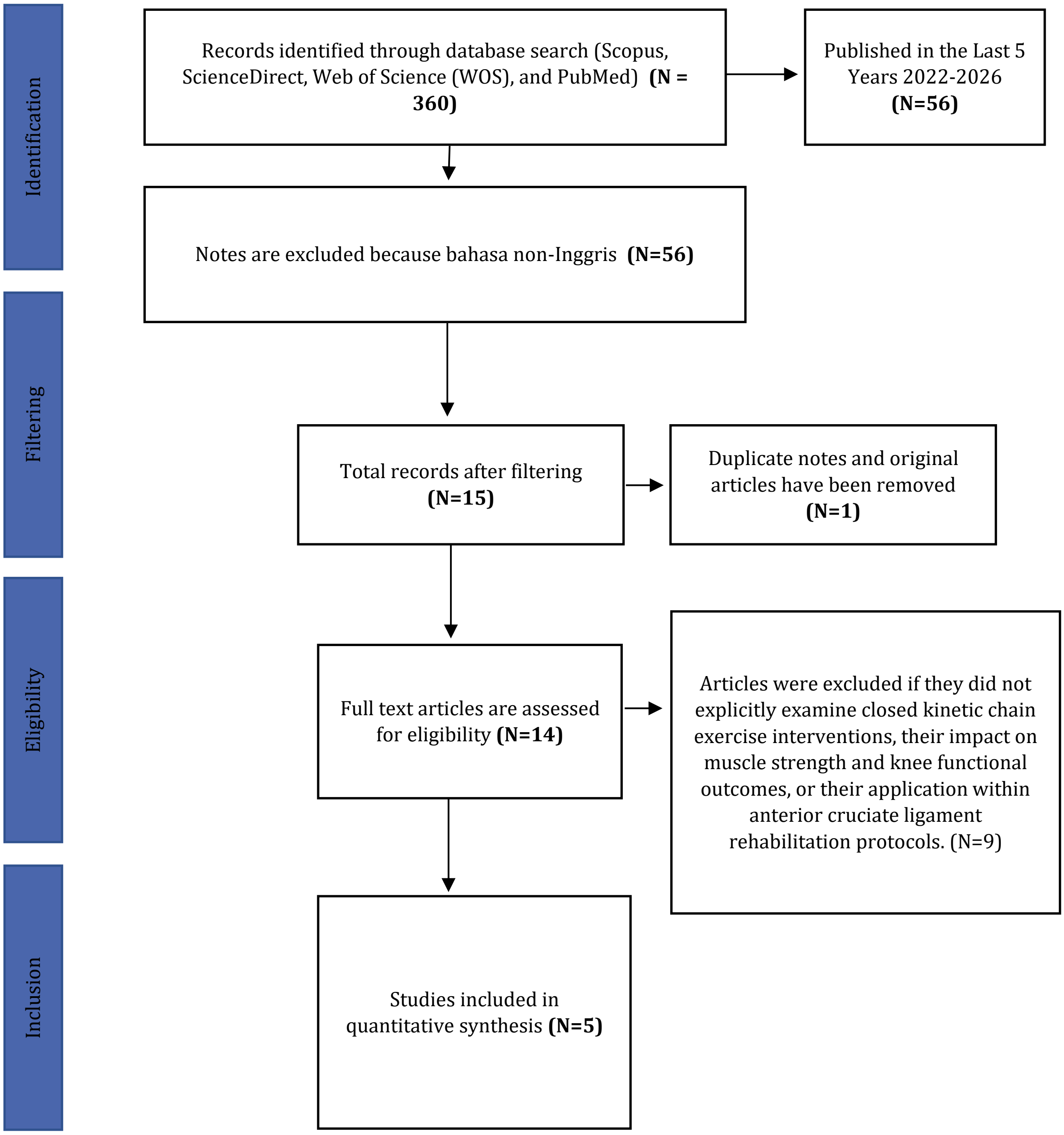
This study employed a systematic review design to synthesize current evidence regarding the effects of closed kinetic chain (CKC) exercises on muscle strength and functional outcomes following anterior cruciate ligament reconstruction (ACLR). The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, reproducibility, and methodological rigor. PRISMA provides a structured framework for identifying, screening, and synthesizing relevant studies, including clearly defined stages such as literature identification, eligibility assessment, and inclusion of studies in the final synthesis [12]. The overall procedure consisted of (1) defining the research question using the PICO framework (Population, Intervention, Comparison, Outcome), (2) conducting a comprehensive literature search, (3) screening and selecting eligible studies, (4) extracting and synthesizing data, and (5) reporting findings using a narrative synthesis approach. This structured design is widely recommended to enhance the validity and reliability of evidence synthesis in health and rehabilitation research.

Search and Selection Strategy

A comprehensive literature search was conducted across multiple electronic databases, including PubMed, Scopus, Web of Science, and ScienceDirect, to identify relevant studies published between 2020 and 2026. The search strategy was developed using a combination of controlled vocabulary (e.g., MeSH terms) and free-text keywords, such as "anterior cruciate ligament," "ACL reconstruction," "closed kinetic chain exercise," "rehabilitation," "muscle strength," and "functional outcomes." Boolean operators (AND, OR) were applied to refine the search and ensure sensitivity and specificity. In accordance with PRISMA guidelines, the search strategy, including applied filters (e.g., publication year, human subjects, English language), was explicitly defined to enhance reproducibility and minimize bias [13]. All retrieved records were imported into reference management software (e.g., Mendeley) for duplicate removal. Subsequently, a two-stage screening process was conducted, consisting of title and abstract screening followed by full-text assessment. Study selection was performed independently by two reviewers to reduce selection bias, with discrepancies resolved through discussion or consultation with a third reviewer.

Inclusion and Exclusion Criteria

Eligibility criteria were established based on the PICO framework to ensure consistency and relevance of included studies. Inclusion criteria comprised: (1) studies involving individuals undergoing ACL reconstruction, (2) interventions incorporating closed kinetic chain exercises as a primary or combined rehabilitation approach, (3) outcomes measuring muscle strength and/or knee functional performance, (4) experimental or quasi-experimental study designs, and (5) articles published in peer-reviewed journals between 2022 and 2026. Exclusion criteria included: (1) studies involving non-human subjects, (2) qualitative studies, reviews, or meta-analyses, (3) studies not reporting relevant outcome variables, and (4) articles published in languages other than English. These criteria align with PRISMA recommendations, which emphasize the need to explicitly define study characteristics (e.g., population, intervention, outcomes, and study design) to ensure transparency and reduce bias in systematic reviews [14]. Data extraction was performed using a standardized form, and the methodological quality of included studies was assessed using appropriate appraisal tools (e.g., PEDro scale or Cochrane risk-of-bias tool). Data were analyzed using a narrative synthesis approach, supported by tabulation of study characteristics and findings, with additional analysis conducted using Microsoft Excel and reference management tools to organize and visualize data patterns.



RESULTS AND DISCUSSION

Table 1 summarizes the methodological characteristics of the included studies published between 2022 and 2026. The findings indicate that closed kinetic chain (CKC) exercises play a central role in anterior cruciate ligament (ACL) rehabilitation, particularly in improving muscle strength, joint stability, and functional performance outcomes [15]; [16]. Several studies demonstrate that CKC-based interventions contribute to enhanced neuromuscular control and limb symmetry, which are essential for functional recovery and return-to-sport readiness [17]; [18]. In addition, rehabilitation programs integrating CKC with other modalities, such as open kinetic chain (OKC) exercises and neuromuscular training, tend to produce greater improvements in quadriceps and hamstring strength without increasing graft laxity (Forelli et al., 2023; Forelli et al., 2024). Case-based evidence further supports the effectiveness of individualized rehabilitation programs incorporating CKC principles in facilitating successful return to sport following reinjury [19]. However, several limitations remain, including variability in intervention protocols, lack of standardization in exercise dosage and progression, and limited high-quality experimental studies focusing exclusively on CKC interventions. Overall, these findings highlight the importance of optimizing CKC-based rehabilitation strategies and integrating them with individualized, evidence-based approaches to improve muscle strength and functional outcomes following ACL reconstruction.

Table 1. Summary of Included Studies

Author	Characteristics of the sample	Method	Conclusion
[19]	Single case: 20-year-old male collegiate volleyball athlete with ACL graft rupture post-reconstruction	Case report; nonoperative rehabilitation focusing on movement fear and sport-specific training	Personalized rehabilitation can restore function and enable return to sport, highlighting the importance of biopsychosocial factors in ACL rehabilitation
[18]	114 licensed physical therapists in Saudi Arabia	Cross-sectional online survey on preoperative ACL rehabilitation practices	CKC exercises are widely used in preoperative rehabilitation; however, lack of standardization and referral limits optimal implementation
[17]	34 adults post-ACLR	Cross-sectional study using Y-Balance, single-leg hop, FMS, and isokinetic testing (OKC & CKC strength)	Operated limbs showed reduced functional performance; muscle strength is associated with limb symmetry and functional outcomes
[16]	53 ACLR patients (CKC vs CKC+OKC groups)	Retrospective controlled study comparing graft laxity and strength over 6 months	Addition of OKC to CKC does not increase graft laxity, indicating CKC-based rehab remains safe and effective
[15]	103 ACLR patients (intervention vs control group)	Cohort study assessing strength (isokinetic testing) and graft laxity at 3 and 6 months	Combining OKC with CKC improves quadriceps and hamstring strength without increasing graft laxity

To provide a clearer synthesis, the main findings were categorized into three key domains: muscle strength, functional outcomes, and graft laxity.

1. Muscle Strength Outcomes

Across the included studies, improvements in muscle strength particularly in the quadriceps and hamstring muscles were consistently reported as a primary outcome of rehabilitation interventions. [15] demonstrated that the combination of CKC and OKC exercises resulted in significantly greater quadriceps and hamstring strength compared to CKC alone, as measured by limb symmetry index (LSI) and peak torque-to-body weight ratio. Similarly, [20] emphasized that CKC-based rehabilitation protocols contribute substantially to restoring muscle strength, especially when integrated with neuromuscular and progressive resistance training. However, the evidence suggests that CKC exercises alone may not fully optimize isolated muscle strengthening, particularly for the quadriceps, which may benefit from complementary OKC interventions.

2. Functional Outcomes

Functional recovery, including dynamic balance, movement control, and return-to-sport readiness, was another key outcome assessed across studies. [17] reported that although dynamic balance (Y-Balance Test) did not significantly differ between operated and non-operated limbs, functional performance deficits persisted in single-leg hop tasks, indicating incomplete recovery. Furthermore, [19] highlighted that individualized rehabilitation focusing on sport-specific movements and psychological readiness resulted in successful return to sport, supported by significant improvements in functional scores and symmetry (>90%). These findings indicate that CKC exercises contribute to functional improvements; however, functional recovery is multifactorial and influenced by neuromuscular control and psychological factors.

3. Graft Laxity and Joint Stability

Graft integrity and joint stability were evaluated in studies comparing CKC with combined CKC+OKC protocols. [16] found no significant differences in graft laxity between groups, suggesting that the addition of OKC exercises does not compromise joint stability when appropriately prescribed. Similarly, [15] reported that early integration of OKC exercises alongside CKC did not increase anterior knee laxity at 3 and 6 months postoperatively. These findings reinforce the safety of CKC-based rehabilitation and suggest that concerns regarding increased graft strain with additional strengthening exercises may be overstated when progression is properly controlled.

The present systematic review highlights that closed kinetic chain (CKC) exercises play a fundamental role in anterior cruciate ligament (ACL) rehabilitation, particularly in enhancing muscle strength, functional performance, and joint stability. From a biomechanical perspective, CKC exercises facilitate co-contraction of the quadriceps and hamstring muscles, thereby reducing anterior tibial translation and promoting joint stability [21]. This mechanism aligns with the findings of the included studies, which consistently reported improvements in strength and functional outcomes following CKC-based interventions.

However, the results also indicate that CKC exercises alone may not be sufficient to maximize rehabilitation outcomes, particularly in terms of isolated muscle strength. The superior improvements observed in combined CKC and OKC protocols [15] suggest that a multimodal approach may be more effective. This supports current rehabilitation frameworks that emphasize progressive loading and specificity of training to address both global and isolated muscular deficits [8]. Therefore, rather than viewing CKC and OKC exercises as competing modalities, the evidence suggests they should be integrated strategically within different phases of rehabilitation.

In terms of functional recovery, the findings reveal that improvements in muscle strength do not necessarily translate directly into full functional restoration. Persistent deficits observed in hop performance and limb symmetry [17] indicate that neuromuscular control and movement quality are critical determinants of recovery. This aligns with the neuromuscular control theory, which emphasizes the role of sensorimotor integration in dynamic joint stability [4]. Additionally, the case report by [19] underscores the importance of psychological readiness, suggesting that rehabilitation outcomes are influenced by biopsychosocial factors beyond physical parameters.

Another important finding is the consistent evidence supporting the safety of CKC exercises in maintaining graft integrity. Concerns regarding increased graft laxity, particularly with early loading, were not supported by the included studies [16]. This suggests that appropriately dosed and supervised exercise progression does not compromise surgical outcomes. These findings are consistent with contemporary clinical guidelines, which advocate for early but controlled loading to facilitate tissue adaptation and functional recovery [6].

Despite these positive findings, several limitations were identified. First, there is considerable heterogeneity in intervention protocols, including variations in exercise type, intensity, frequency, and duration, which limits comparability across studies. Second, the lack of standardized outcome measures particularly for functional performance poses challenges in synthesizing evidence. Third, the limited number of high-quality randomized controlled trials focusing exclusively on CKC interventions highlights a gap in the literature. Additionally, some studies relied on small sample sizes or observational designs, which may reduce the generalizability of findings.

Based on these limitations, future research should focus on developing standardized, evidence-based rehabilitation protocols that clearly define CKC exercise parameters, including progression criteria and dosage. Furthermore, high-quality randomized controlled trials are needed to isolate the effects of CKC exercises and compare them with other modalities. Future studies should also incorporate multidimensional outcome measures, including biomechanical, neuromuscular, and psychological variables, to provide a more comprehensive understanding of rehabilitation outcomes.

Overall, this study contributes to the growing body of evidence supporting the integration of CKC exercises within ACL rehabilitation programs. The findings emphasize the importance of a multimodal, individualized approach that combines strength training, neuromuscular control, and psychological readiness to optimize recovery and reduce the risk of reinjury.

CONCLUSION

This systematic review demonstrates that closed kinetic chain (CKC) exercises play a critical role in anterior cruciate ligament (ACL) rehabilitation, contributing to improvements in muscle strength, joint stability, and functional outcomes, while maintaining graft integrity. The findings indicate that CKC-based interventions are effective as a foundational rehabilitation approach; however, optimal recovery is more likely achieved when CKC exercises are integrated with complementary modalities, such as open kinetic chain and neuromuscular training, to address both isolated muscle deficits and functional performance. Theoretically, this study reinforces the integration of biomechanical and neuromuscular control principles in exercise-based rehabilitation, while practically, it provides evidence to support clinicians in designing structured, progressive, and individualized rehabilitation programs to enhance return-to-sport outcomes. Despite these contributions, the review is limited by heterogeneity in intervention protocols, variations in outcome measures, and a limited number of high-quality studies focusing exclusively on CKC interventions, which may affect the generalizability of findings. Therefore, future research is recommended to develop standardized CKC-based rehabilitation protocols, conduct high-quality randomized controlled trials, and incorporate multidimensional outcome measures, including biomechanical, neuromuscular, and psychological factors, to further optimize rehabilitation strategies and long-term functional recovery following ACL reconstruction.

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AUTHOR CONTRIBUTION STATEMENT

The writing of this article involved roles in devising the research concept and design, reviewing and analyzing relevant literature, and drafting the overall manuscript

CONFLICT OF INTEREST AND FUNDING

There is no conflict of interest

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