Comparative Effects of Closed versus Open Kinetic Chain Exercises on Knee Stability, Quadriceps Strength, Proprioception, and Functional Performance in Early Rehabilitation after Anterior Cruciate Ligament Reconstruction

Dr. Sarfraz Ahmad[1], Prof. Dr. Muhammad Riaz Baig Chugtai[2], Rumman Anwar[3], Maryam Noor[4], Hafiza Mubeen Sahar[5], Maria Mehmood[6], Shahira Safder[7], Ishma Ilyas[8]

[1]Neuro Spine and Joints Pain Care Consultant, Physical Therapist, Lahore, Pakistan [2]Department of Rehabilitation & Health Sciences, Nazeer Hussain University, Karachi, Pakistan [3]Physiotherapist, Rabia Trust Hospital, Faisalabad, Pakistan [4]Physical Therapist, Faisalabad, Pakistan [5]Consultant Physiotherapist, Al-Kareem Hospital, Faisalabad, Pakistan [6]Physical Therapist, Faisalabad, Pakistan [7]Lecturer, BIRS (BMDC), Pakistan [8]Physiotherapist, InMotion Rehabilitation Clinic, Faisalabad, Pakistan

**Corresponding Author: Dr. Hafiza mubashra, Hafizamubashra123@gmail.com*

ABSTRACT

Background: Anterior cruciate ligament (ACL) reconstruction remains one of the most common orthopedic surgical interventions, yet optimal rehabilitation protocols remain incompletely defined. While both closed kinetic chain (CKC) and open kinetic chain (OKC) exercises are widely employed in clinical practice, direct comparative evidence regarding their differential efficacy during early rehabilitation phases is limited. Objective: This study aimed to compare the differential effects of CKC versus OKC exercise protocols on knee stability, quadriceps strength, proprioception, and functional performance during early post-ACL reconstruction rehabilitation (weeks 6-12 post-operatively). Methods: A prospective randomized controlled trial was conducted with 60 participants (36 male, 24 female; mean age 28.3 ± 8.5 years) randomly allocated to CKC (n=30) or OKC (n=30) groups. Primary outcome measures included anterior knee laxity measured via Lachman test, quadriceps strength assessed by isokinetic dynamometry at 60°/second, proprioceptive function evaluated through single-leg stance testing, and functional performance determined using the 6-minute walk test and Timed Up-and-Go test. Assessments were conducted at baseline (week 6), mid-intervention (week 9), and post-intervention (week 12) phases. Results: Both interventions produced statistically significant improvements across all outcome measures ($p<0.05$). The CKC group demonstrated superior knee stability improvements (59.7% reduction from baseline) and enhanced proprioceptive gains (234.1% improvement; $p=0.009$), whereas the OKC group achieved substantially greater quadriceps strength development (113.2% improvement; $p=0.003$). Functional performance improvements were comparable between groups ($p>0.05$). Conclusions: Both CKC and OKC exercise modalities produce clinically meaningful improvements during early ACL rehabilitation, with distinct profiles of benefit. CKC exercises appear more beneficial for stability and proprioceptive restoration, while OKC exercises provide superior isolated strength gains. A combined sequential approach incorporating both modalities is recommended for comprehensive functional restoration.

Keywords: Anterior cruciate ligament reconstruction, closed kinetic chain exercises, open kinetic chain exercises, knee stability, proprioception, quadriceps strength, physical rehabilitation

INTRODUCTION

Anterior cruciate ligament injuries represent a significant healthcare burden, particularly among active populations and athletes. The epidemiology of ACL injuries demonstrates an estimated annual incidence exceeding 200,000 cases in the United States, with comparable rates documented across developed nations. Reconstruction has emerged as the gold standard surgical intervention, with contemporary arthroscopic techniques achieving graft integrity rates surpassing 90% and sustained patient satisfaction in the majority of treated individuals.

However, anatomically successful surgical reconstruction does not automatically ensure functional recovery or safe return to pre-injury activity levels. Post-operative rehabilitation represents a critical determinant of long-term functional outcomes, return-to-sport success, and the prevention of secondary degenerative joint disease. Contemporary evidence emphasizes that the quality and specificity of rehabilitation programming substantially influences patient outcomes and longevity of graft function.

Current rehabilitation literature recognizes distinct biomechanical properties of closed kinetic chain (CKC) and open kinetic chain (OKC) exercises. Open kinetic chain exercises involve movement of the distal segment relative to a fixed proximal base, enabling isolated muscle strengthening with precise resistance control. Conversely, closed kinetic chain exercises maintain distal segment fixation while movement occurs proximally, promoting neuromuscular co-contraction patterns and enhanced proprioceptive feedback. While individual efficacy of each modality has been documented in the literature, comparative effectiveness studies specifically examining their relative benefits during the critical early post-operative phase (weeks 6-12) remain limited.

The purpose of this investigation was to conduct a direct comparative analysis of CKC and OKC exercise modalities across multiple rehabilitation outcomes during early ACL reconstruction recovery. We hypothesized that differential exercise modalities would produce differential outcomes on specific measures, with CKC exercises demonstrating advantages in proprioceptive and stability outcomes, while OKC exercises would yield superior isolated strength gains. Understanding these differential effects will inform evidence-based clinical decision-making and enable clinicians to strategically sequence interventions according to rehabilitation-specific objectives.

METHODS

Study Design and Participants

This investigation was conducted as a prospective randomized controlled trial over a 24-month enrollment period. Sixty participants (36 male, 24 female; mean age 28.3 ± 8.5 years, range 18-42 years) undergoing primary ACL reconstruction were recruited from orthopedic surgery and sports medicine clinics. Inclusion criteria were: (1) primary, unilateral ACLR performed within 4 weeks of enrollment; (2) age range 18-45 years at time of injury; (3) absence of prior ACL pathology on either limb; and (4) absence of concurrent injuries to other knee structures requiring operative intervention. Exclusion criteria encompassed: advanced articular cartilage pathology (International Cartilage Repair Society

Grade ≥3), concurrent meniscal injuries requiring immobilization beyond 6 weeks, systemic inflammatory joint disease, neurological impairments affecting motor control or proprioception, and inability to complete the 6-week intervention protocol due to medical or logistical reasons.

Random allocation to intervention groups was accomplished using computer-generated randomization sequences stratified by biological sex and graft type (hamstring autograft versus patellar tendon autograft) to ensure balanced distribution of potential confounding variables. Institutional Review Board approval was obtained prior to participant enrollment, and all participants provided written informed consent in accordance with institutional policies and principles outlined in the Declaration of Helsinki.

Intervention Protocols

Both groups received standardized general rehabilitation components including range of motion exercises (progressively advancing from 0-10° extension toward complete extension, with flexion advancing from 0-60° to 0-110° over the initial 6 weeks), soft tissue mobilization techniques, proprioceptive neuromuscular facilitation procedures, and cardiovascular conditioning via stationary cycling and treadmill walking. The primary differentiating intervention variable was the strengthening exercise modality implemented during weeks 6-12 post-operatively.

Closed Kinetic Chain (CKC) Group Exercises:

• Double-leg squats with progressive range progression (0-30° weeks 6-8; 0-60° weeks 9-12) • Step-ups and step-downs on 4-6 inch platform • Mini lateral lunges using body weight resistance • Seated leg press machine exercises with progressive resistance • Walking activities incorporating proprioceptive demands (forward and lateral) • Single-leg stance activities with progressive difficulty progression

Open Kinetic Chain (OKC) Group Exercises:

• Seated knee extension exercises (isotonic and isokinetic modes) • Prone knee flexion exercises • Supine straight leg raising with progressive external resistance • Supine hip flexion, abduction, and adduction exercises • Resistance band exercises applied in multiple planes (flexion, extension, internal/external rotation) • Isolated quadriceps sets with visual biofeedback

Outcome Measures and Assessment Procedures

All assessments were conducted at three time points: baseline (week 6 post-operatively), mid-intervention (week 9), and post-intervention (week 12). Assessors were licensed physical therapists blinded to group allocation and trained in standardized assessment protocols. Primary outcome measures included: (1) anterior knee stability quantified via Lachman test performed at 20-30° knee flexion, with anterior tibial translation measured in millimeters; (2) quadriceps muscle strength assessed using isokinetic dynamometry (Biodex System 3, Shirley, NY, USA) at 60°/second angular velocity, expressed as peak torque normalized to body weight (Nm/kg); (3) proprioceptive capacity evaluated through single-leg stance testing on a firm surface with open eyes, with duration recorded in seconds;

and (4) functional performance assessed using the 6-minute walk test (distance in meters) and Timed Up-and-Go test (time in seconds).

Statistical Analysis

Statistical analyses were performed using SPSS software (version 25.0, IBM Corporation, Armonk, NY, USA) with statistical significance defined as $p<0.05$. Descriptive statistics including means and standard deviations were calculated for all variables. Data normality was assessed using the Shapiro-Wilk test. Between-group differences at baseline were evaluated using independent samples t-tests for continuous variables and chi-square tests for categorical variables. Longitudinal within-group changes across time points were analyzed using repeated measures analysis of variance (ANOVA) with Bonferroni correction for multiple comparisons. Between-group differences at each assessment time point were assessed using independent samples t-tests. Effect sizes were quantified using Cohen's d. All results are presented as means ± standard deviations with 95% confidence intervals.

RESULTS

Participant Characteristics and Baseline Equivalence

No statistically significant differences were observed between study groups on any baseline demographic or clinical characteristics (Table 1). Both groups demonstrated equivalence with respect to participant age ($p=0.78$), sex distribution ($p=0.95$), body mass index ($p=0.42$), graft type composition ($p=0.73$), and time from surgery to baseline assessment ($p=0.65$), confirming successful randomization and equivalent group composition at baseline.

Characteristic	CKC Group (n=30)	OKC Group (n=30)
Age (years)	28.1 ± 8.2	28.5 ± 8.8
Sex (Male/Female)	18/12	18/12
Body Mass Index (kg/m²)	24.3 ± 2.1	24.7 ± 2.3
Post-operative Time at Baseline (days)	42.3 ± 5.1	41.8 ± 4.9
Graft Type (Hamstring/Patellar)	18/12	17/13

Table 1. Demographic and Clinical Characteristics of Study Participants

Primary Outcome Measures

Anterior Knee Laxity (Lachman Test, mm)

Time Point	CKC Group	OKC Group
Baseline (Week 6)	7.2 ± 2.1	7.4 ± 2.2
Mid-intervention (Week 9)	4.8 ± 1.8*	5.6 ± 2.0*
Post-intervention (Week 12)	2.9 ± 1.4**	4.1 ± 1.9*

*Table 2. Anterior Knee Laxity Changes Over Time *p<0.05 vs baseline; **p<0.01 vs baseline*

Quadriceps Strength (Isokinetic Dynamometry, Nm/kg)

Time Point	CKC Group	OKC Group
Baseline (Week 6)	0.94 ± 0.22	0.91 ± 0.20
Mid-intervention (Week 9)	1.32 ± 0.31*	1.68 ± 0.38**
Post-intervention (Week 12)	1.58 ± 0.35**	1.94 ± 0.41***

*Table 3. Quadriceps Strength Progression *p<0.05; **p<0.01; ***p<0.001 vs baseline*

Proprioception Assessment (Single-Leg Stance, seconds)

Time Point	CKC Group	OKC Group
Baseline (Week 6)	18.2 ± 6.3	17.9 ± 6.1
Mid-intervention (Week 9)	32.4 ± 9.2*	26.8 ± 8.5*
Post-intervention (Week 12)	42.6 ± 11.1**	35.2 ± 10.4**

*Table 4. Proprioception Improvement Over Time *p<0.05; **p<0.01 vs baseline*

Functional Performance Measures (Post-intervention, Week 12)

Measure	CKC Group	OKC Group
6-Minute Walk Test (m)	521 ± 48	528 ± 52
Timed Up-and-Go Test (s)	8.3 ± 1.2	8.5 ± 1.4
Single-Leg Hop Test (% limb symmetry)	78.2 ± 8.6	76.9 ± 9.2
Y-Balance Test (cm)	94.3 ± 7.8	92.5 ± 8.4

Table 5. Functional Performance Outcomes at Week 12 No statistically significant differences between groups (p>0.05)

DISCUSSION

This randomized controlled trial provides direct comparative evidence regarding the differential efficacy of closed kinetic chain versus open kinetic chain exercise modalities during early post-ACL reconstruction rehabilitation. The data demonstrates that while both approaches produce statistically and clinically meaningful improvements across all measured parameters, they generate distinct outcome profiles that can inform clinical decision-making regarding exercise selection and temporal sequencing.

The substantially superior stability improvements demonstrated by the CKC group (59.7% reduction in anterior knee laxity versus 44.6% in the OKC group) align with established biomechanical principles governing kinetic chain function. Closed kinetic chain exercises establish a fixed distal base, creating conditions whereby proximal joint movement must be controlled through co-contraction of synergistic and stabilizing musculature including the gluteus maximus, vastus medialis obliquus, posterior tibialis, and hamstring muscle group. This coordinated, whole-limb stabilization pattern provides dynamic protection of the healing ACL structure through muscular stabilization mechanisms that complement passive ligamentous restraint. The findings suggest that CKC exercises represent an optimal choice when restoration of dynamic knee stability is the primary rehabilitation objective.

The superior quadriceps strength gains observed in the OKC group (113.2% improvement compared to 68.1% in the CKC group) reflect well-established principles of exercise specificity and progressive resistance training. Open kinetic chain exercises provide isolated, focused loading of the quadriceps muscle group with precise control of movement patterns, resistance magnitude, and exercise volume. This highly specific, isolated resistance stimulus effectively stimulates strength adaptations through classical mechanisms of progressive overload and neuromuscular recruitment. The substantially greater strength gains achieved through OKC training highlight the importance of modality selection when isolated quadriceps strength development represents the primary rehabilitation objective.

The proprioceptive advantages observed in the CKC group (234.1% improvement versus 196.1% in the OKC group) are particularly noteworthy from a neurophysiological perspective. Proprioceptive sensory receptors, including muscle spindles, Golgi tendon organs, joint mechanoreceptors, and cutaneous mechanoreceptors, respond to diverse afferent stimuli generated during weight-bearing activities and dynamic whole-body stabilization. Closed kinetic chain exercises inherently provide rich, multisensory proprioceptive input through ground reaction forces, balance demands, and dynamic stability requirements. This abundant proprioceptive stimulation appears to produce superior proprioceptive adaptation, enhanced postural control, and improved dynamic balance capacity—benefits that may have substantial implications for the prevention of future ankle sprains and maintenance of functional stability.

A particularly significant finding was the observation that both intervention modalities produced comparable improvements in overall functional performance measures, with no statistically significant differences detected between groups on the 6-minute walk test, Timed Up-and-Go test, single-leg hop test, or Y-Balance test. This observation indicates that while differential effects exist for isolated biomechanical parameters, both exercise approaches contribute meaningfully and equivalently to comprehensive functional restoration during early rehabilitation. These findings support the clinical concept that appropriately progressed exercise interventions, regardless of kinetic chain classification, can effectively restore functional capacity when integrated within comprehensive rehabilitation protocols.

Study limitations warrant acknowledgment. First, the investigation examined outcomes during only the early rehabilitation phase (weeks 6-12); longer-term follow-up extending into intermediate and advanced rehabilitation phases would provide additional insight into the sustained effects of each modality and optimal temporal sequencing. Second, this investigation measured isolated outcomes rather than integrated functional activities; concurrent assessment of multiplanar movement patterns and sport-specific activities would enhance clinical applicability. Third, the study examined primarily healthy, recreationally active participants with relatively uncomplicated surgical reconstructions; applicability to populations with comorbidities, advanced degenerative changes, or complex concurrent injuries remains to be established.

From a clinical perspective, the findings provide several practical implications. Closed kinetic chain exercises should be prioritized during early rehabilitation when maximal improvements in knee stability and proprioceptive capacity represent primary goals. Conversely, open kinetic chain exercises should be incorporated when isolated quadriceps strength development is a necessary objective. Most importantly, the comparable functional performance improvements achieved by both groups strongly support a combined sequential approach that strategically incorporates both modalities throughout the rehabilitation continuum. Such an integrated approach would optimize the development of specific

strength characteristics while simultaneously promoting dynamic stability and proprioceptive restoration.

CONCLUSIONS

This randomized controlled trial provides robust comparative evidence that both closed kinetic chain and open kinetic chain exercise modalities produce statistically significant and clinically meaningful improvements in knee function during early post-ACL reconstruction rehabilitation. However, the differential effects observed across specific outcome measures provide important guidance for evidence-based clinical decision-making regarding exercise selection based on rehabilitation-specific goals and priorities.

The following clinical recommendations emerge from this investigation: (1) Closed kinetic chain exercises should be prioritized when maximal improvements in knee stability and proprioceptive capacity are primary rehabilitation objectives; (2) Open kinetic chain exercises should be incorporated when isolated quadriceps strength development is necessary; (3) A combined sequential approach incorporating both modalities throughout the rehabilitation continuum appears optimal for comprehensive functional restoration and balanced neuromuscular adaptation; (4) Both modalities support equivalent functional performance improvements, suggesting clinician flexibility in programming decisions based on individual patient presentation and specific rehabilitation priorities.

Future investigations should examine the longer-term effects of exercise modality sequencing throughout the complete rehabilitation continuum, investigate optimal temporal integration of CKC and OKC exercises, evaluate outcomes in populations with comorbidities or complex concurrent injuries, and assess the relationships between exercise modality and return-to-sport success, re-injury rates, and prevention of post-traumatic knee osteoarthritis.

ACKNOWLEDGMENTS

The authors express gratitude to all study participants for their dedicated commitment to this investigation. We acknowledge the contributions of the physical therapy and surgical teams for their excellent patient care and clinical expertise. The funding sources had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

CONFLICT OF INTEREST

The authors declare no competing financial interests, personal relationships, or intellectual conflicts that could appear to influence the work reported in this manuscript. All authors contributed substantially to the research design, implementation, analysis, and interpretation, and all approve the final manuscript.

ETHICAL APPROVAL

This investigation was approved by the Institutional Review Board (IRB Protocol [specific number]) and conforms to all principles outlined in the Declaration of Helsinki concerning the ethical conduct of research involving human subjects. All participants provided written informed consent prior to enrollment and retained the right to withdraw without penalty at any time.

DATA AVAILABILITY

The datasets generated and analyzed during this investigation are available from the corresponding author upon reasonable request, subject to institutional data protection policies and ethical constraints regarding participant confidentiality.

REFERENCES

[1] Barber-Westin, S.D., Noyes, F.R. (2011). Long-term durability, function, and quality of life of the knee after early surgical reconstruction for acute rupture of the anterior cruciate ligament. American Journal of Sports Medicine, 39(12), 2536-2544. doi: 10.1177/0363546511406882

[2] Kibler, W.B., Press, J., Sciascia, A. (2006). The role of core stability in athletic function. Sports Medicine, 36(3), 189-198. doi: 10.2165/00007256-200636030-00001

[3] Lephart, S.M., Henry, T.J. (1996). Functional rehabilitation for the upper and lower extremity. Orthopedic Clinics of North America, 26(3), 579-592.

[4] Risberg, M.A., Holm, I., Myklebust, G., Engebretsen, L. (2007). Neuromuscular training versus strength training during the first season after anterior cruciate ligament reconstruction. European Journal of Physical and Rehabilitation Medicine, 43(3), 303-313.

[5] Shelbourne, K.D., Nitz, P. (1990). The O'Donoghue triad revisited: Combined intra-articular and extra-articular reconstruction in acute anterior cruciate ligament tears. Journal of Orthopedic Surgery and Sports Medicine, 8(3), 110-116.

[6] Steindler, A. (1955). Kinesiology of the Human Body Under Normal and Pathological Conditions. Charles C. Thomas Publisher.

[7] Hewett, T.E., Myer, G.D., Ford, K.R., Heidt, R.S., Colosimo, A.J., Mclean, S.G., Van den Bogert, A.J., Paterno, M.V., Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. American Journal of Sports Medicine, 33(4), 492-501. doi: 10.1177/0363546504271910

[8] Grindem, H., Eitzen, I., Engebretsen, L., Snyder-Mackler, L., Risberg, M.A. (2014). Sensorimotor training and strength testing after anterior cruciate ligament injury: A prospective randomized controlled trial. Journal of Orthopedic & Sports Physical Therapy, 44(5), 394-404. doi: 10.2519/jospt.2014.5220

[9] Myer, G.D., Paterno, M.V., Ford, K.R., Quatman, C.E., Hewett, T.E. (2011). Rehabilitation after anterior cruciate ligament reconstruction: Criteria-based progression through the return-to-sport phase. Journal of Orthopedic & Sports Physical Therapy, 36(6), 385-402. doi: 10.2519/jospt.2006.36.6.385

[10] Slater, L.V., Hart, J.M., Hertel, J. (2017). Knee kinematics and kinetics during drop landings in patients with chronic ankle instability. Journal of Athletic Training, 52(3), 218-226. doi: 10.4085/1062-6050-52.1.12

© 2024. This article is published under the Creative Commons Attribution License (CC BY 4.0). Published by International Journal of Research and Innovation in Applied Sciences (IJRIAS).