

Effect of Knee Angle Specific (60°–90°) Combine versus Isolated Kinetic Chain on Post ACL Recovery Outcomes: A Randomized Control Trial

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Background: The demand for anterior cruciate ligament (ACL) reconstruction is steadily rising, necessitating a comprehensive post-ACL rehabilitation plan to accelerate recovery. This study explores the comparative effects of Open Kinetic Chain (OKC), Closed Kinetic Chain (CKC), and their combined effect at a specific knee angle (60° to 90°) in post-ACL reconstruction patients.

Methodology: This clinical trial was registered in the Iranian Registry of Clinical Trials (IRCT) on 21-04-2020 (Ref# IRCT20200331046903N1) and conducted on 54 post-ACL reconstruction patients, randomly allocated to three groups (OKC, CKC, and Combined KC) using the lottery method. All groups underwent 16-week rehabilitation programs. Outcomes assessed were pain, range of motion (ROM), and knee function using the visual analog scale, goniometer, and Lysholm score, respectively. Statistical analysis was conducted using one-way and repeated measures ANOVA in SPSS-25.

Results: The mean age was 27.25±4.16 years and BMI 25.12±4.03 kg/m². All groups showed statistically significant improvement over 16 weeks (p<0.0001). At week 16, mean pain scores were 10.56±4.38 (Group A), 9.78±3.81 (Group B), and 3.28±3.12 (Group C) (p<0.001); ROM improved to 131.83±7.35, 129.22±7.57, and 140.61±6.13, respectively (p=0.001); knee function scores reached 90.78±4.83, 91.67±4.49, and 97.50±2.15, respectively (p=0.001). All outcome measures showed significant main effects of Group and Visit, with large effect sizes and significant Group×Visit interactions. From baseline to week 16, pain decreased by 85% (Group A), 86% (Group B), and 95% (Group C); ROM increased by 73%, 72%, and 90%; knee function improved by 58%, 63%, and 72%, respectively.

Conclusion: These findings indicate that the combined kinetic chain approach is most effective in improving ROM, knee function, and pain reduction following ACL reconstruction.

Trial Registration: <https://irct.behdasht.gov.ir/>.

Keywords: ACL reconstruction, knee rehabilitation, pain reduction, range of motion, functional recovery

Introduction

Anterior cruciate ligament reconstruction procedures are the most commonly performed orthopedic procedures in sports medicine, particularly in active and athletic populations most frequently, with tear cases ranging over 200,000 worldwide annually, with 75–97% success rates (return to sport level).¹ A study conducted in six countries, including the United States and five European countries, investigated 100,000 ACL reconstruction surgeries and recognized the demographics and causes of male and soccer-related injuries, respectively. Autografts are used more frequently in the US than in Europe, with revision rates of 2.8% and 3.7%, respectively.² ACL reconstruction frequency and outcomes are affected in low- and middle-income countries, such as Pakistan, because of little or no access to specialized surgical care, comprehensive rehabilitation, healthcare services, and infrastructure. The demand for ACL reconstruction is increasing

in Asia because of higher participation in sports due to the discrepancy in access and persistent expertise, which emphasizes the need for superior surgical techniques and rehabilitation protocols for better patient outcomes globally.³

The aims of anterior cruciate ligament rehabilitation are functional restoration, quality of life preventing further injury and osteoarthritis, and allowing return to sports or work.⁴ In developed countries, physiotherapists play a vital role in providing the rehabilitation required to return patients to their pre-injury functional level.⁴ Postanterior cruciate ligament surgery and physiotherapy rehabilitation play a vital role in the recovery process and remarkably improve function and recovery outcomes. Extensive structured physical therapy and rehabilitation programs include tailored exercises, intensive therapy, and accelerated recovery by augmenting range of motion, knee function, and muscle strength.^{5,6} Rehabilitative exercises, which primarily include isotonic, isokinetic, and isometric exercises, are effective in reducing pain and improving strength and flexibility.^{7,8}

The rehabilitation regimen for ACL injuries includes an open kinetic chain (OKC) or closed kinetic chain (CKC) during the recovery phase, which offers distinctive benefits tailored according to the respective phase. OKC is defined as movement in which the distal segment moves freely; for example, leg extensions and hamstring curls are predominately proven effective in increasing quadriceps strength during the early stage of rehabilitation and show prominent improvement within 3–4 months post injury.^{8–10} In the initial recovery phase, these exercises exert minimal stress on the knee joint, thereby reducing the risk of graft laxity.¹⁰ Alternatively, in CKC, the distal segment is fixed; for example, squats and leg presses have proven effective in later rehabilitation stages, suitable for improving functional outcome, stabilizing the knee, and reducing pain.^{10,11} CKC is strongly associated with enhanced lower extremity functions, including agility and reduced joint and stress, but it does not target specific muscle groups compared to OKC.^{8,12}

CKC and OKC promote proximal muscle hypertrophy and distally shift muscle mass.¹³ Both chains provide equal improvements in QoL and pain management in patients with knee osteoarthritis.¹⁴ Therefore, the choice of application depends on the patient-specific conditions and individual rehabilitation goals. Furthermore, combining these two chains yields balanced rehabilitation, which can accelerate motor function and decrease muscle atrophy.¹⁵

Mikkelsen and Werner found that patients who engaged in both CKC and OKC demonstrated significantly greater improvements in quadriceps strength versus CKC alone, while hamstring strength remained comparable between the two groups. Additionally, a higher number of patients in the combined group returned to pre-injury sports levels (12 vs 5), and they did so on average two months earlier than those in the CKC-only group. These findings imply that adding CKC to the rehabilitation regime increases quadriceps strength and reduces the time to return to sports and activities that affect knee joint stability.¹⁶ However, no further studies have been conducted on the combined effectiveness of CKC and OKC in rehabilitation.

The clinical practice guideline on post-ACLR rehabilitation suggests that it should start with immediate knee mobilization in the first week to improve motion and reduce pain. Strength and neuromuscular training are essential, beginning with isometric quadriceps work, followed by concentric and eccentric closed kinetic chain exercises, and ongoing neuromuscular re-education. Early full weight bearing is encouraged as tolerated. CKC should be prioritized early, while OKC (90–45°) may begin at 4–6 weeks, avoiding resistance for 12 weeks if a hamstring graft is used. Cryotherapy is recommended postoperatively, and neuromuscular electrical stimulation can assist quadriceps activation in the first 6–8 weeks. Continuous passive motion and routine functional bracing are discouraged. Return to sport should follow criteria-based progression using tools like KOOS, IKDC, ACL-RSI, and hop tests, with limb symmetry index $\geq 90\%$ (or $\geq 100\%$ for contact sports), no pain or instability, and confidence in full activity.¹⁷

The debate on the utilization of OKC and CKC in ACL rehabilitation and its associated specific disadvantages suggest the need for further research. During early post-injury rehabilitation stages, CKC exercise might limit range of motion, possibly delaying full recovery and putting stress on the knee joint, which might not be ideal in the early stages for all patients.¹⁸ OKC exercises may raise concerns regarding joint laxity; however, the literature suggests that there is no difference in laxity when compared with CKC exercises.¹⁹ Another concern is that OKC affects quadriceps and knee mechanics and leads to muscle imbalance.²⁰ To achieve optimized recovery outcomes, considering the strengths and limitations of both kinetic chains, future research are needed to explore individualized rehabilitation strategies for combining kinetic chains for better results.

Although the benefits of CKC and OKC exercises are well established, research combining both kinetic chains in a single rehabilitation program remains restricted. Early studies have indicated that combining both kinetic chain exercises could accelerate recovery, increase muscle strength, and quickly return to pre injury level without affecting joint stability. However, combining this approach with comprehensive investigations is rare, creating a gap in the literature. Also literature indicates that open and close chain can be safely performed at 90° to 40° of knee flexion post ACL reconstruction without putting strain on ACL.²¹ Loaded exercises shall be applied when restricted with >30° in early-stage rehabilitation.²² At the best of researcher knowledge, no more studies are conducted to check the efficacy of post ACL knee angle specific open and close chain.

To bridge in this gap, this study aimed to explore the effects of OKC and CKC at specific knee angle of 60° to 90° on outcomes such as pain, range of motion, and knee function after post-ACL reconstruction surgery. Converging a rehabilitation strategy that combines both kinetic chains harnesses the strengths of both types within a specific range. This study contributes valuable information for the development of more effective and personalized rehabilitation protocols. Most of the literatures focus on just comparing the effectiveness of open and close kinetic chain without introducing any specific angle and the combine efficacy of both. By introducing these advancements could enhance the long-term outcomes of individuals and athletes recovering from ACL injuries, eventually improving their performance and quality of life in physical activities.

Materials and Methods

Study Design

The three-arm parallel-design clinical trial registered on 21-04-2020 (Registry # Ref# IRCT20200331046903N1), and the study started in 2021 ended in 2023 at the Department of Physical Therapy, Northwest General Hospital and Research Centre, Peshawar, Pakistan. Prior to initiation of this study, ethical approval was obtained on 23rd January, 2020 from the Institutional Research Board (IRB-UOL-FASH/695/2020) of the University of Lahore, Lahore, Pakistan. This study was single-blinded, in which one assessor was blinded due to the nature of the intervention, and the patients were not blinded. Furthermore, the pre-coded anonymized form of the data was handed over to the statistician to keep him blinded to the group allocation. This study was conducted in accordance with the principles stated in the Declaration of Helsinki.

Study Participants

Patients who had undergone ACL reconstruction surgery were recruited from the Department of Orthopedics and referred to the Department of Physical Therapy at the Northwest General Hospital and Research Center, Peshawar. Upon referral for rehabilitation, a licensed physical therapist conducted a comprehensive evaluation to assess eligibility based on the predefined inclusion and exclusion criteria. Participants were between 18 and 50 years of age and had undergone primary ACL reconstruction with no history of knee joint disorders beyond surgical intervention. All these participants were from general population not sports person. The postoperative condition was confirmed to be stable by the treating orthopedic surgeon. Patients with additional injuries to other ligaments, significant comorbidities that could affect rehabilitation (eg, neurological or severe cardiovascular conditions), or contraindications to exercise were excluded. Exclusion criteria also encompassed individuals with previous knee surgeries, those who had received physical therapy within the past three months, or individuals unable to provide informed consent were excluded. Before recruitment, all participants provided written informed consent, acknowledging their comprehension of the study's goals, procedures, and potential ramifications.

Sample Size

The sample size was calculated using pain intensity data reported by Uçar et al, with mean values of 41.4 ± 12.9 for the closed kinetic chain (CKC) group and 48.6 ± 11.4 for the open kinetic chain (OKC) group.²³ With a 95% confidence level and 80% statistical power, the calculation indicated that 54 participants were required to detect statistically significant differences between groups.

Randomization

Randomization was conducted following baseline assessments using a lottery method to ensure an unbiased allocation of participants. The primary auditor assigned each participant a unique number, which was then randomly selected from a box. The participants were divided into three groups: CKC, OKC, and combined kinetic chain (combined KC), in a 1:1:1 ratio. The randomization approach provided equal representation in all groups while minimizing selection bias. A CONSORT flow diagram for this investigation is shown in [Figure 1](#).

Group and Intervention Procedure

Upon completing the informed consent process, the participants volunteered to participate in the study and were randomly assigned to one of the three groups, with each group comprising 18 participants at baseline. Group A received CKC exercises, Group B performed OKC exercises, and Group C underwent a combination of both interventions. All groups participated in a standardized 60-minute session three times a week, amounting to 36 sessions over the study period. A minimum of 33 sessions was required for inclusion in the final analysis.

An independent assessor, who was blinded to the study objectives and group assignments, evaluated the participants. Pain intensity, range of motion (ROM), and knee function were measured at baseline, as well as at the 6th, 12th, and 16th weeks. To ensure consistency and reliability, interventions and assessments were conducted at the same time of day. The participants maintained standard treatment regimens throughout the study to prevent confounding factors that could influence outcomes.

Intervention Protocol

Group A (Closed Kinetic Chain – CKC)

Participants in this group underwent 60-minute sessions, three times a week on alternate days for 12 weeks. The sessions consisted of controlled squats by using a closed kinetic chain. The patient's leg was supported in a closed-chain position (foot firmly on the ground) using either a specially designed chair or strap secured below the knee joint line, managed by the therapist. Movements included a fully extended knee in the standing position to 90-degree flexion (eccentric activity) and then returning to the starting standing position (concentric activity). These movements are administered with routine physical therapy modalities and exercise regimes for the contralateral upper and lower limbs, the respiratory system, and the trunk.

Group B (Open Kinetic Chain – OKC)

Participants in this group underwent 60-minute sessions, three times a week on alternate days for 12 weeks, which consisted of controlled quadriceps and hamstring activities in an open kinetic chain setup. The patient was seated on the table or modified chair with permissible knee movement against a predetermined resistance within 60° to 90° flexion in the pain-free range. These movements are administered with routine physical therapy modalities and exercise regimes for the contralateral upper and lower limbs, the respiratory system, and the trunk.

Group C (Combined Kinetic Chain)

Participants in the group administered a combined kinetic chain (OKC + CKC). The sessions were 60-minutes, three times a week on alternate days, for 12 weeks. These include control squats, quadriceps, and hamstring activities from closed and open kinetic chains, respectively. These movements are administered with routine physical therapy modalities and exercise regimes for the contralateral upper and lower limbs, the respiratory system, and the trunk.

The training groups were divided into three progressive phases based on intensity, movement speed, and set-replicates ([Table 1](#)). The rehabilitation compliance was 100% as all the activities were performed under researcher's guidance. No home recommendation was given.

All participants also received routine physical therapy modalities, including thermotherapy (hot packs), and manual therapy techniques. No home exercise recommendations were given to maintain uniformity. Adherence was 100% as all sessions were supervised.

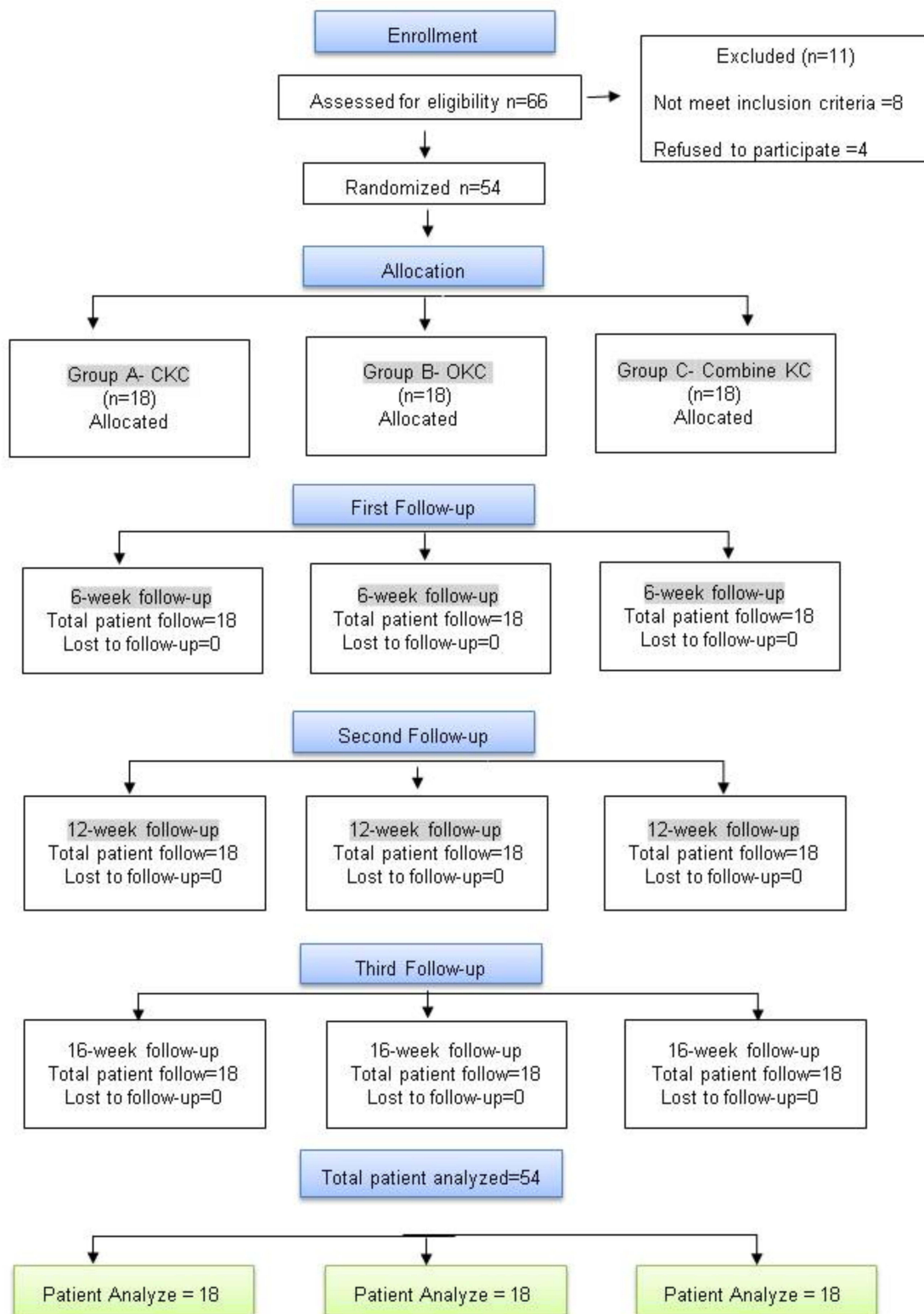


Figure 1 Flow diagram of the study process.

Notes: CONSORT figure adapted from Schulz KF, Altman DG, Moher D. CONSORT 2010 Statement: Updated Guidelines for Reporting Parallel Group Randomised Trials. *PLoS Med.* 2010;7(3): e1000251. Copyright: © 2010 Schulz et al. Creative Commons.²⁴

Table 1 Strength Training Weekly Progression

Weeks	Intensity (% of Body Weight)	Movement/Speed	Sets
1-5	25-50%	Slow & Controlled 2–3 Sec concentric and Eccentric	2-3 sets of 10 to 15 rep, rest 20 to 60sec
6-10	50-70%	Controlled to moderate 2 sec each phase	3-4 sets of 8 to 12 rep, rest 60 to 90sec
11-16	70-100%	Moderate to fast 1 to 2 sec concentric to control eccentric	3-5 sets of 6 to 10 rep, rest 1 to 2 min

Adverse Event Monitoring

In clinical studies, adverse events are defined as unfavorable medical conditions experienced by participants during or after treatment.²⁵ Common potential adverse events include increased pain, swelling, muscle soreness, joint instability, patellar tendinitis, and nerve irritation, which require close monitoring and protocol adjustments to ensure participant safety.²⁶ In this trial, all participants were closely monitored for such events; however, no adverse events were reported throughout the study.

Outcome Measures

The participants were assessed for pain intensity, range of motion (ROM), and knee function at baseline, the 6th and 12th weeks of therapy, and the 16th week of follow-up. Pain intensity was evaluated using the visual analog Scale (VAS-100), with higher scores indicating greater pain. Range of motion was measured using a goniometer to assess joint motion.²⁷ Knee function was measured using the validated Lysholm Knee Scoring Scale to evaluate the functional outcomes of the knee.¹⁹

Statistical Analysis

SPSS version 25 was used to enter the data and perform statistical analysis SPSS version. Descriptive statistical analysis was performed using the mean and standard deviation for continuous variables, such as age, BMI, and years of schooling, whereas categorical data analysis was performed to calculate frequencies and percentages. Kolmogorov–Smirnov and Shapiro–Wilk tests were used to check data normality, and the results indicated that the data had a normal distribution in both the control and experimental groups. The comparative mean score determined the effectiveness of the therapies ($p < 0.05$), indicating statistical significance. These findings show that therapies reduce pain, increase range of motion, and enhance knee functionality. To compare results across the three groups, one-way ANOVA was used, and for results within groups, repeated-measures ANOVA was used at a significance level of 0.05. For multiple comparisons, Bonferroni post-hoc test was used.

Results

Our study included 54 individuals, predominantly male 43 (79.6%). The mean age of the participant was 30.17 ± 1.14 years, ranging from 18 to 50 years.

The baseline characteristics of the study participants among the three comparative groups (CKC, OKC, and Combine KC) demonstrated that all three groups had significant differences at the baseline level (p -value > 0.05) for all variables like (age, sex, BMI, year of education, and affected side, right or left), which suggests that all three groups were homogenous with respect to the baseline characteristics (Table 2).

The mean changes between the groups (CKC, OKC, and combined KC) were compared. The results revealed that, at baseline, the three groups did not differ significantly in pain intensity ($p = 0.697$), range of motion ($p = 0.114$), or knee function ($p = 0.841$), indicating that the groups were similar prior to the intervention. But by the 6th week, the differences in all three outcomes were significant ($p < 0.001$ for pain intensity and knee function and $p = 0.002$ for range of motion). From baseline to the 16th week, all three intervention groups demonstrated significant improvements, with the combined KC (Group C) displaying the greatest change. Pain intensity reduced by 85% in Group A, 86% in Group B, and 95% in

Table 2 Baseline Characteristics of Patient Among Groups

Characteristics	Group-A (CKC, n=18)	Group-B (OKC, n=18)	Group-C (Combine KC) n=18)	p-value
Age	27.33±6.61	33.22±9.81	29.94±7.78	0.106
Gender (male/female)	14/4	15/3	14/4	0.898
BMI (kg/m ²)	25.94±3.49	26.94±2.27	25.61±2.78	0.545
Year of Education	12.83±0.56	12.77±0.74	13.61±0.88	0.675
Affected Side (right/left)	10/8	9/9	11/7	0.461

Group C, indicating greater pain relief in the combined group. ROM was increased by 73% in Group A, 72% in Group B, and 90% in Group C, reflecting higher gains in joint flexibility in the combined protocol. Knee function too was better by 58% in Group A, 63% in Group B, and 72% in Group C, showing that the combined kinetic chain protocol was superior in augmenting the overall recovery after ACL reconstruction (Table 3).

The multiple comparison test indicates that there were no significant differences between groups at baseline in pain intensity, ROM, or KF (all p-values >0.05). However, by 6th week, Group C showed significantly greater improvement than both Group A and B across all outcomes. Pain intensity decreased significantly in Group C compared to Group A (mean difference = 10.72, p < 0.001) and showed a near-significant trend versus Group B (mean difference = 6.50, p = 0.062). ROM and KF also improved significantly in Group C compared to both A (mean difference = 5.89 and 9.56, respectively) and B (mean difference = 8.11 and 10.67, all p ≤ 0.001). At the 12th week, Group C showed markedly better outcomes than Group A and B in all measures: pain intensity differences were 16.67 vs Group A and 14.94 vs B), ROM 7.22 and 9.22, and KF 10.83 and 9.94 (all p < 0.001). By the 16th week, Group C continued to outperform both other groups. Pain intensity differences remained significant (C vs A = 7.28, C vs B = 6.50, p < 0.001), ROM (C vs A = 8.78, C vs B = 11.39) and KF (C vs A = 6.72, C vs B = 5.83), (p < 0.001) (Table 4).

Repeated measures ANOVA demonstrate statistically significant improvements across all three outcome measures, within all groups (A, B, and C) from baseline to the 16th week (p < 0.001). Group C consistently demonstrated superior outcomes across all measures. In terms of pain intensity (VAS score), Group C showed the most pronounced reduction,

Table 3 Difference Between Groups Regarding Mean Scores of Outcome Measures

Outcome	Outcome Measures	Groups	Baseline (Mean±SD)	6th Week (Mean±SD)	12th Week (Mean±SD)	16th Week (Mean±SD)	Percent Change
Pain Intensity	VAS score	Group A	72.22 ± 6.58	51.33 ± 7.37	28.11 ± 6.12	10.56 ± 4.38	85%
		Group B	70.44 ± 6.51	46.39 ± 7.46	26.39 ± 5.61	9.78 ± 3.81	86%
		Group C	70.61 ± 7.56	40.61 ± 7.56	11.44 ± 6.49	3.28 ± 3.12	95%
		F	0.364	9.301	40.882	19.834	
		p value	0.697	<0.001	<0.001	<0.001	
Range of Motion	Goniometer	Group A	28.83 ± 5.69	49.83 ± 6.65	113.94 ± 6.22	131.83 ± 7.35	73%
		Group B	26.83 ± 5.69	47.61 ± 6.45	111.94 ± 6.22	129.22 ± 7.57	72%
		Group C	25.22 ± 3.64	55.72 ± 6.54	121.17 ± 7.30	140.61 ± 6.13	90%
		F	2.265	7.370	9.730	12.916	
		p value	0.114	0.002	<0.001	<0.001	
Knee Function	Lysholm score	Group A	57.28 ± 5.57	65.17 ± 5.42	82.11 ± 5.43	90.78 ± 4.83	58%
		Group B	56.22 ± 5.43	64.06 ± 5.15	83.00 ± 5.58	91.67 ± 4.49	63%
		Group C	56.67 ± 5.20	74.72 ± 5.11	92.94 ± 3.06	97.50 ± 2.15	72%
		F	0.173	22.660	27.889	14.972	
		p value	0.841	<0.001	<0.001	<0.001	

Table 4 Multiple Comparison Test of Difference Between Groups Regarding Mean Scores of Outcome Measures

Visit	Dependent Variable	Group A vs B (Mean Diff, p value)	Group A vs C (Mean Diff, p value)	Group B vs C (Mean Diff, p value)
Baseline	Pain intensity	1.78 (p = 0.721)	1.61 (p = 0.764)	0.17 (p = 0.997)
	Range of motion	2.00 (p = 0.472)	3.61 (p = 0.095)	1.61 (p = 0.613)
	Knee function	1.06 (p = 0.828)	0.61 (p = 0.939)	0.44 (p = 0.967)
6th week	Pain intensity	4.22 (p = 0.126)	10.72 (p < 0.001)	6.50 (p = 0.062)
	Range of motion	2.22 (p = 0.569)	5.89 (p = 0.025)	8.11 (p = 0.001)
	Knee function	1.11 (p = 0.800)	9.56 (p < 0.001)	10.67 (p < 0.001)
12th week	Pain intensity	1.72 (p = 0.674)	16.67 (p < 0.001)	14.94 (p < 0.001)
	Range of motion	2.00 (p = 0.637)	7.22 (p = 0.005)	9.22 (p < 0.001)
	Knee function	0.89 (p = 0.846)	10.83 (p < 0.001)	9.94 (p < 0.001)
16th week	Pain intensity	0.78 (p = 0.814)	7.28 (p < 0.001)	6.50 (p < 0.001)
	Range of motion	2.61 (p = 0.511)	8.78 (p = 0.001)	11.39 (p < 0.001)
	Knee function	0.89 (p = 0.784)	6.72 (p < 0.001)	5.83 (p < 0.001)

from a baseline mean of 70.61 to 3.28 at 16 weeks, followed by Group B (70.44 to 9.78) and Group A (72.22 to 10.56). ROM in Group C improved from 25.22° at baseline to 140.61° at 16 weeks, exceeding improvements seen in Group B (26.83° to 129.22°) and Group A (28.83° to 131.83°). Similarly, KF (Lysholm Score) increased most in Group C, from 56.67 to 97.50, compared to Group B (56.22 to 91.67) and Group A (57.28 to 90.78). The partial eta squared (η^2) values indicated large effect sizes for both group differences and visit effects, particularly for pain ($\eta^2 = 0.319$ for group, 0.992 for visit) and knee function ($\eta^2 = 0.321$ for group, 0.992 for visit), suggesting that the time of assessment had a stronger impact than group allocation (Table 5).

Table 5 Within Group Comparison of Mean Scores of Outcome Measures by Using Two Way Repeated Measure ANOVA

Outcome (Outcome Measures)	Groups	Statistical Measures	Baseline	6th Week	12th Week	16th Week	P value
Pain Intensity (VAS Score)	Group A	Mean±SD	72.22 ± 6.58	51.33 ± 7.37	28.11 ± 6.12	10.56 ± 4.38	<0.001
		95% CI	69.80–74.64	48.63–54.04	25.87–30.35	9.00–12.11	
	Group B	Mean±SD	70.44 ± 6.51	46.39 ± 7.46	26.39 ± 5.61	9.78 ± 3.81	<0.001
		95% CI	68.05–72.83	43.65–49.13	24.36–28.42	8.38–11.18	
	Group C	Mean±SD	70.61 ± 7.56	40.61 ± 7.56	11.44 ± 6.49	3.28 ± 3.12	<0.001
		95% CI	67.85–73.36	37.85–43.36	9.12–13.75	2.14–4.41	
	Group	Partial η^2	0.319				<0.001
	Visit		0.992				<0.001
	Group x Visit		0.582				<0.001

(Continued)

Table 5 (Continued).

Outcome (Outcome Measures)	Groups	Statistical Measures	Baseline	6th Week	12th Week	16th Week	P value	
Range of Motion (Goniometer)	Group A	Mean±SD	28.83 ± 5.69	49.83 ± 6.65	113.94 ± 6.22	131.83 ± 7.35	<0.001	
		95% CI	26.76–30.90	47.38–52.29	111.67–116.21	129.14–134.52		
	Group B	Mean±SD	26.83 ± 5.69	47.61 ± 6.45	111.94 ± 6.22	129.22 ± 7.57	<0.001	
		95% CI	24.76–28.90	45.20–50.01	109.67–114.21	126.47–131.96		
	Group C	Mean±SD	25.22 ± 3.64	55.72 ± 6.54	121.17 ± 7.30	140.61 ± 6.13	<0.001	
		95% CI	23.87–26.57	53.27–58.17	118.50–123.84	138.35–142.87		
	Group	Partial η^2	0.195					<0.001
	Visit		0.997					<0.001
	Group x Visit		0.495					<0.001
	Knee Function (Lysholm Score)	Group A	Mean±SD	57.28 ± 5.57	65.17 ± 5.42	82.11 ± 5.43	90.78 ± 4.83	<0.001
95% CI			55.27–59.30	63.22–67.12	80.15–84.06	89.18–92.38		
Group B		Mean±SD	56.22 ± 5.43	64.06 ± 5.15	83.00 ± 5.58	91.67 ± 4.49	<0.001	
		95% CI	54.25–58.18	62.17–65.95	81.01–84.98	90.25–93.08		
Group C		Mean±SD	56.67 ± 5.20	74.72 ± 5.11	92.94 ± 3.06	97.50 ± 2.15	<0.001	
		95% CI	54.77–58.56	72.86–76.58	91.82–94.06	96.51–98.49		
Group		Partial η^2	0.321					<0.001
Visit			0.992					<0.001
Group x Visit			0.703					<0.001

Moreover, multiple comparisons confirmed significant improvements at each follow-up interval for all outcomes ($p < 0.0001$), with the greatest changes occurring between baseline and the 16th week. The magnitude of change was highest for ROM, followed by pain reduction and knee function improvement (Table 6).

Figures 2–4 visually represent the mean pain, ROM and KF across the group over a time span of 16 week.

Table 6 Multiple Comparison Test of Difference Between Visit Regarding Mean Scores of Outcome Measures

Visits Compared	Group A vs B (Mean Diff, p value)	Group A vs C (Mean Diff, p value)	Group B vs C (Mean Diff, p value)
Baseline vs 1st follow-up	24.981 (<0.0001)	24.093 (<0.0001)	11.259 (<0.0001)
Baseline vs 2nd follow-up	49.111 (<0.0001)	88.722 (<0.0001)	29.296 (<0.0001)
Baseline vs 3rd follow-up	63.222 (<0.0001)	106.926 (<0.0001)	36.593 (<0.0001)
1st follow-up vs 2nd follow-up	24.130 (<0.0001)	64.630 (<0.0001)	18.037 (<0.0001)
1st follow-up vs 3rd follow-up	38.241 (<0.0001)	82.833 (<0.0001)	25.333 (<0.0001)
2nd follow-up vs 3rd follow-up	14.111 (<0.0001)	18.204 (<0.0001)	7.296 (<0.0001)

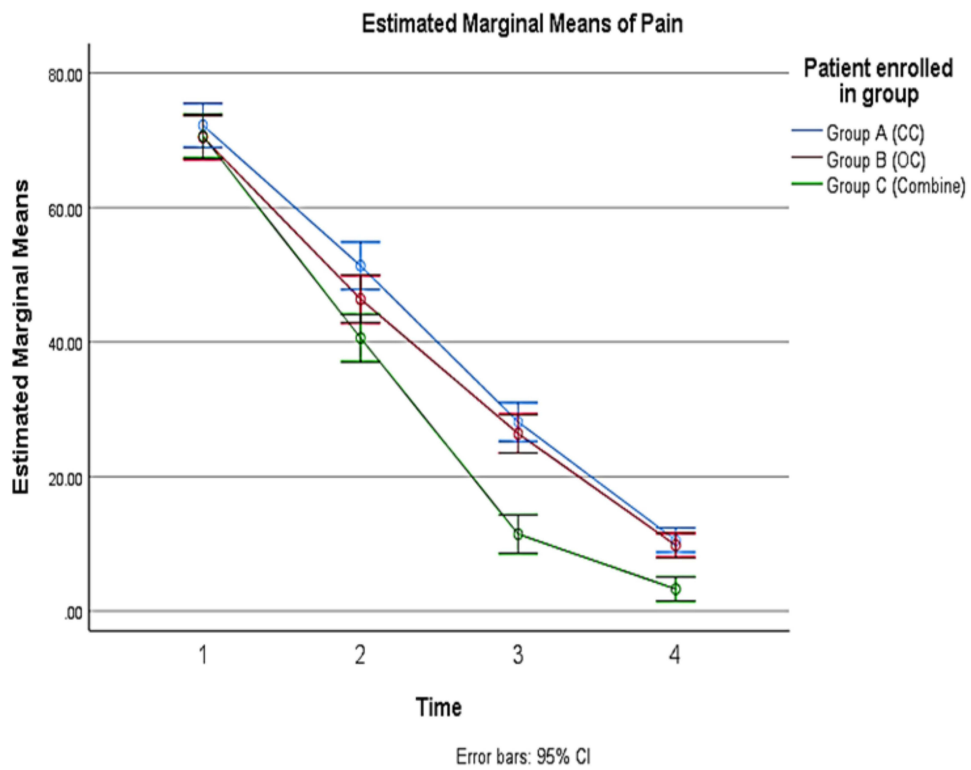


Figure 2 Mean pain among groups recorded over time.

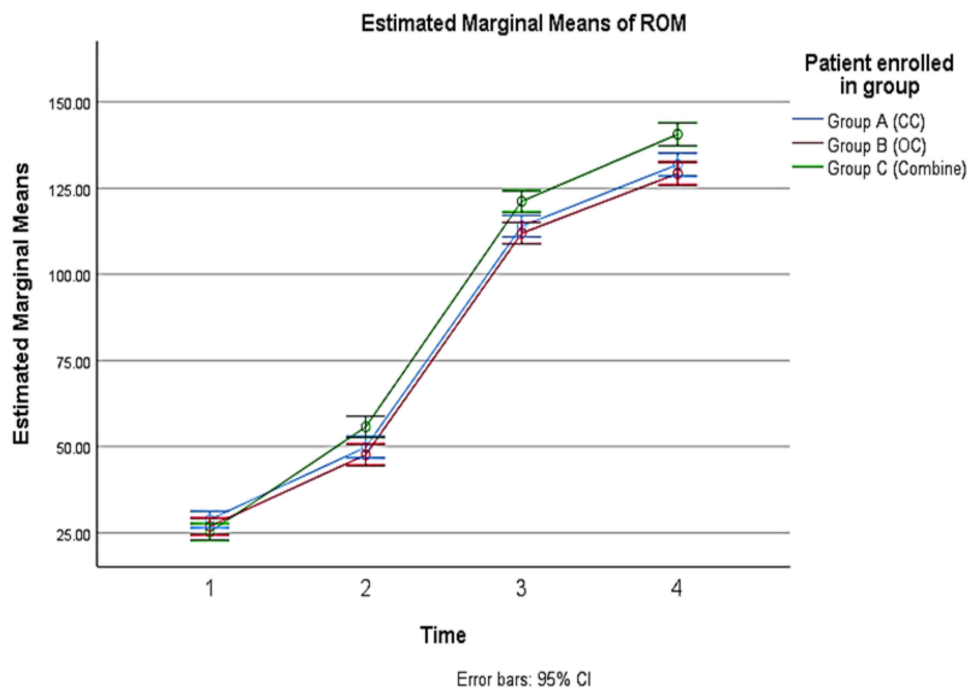


Figure 3 Mean range of motion among groups recorded over time.

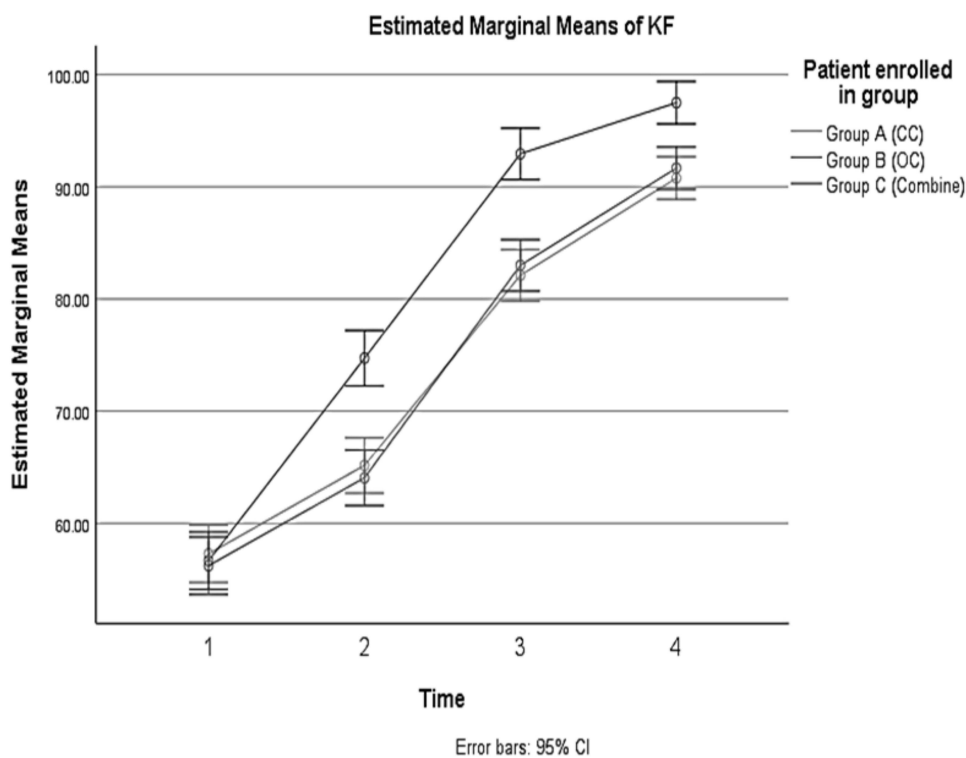


Figure 4 Mean knee function among groups recorded over time.

Discussion

This study aimed to explore the effects of OKC, CKC, and combined KC at specific knee angle of 60° to 90° on outcomes such as pain, range of motion, and knee function after post-ACL reconstruction surgery. Our study results portray Combine KC compared to individual kinetic chain regimens, combined KC significantly reduced pain and improved knee function and range of motion. The Group C – Combined kinetic chain group – exhibited the most statistically significant reduction in pain, enhancement in knee function and range of motion at all-time points (6th, 12th, and 16th weeks), this suggests that combined kinetic chain rehabilitation strategy is more effective than either kinetic chain alone. The superior effect of combined KC (Group C) in reducing pain intensity at the 16th week on the VAS scale was the highest at 3.28 compared to the CKC group (Group A), 10.56, and the OKC group (Group B), 9.78.

These findings highlight the efficacy of combining KC with rehabilitation. In line with the current findings of this study and published research related to chain (OKC) and closed kinetic chain (CKC), CKC demonstrated more improvements in pain reduction and knee function than OKC. CKC is consistently reported in studies showing statistically significant pain reduction following CKC exercises and lower scores on the Pain Rating Scale in CKC groups (NPRS= 4.160) than in the OKC groups (NPRS= 4.280).^{10,23} Conversely, OKC is particularly effective in pain reduction in the early stages of rehabilitation. This chain is associated with a significant reduction in pain when integrated into the early stages of a rehabilitation plan.⁸ Furthermore, the effectiveness of OKC is inconsistent with that of CKC.⁸ A more comprehensive approach yields the strengths of the regime to optimize rehabilitation outcomes by combining OKC and CKC chains. This combination offers improved results in terms of pain reduction and functional recovery.¹⁵ Although CKC tends to be more effective for pain reduction, the integration of both OKC and CKC into rehabilitation protocols could lead to more favorable outcomes. However, caution is advised in the aggressive use of OKC as it may pose potential risks to the ACL graft.²⁸ The findings of this study, with Group C showing superior pain reduction, further supports the benefits of combining both kinetic chains for optimal recovery.¹⁶ However, the pain reduction observed in this study surpasses that reported in earlier trials, possibly because of the more targeted approach of knee angle-specific

kinetic chain, specifically focusing on the 60°–90° knee angle range, which may better mimic functional movements and address pain at critical phases of recovery.

A substantial improvement in range of motion (ROM) was observed in the combined treatment group (Group C). By the 16th week, Group C showed the largest increase in ROM, from 28.83° at baseline to 140.61°, highlighting the effectiveness of the combined approach. Although all groups demonstrated ROM improvements, the combined exercise modality yielded a more significant increase than OKC or CKC alone. Research supports the effectiveness of both open kinetic chain (OKC) and closed kinetic chain (CKC) in improving ROM after anterior cruciate ligament (ACL) rehabilitation, although CKC tends to be more effective, particularly in the early stages. Exercises such as wall sits and squatting lunges (CKC) have shown greater improvements in knee ROM than OKC exercises such as leg extensions and isotonic quadriceps exercises.¹⁰ A study involving ACL reconstruction indicated that combining OKC and CKC leads to superior quadriceps strength without increasing graft laxity, suggesting that a balanced rehabilitation approach is beneficial.⁹ However, the introduction of kinetic chain at angles between 60° and 90° renders it safer. As the literature, quadriceps activity does not strain the ACL when the knee is flexed beyond 60° so there are minimal chances of reoccurrence.²⁹

Combining OKC and CKC further optimized rehabilitation outcomes. The early introduction of OKC exercises did not negatively affect graft laxity but improved muscle strength.^{9,16} Combining both kinetic chains in comprehensive rehabilitation strategies helps address both strength and ROM.^{21,22} CKC has advantages over OKC in achieving early ROM recovery, whereas OKC plays a vital role in increasing muscle strength without compromising joint stability. Our study supports these findings and yields a combined kinetic chain (Group C), resulting in significantly enhanced ROM and strength, which suggests that tailored rehabilitation programs must incorporate both kinetic chains for optimal recovery outcomes.

Knee function, assessed using the Lysholm Knee Scoring Scale, showed significant improvement in all groups. However, Group C demonstrated greater improvement, ranging from 56.28 to 97.50 at baseline and 16 weeks, respectively.

These findings consistently emphasize that combining the kinetic chain strategy helps optimize functional recovery after ACL reconstruction. Both kinetic chain amalgams individually contribute to optimizing knee function by strengthening different groups of muscles and result in balance restoration by addressing both stability and dynamic control.

OKC and CKC are beneficial in rehabilitation, as supported by the literature; however, they have distinctive effects on knee function and strength, which can eventually influence Lysholm scores, and showed significant improvement in quadriceps strength at 3 and 6 months compared with CKC in rehabilitation post-ACL reconstruction.^{9,16} The combination of OKC and CKC exercises leads to better muscle strength without increasing graft laxity.¹⁸ Although specific differences in Lysholm scores between combined and individual exercise approaches remain inconclusive,³⁰ the integration of both modalities is likely to enhance overall functional performance. This finding supports the idea that a tailored rehabilitation program incorporating both OKC and CKC exercises could optimize recovery outcomes and improve knee function more effectively than either modality alone.

Literature suggests the minimal mean magnitude difference between OKC and CKC. A systematic review by Putri et al (2023)³¹ reported a mean difference of -1.66 in functional recovery outcomes between OKC and CKC groups, with a p-value of 0.65, indicates a statistical insignificance and clinical similarity between the two modalities. Similarly, Jewiss et al (2017)³² found no substantial differences in knee laxity or functional scores, while Wang et al (2023)²² noted only minor biomechanical strain differences between OKC and CKC, further supporting their interchangeability. This study reveals a more pronounced magnitude of difference, particularly when combining both exercise types. At the 6th week, Group C (combined OKC + CKC) outperformed Group A (CKC) and Group B (OKC) in pain reduction (mean difference: 10.72 vs A, 6.50 vs B), ROM (5.89 vs A, 8.11 vs B), and knee function (KF) scores (9.56 vs A, 10.67 vs B). By the 16th week, these differences widened further: pain intensity differences were 7.28 (C vs A) and 6.50 (C vs B), ROM differences were 8.78 and 11.39, and KF differences were 6.72 and 5.83, respectively (all $p < 0.001$).³¹

The findings of this study are consistent with those of Mikkelsen and Werner (2000),¹⁶ who found that combining OKC and CKC exercises led to superior outcomes in quadriceps strength and return to sports compared to CKC alone. However, the present study adds to the existing literature by focusing on knee angle-specific exercises (60°–90°) and showing their effectiveness not only in strength development, but also in reducing pain, improving ROM, and enhancing knee function. The improvement in ROM and knee function in Group C aligns with findings from other studies that

advocate a combined rehabilitation strategy, although the specific emphasis on knee angles within the combined approach in this study is a unique contribution.

OKC exercises provide specific muscular activation, particularly in the quadriceps, which CKC alone may not adequately stimulate. Meanwhile, CKC exercises improve joint stability by coordinating the contraction of surrounding muscles and distributing weight across many joints. Thus, the combined therapy appears to improve strength recovery while retaining joint protection.⁹

Furthermore, this study supports the growing body of evidence suggesting that while both OKC and CKC exercises offer benefits, their combination provides the most holistic rehabilitation strategy. This approach may particularly benefit patients who are in the early stages of recovery and those aiming to return to sports and high-level activities.

Limitations and Future Directions

Regardless of significant findings, the current study has some limitations including small sample size and single center setting which limit generalizability of results. Further studies are recommended to explore the long-term sustainability of these outcomes. Moreover, while the outcomes of pain, ROM, and knee function significantly improved, other factors, such as quadriceps muscle strength or force production, quality of life, psychological outcomes, and return-to-sport timelines were not evaluated in this study. These aspects could provide a more comprehensive understanding of the benefits of the combined kinetic chains in rehabilitation programs. In addition, the impact of variations in exercise intensity, frequency, and progression on recovery outcomes should be explored. Future researchers are encouraged to explore these aspects.

Conclusion

The findings of this study showed that a combination of open kinetic and closed kinetic chains (combined kinetic chain) at a specific angle appears to be the most effective treatment for improving range of motion, knee function, and pain reduction for the rehabilitation of patients with Post ACL reconstruction surgery compared to OKC and CKC alone.

Data Sharing Statement

The data for this study are available from the corresponding author upon reasonable request.

Consent for Publication

Informed Consent for publication was obtained from all individuals whose data are included in this paper.

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Disclosure

The authors declared no conflict of interest.

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