

COMPARATIVE EFFECTS OF CLOSED KINETIC CHAIN EXERCISES
VERSUS NEUROMUSCULAR TRAINING ON PAIN, POSTURAL
STABILITY, AND FUNCTION IN PATIENTS WITH ACUTE LATERAL
ANKLE SPRAIN

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Abstract

Background: Acute lateral ankle sprain is one of the most prevalent musculoskeletal injuries and is frequently associated with pain, impaired postural control, and limitations in functional performance. Although both closed kinetic chain (CKC) exercises and neuromuscular training (NMT) are routinely incorporated into ankle rehabilitation programs, their comparative effectiveness in individuals with acute Grade I–II lateral ankle sprain remains insufficiently established.

Objective: To compare the effects of CKC exercises and NMT on pain intensity, dynamic postural stability, and functional performance in individuals with acute Grade I–II lateral ankle sprain.

Methods: This randomized controlled trial included participants aged 18–45 years with acute Grade I–II lateral ankle sprain. Participants were randomly allocated to either a CKC exercise group (n = 39) or an NMT group (n = 39). Both groups received supervised rehabilitation three times weekly for 12 weeks. Pain intensity was assessed using the Visual Analogue Scale (VAS), dynamic postural stability using the Y-Balance Test (YBT), and functional performance using the Foot and Ankle Ability Measure (FAAM), comprising the Activities of Daily Living (ADL) and Sports subscales. Data were analyzed using SPSS. Descriptive statistics were used to summarize participant characteristics, while the Shapiro–Wilk test was employed to assess data normality. Within-group changes were analyzed using the Wilcoxon signed-rank test, whereas between-group differences were examined using the Mann–Whitney U test. Statistical significance was established at $p < 0.05$.

Results: Following six weeks of rehabilitation, both groups demonstrated statistically significant improvements in pain, dynamic postural stability, and functional performance ($p < 0.001$). However, the NMT group demonstrated significantly greater improvements than the CKC group in pain reduction ($U = 128.000$, $p < 0.001$), dynamic postural stability as measured by the Y-Balance Test ($U = 403.000$, $p < 0.001$), FAAM-ADL

scores ($U = 302.500$, $p < 0.001$), and FAAM-Sports scores ($U = 470.500$, $p = 0.003$).

Conclusion: Both CKC exercises and NMT were effective in reducing pain and enhancing dynamic postural stability and functional performance among individuals with acute Grade I–II lateral ankle sprain. Nevertheless, NMT produced significantly superior improvements across all assessed clinical outcomes and may therefore represent a more effective rehabilitation approach for this population.

1. INTRODUCTION

Lateral ankle sprain (LAS) is one of the most common musculoskeletal injuries, particularly among physically active and athletic populations. It generally occurs through excessive plantar flexion and inversion, primarily affecting the anterior talofibular ligament and, with greater injury severity, the calcaneofibular ligament. Depending on the extent of ligamentous damage, LAS may be classified as Grade I, II, or III [1, 2]. Although frequently considered a minor injury, inadequate rehabilitation can result in persistent symptoms, recurrent sprains, chronic ankle instability, and long-term functional impairment [2, 3].

The epidemiological burden of LAS is substantial, with approximately 2–7 cases occurring per 1,000 person-years in the general population. Ankle sprains account for approximately 15% of sports-related injuries, with an incidence of 0.93 per 1,000 athletic exposures [4]. Importantly, up to 30–33% of individuals may develop chronic ankle instability, while persistent pain, swelling, weakness, and instability have been reported in up to 72% of cases [4]. Recurrence rates may reach 40%, increasing healthcare utilization and the risk of long-term complications, including post-traumatic osteoarthritis [5].

The consequences of LAS extend beyond ligamentous damage. Injury to the lateral ligament complex can impair mechanical stability and alter joint loading, while disruption of ligament-associated mechanoreceptors may compromise proprioception, joint position sense, and neuromuscular responses [2, 6, and 7]. These impairments can manifest as pain, swelling, restricted movement, muscular weakness, impaired balance, and a subjective sensation of ankle instability or giving way, ultimately

limiting daily and sporting activities [1,5,8]. Restoration of postural stability and neuromuscular control is therefore a central objective of contemporary ankle rehabilitation [9, 10].

Traditional management of acute LAS involves symptom control followed by progressive restoration of range of motion, strength, weight-bearing capacity, and functional activity [11]. However, conventional rehabilitation may not sufficiently address persistent proprioceptive and sensorimotor deficits, which are important contributors to recurrent injury and chronic instability [12]. Consequently, exercise-based interventions targeting both functional loading and neuromuscular control have gained increasing clinical attention.

Closed kinetic chain (CKC) exercises involve weight-bearing activities in which the distal segment is fixed or stabilized against a supporting surface. Exercises such as squats, lunges, and step-ups facilitate coordinated activation of multiple muscle groups, co-contraction, functional strengthening, and proprioceptive stimulation [13]. Their functional and weight-bearing characteristics may promote restoration of movement patterns and progressive loading of the injured limb [14].

Neuromuscular training (NMT), in contrast, primarily targets proprioception, balance, coordination, and sensorimotor integration. It commonly incorporates progressively challenging balance and stability exercises, including tasks performed on unstable or compliant surfaces. By enhancing postural responses and neuromuscular coordination, NMT may improve dynamic ankle stability and reduce the risk of recurrent injury [15, 16].

Although both CKC exercises and NMT are used in the rehabilitation of LAS, they

emphasize different therapeutic mechanisms. CKC exercises primarily facilitate functional strength, weight-bearing capacity, and joint stability, whereas NMT places greater emphasis on proprioception, balance, and sensorimotor control [12–16]. However, comparative evidence regarding their effectiveness in acute Grade I–II LAS remains limited, particularly across pain, dynamic postural stability, and functional performance.

Therefore, the present study aimed to compare the effects of CKC exercises and NMT on pain, postural stability, and functional performance in individuals with acute Grade I–II lateral ankle sprain. The findings may assist clinicians in identifying a more effective rehabilitation approach for optimizing recovery and reducing persistent functional deficits following acute LAS.

Objective and Hypothesis: The objective of this study was to compare the effectiveness of closed kinetic chain exercises and neuromuscular training in reducing pain intensity and improving postural stability and functional ankle performance among individuals with acute Grade I–II lateral ankle sprain. It was hypothesized that both interventions would produce significant improvements in pain, postural stability, and functional performance; however, neuromuscular training would result in greater improvements than closed kinetic chain exercises.

2. CRITICAL ANALYSIS OF THE LITERATURE

Recent literature indicates that both closed kinetic chain (CKC) exercises and neuromuscular training (NMT) can improve clinically relevant outcomes following lateral ankle injury, although their relative effectiveness remains uncertain. Evidence suggests that NMT is particularly beneficial for addressing proprioceptive deficits, dynamic postural control, and sensorimotor function. Singh [15] reported that a 12-week NMT program incorporating balance-board exercises, single-leg hopping, dynamic stabilization, and plyometric significantly reduced ankle-sprain incidence and improved

functional stability and postural sway in competitive basketball players. Similarly, Yesilkir and Sahin [19, 20] found that balance training and dynamic neuromuscular stabilization produced greater improvements in functional performance and postural control than conventional physiotherapy in athletes with chronic ankle instability. Huang et al. [21] also demonstrated that plyometric and combined plyometric-balance training improved ankle joint position awareness and muscle activation, providing further evidence for the sensorimotor benefits of neuromuscular exercise. However, most of these investigations involved chronic ankle instability or injury-prevention populations rather than individuals undergoing rehabilitation for acute Grade I–II LAS, limiting direct clinical generalizability. Moreover, differences in intervention content, outcome measures, and rehabilitation duration make direct comparison between studies difficult.

Evidence regarding CKC exercise is similarly supportive but less consistent when compared directly with NMT. Sajjad et al. [14] reported significant improvements in pain and functional outcomes following CKC and open kinetic chain exercise in athletes with chronic ankle instability, although no significant between-group difference was observed for functional performance. In contrast, Zafar et al. [17] found that CKC exercise produced greater improvements than NMT in selected dynamic balance measures, including the Star Excursion Balance Test and Y-Balance Test, among football players with chronic ankle sprains. Importantly, Memon et al. [13] directly compared CKC and NMT in athletes with acute Grade I–II LAS and found significant improvements in pain, range of motion, balance, and functional performance in both groups, with NMT demonstrating greater overall improvements. These findings provide the most direct support for NMT in acute LAS; however, the relatively small sample and four-week intervention period limit the strength and generalizability of the conclusions. Evidence from Karimijashni et al. [18], although derived from an anterior cruciate ligament reconstruction population, further

supports the potential of neuromuscular exercise to improve balance and reduce pain, but its different injury characteristics restrict direct extrapolation to LAS. Collectively, these findings suggest that CKC exercise may be effective for functional strengthening and weight-bearing control, whereas NMT may provide additional benefits through proprioceptive and sensorimotor mechanisms [34].

A further concern within the existing literature is the methodological and clinical heterogeneity of LAS rehabilitation research. Many studies have focused on chronic ankle instability rather than the acute phase, while several have involved small samples, short intervention periods, or outcome measures that differ substantially between investigations [14, 17, 19–21]. Wisemans et al. [12] further highlighted that rehabilitation progression in clinical practice is frequently guided by subjective criteria, with more than 46% of surveyed physiotherapists reporting no routine use of objective measures to determine progression. Although current evidence supports both CKC and NMT, there remains insufficient high-quality comparative evidence establishing which approach provides greater benefit during acute Grade I–II LAS rehabilitation [35]. The available direct evidence from Memon et al. [13] favors NMT, whereas findings from chronic ankle populations have produced conflicting results [14, 17, 19, and 20]. Therefore, a further controlled comparison incorporating clinically meaningful measures of pain, dynamic postural stability, and functional performance is warranted. The present study addresses this gap by comparing six weeks of CKC exercise and NMT in individuals with acute Grade I–II LAS using the Visual Analogue Scale, Y-Balance Test, and FAAM-ADL and Sports subscales.

3. RESEARCH METHODOLOGY

3.1 Study Design and Setting

A randomized controlled trial (RCT) was conducted to compare the effects of closed kinetic chain (CKC) exercises and neuromuscular training (NMT) on pain, dynamic postural stability, and functional

ankle performance in individuals with acute Grade I–II lateral ankle sprain. The study was conducted in the Departments of Physiotherapy at Ghurki Trust Teaching Hospital, Lahore, and General Hospital, Lahore.

3.2 Sample Size and Study Population

The sample size was calculated using G*Power 3.1, considering an effect size of 0.65, an alpha level of 0.05, and statistical power of 0.80, resulting in a total sample of 78 participants. The effect size was based on previous research comparing CKC exercises and NMT in individuals with acute lateral ankle sprain [13]. The study population comprised males and females aged 18–45 years with clinically diagnosed Grade I–II acute lateral ankle sprain. Eligible participants were recruited using purposive sampling and were informed about the study procedures before providing written informed consent. Following baseline assessment, participants were randomly allocated into two groups, with Group A receiving CKC exercises ($n = 39$) and Group B receiving NMT ($n = 39$).

3.3 Intervention and Study Duration

Both groups received supervised rehabilitation three times per week for 12 weeks according to their respective intervention protocols. The study was completed over six months, including participant recruitment, baseline assessment, intervention, post-intervention assessment, and data analysis. Outcome measures were recorded at baseline and following completion of the 12-week intervention.

3.4 Selection Criteria

Participants aged 18–45 years of either sex were included if they had a clinically diagnosed Grade I–II acute lateral ankle sprain, were able to participate in exercise-based rehabilitation, and reported pain intensity of ≥ 3 on the Visual Analogue Scale (VAS). Individuals with a history of ankle fracture or surgery, neurological or systemic disorders affecting rehabilitation, Grade III ankle sprain or instability beyond Grade II, or concurrent

participation in another rehabilitation program were excluded.

3.5 Study Variables

The independent variable was the type of rehabilitation intervention, comprising CKC exercises and NMT. The dependent variables were pain intensity, dynamic postural stability, and functional ankle performance. Pain was assessed using the VAS, dynamic postural stability using the Y-Balance Test (YBT), and functional performance using the Foot and Ankle Ability Measure (FAAM), including its Activities of Daily Living (ADL) and Sports subscales.

3.6 Outcome Measurement Tools

Three validated outcome measures were used to assess pain intensity, dynamic postural stability, and functional ankle performance at baseline and after the 12-week intervention. Visual Analogue Scale (VAS): Pain intensity was measured using a 10-cm VAS ranging from 0 to 10, where 0 represents no pain and 10 represents the worst imaginable pain.

Reach Score (CRS):

$$\text{YBT-UQ Composite Score} = \frac{(\text{Medial} + \text{Inferomedial} + \text{Superomedial})}{(3 \times \text{Limb Length})} \times 100$$

$$\text{YBT-LQ Composite Score} = \frac{(\text{Anterior} + \text{Posteromedial} + \text{Posterolateral})}{(3 \times \text{Limb Length})} \times 100$$

Upper limb injury risk: ≤88% males, ≤85% females; Lower limb: ≤98% males, ≤92% females; side-to-side difference >4 cm indicates asymmetry; higher scores indicate better stability. The YBT demonstrates good-to-excellent reliability. Test-retest reliability: ADL = 0.89, Sports = 0.87 and requires approximately 5–10 minutes to administer [24, 25].

Foot and Ankle Ability Measure (FAAM): Functional ankle performance was assessed using the FAAM, comprising the FAAM-Activities of Daily Living (FAAM-ADL) and FAAM-Sports subscales. The FAAM-ADL contains 21 items, while the Sports subscale contains 8 items. Each item is scored from 0 to 4, where 0 = unable to perform the activity, 1 = extreme difficulty, 2 = moderate difficulty, 3 = slight difficulty, and 4 = no difficulty. The total

Participants marked a point on the scale corresponding to their perceived pain intensity. The score was determined by measuring the distance in centimeters from the zero point to the participant's mark. Scores are commonly interpreted as 0 = no pain, 1–3 = mild pain, 4–6 = moderate pain, and 7–10 = severe pain. The VAS demonstrates excellent reliability and good validity for assessing pain intensity. High construct validity; strong correlation with NRS and verbal rating scales ($r = 0.62$ – 0.91); sensitive to clinically meaningful changes and requires approximately one minute to administer [22, 23].

Y-Balance Test (YBT): Dynamic postural stability was assessed using the YBT, in which participants maintained single-leg stance while reaching maximally in the anterior, posteromedial, and posterolateral directions. Each direction was performed according to standardized testing procedures, and the maximum successful reach distance was recorded. The three reach distances were used to calculate the Composite

score for each subscale is calculated by summing the item scores and converting the result to a percentage: $[(\text{actual score} / \text{maximum possible score}) \times 100]$. Thus, the FAAM-ADL is expressed as a percentage of a maximum 84 points, while FAAM-Sports is expressed as a percentage of a maximum 32 points. Higher percentages indicate better functional ability, whereas lower scores indicate greater functional limitation. The FAAM demonstrates good test-retest reliability. Interrater test-retest: ICC = 0.80–0.85; Intrarater: ICC = 0.85–0.91; Composite reach score: ICC = 0.91–0.99 and responsiveness to changes in foot and ankle function [26, 27].

3.7 Intervention Protocols

Participants were randomly allocated to either the closed kinetic chain (CKC) exercise group

or the neuromuscular training (NMT) group. Both interventions were administered under physiotherapist supervision for 12 weeks, with three sessions per week and approximately 20–30 minutes per session. All participants received standard physiotherapy care, including acute symptom management, education regarding protection and progressive weight bearing, and appropriate use of ice, compression, elevation, ankle support, and manual therapy where clinically indicated. The exercise programs were progressively modified according to individual tolerance, clinical status, movement quality, and functional improvement.

3.7.1 Closed Kinetic Chain Exercise Group

Participants in the CKC group performed a progressive weight-bearing exercise program targeting lower-limb strength, ankle stability, proprioception, and functional control. During weeks 1–2, participants performed partial squats, supported step-ups, supported single-leg stance, heel raises, and mini-lunges. During weeks 3–4, exercises were progressed to full squats, step-up and step-down activities, controlled weight shifting, heel raises, and lunges with greater movement demands. During weeks 5–8, participants performed unstable-surface squats, lateral step-ups, single-leg mini-squats, single-leg heel raises, walking lunges, and resisted exercises as tolerated. During weeks 9–12, advanced functional activities including single-leg squats, multidirectional lunges, and resisted step-ups and walking lunges, advanced heel raises, and functional balance activities were introduced. Progression was achieved through gradual increases in resistance, repetitions, range of motion, unilateral loading, and functional complexity [13].

3.7.2 Neuromuscular Training Group

Participants allocated to the NMT group completed a progressive program primarily targeting proprioception, balance, coordination, postural control, and dynamic ankle stability. During weeks 1–2, training consisted of supported single-leg stance, stable-surface balance, and basic balance-board exercises. During weeks 3–4, visual-input

challenges, dynamic balance-board activities, controlled weight shifting, and lateral hopping were introduced. During weeks 5–8, training progressed to wobble-board exercises, multidirectional weight shifting, single-leg hopping, forward and backward hopping, and balance activities incorporating reaching. During weeks 9–12, participants performed multidirectional single-leg hops, repeated jumps, reactive landing and balance tasks, unstable-surface activities, and change-of-direction exercises. Exercise difficulty was progressively increased by reducing external support, increasing movement speed and complexity, and introducing unstable surfaces and multidirectional tasks [28].

3.7.3 Progression and Safety

Exercise intensity and complexity were individually progressed according to clinical status, exercise tolerance, movement quality, and functional improvement. Progression was achieved through changes in repetitions, resistance, and range of motion, movement speed, surface stability, and external support. Participants were instructed to maintain controlled technique throughout each exercise. Exercises were modified or temporarily discontinued in the presence of excessive pain, marked discomfort, loss of balance, or inability to perform the activity safely. Attendance, adherence, tolerance, and adverse events were monitored throughout the intervention. Both groups received comparable supervised treatment time, with the principal difference being the therapeutic focus: CKC training emphasized progressive weight-bearing and functional strengthening, whereas NMT emphasized proprioception, balance, coordination, and dynamic neuromuscular control.

3.8 Ethical Considerations

Ethical approval was obtained from the relevant Institutional Review Board, and permission to conduct the study was obtained from Ghurki Trust Teaching Hospital, Lahore, and General Hospital, Lahore. Written informed consent was obtained from all participants before enrolment. Participants were informed about the study objectives,

procedures, potential benefits, and possible risks. Confidentiality and privacy were maintained throughout the study, and participation was voluntary. Participants were informed of their right to withdraw from the study at any stage without consequence.

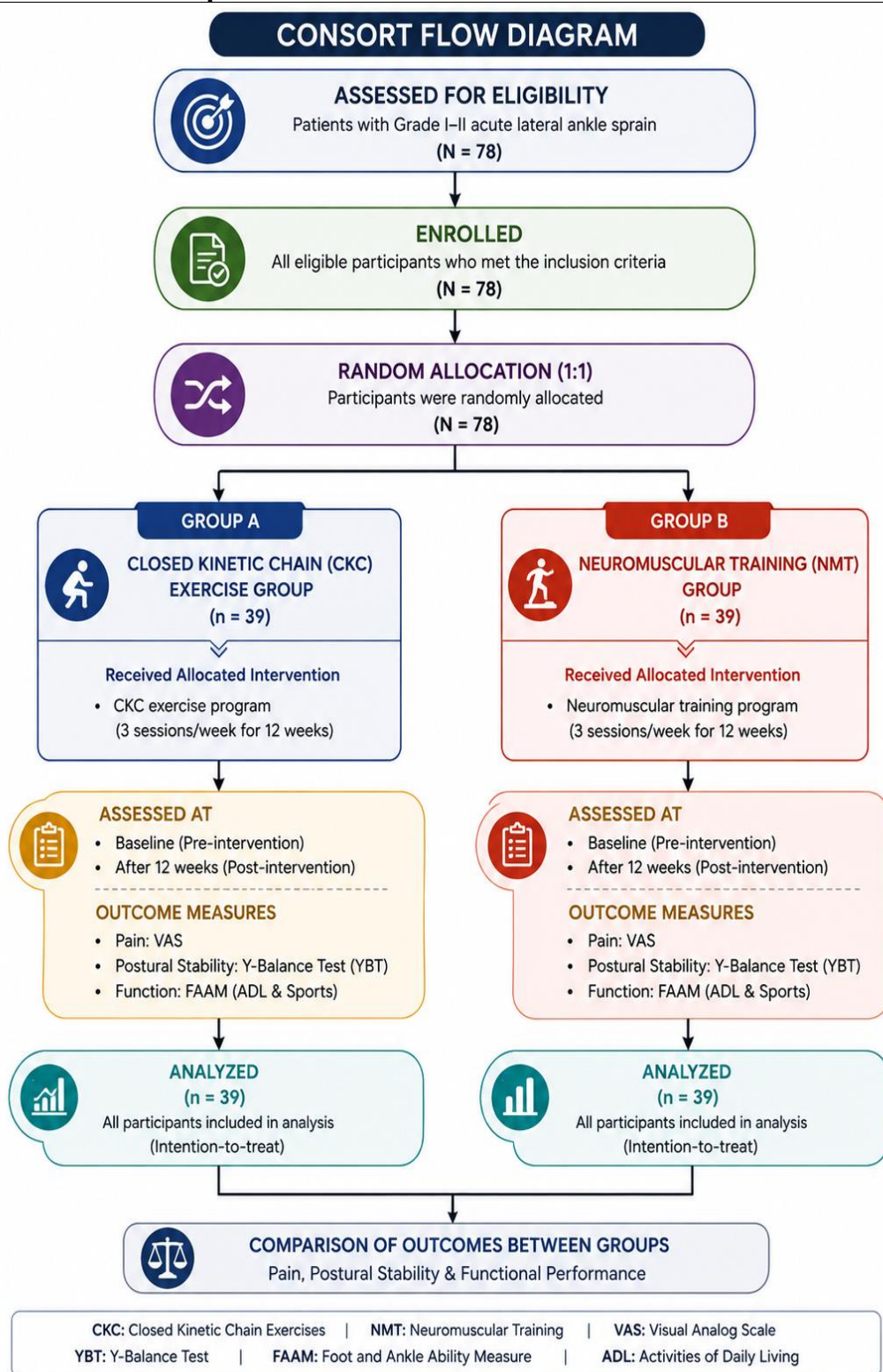
3.9 Data Collection Procedure

Data were collected from the outpatient physiotherapy departments of Ghurki Trust Teaching Hospital and General Hospital, Lahore, following institutional approval. After eligibility screening and written informed consent, demographic and relevant clinical information was recorded. Participants were then randomly allocated to the CKC or NMT group using a computer-generated randomization procedure. Baseline assessment included pain intensity using the Visual Analogue Scale (VAS), dynamic postural stability using the Y-Balance Test (YBT), and functional ankle performance using the Foot and Ankle Ability Measure (FAAM), including the ADL and Sports subscales. Participants subsequently completed their assigned intervention three times weekly for 12 weeks,

with each session lasting approximately 20–30 minutes. Exercise progression, attendance, adherence, and adverse events were monitored throughout the intervention. Following completion of the 12-week program, the same outcome measures were reassessed. All collected data were recorded on structured data collection forms and subsequently entered into a secure electronic database.

3.10 Data Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to summarize demographic and clinical characteristics. The Shapiro–Wilk test was used to assess the normality of continuous variables. As the outcome data were non-normally distributed, within-group pre- to post-intervention changes were analyzed using the Wilcoxon signed-rank test, while between-group differences were assessed using the Mann–Whitney U test. Statistical significance was established at $p < 0.05$.



4. RESULTS

The demographic and baseline characteristics of the participants are presented in **Table 1**. The mean age, height, weight, and BMI were

comparable between the CKC and NMT groups. The CKC group included 20 (51.3%) males and 19 (48.7%) females, while the NMT group comprised 17 (43.6%) males and 22

(56.4%) females. Left-leg dominance was observed in 56.4% of the CKC group and 53.8% of the NMT group. Previous ankle sprain was reported by 59.0% of participants in the CKC group and 51.3% in the NMT group. Activity levels were distributed across

sedentary, recreational, and competitive categories, while participants represented diverse occupational groups. Overall, the two groups demonstrated broadly comparable demographic and baseline characteristics.

Table 1. Demographic and baseline characteristics of participants

Variable	Category	CKC (n = 39)	NMT (n = 39)
Age (years)	Mean $\pm$ SD	31.79 $\pm$ 8.46	31.54 $\pm$ 8.43
Height (cm)	Mean $\pm$ SD	169.86 $\pm$ 9.81	170.59 $\pm$ 10.13
Weight (kg)	Mean $\pm$ SD	73.21 $\pm$ 11.82	72.19 $\pm$ 10.20
BMI (kg/m ²)	Mean $\pm$ SD	25.68 $\pm$ 5.30	25.07 $\pm$ 4.73
Gender	Male	20 (51.3%)	17 (43.6%)
	Female	19 (48.7%)	22 (56.4%)
Dominant leg	Left	22 (56.4%)	21 (53.8%)
	Right	17 (43.6%)	18 (46.2%)
Previous ankle sprain	Yes	23 (59.0%)	20 (51.3%)
	No	16 (41.0%)	19 (48.7%)
Activity level	Sedentary	13 (33.3%)	7 (17.9%)
	Recreational	14 (35.9%)	16 (41.0%)
	Competitive	12 (30.8%)	16 (41.0%)
Occupation	Student	3 (7.7%)	4 (10.3%)
	Office	5 (12.8%)	4 (10.3%)
	Healthcare	4 (10.3%)	4 (10.3%)
	Manual	8 (20.5%)	5 (12.8%)
	Athlete	5 (12.8%)	4 (10.3%)
	Self-employed	4 (10.3%)	6 (15.4%)
	Homemaker	5 (12.8%)	6 (15.4%)
	Retired	5 (12.8%)	6 (15.4%)

Note: Continuous variables are presented as mean $\pm$ standard deviation (SD), while categorical variables are presented as frequency and percentage, n (%). CKC = closed kinetic chain; NMT = neuromuscular training; BMI = body mass index.

The clinical outcomes before and after the intervention are presented in **Table 2**. Both groups demonstrated improvements across all assessed outcomes following the 12-week rehabilitation program. VAS scores decreased from 7.25 $\pm$ 1.04 to 4.14 $\pm$ 1.25 in the CKC group and from 7.39 $\pm$ 1.21 to 3.11 $\pm$ 1.40 in the NMT group, indicating greater pain reduction following NMT. Y-Balance composite scores increased from 82.24 $\pm$ 5.15 to 89.52 $\pm$ 5.34 in the CKC group and from 80.18 $\pm$ 5.69 to 88.78 $\pm$ 5.93 in the NMT

group, demonstrating improved dynamic postural stability in both groups. Similarly, FAAM-ADL scores increased from 52.54 $\pm$ 9.85 to 64.15 $\pm$ 10.80 in the CKC group and from 55.13 $\pm$ 9.19 to 70.46 $\pm$ 9.22 in the NMT group. The corresponding FAAM-ADL percentage scores increased from 62.54 $\pm$ 11.73% to 76.37 $\pm$ 12.86% with CKC and from 65.64 $\pm$ 10.94% to 83.88 $\pm$ 10.97% with NMT, indicating greater improvement in functional ability following neuromuscular training.

Table 2. Clinical Outcome Measures Before and After the Intervention

Outcome Measure	Group	Before Intervention Mean $\pm$ SD	After Intervention Mean $\pm$ SD
VAS Score	CKC	7.25 $\pm$ 1.04	4.14 $\pm$ 1.25
	NMT	7.39 $\pm$ 1.21	3.11 $\pm$ 1.40
Y-Balance Test Composite Score	CKC	82.24 $\pm$ 5.15	89.52 $\pm$ 5.34
	NMT	80.18 $\pm$ 5.69	88.78 $\pm$ 5.93
FAAM-ADL Score	CKC	52.54 $\pm$ 9.85	64.15 $\pm$ 10.80
	NMT	55.13 $\pm$ 9.19	70.46 $\pm$ 9.22
FAAM-ADL Percentage (%)	CKC	62.54 $\pm$ 11.73	76.37 $\pm$ 12.86
	NMT	65.64 $\pm$ 10.94	83.88 $\pm$ 10.97

Note: Values are presented as mean $\pm$ standard deviation (SD). VAS = Visual Analogue Scale; YBT = Y-Balance Test; FAAM-ADL = Foot and Ankle Ability Measure–Activities of Daily Living; CKC = closed kinetic chain; NMT = neuromuscular training.

As the Shapiro–Wilk test showed non-normal distributions for several outcome and change scores, particularly for the FAAM measures, non-parametric tests were used for inferential analysis. The Wilcoxon signed-rank test was applied for within-group comparisons, while

the Mann–Whitney U test was used to compare changes between the CKC and NMT groups. A p-value <0.05 was considered statistically significant (Table 3).

Table 3. Test of Normality (Shapiro–Wilk)

Variable	CKC: W (p)	NMT: W (p)	Distribution
VAS – Pre	0.950 (0.082)	0.883 (0.001)	Mixed
VAS – Post	0.978 (0.639)	0.954 (0.109)	Normal
Y-Balance – Pre	0.938 (0.033)	0.905 (0.003)	Non-normal
Y-Balance – Post	0.974 (0.479)	0.946 (0.061)	Normal
FAAM-ADL – Pre	0.899 (0.002)	0.925 (0.013)	Non-normal
FAAM-ADL – Post	0.931 (0.019)	0.936 (0.029)	Non-normal
FAAM-Sports – Pre	0.908 (0.004)	0.909 (0.004)	Non-normal
FAAM-Sports – Post	0.927 (0.014)	0.979 (0.675)	Mixed
Change in VAS	0.944 (0.053)	0.909 (0.004)	Mixed
Change in Y-Balance	0.950 (0.079)	0.896 (0.002)	Mixed
Change in FAAM-ADL	0.898 (0.002)	0.921 (0.009)	Non-normal
Change in FAAM-Sports	0.858 (<0.001)	0.898 (0.002)	Non-normal

Note: W = Shapiro–Wilk statistic. $P \geq 0.05$ indicates no significant departure from normality, whereas $p < 0.05$ indicates non-normality.

The Wilcoxon signed-rank analysis demonstrated statistically significant pre- to post-intervention improvements in pain, dynamic postural stability, and functional

performance within both groups (Table 4). All outcomes demonstrated $p < 0.001$, indicating significant improvement following both CKC and NMT interventions.

Table 4. Within-Group Comparison of Clinical Outcomes before and After Intervention

Outcome Measure	Group	n	Z value	p-value
VAS	CKC	39	–5.445	<0.001
	NMT	39	–5.447	<0.001
Y-Balance Composite Score	CKC	39	–5.443	<0.001

	NMT	39	-5.443	<0.001
FAAM-ADL	CKC	39	-5.461	<0.001
	NMT	39	-5.455	<0.001
FAAM-Sports	CKC	39	-5.478	<0.001
	NMT	39	-5.472	<0.001

Note: Within-group comparisons were performed using the Wilcoxon signed-rank test. VAS = Visual Analogue Scale; FAAM-ADL = Foot and Ankle Ability Measure-Activities of Daily Living; CKC = closed kinetic chain; NMT = neuromuscular training.

The between-group analysis demonstrated statistically significant differences in the magnitude of change for all outcomes (Table 5). The NMT group consistently demonstrated higher mean ranks than the CKC group, indicating greater improvement in pain

reduction, dynamic postural stability, and functional performance. The largest between-group difference was observed for change in VAS ($U = 128.000$, $Z = -6.329$, $p < 0.001$), while significant advantages for NMT were also observed for Y-Balance performance, FAAM-ADL, and FAAM-Sports outcomes.

Table 5. Between-Group Comparison of Changes in Clinical Outcomes

Outcome Measure	Group	n	Mean Rank	Mann-Whitney U	Z value	p-value
Change in VAS	CKC	39	23.28	128.000	-6.329	<0.001
	NMT	39	55.72			
Change in Y-Balance Composite Score	CKC	39	30.33	403.000	-3.574	<0.001
	NMT	39	48.67			
Change in FAAM-ADL	CKC	39	27.76	302.500	-4.603	<0.001
	NMT	39	51.24			
Change in FAAM-Sports	CKC	39	32.06	470.500	-2.951	0.003
	NMT	39	46.94			

Note: Between-group comparisons were performed using the Mann-Whitney U test. VAS = Visual Analogue Scale; FAAM-ADL = Foot and Ankle Ability Measure-Activities of Daily Living; CKC = closed kinetic chain; NMT = neuromuscular training.

5. DISCUSSION

The present randomized controlled trial demonstrated that both closed kinetic chain (CKC) exercises and neuromuscular training (NMT) significantly improved pain, dynamic postural stability, and functional performance in individuals with Grade I-II acute lateral ankle sprain after 12 weeks. However, NMT produced significantly greater improvements in all major outcomes. These findings suggest that although CKC exercises effectively restore weight-bearing capacity and lower-limb strength, NMT may provide additional benefits through greater emphasis on proprioception, balance, coordination, and dynamic neuromuscular control.

Pain significantly decreased in both groups,

from 7.25 ± 1.04 to 4.14 ± 1.25 in the CKC group and from 7.39 ± 1.21 to 3.11 ± 1.40 in the NMT group ($p < 0.001$). However, the reduction was significantly greater with NMT ($U = 128.000$, $p < 0.001$). This is consistent with Memon et al. [28], who reported greater pain reduction with neuromuscular training than CKC exercise in acute Grade I-II ankle sprains. Norouzi et al. [27] also reported significant pain improvement following rehabilitation for Grade II lateral ankle sprain. The greater effect of NMT may be related to enhanced proprioceptive input and coordinated activation of ankle stabilizing muscles, which can improve joint control, reduce abnormal loading, and decrease protective muscle activity around the injured

ankle.

Dynamic balance also improved significantly in both groups, with Y-Balance scores increasing from 82.24 ± 5.15 to 89.52 ± 5.34 in CKC and from 80.18 ± 5.69 to 88.78 ± 5.93 in NMT. The between-group difference favored NMT ($U = 403.000$, $p < 0.001$). These findings are comparable with Yeşilkır and Şahin [29] and Kim et al. [30,32], who reported significant improvements in postural control following neuromuscular and balance-based rehabilitation. NMT may have produced greater improvements because repeated single-leg stance, weight shifting, hopping, landing, and multidirectional activities directly challenge proprioception and reactive postural control. Such exercises may improve sensory feedback and the timing of ankle muscle activation, thereby enhancing the ability to maintain stability during dynamic movement. Functional ability similarly improved in both groups. FAAM-ADL increased from 52.54 ± 9.85 to 64.15 ± 10.80 in CKC and from 55.13 ± 9.19 to 70.46 ± 9.22 in NMT, with a significant between-group difference favoring NMT ($U = 302.500$, $p < 0.001$). This supports Martin et al. [31] and Kim et al. [32], who reported improved functional outcomes following structured exercise and neuromuscular rehabilitation. The greater improvement with NMT may be explained by its task-specific nature, as balance, hopping, landing, and directional-change exercises closely resemble the demands of daily functional activities. Similarly, FAAM-Sports scores improved significantly in both groups, with NMT showing greater improvement ($U = 470.500$, $p = 0.003$). This finding agrees with Matsusaka et al. [33], although Silva et al. [34] reported no superiority between rehabilitation approaches in professional athletes with chronic ankle instability. This difference may reflect variations in injury stage and population, as the present study focused on acute Grade I-II ankle sprains [34].

Overall, the findings indicate that both CKC and NMT are effective for acute lateral ankle sprain rehabilitation, but NMT appears more effective for reducing pain and restoring balance and functional performance. Its greater effectiveness may be associated with its

specific emphasis on proprioception, reactive stability, coordinated muscle activation, and functional movement, while CKC exercises primarily contribute through progressive weight-bearing and strengthening. Thus, incorporating neuromuscular training into rehabilitation may provide greater functional benefits than CKC exercise alone [27–34].

5.1 CONCLUSION

The study concluded that both closed kinetic chain exercises and neuromuscular training were effective in reducing pain, improving dynamic postural stability, and enhancing functional performance among individuals with Grade I-II acute lateral ankle sprains following the 12-week rehabilitation program. However, neuromuscular training demonstrated significantly greater improvements in pain, Y-Balance performance, FAAM-ADL, and FAAM-Sports outcomes compared with closed kinetic chain exercises. Therefore, neuromuscular training may be considered a more effective rehabilitation approach for improving overall clinical and functional outcomes in acute lateral ankle sprain.

5.2 LIMITATIONS

The study was conducted at selected rehabilitation centers in Lahore, which may limit the generalizability of the findings to other clinical settings and populations. The study included only individuals with Grade I–II acute lateral ankle sprains; therefore, the findings may not be applicable to patients with more severe injuries or chronic ankle instability. The assessment primarily relied on patient-reported outcomes and functional performance tests, without incorporating objective measures such as biomechanical analysis, gait assessment, electromyography, or imaging. Furthermore, recurrence and re-injury following completion of the rehabilitation program were not assessed. Participants' physical activity levels, adherence to home exercises, and lifestyle factors were also not systematically monitored, which may have influenced the observed outcomes.

5.3 RECOMMENDATIONS

Future studies should include larger, multi-center samples to improve the generalizability of the findings and should incorporate long-term follow-up to determine whether treatment benefits are maintained and whether rehabilitation reduces the risk of recurrent ankle sprain. Further research should also evaluate the effectiveness of neuromuscular training and closed kinetic chain exercises in patients with more severe or chronic ankle instability. The inclusion of objective measures such as gait analysis, muscle strength testing, electromyography, motion analysis, and biomechanical assessment would provide a more comprehensive evaluation of rehabilitation outcomes. Future researchers should also monitor adherence to home exercise programs and physical activity levels. Comparative studies investigating combined rehabilitation programs and other physiotherapy interventions may further help identify the most effective rehabilitation strategy for acute lateral ankle sprain.

REFERENCES

1. Cavazos GJ Jr, Harkless LB. The epidemiology, evaluation, and assessment of lateral ankle sprains in athletes. *J Sports Med Ther.* 2021;6:008.
2. Schurz AP, Wagemans J, Bleakley C, Kuppens K, Vissers D, Taeymans J. Impairment-based assessments for patients with lateral ankle sprain: a systematic review of measurement properties. *PLoS One.* 2023;18(2):e0280388.
3. Michels F, Wastyn H, Pottel H, Stockmans F, Vereecke E, Matricali G. The presence of persistent symptoms 12 months following a first lateral ankle sprain: a systematic review and meta-analysis. *Foot Ankle Surg.* 2022;28(7):817-26.
4. Lee YH, Lee KJ, Nam SH, Kim KM. Clinical impairments associated with ankle disability in patients with acute lateral ankle sprain. *Front Public Health.* 2025;13:1617269.
5. Hong CC, Calder J. The burden of the "simple ankle sprains": a review of the epidemiology and long-term impact. *Foot Ankle Clin.* 2023;28(2):187-200.
6. Zahra W, Meacher H, Heaver C. Ankle sprains: a review of mechanism, pathoanatomy and management. *Orthop Trauma.* 2024;38(1):25-34.
7. Flore Z, Hambly K, De Coninck K, Welsch G. Time-loss and recurrence rate of lateral ankle sprains in male professional football players depending on the severity grade: do we trivialise LAS? *BMJ Open Sport Exerc Med.* 2025;11(1).
8. Fraser JJ, Koldenhoven RM, Jaffri AH, Park JS, Saliba SF, Hart JM, Hertel J. Foot impairments contribute to functional limitation in individuals with ankle sprain and chronic ankle instability. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(5):1600-10.
9. Lee JH, Lee SH, Choi GW, Jung HW, Jang WY. Individuals with recurrent ankle sprain demonstrate postural instability and neuromuscular control deficits in unaffected side. *Knee Surg Sports Traumatol Arthrosc.* 2020;28(1):184-92.
10. Naderifar H, Babakhanian S, Najafi-Vosough R, Ardakani MK. Neuromuscular control training is effective to prevent ankle sprains in athletes. *Muscles Ligaments Tendons J.* 2024;14(1).

11. Tee E, Melbourne J, Sattler L, Hing W. Evidence for rehabilitation interventions after acute lateral ankle sprains in athletes: a scoping review. *J Sport Rehabil.* 2021;31(4):457-64.
12. Wagemans J, Dingenen B, Clockaerts S, Bleakley C. Physiotherapists approach in lateral ankle sprain rehabilitation: a survey study. *J Sport Rehabil.* 2025;1(aop):1-8.
13. Memon AG, Chandran SP, Hameed A, Saleem S, Sheraz A. Comparing neuromuscular training and closed chain exercises in athletes with ankle sprains: efficacy in pain reduction, joint mobility, balance, and functional disability: a randomized control trial. *J Riphah Coll Rehabil Sci.* 2025 Sep 24.
14. Sajjad MA, Rehman RA, Azfar H, Qazi ZN, Khalid MU, Ahmad HZ. Effects of open versus closed kinetic chain exercises on pain, instability and balance in athletes with chronic ankle instability. *Found Univ J Rehabil Sci.* 2024;4(2):94-9.
15. Singh LS. Effect of neuromuscular training on prevention of ankle sprains in basketball players. *J Sports Physiother.* 2025;1(01):1-8.
16. Ahmed MI, Hassan AS, Osman AM, Abdel-Halim KM. Effect of a neuromuscular training program on the recurrence rate of ankle injuries among handball players. *Assiut J Sport Sci Arts.* 2025;2025(1):45-57.
17. Zafar MH, Saeed Z, Rukh S, Mehboob A, Khan S, Karim I, Khan S, Aslam I. Effects of closed-chain exercise versus neuromuscular training on functional performance in football players with chronic ankle sprain: closed-chain vs. neuromuscular training for ankle sprain. *J Health Rehabil Res.* 2024;4(3):1-5.
18. Karimijashni M, Sarvestani FK, Yoosefinejad AK. The effect of contralateral knee neuromuscular exercises on static and dynamic balance, knee function, and pain in athletes who underwent anterior cruciate ligament reconstruction: a single-blind randomized controlled trial. *J Sport Rehabil.* 2023;32(5):524-39.
19. Yesilkir S, Ergezen Sahin G. Dynamic neuromuscular stabilization, balance, and conventional training for chronic ankle instability in amateur athletes: a randomised controlled trial. *BMC Sports Sci Med Rehabil.* 2025;17(1):286.
20. Yesilkir S, Sahin GE. Dynamic neuromuscular stabilization training for chronic ankle instability: a randomized controlled trial in amateur athletes. *J Back Musculoskelet Rehabil.* 2025 May 11:10538127251338170.
21. Huang PY, Jankaew A, Lin CF. Effects of plyometric and balance training on neuromuscular control of recreational athletes with functional ankle instability: a randomized controlled laboratory study. *Int J Environ Res Public Health.* 2021;18(10):5269.

22. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual analog scale for pain (VAS pain), numeric rating scale for pain (NRS pain), McGill Pain Questionnaire (MPQ), short-form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 bodily pain scale (SF-36 BPS), and measure of intermittent and constant osteoarthritis pain (ICOAP). *Arthritis Care Res.* 2011;63(S11):S240-S252.
23. Bijur PE, Silver W, Gallagher EJ. Reliability of the visual analog scale for measurement of acute pain. *Acad Emerg Med.* 2001;8(12):1153-7.
24. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. *N Am J Sports Phys Ther.* 2009;4(2):92.
25. New Zealand Defence Force. Y-Balance musculoskeletal screening (Internet). n.d. (cited 2026 Jan 30). Available from: <https://health.nzdf.mil.nz/assets/Documents/NZDF-Y-BALLANCE.pdf>
26. O'Driscoll J, Kerin F, Delahunt E. Effect of a 6-week dynamic neuromuscular training programme on ankle joint function: a case report. *Sports Med Arthrosc Rehabil Ther Technol.* 2011;3(1):13.
27. Norouzi A, Delkhoush CT, Mirmohammadkhani M, Bagheri R. A comparison of mobilization and mobilization with movement on pain and range of motion in people with lateral ankle sprain: A randomized clinical trial. *Journal of bodywork and movement therapies.* 2021 Jul 1;27:654-60.
28. Memon AG, Chandran SP, Hameed A, Saleem S, Sheraz A. Comparing Neuromuscular Training and Closed Chain Exercises in Athletes with Ankle Sprains: Efficacy in Pain Reduction, Joint Mobility, Balance, And Functional Disability: A Randomized Control Trial. *Journal Riphah College of Rehabilitation Sciences.* 2025 Sep 24.
29. Yesilkir S, Ergezen Sahin G. Dynamic neuromuscular stabilization, balance, and conventional training for chronic ankle instability in amateur athletes: a randomised controlled trial. *BMC Sports Science, Medicine and Rehabilitation.* 2025 Oct 1;17(1):286.
30. Kim KM, Estepa-Gallego A, Estudillo-Martínez MD, Castellote-Caballero Y, Cruz-Díaz D. Comparative effects of neuromuscular-and strength-training protocols on pathomechanical, sensory-perceptual, and motor-behavioral impairments in patients with chronic ankle instability: randomized controlled trial. *InHealthcare* 2022 Jul 22 (Vol. 10, No. 8, p. 1364). MDPI.
31. Martin, R.L., Davenport, T.E., Fraser, J.J., Sawdon-Bea, J., Carcia, C.R., Carroll, L.A., Kivlan, B.R. and Carreira, D., 2021. Ankle stability and movement coordination impairments: lateral ankle ligament sprains revision 2021: clinical practice guidelines linked to the international classification of functioning, disability and health from the academy of orthopaedic physical

- therapy of the American physical therapy association. *Journal of Orthopaedic & Sports Physical Therapy*, 51(4), pp.CPG1-CPG80.
32. Kazemi K, Javanshir K, Saadi F, Goharpey S, Shaterzadeh Yazdi MJ, Calvo-Lobo C, López-López D, Nassadj G. The effect of additional neuromuscular training on peri-ankle muscle morphology and function in chronic ankle instability subjects: a randomized controlled trial. *Sports Health*. 2025 May;17(3):572-84.
33. Samakosh HM, Brito JP, Shojaedin SS, Hadadnezhad M, Oliveira R. What does provide better effects on balance, strength, and lower extremity muscle function in professional male soccer players with chronic ankle instability? Hopping or a balance plus strength intervention? A randomized control study. In *Healthcare 2022* (Vol. 10, No. 10, p. 1822). MDPI AG.
34. Qamar MM, Basharat A, Kiran Q, Nazir A, Ahmad W, Basharat S. Comparison of the Effects of Conventional Physical Therapy Versus Progressive Overload Training in Patients with Shoulder Impingement Syndrome; A Randomised Clinical Trial. *Annals of King Edward Medical University*. 2023 Jul 4;29(1):50-4.
35. Ashraf S, Kiran Q, Malik A, Mubashar H, Subhani AH, Ahmed S, Saleem A, Ahmed S. Effects of different testing postures on hand grip strength among healthy individuals. *Pakistan BioMedical Journal*. 2022 Jan 31:164-7.