Effect of Closed Kinematic Chain exercises versus Open Kinematic Chain exercises on Knee Extensor strength, Gait Velocity and Functional strength of Lower limb in subjects with subacute stroke

Pula Ruchitha[1], Dr. G. Kameswari[2], Dr. V. Srikumari[3], Dr. K. Madhavi[4]

[1]MPT (Neuro), Department of Physiotherapy, COP, SVIMS, Tirupati.

[2]MPT (Neuro), phD, Teaching faculty, COP, SVIMS, Tirupati.

[3]MPT (Neuro), phD, Associate professor, COP, SVIMS, Tirupati.

[4]MPT Cardiothoracic, PhD, Principal, COP, SVIMS, Tirupati.

Corresponding author

G.Kameswari

Sri Venkateswara Institute of Medical Sciences

Mail: kameshwarigaali@gmail.com

Ph no: 7382616752

ABSTRACT

AIM: The aim of this study is to evaluate the effect of Closed kinematic chain exercises versus Open kinematic chain exercises on knee extensor strength, gait velocity and functional strength of lower limb in subjects with subacute stroke.

OBJECTIVE: The objective of this study is to evaluate and compare the efficacy of Closed kinematic chain exercises versus Open kinematic chain exercises on knee extensor strength by using Biodex system 4 pro Isokinetic dynamometer, on Gait velocity by 10-Meter walk test, on Functional strength of affected lower limb by 5-repetititon sit-to-stand test.

BACKGROUND: Stroke is a rapidly developing clinical sign of focal disturbances in cerebral function with symptoms lasting 24 hours or longer or leading to death with no apparent cause other than vascular origin. In stroke recovery the exercises plays an important role in which Progressive resistance training includes Closed kinematic chain exercises

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(CKC) and Open kinematic chain exercises (OKC). CKC exercises are the exercises that involve the fixed distal ends creating compressive forces whereas the OKC exercises are the type of exercises in which the distal ends are movable and helps in improving strength and proprioception.

RESULTS: The results of this study showed a marked improvement in Peak Knee extensor torque in CKC group (49.6) compared to OKC group (34.7) with a p value of 0.05. There were a good notable difference in gait velocity in CKC group with 0.85 comparing to OKC group which has 0.63 and a notable improvement was also seen in 5-STS Test also.

CONCLUSION: In conclusion, CKC exercises should be prioritised as the primary strengthening modality in subacute stroke rehabilitation protocols targeting Peak knee extensor torque, Gait velocity, and Functional lower limb strength, while OKC exercises serve as a valuable adjunct, particularly in the earlier stages of recovery when full weight-bearing is not the option of the treatment.

KEY WORDS: Closed kinematic chain exercises, Open kinematic chain exercises, Biodex system 4 pro Isokinetic device**,** 10-Meter walk test**,** 5-repetititon sit-to-stand test**.**

INTRODUCTION

Stroke is a rapidly developing clinical sign of focal disturbances in cerebral function with symptoms lasting 24 hours or longer or leading to death with no apparent cause other than vascular origin as defined by World Health Organization (1).

Stroke results in the atrophy of type II muscle fibers in paretic limbs in long standing cases. Along with that, reduced oxidative capacity and blood flow impairment can also be seen. This leads to the strength loss on the paretic side of the body (2).

Muscle weakness in the paretic lower limb, especially in the knee extensors and ankle dorsiflexors, leads to reduced joint torque, impaired balance, and slower gait velocity, limiting independence of functional activities of the daily living (3).

According to research, the average gait velocity of healthy individuals of similar ages is approximately 1.4 m/s, whereas the gait velocity of stroke patients varies from 0.18 to 1.03 m/s depending on the severity of their stroke (4).

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In subacute stroke patients, the paretic leg produced only about 53% of the maximal voluntary torque compared to healthy controls. The non-paretic leg also exhibited reduced strength, generating around 71% of normal torque levels (5). In the majority of individuals with subacute stroke, quadriceps weakness is more responsible for impaired walking than quadriceps spasticity (6).

Muscle strengthening in stroke patients is typically categorized into low-intensity resistance training, high-intensity training, and progressive resistance training. Progressive resistance training (PRT) involves gradually increasing the amount of resistance applied to a muscle, aiming to enhance the muscle's capacity to generate and maintain force over time (7). It is an effective method to improve overall muscle strength, which involves using weights or loads that are at least 70% or more of an individual's maximum strength (8).

Axial-load exercises, also referred to as Closed Kinematic Chain (CKC) exercises, have become increasingly popular in recent years. Each bodily segment's function is evaluated biomechanically in respect to other associated segments. The entire body is thought of as a chain, with each element moving in response to the others (9). CKC exercises for the lower limbs are generally done with the feet positioned on a stable surface, creating compressive forces across the hip, knee, and ankle joints (10).

Open Kinematic Chain (OKC) exercises involve movements where the hand or foot is not fixed and can move freely. These exercises are primarily aimed at enhancing muscle strength, rather than improving proprioception, particularly during knee flexion and extension (11).

METHODS AND MATERIALS

METHODS

Study design: Randomized controlled trail - Comparative study.

Sampling technique: Purposive sampling method.

Sample size: N=30 subjects (Group 1, n= 15 subjects and Group 2, n = 15 subjects).

Randomization method: By simple randomization technique –lottery method.

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Study settings: College of Physiotherapy, Neurology ward, General ward of SVIMS Hospital, Tirupati.

Study duration: 6 months.

Treatment duration: - 60 minutes/day; 5 sessions per week for a total duration of 6 weeks.

Institutional Ethics Committee approval code: Roc.No.AS/11/SVIMS/2017

Clinical Trail Registry-India (CTRI) ID: CTRI/2026/01/100859.

MATERIALS

Biodex system 4 pro Isokinetic dynamometer, Low couch, Rowing machine, Stationary bicycle ergometer, Sand bags with various weights, Stop watch, Arm less chair, Inch tape, Marker.



Figure 1: Biodex system 4 pro Isokinetic dynamometer

INCLUSION CRITERIA

Subjects with subacute stroke.

Subjects with AHS and AIS are included.

Subjects of either side unilateral stroke are included.

Age between 30- 50.

MMSE Score >22.

VCG 2 or more.

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MAS 0 to 2.

BBS Score >29

Subjects who were able to walk atleast 10 meters with or without minimal support.

EXCLUSION CRITERIA

Subjects with acute and chronic stroke.

Subjects who are having hip and knee contractures or lower limb musculoskeletal problems.

Subjects having unstable angina pectoris, epilepsy, cognitive defects.

METHODOLOGY

Subjects who met the inclusion criteria were recruited for the study. The procedure was explained to them, and written informed consent was obtained in both English and Telugu. Group 1 received closed kinematic chain exercises for 30 minutes in addition to 30 minutes of conventional physiotherapy. Group 2 received open kinematic chain exercises for 30 minutes in addition to conventional physiotherapy for 30 minutes.

TREATMENT PROTOCOL

For both the groups, Warm up exercises were given prior to the treatment protocol and the treatment protocol was followed by the Conventional physiotherapy and Cool down.

Warm up

AROM Exercises for both UL's and LL's.

Gentle stretchings for major muscle groups for both UL's and LL's.

Conventional physiotherapy (30minutes/ session)

Electrical stimulations to wrist extensors and dorsiflexors. (15 contractions/set; 2 set /session; 1 session/day).

Stretchings to spastic muscle groups (3 repetitions/session; 1 session/day). Mat activities (3 repetitions/session; 1 session/day).

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Balance training- pertubations and reaching exercises (3 repetitions/session; 1 session/day). Active Range of motion exercises. (5 repetitions/session; 1 session/day)

Cool down

Gentle stretchings for major muscle groups for both UL's and LL's. (3 repetitions with 10 second hold per session are given)

EXPERIMENTAL GROUP -1 (Closed kinematic chain exercises group)

One repetition maximum (1RM) is the greatest amount of weight a patient can lift for a single complete repetition with proper technique. **Protocol includes 5 repetitions/ set; 1 set per session with 70% 1RM per session was given; 1RM was calculated per each week.**

Table 1: Closed kinematic chain exercises

S. No	Name of exercise	Procedure
1	Hip Control with Foot on the Bed	Subject was made to lie down in supine position with one foot flat on the bed, knee bent and was instructed to slowly take the knee to the medial side and again to lateral sides.
2	Pelvic Bridging	Subject lied supine position with both knees bent and feet flat on the bed and instructed to lift the pelvis off the bed by squeezing the glutes, forming a straight line from shoulders to knees. The subject was asked to hold for 10 seconds.
3	Stationary Bicycling	The subject was seated on a stationary cycle with seat height adjusted so the knee is slightly bent at full pedal extension and instructed to pedal at a controlled pace for a set duration, typically 5 minutes
4	Rowing Exercises	Subject was seated on a rowing machine using a resistance band anchored in front and instructed the subject to pull the handle toward

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		the abdomen while maintaining an upright trunk posture.
5	Standing Active Knee Control Exercises	Subject was allowed to stand on one limb while the opposite knee is actively flexed and extended in a controlled manner and instructed the subject to maintain hip and trunk alignment throughout the movement without compensating.
6	Heel Banging	Subject was asked to stand with feet shoulder width apart and rises onto their toes. Then asked to drop sharply back onto the heels and drag backwords, generating an axial load through the lower limb
7	Mini Lunges (Forward and Backward)	Subject was asked to stands upright and steps forward or backward into a controlled lunge, lowering the back knee toward the floor while maintaining the knee alignment over the second toe and trunk upright throughout.
8	Standing Hip Circles with Foot Fixed	Subject was asked to stand on one limb with the foot planted and perform slow, controlled circular hip movements in both directions by moving through full available range while keeping the foot and knee stationary.
9	Standing Hip Internal and External Rotation with Foot Fixed	Subject was asked to stand with the foot flat on the ground and rotates the hip inward and outward while keeping the foot fixed. Without lifting or pivoting the foot, subject was asked to perform slow, controlled rotation through the available range.

EXPERIMENTAL GROUP -2 (Open kinematic chain exercises group)

One repetition maximum (1RM) is the greatest amount of weight a patient can lift for a single complete repetition with proper technique. **Protocol includes 5 repetitions/ set; 1**

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set per session with 70% 1RM per session was given; 1RM was calculated per each week.

Table 2: Open kinematic chain exercises

S. No	Name of exercise	Procedure
1	Control of Knee Extension throughout the Range	Subject was made to lie down in supine position with the affected limb supported and performs a slow, controlled knee extension from full flexion to full extension. The subject was instructed to maintain a smooth, continuous arc of motion without jerking or quadriceps lag throughout the range.
2	Terminal Knee Extensions	Subject was asked to sit in long sitting with a pillow placed below his knee and asked to extend the knee by pressing the pillow with the knee and maintain the pressure for 10 seconds**.**
3	Sitting Hip Flexion with Knee at 90°	Subject was seated upright on a firm surface with the hip and knee of the affected limb positioned at 90° of flexion and instructed to actively lift the thigh off the surface by flexing the hip, holding briefly at end range before lowering in a controlled manner.
4	Sitting with Affected Leg Crossed	Subject was seated upright in a chair and cross the affected limb over the contralateral limb, resting the ankle above the opposite knee in a figure-four position and instructed to maintain an upright trunk posture and apply gentle downward pressure on the affected knee if tolerated.
5	Seated Leg Extensions	Subject was seated on a chair or plinth with the knee of the affected limb flexed to approximately 90° at the starting position and asked to actively extend the knee to full extension in a slow, controlled manner against gravity or added resistance, then lower back to the start.
6	Marching at a Place	Subject was asked to stand upright with feet hip width apart and performs alternating high knee marching in a stationary position and instructed to lift each knee to at least 90° of hip flexion while maintaining an upright trunk and stable pelvis throughout.

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7	Releasing the Knee and Moving the Affected Leg	Subject was positioned in standing with weight suspended to the affected lower limb and was asked to lift the toe off the ground by flexing the knee and clearing the ground.
8	Hamstring Curl	Subject was asked to stand with weight attached to the lower limb and instructed to flex the knee without flexing the hip.
9	Step Up and Step Down	Subject was asked to stand facing a standardized step of measured height, typically 15cm, with the affected limb leading for step up and controlling descent for step down and instructed to step up onto the platform with affected limb, achieve full knee extension at the top, then lower the contralateral limb back to the floor in a slow, eccentric controlled manner.

OUTCOME MEASURES

Peak Knee extensor strength:

The peak knee extensor torque was measured by using the Biodex System 4 PRO isokinetic dynamometer at an angular velocity of 60°/s. The subject was made to sit with the hips and knees at 90° of flexion, and the lateral femoral epicondyle will be aligned with the dynamometer's axis of rotation. The lower leg was strapped to the lever arm just above the ankle, and stabilization straps will be applied to the trunk, pelvis, and thigh. Subject performed 10 maximal concentric knee extensions through the full range of motion, with strong verbal encouragement and auditory cueing. The highest torque value, measured in Newton-meters, will be recorded as peak torque (12).

Gait velocity

The 10-Meter Walk Test was conducted to measure the participant's maximum gait velocity by timing of their walk over the central 10 meters of a 14-meter straight path. The initial 2 meters and final 2 meters served as acceleration and deceleration zones. Timing was begun when the participant's leading foot crosses the 2-meter point and ended when it crosses the 12-meter point (12).

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5-repetition sit-to-stand test

The participant was made to sit on a standard chair without armrests, feet flat on the ground, and arms crossed over the chest. They were asked to stand up completely and then sit back down five times as fast as possible, without pushing off with their arms. The total time taken to complete the five repetitions was timed using a stopwatch. This test evaluates lower limb strength and functional mobility (13).

ETHICAL CONSIDERATIONS

The dissertation documents approval from the Institutional Ethics Committee and confirms that written informed consent was obtained from participants or their attenders. The clinical trial was registered with the Clinical Trials Registry-India (CTRI) under registration number CTRI/2026/01/100859.

STATISTICAL ANALYSIS

The data was entered into excel sheet for tabulation. All data were analysed using appropriate statistical tests to know the effect of CKC Versus OKC in subjects with subacute stroke. Descriptive statistics were presented as mean ± standard deviation (SD). Between group comparisons for continuous variables such as Age, duration, NIHSS, MMES, VCG, BBS, Paretic side, type of stroke and dominant hand, knee extensor strength, gait velocity, 5- STS test were analysed using chi square test. Pre-post values were analysed using dependent t-test and post- post values were analysed using independent t-test.

RESULTS

A total of 30 participants completed the six-week intervention, with 15 participants in each group. The study population had a mean age of 40.5±1.6 years for CKC group, and 40.6±1.85 for OKC group ranging ranging between 30 to 50 years. The gender distribution was identical in both groups, comprising 10 males and 5 females each.

Both groups showed improvements following the intervention. In the CKC group, peak knee extensor torque increased from 23.26 ± 16.91 to 49.60 ± 21.16 Nm, gait velocity improved from 0.52 ± 0.37 to 0.85 ± 0.34 m/s, and 5-STS time decreased from 45.45 ± 38.84 to 22.78 ± 17.18 seconds. In the OKC group, knee extensor torque increased from 22.90 ± 18.01 to 34.73 ± 18.83 Nm, gait velocity increased from 0.50 ± 0.28 to 0.64 ± 0.29 m/s, and 5-STS

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time decreased from 51.42 ± 38.95 to 33.29 ± 23.11 seconds. Improvements were statistically significant in the CKC group ($p < 0.05$), whereas changes in the OKC group were not statistically significant ($p > 0.05$). Between-group comparison of post-intervention outcomes favoured CKC training, with a borderline significant difference in knee extensor torque ($p = 0.05$), while differences in gait velocity ($p = 0.069$) and 5-STS performance ($p = 0.16$) were not statistically significant.

Table 3: Baseline demographics and clinical characteristics of participants in CKC and OKC.

Variable		**CKC(Mean± SD)**	**OKC(Mean± SD)**
Gender			
	Male	66.66%	66.66%
	Female	33.33%	33.33%
Age		40.5±1.6	40.6±1.85
Post Stroke Duration		3.33± 1.58	2.86±1.5
Paretic Side			
	Right	8(53.3%)	6(40%)
	Left	7(46.6%)	9(60%)
Type of Stroke			
	Ischemic stroke	12(80%)	11(73.33%)
	Haemorrhagic stroke	3(20%)	4(26.66%)
Hand dominance			

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	Right	10(66.66%)	11(73.33%)
	Left	5(33.33%)	4(26.66%)
NIHSS		7.2±4.4	7±3.9
MMSE		26.6±2.1	27.3±1.6
VCG		4.9±1.3	4.8±0.9
MAS		1± 0.6	1± 0.66
BBS		42±9.0	45±7.2

Table 4: Within-Group Analysis of Pre and Post-Intervention Mean Values in the CKC Group

S/No	**Pre (Mean ± SD)**	**Post (Mean ± SD)**	**t- Value**	**P Value**
Peak knee extensor torque	23.26± 16.91	49.6± 21.16	3.76	< 0.001
Gait velocity	0.52± 0.37	0.85± 0.34	2.46	0.019
5- STS Test	45.45± 38.84	22.78± 17.18	2.06	0.048

Table 5: Within-Group Analysis of Pre and Post-Intervention Mean Values in the OKC Group

S/No	**Pre (Mean ± SD)**	**Post (Mean ± SD)**	**t- Value**	**P Value**
Peak knee extensor torque	22.9± 18.01	34.73± 18.83	1.7	0.09
Gait velocity	0.50± 0.28	0.636± 0.29	1.21	0.23

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5- STS Test	51.42± 38.95	33.29± 23.11	1.55	0.13

Table 6: Between-Group Comparison of Post-Intervention Mean Values in the CKC and OKC Groups

S/No		Mean ± SD	T Value	P Value
Peak knee extensor torque	CKC	49.6± 21.16	2.03	0.05
	OKC	34.7± 18.83		
Gait velocity	CKC	0.85± 0.34	1.89	0.069
	OKC	0.63± 0.29		
5- STS Test	CKC	22.78± 17.18	1.41	0.16
	OKC	33.29± 23.11		

DISCUSSION

The present randomized controlled trial compared the effects of Closed Kinematic Chain (CKC) exercises versus Open Kinematic Chain (OKC) exercises on knee extensor torque, gait velocity, and functional lower limb strength as measured by the 5-repetition Sit-to-Stand (5-STS) test in subjects with subacute stroke. 30 participants were randomly allocated into two groups of 15 each and underwent a 6 week progressive resistance training protocol at 70% of one-repetition maximum, five sessions per week, in addition to conventional physiotherapy.

Peak Knee Extensor Torque

In the present study, the CKC group demonstrated a significant increase in peak knee extensor torque, moving from 23.26 ± 16.91 Nm to 49.6 ± 21.16 Nm ($t = 3.76$, $p < 0.001$), whereas the OKC group showed a smaller improvement, from 22.9 ± 18.01 Nm to 34.73 ± 18.83 Nm, which is not a statistical significant ($t = 1.7$, $p = 0.09$). And also, when the two

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groups were compared post-intervention, the CKC group's peak knee extensor torque value (49.6 ± 21.16) was found to be significantly greater than that of the OKC group (34.7 ± 18.83), with $t = 2.03$ and $p < 0.05$.

This is in line with Shinde and Krishna et al, who found that although both the CKC and OKC exercise groups exhibited a significant increase in lower limb muscle strength ($P < 0.001$), the CKC group had achieved a substantially greater strength gain ($P < 0.001$) [14]. In addition to this, rectus femoris and biceps femoris muscle activation was found to be considerably higher in both the CKC and OKC groups relative to controls. However, only the CKC group showed a marked rise in gastrocnemius and tibialis anterior activation, together with reduced anteroposterior and mediolateral sway velocities, as observed by Lee et al. [15].

Further supporting this outcome measure, knee extensor muscle strength was found to indicate global lower limb strength in individuals following stroke, as reported by Aguiar et al. [16].

In addition, stroke survivors were found to generate only about 49.6% of the muscular power produced by age-matched healthy controls within three months of onset. This is due to reduced type II (fast-twitch) fibre recruitment, diminished descending corticospinal drive, and altered motor unit firing rates following the stroke insult, as reported by Kostka et al. [17].

Gait Velocity

In the present study, gait velocity in the CKC group improved from 0.52 ± 0.37 m/s to 0.85 ± 0.34 m/s ($t = 2.46$, $p = 0.019$), whereas the OKC group improved from 0.50 ± 0.28 m/s to 0.636 ± 0.29 m/s, a change was not much significance ($t = 1.21$, $p = 0.23$). On between-group comparison, the CKC group's post-intervention gait velocity (0.85 ± 0.34 m/s) was higher than that of the OKC group (0.63 ± 0.29 m/s), with $t = 1.89$ and $p = 0.069$, a difference obtained is not significant.

Similarly, following six weeks of progressive resistance training in chronic post stroke patients, the CKC group’s walking capacity was found to improve slightly more than that of the OKC group, though this between group difference did not reach statistical significance ($P< 0.002$), as reported by Wibisono and Isma et al. This was explained through the principle of task specificity, with the reasoning that CKC exercises more closely mimic the weight bearing. As the closed chain demands weight bearing on the limb during the stance phase of

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gait, this helps to produce improvements that carry over more directly into functional walking ability, even though the difference was observed between groups [18].

In addition to these findings, Bohannon et al. observed that strength deficits are strong predictives of gait performance in stroke patients, a relationship explained by the requirement for sufficient knee extensor and hip extensor torque to control tibial advancement and prevent the limb from buckling during single-limb support [19]. From this basis, a later meta-analysis by Bohannon et al. confirmed a strong correlation between paretic knee extension strength and comfortable gait speed after stroke, lending further support to the view that the capacity to generate torque directly constrains the propulsive and stabilising forces drawn on during walking [20].

In keeping with this evidence, Kim et al. found that paretic knee extensor strength, gait velocity, and fat mass were among the major determinants of peak aerobic capacity in subacute stroke, explaining that reduced quadriceps torque which leads to a slower, more cautious gait pattern to compensate for insufficient limb stability, which in turn reduces overall walking economy and cardiovascular conditioning [21].

Functional Strength of Lower Limb

In the present study, the 5-repetition sit-to-stand (5-STS) time in the CKC group reduced significantly, from 45.45 ± 38.84 seconds to 22.78 ± 17.18 seconds ($t = 2.06$, $p = 0.048$), while the OKC group improved from 51.42 ± 38.95 seconds to 33.29 ± 23.11 seconds , which is a non-significant ($t = 1.55$, $p = 0.13$). On comparing the two groups, the CKC group completed the test faster (22.78 ± 17.18 seconds) than the OKC group (33.29 ± 23.11 seconds), although this difference did not reach statistical significance ($t = 1.41$, $p = 0.16$).

Supporting this, Mong et al. reported that the 5-repetition sit-to-stand test is a valid and reliable measure of lower limb functional strength in chronic stroke patients, with a strong correlation observed between 5-STS performance and lower limb muscle strength in both limbs ($\rho = –.753$ to $–.830$, $P < 0.00556$). This relationship was explained through the biomechanical demands placed on the body during the sit-to-stand task, which requires the rapid, forceful generation of knee and hip extensor torque against gravity in order to lift and stabilise body mass, making the test a direct functional readout of lower-limb strength rather than a measure confined to an isolated joint [13].

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Finally through our study, the improvements were seen in the Knee extensor torque which improved inline with the functional strength of lower limbs and inturn that improved the gait velocity.

LIMITATIONS

The study measured functional outcomes (torque, gait velocity, 5-STS time) but did not include electromyographic (EMG) assessment of muscle activation patterns during exercise or functional tasks. The balance and spasticity considered in inclusion criteria but not as secondary outcome. This would have provided a more comprehensive picture of the functional recovery achieved.

RECOMMENDATIONS

Future research should employ larger sample sizes, the sample size calculated through power analysis, across multiple centres and long term followup's.

Subsequent research trails should include a conventional physiotherapy only control group to isolate the specific contributions of CKC and OKC exercises from the effects of standard care.

Future mechanistic studies should integrate neuroimaging measures such as functional MRI (fMRI) or transcranial magnetic stimulation (TMS) to quantify cortical reorganisation and use-dependent neuroplasticity following CKC and OKC training.

The incorporation of surface EMG analysis in further studies would provide mechanistic insight on functional outcomes and should imply patient-reported outcome measures such as the Stroke-Specific Quality of Life Scale (SS-QoL) to translate into meaningful improvements in participation, independence, and quality of life for stroke survivors.

CONCLUSION

The present study found that both Closed kinematic chain and Open kinematic chain exercises, when combined with conventional physiotherapy, produced improvements in knee extensor strength, gait velocity and functional strength of the lower limb in subjects with subacute stroke. The CKC group showed statistically significant within-group improvements in all three outcomes, whereas the OKC group showed favourable but statistically non-significant improvements. Between-group analysis showed a significant or borderline

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significant advantage of CKC exercises for knee extensor peak torque, while 5-STS and gait velocity performance showed clinically favourable trends without statistical significance. Hence, CKC exercises may be considered an effective strengthening strategy for improving knee extensor strength in subacute stroke rehabilitation, while OKC exercises may be useful as an adjunct, especially in patients with limited balance or reduced weight-bearing ability.

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