Comparative Efficacy of Open-chain Kinematics and Closed-chain Kinematics on Walking Proficiency and Societal Integration in Post-stroke Individuals: a Pretest- Post-test Experimental Study

Obianuju Nwaedozie

University of Lagos

Caleb Gbiri

University of Lagos

Olajide Olawale

University of Lagos

Ukamaka Mgbeojedo (✉ amakamgbeojedo@yahoo.com)

University of Nigeria - Enugu Campus <https://orcid.org/0000-0002-8090-7803>

Caleb Adeagbo

University of Lagos

Research Article

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Abstract

Background

Post-stroke hemiplegic gait is a mixture of deviations and compensatory motion dictated by residual function. To improve stroke survivors' walking ability, it is necessary to evaluate different rehabilitation approaches and identify those that have a greater effect on locomotor recovery of stroke patients.

Objectives

This study was designed to compare the effect of open-chain kinematics (bicycle ergometry) and closed-chain kinematics (treadmill) on walking proficiency in post-stroke individuals and their societal integration.

Methods

This was a pretest- posttest- experimental study involving 35 ambulatory hemiplegic stroke survivors (18males and 17 females) with a mean age of 53.77 ± 10.95 undergoing rehabilitation at the two Teaching Hospitals in Lagos. Patients went through a 10-week rehabilitation and were randomly assigned to two intervention groups. Spatio-temporal gait parameters were measured by the six-metre walkway and community integrated questionnaire was used to examine home integration, social integration and productive activities. Data were subjected to inferential and descriptive statistics. The level of significance was set at $p < 0.05$.

Results

Results showed significant difference between baseline and post intervention scores for all the gait parameters in the bicycle ergometer group except for stride length ($p = 0.078$). There was also a significant difference in the mean change in cadence between the treadmill and bicycle ergometer group ($p = 0.04$).

Conclusions

Both open-chain and closed-chain kinematics are effective, but closed- chain is most effective in re-educating ambulation and re-gaining spatio-temporal gait parameters after stroke and should be structured into the patients' treatment regimen to effectively improve functional capability in post-stroke individuals.

Plain English Summary

Stroke is the leading cause of long-term disability, and its burden increases worldwide. Recovery from stroke is often slow and incomplete, leading to partial or complete loss of movement. The ability to walk independently is a prerequisite for the performance of most daily activities. In a post stroke hemiplegic gait, there is decreased walking speed, short or uneven step and stride length, increased stride width, increased double support, and dependence on support through the hands. Hence, the restoration of gait in stroke survivors became a major goal in rehabilitation with intervention aimed at optimizing walking performance

Treadmill training has been recently introduced as a measure to improve the post stroke gait pattern, but there is still limited data on the use of the bicycle ergometer. This study was intended to compare the effect of bicycle ergometry and treadmill on walking proficiency and societal integration in post-stroke individuals. Findings from this study reveal that both bicycle ergometry and treadmill are effective, but treadmill is most effective in re-educating walking after stroke and should be structured into the patients' treatment regimen to effectively improve functional capability in post-stroke individuals.

Introduction

Stroke is one of the principle causes of morbidity and mortality in adults worldwide and it is known to be a neurological deficit attributed to an acute, focal or global injury of the central nervous system by a vascular cause [1]. It is the leading cause of long-term disability, and its burden increases across the globe [2, 3]. Recovery from stroke is often slow and incomplete, leading to partial or complete loss of locomotion, activities of daily living, cognition and communicative skills. The devastating stroke consequences have enormous personal, social and economic impact on oneself and the society at large [4].

Impairments resulting from stroke often lead to persistent difficulties with walking. Walking is an important human activity which enables us to be productive and participative members of a community [5]. Walking ability has important health implications in providing protective effects against secondary complications common after stroke. Poor walking ability has been found to reduce quality of life with a reduction in participation in activities outside the home and consequent social isolation [6]. The ability to walk independently is a prerequisite for the performance of most daily activities [7].

The capacity to walk in a community setting requires the ability to walk at speeds that enable an individual to cross the street in the time allotted by pedestrian lights, to step on and off a moving walkway, in and out of automatic doors, walk around furniture, under and over objects.

Stroke patients fear dependency more than anything else after a stroke; and the ability to walk independently has been found to provide the greatest protection against dependency [8]. Walking speed of community-dwelling people after stroke has been reported to be around 0.5 m/s with studies reporting a range between 0.3 and 0.8 m/s [9]. Walking capacity has also been found to be markedly reduced with 6-minute distance being reported as around 250 m ranging between 40 and 400 m [10]. Post-stroke hemiplegic gait is a mixture of deviations and compensatory motion dictated by residual function [11]. In

a post stroke hemiplegic gait, there is decreased walking speed, short or uneven step and stride length, increased stride width, increased double support, and dependence on support through the hands [12]. Hence, the restoration of gait in stroke survivors became a major goal in rehabilitation with intervention aimed at optimizing walking performance by preventing adaptive changes in lower limb soft tissue, eliciting voluntary activation in key muscles groups in lower limbs, increasing muscle strength and coordination, increasing walking velocity and endurance, increasing flexibility and increasing cardiovascular fitness [13]. The major aim of stroke rehabilitation is to reduce disabilities and enable patient to return to society. It has been reported that only 7% of patients discharged from rehabilitation met the criteria for community walking which included the ability to walk 500m continuously at a speed that would enable them to cross a road safely [14].

Therefore, it became necessary to evaluate different rehabilitation approaches and identify those that have a greater effect on locomotor recovery of stroke patient for faster societal integration. Recently, treadmill training has been introduced as a measure to improve the post stroke gait pattern [15], but there is still limited data on the use of the bicycle ergometer. Hence, this study was designed to compare the effect of open-chain kinematics and closed-chain kinematics on walking proficiency and societal integration in post-stroke individuals.

Methods

This was a pretest- post-test experimental study involving a total of 38 ambulatory hemiplegic stroke survivors (21 males and 17 females), out of which only 35 (18 males and 17 females) completed the study, giving an attrition rate of 92.1%. Ethical approval for this study was obtained from the Health Research Ethics Committee of Lagos University Teaching Hospital (LUTH) Idi Araba, Lagos and Lagos State University Teaching Hospital (LASUTH) Ikeja, Lagos, Nigeria, where this research was carried out. Thirty five volunteering stroke survivors who were undergoing rehabilitation at the Physiotherapy Outpatient Department of the two tertiary hospitals were purposively recruited for this study. Participants were recruited if they met the inclusion criteria: were older than 18 years and whose diagnoses were confirmed by means of a CT scan and or an MRI, were able to understand verbal instructions and follow commands, were able to walk 6 metres independently with or without a walking aid. They were excluded if they have had previous stroke or brain injury. Informed consent was obtained from the participants before the commencement of the study. The participants' clinical data was obtained from their case note.

Outcome measures

The outcome measures used were the 6-meter walkway and a questionnaire for societal integration.

Stopwatch (Leap Stop watch FXIT, China)

A handheld stopwatch that counts to microseconds of time

Bicycle Ergometer (RUN-700/T, Italy)

It is a device with saddle, pedals and handlebars arranged as on a bicycle but used as exercise equipment instead of transportation. It is also called stationary bicycle or exercise bicycle. It has low impact, does not put much stress on joints, it is safe and effective for cardiovascular exercise.

Treadmill (Woodway 4Front treadmill, Germany)

It is an exercise machine for running or walking in a place with a wide conveyor belt driven by an electric power or flywheel. The rate at which the belt moves is the rate of running or walking.

6-Meter Walkway:

This is a measure that was used to assess the quality of walking of the post stroke subjects. Subjects were asked to walk a short distance (6 meters) at their usual pace and maximum speed and gait parameters (step length, stride length, speed and cadence) were measured.

The Community Integrated Questionnaire (CIQ)

This is a 15 item self-report questionnaire with 3 subscales which examine home integration, social integration and productive activities. School and volunteer activities are scored on a 6-point scale and the other 12- items are scored on a 3-point scale [16]. The three subscales are summed to yield a total score for community integration ranging from 0-29, with higher scores indicating a greater degree of community integration.

Procedures for Data Collection

Participants were assessed at baseline using the 6-meter walkway and a questionnaire for societal integration. All participants were instructed to walk on a 6-meter walkway with sprinkled powder to show the footprints. The prints were utilized to measure the step length, stride length, speed and cadence.

The physiotherapy treatment sessions were carried out two times a week for 10 weeks at the end of which the gait parameters and Community Integration Questionnaire were administered again in order to obtain the post-treatment values.

Treatment procedure

All participants were instructed to walk on a 6-meter walkway with sprinkled powder to show the footprints. Participants were instructed to walk 2m away from the walkway, such that a uniform step would have been established before getting to the walkway. The prints were utilized to measure the step length, stride width, speed and cadence. The step length (cm) was obtained by measuring the linear distance between two successive heel strikes (from affected limb to unaffected limb). The stride length (cm) was obtained by measuring the linear distance from one heel strike of the affected limb to the next heel strike of the same limb. The natural gait speed (walking velocity) (m/s) was determined by dividing the length of the walkway by the time taken by the participant at his natural pace from one end of the walkway to another. The maximum gait speed (m/s) was obtained by dividing the length of the walkway by the time taken by the participant to walk at his maximal safe speed from one end of the walkway to the other. The cadence (step/minute) was determined by dividing the number of steps obtained on the walkway by the time taken to cover the walkway. Gait parameters and societal integration were measured pre and post training.

Data analysis

Data collected was analyzed with SPSS microcomputer software version 20. Means and Standard deviation were computed for all variables. Statistical analysis using the independent t-test was performed to determine significant differences between the groups and paired t-test was used to analyze the outcomes within the two groups. The level of significance was set at $p < 0.05$.

Results

Demographic data of the subjects

The demographic data of the 35 participants who completed the study are shown in Table 1. The group A (Treadmill) consisted of 17 participants (10 males, 7 females), 64.7% were right hemi-paretic. The group B (Bicycle ergometer) consisted of 18 participants, (8 males, 10 females), 55.6% were right hemi-paretic. Mean age and weight of the participants were 53.77 ± 10.95 years and 70.86 ± 10.67 kg respectively.

Changes in gait parameters with treatment

Tables 2 and 3 show the pre-treatment and post-treatment gait parameters and community integration for the subjects with 10 weeks of intervention. The pre-treatment score revealed a significant difference in stride length, gait speed and no significant difference in step length, cadence and community integration

between the groups. The mean differences between the groups and post-treatment scores were significant in cadence between the groups.

Tables 4 and 5 show that there was a significance difference in the gait parameters and community integration within the groups except in stride length in the bicycle ergometer group ($P < 0.05$).

Table 1: Sociodemographic profile of participants

Variables		Threadmill N (%)	Bicycle ergometer N (%)
Gender	Male	10 (58.8)	8 (44.4)
	Female	7 (41.2)	10 (55.6)
Educational attainment	Primary	3 (8.6)	2 (5.5)
	Secondary	6 (17.1)	3 (8.6)
	Tertiary	10 (28.6)	11 (31.4)
Part affected	right	11 (64.7)	10 (55.6)
	left	6 (35.3)	8 (44.4)

Key:

N: Frequency

?: Percentage

Table 2: Pre-treatment gait parameters between groups of participants

Variables	Treadmill	Bicycle Ergometer	t-value	p-value
	Mean $\pm$ SD	Mean $\pm$ SD		
Stride length	77.41 $\pm$ 25.52	59.00 $\pm$ 24.20	2.187	0.04*
Step length	36.05 $\pm$ 12.04	28.94 $\pm$ 14.09	1.608	0.12
Natural Gait Speed	0.60 $\pm$ 0.17	0.42 $\pm$ 0.27	2.426	0.02*
Maximum Gait Speed	0.87 $\pm$ 0.27	0.59 $\pm$ 0.38	2.468	0.02*
Cadence	1.42 $\pm$ 0.34	1.25 $\pm$ 0.62	1.031	0.31
CIS	12.35 $\pm$ 3.9	9.50 $\pm$ 4.00	2.125	0.41

Key:

CIS: Community Integration Score

Table 3: Post-treatment gait parameters of participants

Variables	Treadmill	Bicycle ergometer	t-value	p-value
	Mean $\pm$ SD	Mean $\pm$ SD		
Stride length	6.00 $\pm$ 5.93	2.83 $\pm$ 6.41	1.519	0.13
Step length	4.11 $\pm$ 2.93	2.33 $\pm$ 2.43	1.955	0.06
Natural gait speed	0.19 $\pm$ 0.09	0.11 $\pm$ 0.16	1.731	0.10
Maximum gait speed	0.18 $\pm$ 0.24	0.09 $\pm$ 0.14	1.413	0.17
Cadence	0.20 $\pm$ 0.18	0.83 $\pm$ 0.15	2.088	0.04*
CIS	4.00 $\pm$ 2.98	3.89 $\pm$ 2.40	0.121	0.90

Key:

CIS: Community Integration Score

Table 4: Pre-treatment and post-treatment gait parameters in the treadmill group

Parameters	Mean $\pm$ SD Pre-intervention	Mean $\pm$ SD Post-intervention	t-value	p-value
Stride Length (cm)	77.41 $\pm$ 25.52	83.41 $\pm$ 21.49	-4.174	0.001*
Step Length (cm)	36.05 $\pm$ 12.04	40.18 $\pm$ 11.35	-5.786	0.00*
NGS (m/s)	0.60 $\pm$ 0.17	0.79 $\pm$ 0.17	-9.030	0.00*
MGS (m/s)	0.87 $\pm$ 0.27	1.05 $\pm$ 0.22	-3.110	0.007*
Cadence (step/min)	1.42 $\pm$ 0.34	1.62 $\pm$ 0.32	-4.632	0.00*
CIS	12.35 $\pm$ 3.94	16.35 $\pm$ 3.24	-5.536	0.00*

Key:

CIS: Community Integration Score

NGS: Natural gait speed

MGS: Maximum gait speed

Table 5: Pre-treatment and post-treatment gait parameters in the bicycle ergometry group

Parameters	Mean $\pm$ SD Pre-intervention	Mean $\pm$ SD Post-intervention	t-value	p-value
Stride Length (cm)	59.00 $\pm$ 24.20	61.83 $\pm$ 22.71	-1.875	0.078
Step Length (cm)	28.94 $\pm$ 14.09	31.28 $\pm$ 13.83	-4.082	0.001*
NGS (m/s)	0.42 $\pm$ 0.27	0.53 $\pm$ 0.27	-2.942	0.009*
MGS (m/s)	0.59 $\pm$ 0.38	0.68 $\pm$ 0.43	-2.631	0.018*
Cadence (step/min)	1.25 $\pm$ 0.62	1.33 $\pm$ 0.63	-2.410	0.028*
CIS	9.50 $\pm$ 4.00	13.39 $\pm$ 3.43	-6.880	0.00*

Key:

CIS: Community Integration Score

NGS: Natural gait speed

MGS: Maximum gait speed

Discussion

This study compared the effect of open-chain kinematics (bicycle ergometer) and closed-chain kinematics (treadmill) on improving walking proficiency in post-stroke individuals in order to provide foundation for developing evidence-based gait training in enhancing functional independence and promoting societal integration after stroke. The almost equal number of males (18) and females (17) in this study shows that there is no sex disparity in the epidemiology of stroke. This corroborates the results of previous studies in Nigeria which have shown no gender variability in the occurrence of stroke [17–20]. The mean age (53.77 ± 10.45 years) of the participants corroborates the report that stroke is more common among individuals who are above 45 years old [21, 22]. The result that the right side of the body was more affected than the left side shows that the left hemisphere is more predisposed to stroke than the right hemisphere of the brain. This may not be unconnected with the fact that most people have their dominant cerebral hemisphere at the left and there is more functional orientation from the left cerebral hemisphere [23].

Ambulatory parameters including reduced stride length, speed length (natural and maximal), step length and cadence have been identified as major challenge among stroke patients [11]. This is sequel to motor and sometimes sensory deficit that is associated with stroke and precipitates functional dependency after stroke [24]. Any strategy that will improve ambulatory proficiency in stroke survivors will reduce both primary and secondary burden of stroke and improve productivity [5]. Hence, the results that both an open-chain and a closed-chain kinematics are effective in re-educating ambulation and re-gaining these spatio-temporal gait parameters after stroke provide a way out of the inherent dependency in activity of daily living and disability which are common occurrences with stroke [25]. This calls for the integration of kinematics training into stroke rehabilitation as early as ambulatory performance is to be re-educated. Hence, structuring and integrating kinematics training into stroke patients' treatment regimen may effectively improve their functional capability and functional independence performance after stroke.

Findings in the present study revealed that those in the closed-chain kinematics treatment performed significantly better than the open-chain group in cadence when they are comparable in their improvement in other gait parameters, thus suggesting that closed-chain kinematics has a relatively better advantage in improving gait functional performance after stroke. This better improvement may be explained by the fact that a closed-chain kinematics is a weight bearing exercise which is likely to impact positively on the joint proprioception through the process of joint approximation [26]. Increased proprioception will increase confidence in ambulation as there will be increase in joint positional sense [27]. In addition to improved spatial orientation, weight-bearing exercises as is provided by closed-chain kinematics impact positively on muscle strength and coordination [28]. This is in agreement with previous report that

maintenance of postural balance and gait includes a sensory process involving the articular mechanoreceptors, vestibular system and visual system [29]. Sensorimotor information is then processed in the central nervous system producing a motor response involving various muscle groups such as those around the ankle, thigh and trunk. This improvement could also be attributed to increase in muscle strength and enhanced coordination between both sides of the body. This is supported by other studies. An appropriate motor response for postural balance control and gait training requires an intact neuromuscular system and sufficient muscle strength to return the center of mass within the base of support [30]. The better improvement that occurred in the treadmill group may be due to the stepping practice. Stepping practice strengthened and stabilized the neural network which was involved in producing this pattern [28]. This is in agreement with other reports that treadmill intervention offered repeated opportunities to improve gait and build muscle strength in the lower limbs and stimulate neuronal connections that are involved in generation of independent balanced walking [31, 32].

Although both groups improved significantly in their six minutes-walk performance after intervention, the closed chain group performed relatively better. This may not be unconnected with the fact that the treadmill trains gait and gait-speed and improves ambulatory performance [33]. This supported the findings of Kubo and Ulrich [34] that treadmill training improves the spatio-temporal parameters of gait and produces more normal temporal pattern. It has been shown that the treadmill is considered as a moving surface, so, the post-stroke participants needed to spend more time with both feet on the surface during the walking cycle than when they walked over ground [35]. Furthermore, gait stability, muscle function, aerobic fitness and balance will improve more in participants receiving treadmill training and also community re-integration will be higher [36]. This shows that treadmill training is most effective in achieving spatio-temporal gait parameters in this study and hence, adds further support to a growing body of evidence that treadmill exercise training gives better improvement in gait training in patients with cerebrovascular disease [37, 38].

The results of this study also show that both open-chain and closed-chain kinematics significantly improved the community re-integration in individuals recovering from stroke, and this may be associated with their improvement in gait performances. When an individual can walk better, he/she is likely to manipulate his/her environment better for community functioning [39]. If individuals can function in their community, they will be better re-integrated and contribute to the community. Community re-integration has been shown to be positive outcomes such as motor function after stroke and it is positively associated with improved quality of life [40], subjective well-being and life satisfaction after stroke [41]. Improvement in walking proficiency has been reported to result in significant improvements in the mobility, physical independence performance, works and productivity, and leisure activities after stroke [42].

The better improvement in the community integration of the closed-chain group can be explained by their better performance in both walking independence performance and gait parameters such as cadence. Earlier studies have demonstrated that improvement in mobility will improve every aspect of functional independence performance and quality of life after stroke [41, 42]. Physiotherapist should direct their

rehabilitation efforts at improving quality gait functioning for better societal integration and participation in stroke patients and the close-chain kinematics should be a preferred approach to achieving these.

Conclusions

Open-chain kinematics and closed-chain kinematics effectively improve walking proficiency and societal integration of post-stroke individuals, although closed-chain gave a better improvement. This calls for the integration of kinematics training into stroke rehabilitation as early as ambulatory performance is to be re-educated.

We therefore recommend that future trials should focus more upon longer duration exercise programs for enhancing the walking proficiency of post-stroke individuals. Larger randomized studies are needed to generate evidence-based guidelines for the safe and effective exercise of post-stroke individuals across the spectrum of deficit profiles and recovery phases. It is important to include open-chain kinematics or closed-chain kinematics (bicycle ergometry and/or treadmill training) in the management of stroke. Further studies are required to investigate the mechanisms underlying the observed improvement in gait parameters. One limitation of the present study is the small sample size. Also, the participants were recruited from tertiary institutions, thereby, limiting the generalizability of the results.

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Authors' contributions

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Declaration of competing interests

The authors declare no competing interests.