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Stepping Forward: Evaluating the Impact of Gait Training on Post-Stroke Patients' Energy Cost of Walking: A Pre-Test Post-Test Analysis

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ABSTRACT

Stroke is a leading cause of disability and death globally, increasingly affecting younger populations and presenting significant rehabilitation challenges, particularly in restoring independent ambulation. Despite the established impact of energy cost on walking performance, the specific effects of gait training interventions on walking economy remain underexplored. **Objectives:** To examine the effectiveness of an intensive gait training exercise intervention on Energy cost of walking (ECW) and ambulatory performance in chronic stroke patients. **Methods:** A randomized controlled trial (Clinical trial ID: IRCT20211011052727N2) was conducted from Apr 2023 to Nov 2023, in which fifty-eight chronic stroke patients, aged over 18 and being able to walk 14 meters with or without walking aids, were recruited for this design. The key outcome measures were the Physiological cost index, 10 meter walk test, Fugl-Myer Assessment and the 6-minute walk test. Patient received six weeks of gait training exercise intervention at a university rehabilitation center. Outcome evaluations were conducted at bassline, as well as at two, four and six-weeks post intervention. **Results:** The mean Physiological cost index (PCI) score at baseline was 0.73 ± 0.37 beats/min, was found significantly different from Post intervention score 0.56 ± 0.30 beats/min ($F=52.32$ $p<0.01$). Similarly, significant differences were noted in walking speed and walking endurance post intervention ($p< 0.05$). Post hoc Tukey's multiple compression showed significant improvement in walking economy at 2 weeks ($p<0.05$), 4 weeks ($p<0.01$) and 6 weeks ($p<0.01$). **Conclusions:** Gait training exercises may significantly improve walking economy, ambulatory speed, and endurance in chronic stroke patients over a six-week intervention.

INTRODUCTION

Stroke is the third leading cause of disability and the second most common cause of death Globally [1]. Its prevalence is getting higher worldwide predominantly among younger and middle-aged population. Approximately 33% of stroke patients are under the age of 65 challenging the traditional belief that stroke primarily affects the elderly [2]. The incidence of stroke is also increasing in developing countries, with prevalence rates in KPK, Pakistan ranging from 1.2% to 19% [3, 4]. Post-stroke patients often encounter a range of complications, with the primary concern being the loss of independent ambulation within the community [5]. The central objective of stroke rehabilitation is to restore autonomous walking abilities, but several factors hinder this capability, including diminished motor performance, balance issues, and muscle weakness [6-8]. Stroke survivors frequently struggle with ambulation due to the burden of the paretic limb, which leads to increased energy expenditure [9]. Gait training is a primary component of rehabilitation, helping patients to achieve functional ambulation and to minimize the energy cost of walking (ECW). ECW is typically higher in stroke survivors because of abnormal gait, muscle weakness as well as associated compensatory movements that reduce endurance in those affected. Such difficulties considerably risk the capacity to carry out common tasks and regain basic mobility. Other techniques for containing

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and treating neuromuscular disorders include body weight support treadmill training, muscle strengthening and balance training, and cognitive-motor training, which helps to enhance neuromuscular coordination as well as gait symmetry. While individuals without stroke consumes approximately half of their maximal aerobic capacity during walking, on the other hand stroke patients expend around 75% [10]. Previous studies have established the influence of energy cost of walking (ECW) on comfortable gait speed (CGS) and walking endurance and found curvilinear relationship between 6-minute walk test (6MWT) and 10 meter walk test (10MWT) However, the specific impact of gait training interventions on ECW and walking performance remains underexplored [11, 12]. the current research incorporates Physiological Cost Index (PCI), a validated measure based on heart rate and walking speed, alongside other functional measures such as the 10-Meter Walk Test (10MWT) and the 6-Minute Walk Test (6MWT) to evaluate the hypothesis that patients will exhibit improved walking economy following the intensive gait training exercise intervention.

This study aimed to investigate the efficacy of a comprehensive gait training exercise intervention on ECW and walking performance over a six-week period.

METHODS

This Randomized controlled trial study was conducted in a university rehabilitation center between April to November 2023. (Trial registration number: IRCT20211011052727N2). A total of 54 chronic stroke patients were enrolled for this study. The selection criteria for inclusion of the participants were: male and female stroke patients aged 18 or above; being able to walk independently or with the help of walking aids up to 14 meters; having functional ambulatory category score of 3 or more; stroke onset at least 6 months ago before the start of the study; cognitively stable patients with a score of 24 or above on the mini mental status examination. Patients were excluded if they had a recurrent stroke, uncontrolled hypertension, and unstable heart diseases. This study followed the ethical guidelines of the Helsinki Declaration. Ethical approval was granted by Institutional ethical review board (KMU/EB/ER 22-09/093). Participants were provided with an information sheet and signed informed consent before the start of the study. For sample size calculation G*Power (version 3.1) was employed. A medium effect size of 0.25 was assumed, with a significance level of (alpha) 0.05, and power of 0.95. the study design consists of a single group with 4 repeated measures with a correlation of 0.22 and a non-centrality parameter ( ) of 18.58. The critical F value was 2.77, with the numerator and denominator degrees of freedom being 3 and 55, respectively. Based on these parameters, sample size was calculated to be 54. To calculate the ECW, we utilized the Physiological Cost Index (PCI). The PCI has been validated as a reliable tool for assessing the energy cost of walking, particularly in individuals with neurological impairments, including stroke survivors [13]. The formula of PCI based ECW calculation is as follow,

$$\text{PCI beats/m} = \frac{\text{Walking HR - Resting HR}}{\text{Walking Speed m/min}}$$

The 10MWT was used to assess the CGS of the recruited patients. The 10MWT is a valid and reliable tool for determining the walking speed of chronic stroke patients. Walking endurance was evaluated utilizing the 6MWT. The patient's motor performance was examined with the help of the Fugl-Meyer Assessment [14]. Moreover, functional ambulatory independence was assessed using the Functional ambulatory Category (FAC), and cognitive stability was checked employing the mini-status mental examination (MMSE) [15]. All the outcome measures are well-established, reliable, and valid tools for their respective purposes in chronic stroke patients. Gait training exercises were given to the participants 3 times/week for a total duration of 6 weeks, the duration for each session lasted for 60 minutes and involved several components designed to address various aspects of gait and functional mobility. The intervention included 1)Body weight supported treadmill training, Participants engaged in 15 minutes of treadmill walking with body weight support, performed at a comfortable gait speed 2)Parallel bar gait Training, Participants were instructed to walk forward, backward and sideways inside the parallel bar for 10 minutes 3) participants were given targeted muscle group strengthening 4) lower limb range of motion exercises 5) balance and proprioception training 6) cognitive-motor integration exercises. Participants were given rest period of 15 minutes after treadmill and parallel bar walking. The PCI calculation was conducted at 4-time points, at baselines, and subsequently at weeks 2, 4, and 6 post-interventions. Moreover, CGS, walking endurance, and motor performance were evaluated at these same intervals. The HR measurements were recorded using the Polar H10 sensor (Kempele, Finland) equipped with a Pro strap. To ensure the precision of the PCI measurements, participants were instructed to refrain from caffeinated drinks and chocolates on the days of each evaluation. Upon arrival at the rehabilitation center, patients were asked to rest in a chair for 15 minutes to stabilize their HR. Besides the HR data obtained with the Polar H10 sensor, other patients' vital signs such as blood pressure, respiration rate, and oxygen saturation were also monitored before, during and after each therapy session to guarantee safety. Any abnormal fluctuation in these vital signs during therapy sessions were corrected by either lessening the intensity of the therapy or going ahead to provide a break as was appropriate. All mentioned types of monitoring were conducted under the supervision of a licensed physical therapist to reduce the risks for the patients and achieve

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the best results of the therapy. Ample water was provided to ensure proper hydration throughout the evaluation process. Data analysis was performed using GraphPad Prism version 9.5. Descriptive statistics were computed for univariate variables such as age, BMI, and stroke onset, and results were presented as means and standard deviations. To assess the effectiveness of the gait training exercise intervention, a repeated measures one-way ANOVA was conducted. This was followed by Tukey's post hoc multiple comparison test to determine specific differences between groups. The critical alpha level for statistical significance was set at p<0.05.

RESULTS

The average age of the patients was 56.22 ± 6.84 years with a mean stroke onset of 8.92 ± 3.63 months. sixty-one percent of the included participants were male and 39% were female. Detailed demographic characteristics including stroke types, hemispheric involvement, and FAC scores, are provided in table 1.

Table 1: The Demographic/ Functional Characteristics

Demographic Characteristics N = 54	
Age (Y)	56.22 ± 6.84
BMI (kg/m^2)	27.34 ± 5.36
Stroke Onset (m)	8.92 ± 3.63
Gender N (%)	
Male	33 (61)
Female	21 (39)
Type of Stroke N (%)	
Ischemic Stroke	38 (70)
Thrombotic Stroke	24 (44)
Embolic Stroke	14 (26)
Hemorrhagic Stroke	16 (30)
Intracerebral Hemorrhage	13 (24)
Subarachnoid Hemorrhage	3 (6)
Effected Side N (%)	
Right Hemispheric Stroke	33 (62)
Left Hemispheric Stroke	21 (38)
FAC Score N (%)	
4	23 (42)
<4	31 (58)

Note: values are mentioned as mean standard deviations and number of patients and percent of the whole cohort. Abbreviation: y, years; m, months; kg/m^2, kilograms per square.

The mean Pre-Intervention PCI score was 0.73 ± 0.37, while the Post Intervention PCI score was 0.56 ± 0.30. This resulted in an F-value of 52.32 with a p<0.01 indicating a statistically significant change. Similar analyses were conducted for the 10MWT, the 6MWT, and the FMA-LE, as detailed in table 2.

Table 2: Pre and Post Intervention Analysis

Variables	Pre-Intervention	Post Intervention Week 2	Post Intervention Week 4	Post Intervention Week 6	F	p-Value
PCI (beats /min)	0.73 ± 0.37	0.68 ± 0.33	0.62 ± 0.31	0.56 ± 0.30	52.32	<0.01
10MWT (m/s)	0.47 ± 0.23	0.51 ± 0.19	0.56 ± 0.21	0.58 ± 0.21	42.48	<0.01
6MWT (m)	195.5 ± 72.61	197.7 ± 72.98	200 ± 74.54	205.5 ± 78.08	38.56	<0.01
FMA-LE	19.85 ± 2.84	19.91 ± 2.97	20.1 ± 3.33	20.4 ± 3.23	22.44	>0.05

Note values are Mean ± S.D, P value calculated between pre intervention and post intervention using repeated measure one-way Anova. Abbreviations; PCI, Physiological Cost Index; FMA-LE, Fugl-Meyer Assessment- lower extremity; 10MWT, 10 meter walk test; 6MWT, 6-minute walk test; beats/min, beats per minute; m/s, meter per second; m, meters.

The results revealed significant improvements in both the 10MWT and 6MWT with p-values <0.05. In contrast the FMA-LE did not show statistically significant changes with a p>0.05. Given the significant findings for PCI, 10MWT and 6MWT in the repeated measures ANOVA we performed the Tukey's multiple comparison test (post hoc analysis). Significant differences were observed in the PCI scores of stroke patients at 2 weeks (p<0.05), 4 weeks (p<0.01), and 6 weeks (p<0.01) post-intervention. The detailed comparisons are illustrated in figure 1.

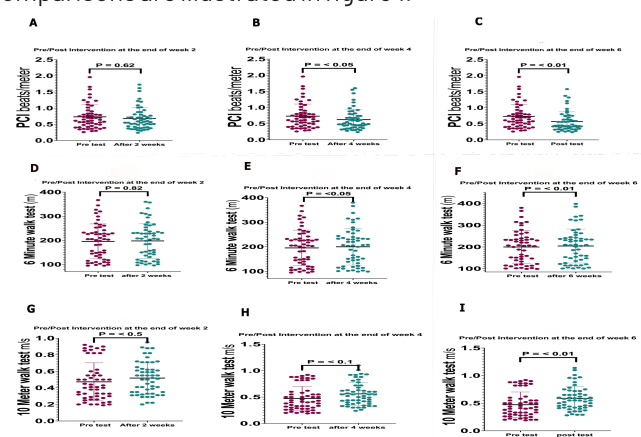

Figure 1: Post Hoc analyses using Tukey's multiple comparison test are depicted in panels A through I. A show the comparison between Pre-Intervention and 2 weeks Post Intervention for PCI values. B illustrates the comparison between Pre-Intervention and 4 weeks Post Intervention PCI values. C presents the comparison between Pre-Intervention and 6 weeks Post Intervention PCI values. D compares Pre-Intervention with 2 weeks Post Intervention for 6MWT distance (meters). E shows the comparison between Pre-Intervention and 4 weeks Post Intervention 6MWT distance (meters). F depicts the comparison between Pre-Intervention and 6 weeks Post Intervention 6MWT distance (meters). G illustrates the comparison between Pre-Intervention and 2 weeks Post Intervention for 10MWT (m/s). H compares Pre-Intervention with 4 weeks Post Intervention 10MWT (m/s). I show the comparison between Pre-Intervention and 6 weeks Post Intervention 10MWT (m/s).

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DISCUSSION

The findings of current study underscore the efficacy of gait training exercises in enhancing both walking economy, walking speed, and endurance among chronic stroke patients. As hypothesized, the results demonstrate that a six-week gait training intervention significantly improves walking economy. While no significant changes in ECW were observed at two weeks post-intervention, a notable reduction in ECW was recorded at both four- and six-weeks post intervention. This finding aligns with recent research suggesting that gait interventions extending beyond four weeks are more effective in enhancing gait speed and endurance compared to shorter interventions [16]. Moreover, this prior study did not evaluate ECW, which is a critical aspect of current investigation. Present study also revealed a significant improvement ($p<0.05$) in walking speed from four to six weeks post-intervention. Earlier studies have established walking speed as a crucial predictor of walking economy [17]. Furthermore, walking speed is instrumental in categorizing individuals into different levels of ambulatory ability such as household ambulators (<0.4 m/s), limited community ambulators (0.4-0.8 m/s), and community ambulators (>0.8 m/s) [18]. In terms of walking endurance, as assessed by the 6MWT, current cohort demonstrated a significant improvement in distance traveled compared to baseline following the six-week intervention. The 6MWT score is a key predictor of community ambulation post-stroke and is vital for assessing walking endurance. Previous studies have indicated that chronic stroke patients who achieve a 6MWT score >205 meters are considered independent community ambulators. Based on this criterion, the patients improved from a mean distance of 195 meters (limited community ambulators) to over 205 meters (independent community ambulators) [19]. However, no significant differences were observed in motor performance, as measured by the FMA-LE, following the six-week gait training intervention. Prior research suggests that a motor performance score >21 is necessary for ambulation, but since the FMA-LE encompasses a range of motor parameters beyond gait performance, other factors may influence overall motor performance [20]. This study represents a pioneering effort in evaluating the impact of a comprehensive gait training exercise intervention on ECW in stroke patients. The strengths of this research include its broad and multidimensional exercise approach, which benefits patients' overall functional outcomes. Nonetheless, a limitation of current study is the absence of a control group. Given that gait training is an integral component of stroke rehabilitation, excluding a control group would have violated the ethical principles of beneficence and non-maleficence. Additionally, we permitted the use of assistive devices during evaluations to support patient safety, although this may have influenced the results.

CONCLUSIONS

In conclusion, current study indicates that gait training exercise intervention may significantly improve walking economy, speed, and endurance in stroke patients following a six-week regimen. These improvements suggest that incorporating gait training into post-stroke rehabilitation could offer substantial benefits, potentially enabling patients to achieve a level of ambulatory independence required for navigating their communities more effectively.

Authors Contribution

Conceptualization: SF, FHA
Methodology: IM
Formal analysis: MI, RM
Writing review and editing: IM, RM, SF, FHA

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

The authors declare no conflict of interest.

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