ORIGINAL ARTICLE

Correlation Between Balance, Lower Limb Muscle Strength, and Energy Cost of Walking in Stroke Survivors: An Analytical Cross-Sectional Study

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Abstract

Background: Globally, stroke is a primary cause of disability, which mostly results in decreased strength of lower limb muscles, insufficiency in gait parameters and impaired balance which eventually increases the energy cost of walking. For developing targeted rehabilitation plan for stroke survivors, understanding of these factors is important.

Objectives: This study aims to examine the correlation between balance, lower limb muscle strength, and the energy cost of walking in stroke survivors.

Methods: This analytical cross-sectional study included 48 stroke survivors (≥3 months post-stroke) who can walk independently with or without assistance (FAC 3–5) at Rehman Medical Institute. Participants with acute stroke, leg pain, impaired balance (Postural Assessment Scale <12.5), or cognitive deficits (MMSE <24) were excluded. Lower limb strength was measured using MRC-MMT, energy cost with the Physiological Cost Index (PCI) and balance with the short-form Berg Balance Scale (BBS). Pearson correlation was applied for analyzing relationships between variables.

Results: Balance demonstrated significant positive correlations with knee extensor strength ($r = 0.306$, $p = 0.034$) and knee flexor strength ($r = 0.318$, $p = 0.028$). PCI showed significant negative correlations with all lower limb muscle strength measures, including hip extensors ($r = -0.534$), hip flexors ($r = -0.529$), knee extensors ($r = -0.511$), knee flexors ($r = -0.531$), ankle dorsiflexors ($r = -0.499$), and plantar flexors ($r = -0.502$) ($p < 0.001$). Strong intercorrelations were also observed among different lower limb muscle groups.

Conclusion: Lower limb muscle strength, particularly knee muscle strength, plays a substantial role in maintaining balance and improving walking efficiency in stroke survivors. Increased muscle strength is associated with reduced physiological cost of walking, highlighting the importance of strength-focused rehabilitation interventions to improve functional mobility after stroke.

Keywords: Stroke; Balance, Lower limb muscle strength, Gait, Energy expenditure, Physiological Cost Index.

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INTRODUCTION:

The most recent Global Burden of Disease (GBD) showed estimated stroke burden as the 2nd most common cause of death (about 7 million) among non-communicable disorders (NCDs) and the third leading cause of disability and death collectively in the world expressed as over 160 million by disability-adjusted life-years lost (DALYs). [1, 2] The data reported in 2021 also mentioned that stroke as the 2nd most cause of death (99,759) in Pakistan with an incidence of 153 and prevalence of 1088 per 100,000 population.[3] Stroke survivors commonly present with reduced lower-limb strength, impaired balance, slower gait, and an increased energy cost of walking as reflected by a higher Physiological Cost Index (PCI) compared with healthy individuals. The prevalence of reduced strength of affected lower limb is reported as 48% having hip extensor as the most compromised muscle 34%.[4] Meanwhile, the balance impairments in stroke survivors ranges from 48.1% to as high as 83%.[5, 6] The elevated energy cost of hemiparetic gait has been attributed to abnormal muscle activation, compensatory movement strategies, and reduced walking speed, all which compromise efficiency and functional mobility after stroke and impair the quality of life ranging from 6 months (29%) to 1 year (42%) after discharge.[7]

After a stroke, aberrant muscle activation patterns, passive or active restraint of agonist activation, and physiological alterations in the paretic weak muscles and their motor units have all been found to impair muscle force production and thus reduce the muscle strength. [8] Furthermore it has been suggested that muscle weakness is one of the main causes of physical limits and decreased gait velocity post-stroke. Gait performance changes can also be observed in gait asymmetry and demand of higher energy cost. [9, 10] Evidence highlighted the association between balance performance and lower limb muscle strength in stroke survivors. Studies reported moderate to strong correlations, often ranging between r ≈ 0.4–0.7, particularly between measures such as knee extensor or hip abductor strength and balance tests like the Timed Up and Go (TUG), Berg Balance Scale (BBS) and Functional Reach. Muscle weakness consistently identified as a major contributor to post-stroke balance impairments, reinforcing the role of strength training as a rehabilitation priority. [11, 12] Importantly, the link between lower-limb strength or balance and PCI is often mediated by gait speed. Stronger muscles and better balance enable faster and more stable walking, and gait speed itself has a well-documented inverse relationship with PCI, since walking more efficiently at higher speeds generally reduces the physiological cost. Several studies have shown that when gait speed is controlled by regression models, the direct association between balance or strength and PCI diminishes, indicating that gait speed is a significant mediator in this relationship. [2, 13]

Pei Yi Lin et. al conducted a descriptive study on a sample of 68 subjects with hemiparesis who could walk independently. The results of this study suggested that gait velocity and temporal symmetry of gait are affected mainly by the strength of dorsiflexor muscles and the extent of spatial gait asymmetry is influenced by the dynamic spasticity of plantar flexor muscles and therefore the treatment which targets different ankle impairments can be used to improve the gait outcomes. [14] The PCI, which is calculated as the difference between mean walking heart rate and resting heart rate divided by walking speed, has been widely used as a field-based measure of the energy cost of walking. In stroke patients, several validation studies have demonstrated that PCI correlates strongly with direct oxygen consumption measures (r ≈ 0.7–0.85), confirming its utility as a practical proxy for metabolic cost when laboratory gas analysis is not feasible.[15] Treatment protocol of strength training with balance exercises have good results in improving overall efficiency of walking and gait speed along with evidence suggesting reduction in physiological and metabolic cost. However, the significance level varies in different studies depending upon patient characteristics, sample size and protocol used .[13, 16, 17]

Most of the stroke survivors experience impairment in gait and balance and weakness in lower extremity but their relationship with energy cost remained unexplored in clinical setting. The neuromuscular deficit due to stroke leads to lower limb weakness which contributes to impairment in balance and walking ability hence leading to increased cost of energy during walking. The previous literature examined the muscle strength and its association with balance and gait performance on functional activities separately however, limited studies were available on the collective relation of these factors on the physiological cost of walking. As these factors are crucial in determining the targeted training approach for stroke patients, understanding the role of it improves the goal setting in clinicians. Therefore, this study aims to explore the correlation between balance, lower limb muscle strength, and the energy cost of walking in stroke survivors.

METHODS

This analytical cross-sectional study was conducted from June till December 2025 in the Physical therapy and Rehabilitation department of Rehman Medical Institute. Total 48 participants visited the department in the given duration, who had history of any type of stroke for last 3 months, can walk independently with or without assistance i,e functional ambulatory scale (FAC) score= 3-5 were recruited through convenience sampling. However, patients with; history of acute stroke, pain in legs during walking, inability to maintain dynamic balance i.e., a score of less than 12.5 points on Postural assessment scale for stroke and individuals with cognitive deficits such as inability to understand information or follow instructions i.e., Mini Mental Scale Exam (MMSE) score less than 24 were excluded. Informed consent was taken, and participants were assessed using MRC-Manual muscle testing scale for lower limb muscle strength, Short form- Berg Balance Scale for balance and physiological cost index (PCI) for estimation of energy cost. The data was analyzed in SPSS software; Participants demographics and clinical characteristics were presented through descriptive statistics, mean ± standard deviation (SD) was used for continuous variables while frequency and percentages were reported for categorical variables. For determining the relationship between balance, lower limb muscle strength, and the energy cost of walking in stroke survivors Pearson's correlation coefficient was used. A p-value of ≤0.05 was considered statistically significant.

RESULTS:

A total of 48 participants out of which n= 34 (70.8%) were males and n=14 (29.1%) were females having mean age of 65.39 ±3.08 years and the mean duration since stroke was 6 ± 3.5. Most participants presented with ischemic stroke n= 38 (79.1%), while n=10 (20.8%) had hemorrhagic stroke and n= had left hemispheric stroke.

Table 1. Demographic and Clinical Characteristics of Study Participants

Variable	Mean ± SD / n (%)
Age (years)	65.39 ±3.08
Duration since stroke (months)	6 ± 3.5
Male	34 (70.8%)
Female	14 (29.1%)
Ischemic stroke	38 (79.1%),
Hemorrhagic stroke	10 (20.8%)
Right-sided involvement	17 (35.4%)
Left-sided involvement	31 (64.6%)

The mean score for lower limb muscle strength was 3.4 ± 0.6 measure through MMT, reflecting decreased muscle strength in the involved lower limb. The score for balance on Berg Balance Scale (BBS) was 38.6 ± 7.4, showing moderate balance impairment while the mean Physiological Cost Index (PCI) was 0.52 ± 0.18 beats/meter, indicating an increased energy cost during walking. Moreover, the mean value for gait speed was 0.64 ± 0.21 m/s, resulting in slower walking performance.

Table 2. Mean Scores and Ranges

Variable	Mean ± SD	Range
Berg Balance Scale	38.6 ± 7.4	22–52
Lower Limb Muscle Strength	3.4 ± 0.6	2–5
Physiological Cost Index	0.52 ± 0.18	0.21–0.88
Gait Speed	0.64 ± 0.21	0.28–1.05

To examine the interrelationship of lower limb strength, balance and physiological cost index (PCI), Pearson correlation analysis was conducted. Significant correlation was observed between Balance with knee flexor strength ($r = 0.318$, $p = 0.028$) and knee extensor strength ($r = 0.306$, $p = 0.034$), suggesting that increased knee muscle strength is required in maintaining functional balance. However, the was no statistically significant correlation found among balance and hip or ankle muscle groups.

PCI showed significant moderate negative correlations with all lower limb muscle strength measures, including hip extensors ($r = −0.534$, $p < 0.001$), hip flexors ($r = −0.529$, $p < 0.001$), knee extensors ($r = −0.511$, $p < 0.001$), knee flexors ($r = −0.531$, $p < 0.001$), ankle dorsiflexors ($r = −0.499$, $p < 0.001$), and ankle plantar flexors ($r = −0.502$, $p < 0.001$) suggesting that to decrease the physiological cost of walking, increased strength in lower limb muscles is required.

Table 3. Association of Lower Extremity Muscle Strength with BBS and PCI Scores

Variable	BBS (r)	PCI (r)
Hip extensor strength	0.216	-0.534
Hip flexor strength	0.223	-0.529
Knee extensor strength	0.306	-0.511
Knee flexor strength	0.318	-0.531
Ankle dorsiflexor strength	0.221	-0.499
Ankle plantar flexor strength	0.196	-0.502

There was strong positive correlations was found among different groups of lower limb muscle indicating that coordinated muscle strength is required across hip, knee and ankle for maintaining balance and gait.

Table 4. Correlation Matrix of Lower Limb Muscle Strength

Variable	Hip Ext	Hip Flex	Knee Ext	Knee Flex	Ankle DF	Ankle PF
Hip Extensor	-	0.994	0.895	0.910	0.662	0.675
Hip Flexor	0.994	-	0.905	0.910	0.670	0.661
Knee Extensor	0.895	0.905	-	0.991	0.680	0.658
Knee Flexor	0.910	0.910	0.991	-	0.684	0.682
Ankle DF	0.662	0.670	0.680	0.684	-	0.976
Ankle PF	0.675	0.661	0.658	0.682	0.976	-

DISCUSSION:

The current study was conducted to investigate the association of lower limb muscle strength, balance and the Physiological Cost Index (PCI) in stroke patients having independent ambulation. The findings indicated that there is a significant positive correlation among strength of knee muscles and balance performance. However, the global muscle strength. These findings highlighted the role of knee muscles in maintaining balance and overall muscle strength of lower limb in reducing the energy cost during gait. The results are consistent with the previous literature suggesting that weakness of lower limb muscle is the primary cause of balance and gait impairment after stroke. Bohannon emphasized the role of muscle strength as a core factor in functional recovery of patients after stroke, [16] while Saraiva et al. proved that there is a strong correlation between balance on TUG and BBS with strength of hip and knee muscles. There was a positive correlation between balance and knee muscle strength indicating that knee strength is crucial and taken into account while planning rehabilitation strategies for patients with compromise balance and gait. [11] The inverse relationship between muscle physiological cost of index and balance mirrors findings of Fredrickson et al. and Danielsson et al. suggesting that increased muscle strength and walking speed were associated with lower PCI values, proving its validity in improving walking efficiency. The findings of this study reinforce the connection of lower limb muscle strength and energy cost during walking which translated in study that muscle strength improves the functional mobility and cardiovascular efficiency. [18]

Interestingly, it was observed that there were strong correlations between agonist–antagonist muscle and adjacent joints, suggesting that the proportionate strength generation takes place across the region rather than in isolation. However, Ozgozen et al. reported that residual decrease in knee and ankle muscles strength serves as a predictor of impaired walking performance. This notion emphasizes the need of comprehensive strength training which targets the multi joint region in order to improve overall strength and eventually gait in patients with stroke and the clinical implications of these results are noteworthy. [19] the training program which emphasizes the strength of lower limb muscles along with overall conditioning has beneficial effects in improving balance and reducing energy cost of walking and movement variability. These outcomes are important for stroke patients as they suffer from fatigue, activity limitations and gait inefficiency.[20] However, methodological considerations must be acknowledged as the use of manual muscle testing which is feasible in clinical setting but lacks precision of dynamometry. Moreover, PCI measurement is subject to change depending upon resting heart rate , steady-state walking conditions, and walking speed. The modest sample size and use of convenience sampling may also limit generalizability of results. Even so, the observed consistency with prior studies lends credibility to the present findings.[13, 15]

Future research should plan to use larger cohorts with standardized assessment tools, including dynamometer and validated metabolic measures, increase sample size, characteristics of patients shall also be taken into account for more comprehensive data. Long-term effects of balance training and its effects on reducing energy cost shall also be considered.

CONCLUSION:

This study concludes that strength of lower limb muscles, specifically the knee extensors and flexors, plays a crucial role in maintaining balance and reducing the physiological cost of walking in stroke patients. There were strong negative correlations between PCI and global lower limb strength highlighting the importance of strength training in improving walking and overall functional outcomes. These findings reinforce the need for comprehensive rehabilitation plan for integrated strength and balance training. These approaches have the possibility to improve independence, reduce fatigue, and improve the quality of life among patients recovering from stroke.

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