

Research Article

Evaluating Functional Recovery in Stroke Patients: Neurostimulation-Assisted Walking Device in Stroke Patients with Drop Foot

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Abstract

Background: Walking recovery is a key concern for post-stroke patients, with up to 46% of first-ever stroke survivors initially unable to walk and 40% of all post-stroke patients requiring rehabilitation. Regaining a more physiological walking pattern can lead to improved gait performance and, consequently, greater independence in activities of daily living.

Materials and methods: 18 post-stroke patients with drop foot completed a treatment program comprising a neurostimulation-assisted walking device (BTL WALK). Functional gait measurements, including the 10-Meter Walk Test (10MWT), 6-Minute Walk Test (6MWT), Stair Climb Test (SCT), and Manual Muscle Grading scale (MMT) were assessed both before and after the program. Additionally, the Barthel Index was used to evaluate the impact of the treatment on independence in daily activities.

Results: Statistically significant improvements were observed in all monitored parameters, with changes of -17.7% in the 10-Meter Walk Test (10MWT), 14.6% in 6-Minute Walk Test (6MWT), -37.0% in Stair Climb Test (SCT), 8.86% in Barthel Index, and 27.8% in Manual Muscle testing scale (MMT). No significant relationship was found between any parameter or its change and the time since stroke onset.

Conclusions: This study highlights the potential of BTL WALK training in mitigating drop foot in post-stroke patients. Improvements in walking speed, distance, and stair-climbing enhanced independence in daily activities and increased muscle strength, serving as a key motivational factor for continued rehabilitation, especially for patients several years post-stroke.

Keywords: Stroke, Drop foot, Neurostimulation-assisted walking, Gait training, Independence in daily activities

Introduction

Stroke remains a leading cause of mortality and long-term disability, with up to 40% of survivors requiring active rehabilitation [1]. Lower extremity motor impairment is present in 44.1% of individuals experiencing a first-ever stroke, and 46.0% are initially unable to walk [2]. Walking recovery is often one of the first concerns raised by post-stroke patients when consulting medical staff, highlighting its critical role in rehabilitation [3]. Among those who regained some walking ability within 3 to 5 days post-stroke, 76.4% were discharged to home care, compared to only 21% of non-ambulatory patients [1]. Walking is not only a key factor in determining discharge to home care but also a fundamental component in restoring independence in daily life [3].

Up to 20% of stroke survivors experience drop foot, a condition characterized by an impaired ability to dorsiflex the foot during the swing phase of gait. This persistent distal weakness in the hemiparetic leg may be associated with weakness of the anterior muscles, spasticity of the posterior leg muscles, or both. Additionally, the condition can be further complicated by the development of plantar-flexion contracture at the ankle [4]. Drop foot leads to disability by promoting undesirable compensatory movement patterns, restricting mobility,

and increasing the risk of falls [4,5]. One potential treatment for drop foot in individuals with hemiparesis is Electrical Stimulation (ES) applied to the peroneal nerve and the tibialis anterior muscle [5].

The most common therapeutic strategies for drop foot are ankle-foot orthosis (AFO) and electrical stimulation [6]. Ankle-foot orthoses (AFOs) are frequently prescribed for individuals with drop foot to maintain ankle neutrality and enhance limb clearance during the swing phase [4,7]. However, this intervention presents several limitations. Restricted ankle mobility associated with AFO use may contribute to contracture development. Furthermore, AFOs do not actively promote dynamic function or facilitate motor recovery [4,6]. Challenges in sit-to-stand transitions and patient discomfort are also commonly reported [4]. Electrical stimulation presents an alternative therapeutic modality for drop foot, targeting branches of the common peroneal nerve distal to the knee. In contrast to AFOs, ES permits physiological ankle range of motion and facilitates active dorsiflexion and eversion without mechanical constraint [4,6]. Clinical evidence indicates that ES, by unrestricted ankle motion, may offer superior functional outcomes compared to AFOs, particularly in complex environments characterized by inclines, uneven terrain, and pedestrian traffic [6,7].

Studies evaluating the immediate effects of ES during therapy have reported positive impacts on walking quality. However, research investigating its long-term effectiveness has yielded divergent results [8,9]. Guzel et al. observed statistically significant improvements in gait quality following a combined conventional physiotherapy, ES, and balance-weighting rehabilitation program in post-stroke patients. Similarly, Street et al. reported positive outcomes in individuals with multiple sclerosis [10,11]. In both patient populations, significant improvements were also observed following ES therapy when compared to the use of AFO [12,13].

This study aims to assess the impact of BTL WALK therapy on post-stroke patients. The research will evaluate the effects on gait parameters, lower limb disability, and the influence of time since stroke on individual outcomes [14,15].

Materials and Methods

The study was conducted at the Hamzova Léčebna Luže-Košumberk rehabilitation center between April and December 2025. Its design adhered to the ethical principles of the 1975 Declaration of Helsinki, as adopted by the Convention on Human Rights and Biomedicine of the Council of Europe and endorsed by the General Assembly of the World Medical Association [17].

Inclusion criteria required participants to be first-time stroke survivors, medically stable, with no cognitive impairment, and presenting with lower extremity involvement in the form of drop foot. Exclusion criteria included febrile conditions, cachexia of any etiology, tuberculosis or other bacterial infections, suspected malignancy, bleeding disorders, menses, the presence of electronic or metal implants in the treatment area, skin inflammation, trophic skin changes, irritated or damaged skin, cardiovascular diseases, sensation disorders, lower limb fractures, dislocations, or conditions adversely affected by motion, electroanalgesia without a confirmed pain etiology, psychopathological syndromes, and inflammatory conditions in the treatment area.

Participants underwent a 4-week treatment program consisting of neurostimulation-assisted walking (BTL WALK) therapy, administered five times per week. Functional assessments were performed before and after treatment, including the 10-Meter Walk Test (10MWT), the 6-Minute Walk Test (6MWT), and the Stair Climb Test (SCT) to evaluate mobility. Muscle strength was assessed by the Manual Muscle Test (MMT). Additionally, participants completed the Barthel Index questionnaire, which assessed their subjective level of disability related to gait impairment.

Before therapy, the patient was seated with the hip, knee, and ankle positioned at a 90° angle. The BTL WALK Pro device (BTL Industries, Ltd.) was placed on the inner calf, with electrode positioning adjusted to stimulate the common peroneal nerve that innervates the peroneal muscles and the tibialis anterior muscle (Figure 1). Following the initiation of therapy, stimulation intensity was gradually increased until ankle dorsiflexion was achieved. The electrode was then further adjusted to maintain the foot in a neutral position, preventing excessive eversion or inversion. The patient was encouraged to walk, with continuous adjustments made to electrode placement and stimulation



Figure 1: Image depicting the placement of BTL WALK on the inner calf to treat drop foot. Permission was granted by BTL Industries, Ltd.

intensity based on their response. Once optimized, a walking session was conducted, during which drop foot pathology was mitigated through muscle stimulation.

To assess objective gait improvements, several functional tests were performed. The 10MWT evaluated gait speed, where the patient was instructed to walk at a comfortable pace over a 10-meter distance. The total time taken to complete the walk was recorded in seconds. No physical assistance was provided unless required for safety reasons. Timing began when the first foot crossed the start line and stopped when the first foot crossed the end line at 10 meters [18].

The 6MWT assessed functional exercise capacity by measuring the maximum distance the patient could walk in six minutes. The test was conducted in a long, straight hallway with cones marking each end of the walking course. The patient was instructed to wear comfortable clothing and non-slip footwear and walk at their own pace. They were allowed to rest if needed, but the timer continued running, and the total distance walked in meters was recorded [19].

Lower limb strength and balance were assessed using the SCT, which measured the time taken to ascend a standard flight of 12–14 steps, each 17–19 cm high. The patient was instructed to climb the stairs at their normal pace, using handrails only if necessary for balance. Timing began at the first step and stopped upon reaching the top, with results recorded in seconds [20].

Strength of the tibialis anterior, peronei, soleus, and gastrocnemius muscles was measured using the 0, meaning no contraction, to 5, meaning normal strength against full resistance, scale of the MMT. Muscle tests were performed by trained examiners following standardized limb positions and stabilization to minimize substitution and optimize repeatability.

In addition to these functional tests, the Barthel Index was used to evaluate the patient’s level of functional independence in performing ten essential daily activities. The assessment was conducted through direct observation and patient interviews, with activities scored based on the level of independence—categorized as independent, partially independent, or dependent. The total score ranged from 0 to 100, with higher values indicating greater independence [21].

The sample size was determined based on the capacity of the rehabilitation center and the minimum required sample size calculation. This calculation was conducted using 6MWT data from a previous study on post-stroke patients, assuming a study power of 80% and an estimated effect size of 15 meters [22,23]. The minimum required sample size of nine patients was increased to 20 to account for facility capacity and potential dropout risk.

For statistical processing and data evaluation, a customized script was developed in the Matlab environment. The data were initially analyzed using the Shapiro-Wilk test to assess normality. Except for the 10-Meter Walk Test (10MWT), the assumption of normal distribution was rejected for all parameters. Consequently, these data were analyzed using the Wilcoxon Signed-Rank test and presented as median values with interquartile range (IQR). In contrast, the 10MWT data, which met the criteria for normality, were compared using a T-test and reported as mean values with Standard Deviation (SD). The Pearson correlation coefficient was used to determine if there was a correlation between the time since stroke onset and the therapy outcome. P-values less than 0.05 were considered indicative of statistical significance.

Results

A total of 18 post-stroke patients, 16 men and 2 women, with a mean age of 70.22 ± 12.70 years and a mean time of symptom duration of 8.7 years. No adverse events occurred during the program, and none of the patients experienced any discomfort that would have hindered their participation. The therapy was generally well tolerated and resulted in improved walking function in the majority of patients.

Monitored parameters showed statistically significant improvements, mean score change, and mean within-patient

percentage change in Table 1. After the treatments, 83.33% of patients improved in 10 MWT, 88.89% of patients improved in 6MinWT, 83.33% of patients improved in SCT, and 50% of patients improved in BI. These patients showed mean improvements in the aforementioned parameters of -18.41%, +23.06%, -28.46%, and 21.61%. The changes in MMT measurements showed the number of patients that improved after the therapies was 22.22% in the tibialis anterior, 33.33% in the peronei muscle, 27.78% in the soleus muscle, and 27.78% in the gastrocnemius muscle. The average change for the MMT score was 27.78%.

The bar graph in Figure 2 visually represents the improvements achieved. The 6MWT and Barthel Index showed increases in the distance covered and the degree of independence in activities of daily living, respectively. Conversely, both the 10MWT and SCT showed decreases in the time needed to walk a set distance or climb a flight of stairs. These results all suggest an overall improvement in lower limb function over the course of the BTL WALK treatment program.

Table 2 displays the Pearson correlation coefficients, which show the relationship between the time since stroke onset and individual outcome measures. The results indicate that time since stroke onset did not have a statistically significant effect on any of the indicators.

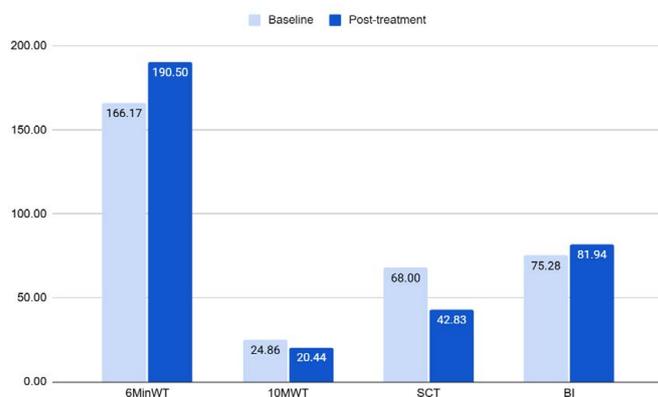


Figure 2: The baseline and post-treatment values of the 10-Meter Walk Test (10MWT), the 6-Minute Walk Test (6MWT), and the Stair Climb Test (SCT) to evaluate mobility.

Table 1: Results of functional tests and functional independence questionnaire obtained before and after the treatment program. P values lower than 0.05 were considered statistically significant.

	Before	After	Diff	%Diff	%Mean within-patient percentage change	P (0.05)
	Mean (SD)	Mean (SD)	Mean score change (SD)			T-test Other: Wilcoxon Signed Rank test
10MWT (seconds)	24.86 (13.50)	20.44 (10.43)	-4.43 (5.41)	-17.77%	-14.20%	0.006
6MWT (meters)	166.17 (75.37)	190.50 (80.67)	24.33 (39.10)	14.64%	19.53%	0.002
SCT (seconds)	68.00 (63.54)	42.83 (20.55)	-25.17 (51.53)	-37.01%	-22.69%	0.006
Barthel Index	75.28 (11.13)	81.94 (5.18)	6.67 (8.91)	8.86%	10.80%	0.035

Table 2: P-value and Pearson correlation coefficient between time since stroke onset and individual outcome measures obtained before starting and after completing the treatment program, and the difference between them.

	Time vs 10MWT		Time vs 6MWT		Time vs SCT		Time vs Barthel Index	
	P (0.05)	r	P (0.05)	r	P (0.05)	r	P (0.05)	r
Before	0.928	0.027	0.662	-0.128	0.355	-0.268	0.578	0.163
After	0.873	0.047	0.57	-0.166	0.591	-0.157	0.757	-0.091
Diff	0.934	0.024	0.711	-0.109	0.358	0.266	0.336	-0.278

Time: Time since stroke onset, r: Pearson correlation coefficient, Diff: difference, 10MWT: 10-Meter Walk Test, 6MWT: 6-Minute Walk Test, SCT: Stair Climb Test.

Discussion

The present study documents statistically significant changes in post-stroke patients' gait as a result of a rehabilitation program based on BTL WALK gait training. These conclusions are supported by existing evidence, both in terms of statistical significance and the extent of the changes achieved [16,22,24]. Comparing the recalculated 10MWT values for speed (before: 0.51 m/s, after: 0.59 m/s) with similar studies, it is evident that the absolute values of gait speed differ significantly across publications. This may be due to variations in measurement methodology (patient instruction, use of aids, treadmill, etc.) and the different composition of patients in terms of indication, age, time from onset of stroke, severity, or brain damage, etc. Patients in the acute and subacute post-stroke phase tend to be more limited in movement and their gait speed reaches an average of around 0.25 m/s [25]. The current research includes patients who are a few weeks post-stroke, but also those who have been suffering from the consequences of stroke for many years. Correlation analysis did not reveal a statistically significant relationship between time since stroke and any outcome measure or its change. The main influence on walking limitation is likely the extent of brain damage [26].

The observed improvements in walking speed, functional exercise capacity, balance, and lower limb strength, as demonstrated through various functional assessments, can be further explained by the underlying mechanism of BTL WALK in post-stroke drop foot rehabilitation. BTL WALK facilitates neuromuscular activation by delivering electrical impulses to the dorsiflexor muscles, inducing muscle contraction, and enabling ankle dorsiflexion during the swing phase of gait. In post-stroke patients experiencing drop foot or impaired foot clearance, this timely and coordinated muscle activation enhances gait performance, contributing to a more physiological walking pattern [27]. Moreover, intensive and prolonged gait training incorporating ES promotes motor relearning, which, over time, can lead to sustained improvements in gait mechanics, potentially reducing the need for assistive devices [28]. This device can significantly affect the quality of life of patients in everyday life if they use the device as a compensatory aid.

Improvements observed in functional gait assessments were also positively reflected in subjective evaluations of activities of daily living. Although these changes were less pronounced compared to speed and distance-based assessments, they nonetheless reached statistical significance. Future research should consider utilizing more sensitive assessment tools capable of detecting the impact of even minor gait pattern deviations on an individual's independence in daily activities.

The conclusions of this study must be interpreted in consideration of its limitations. The primary limitation is the absence of a control group, which would have enabled a direct comparison with patients receiving conventional therapy or no treatment, thereby accounting for the potential effects of spontaneous motor recovery. Additionally, the small sample size may have influenced the findings, particularly in the analysis of the impact of time since stroke onset. Notably, patient inclusion was not stratified based on time post-stroke, which adds a distinctive aspect to the study but also presents a limitation. Future research should aim to investigate specific subgroups of stroke

survivors, particularly those several years post-stroke, as clinical evidence in this population remains limited.

Despite its limitations, this study provides valuable insights, particularly by demonstrating the positive effects of BTL WALK therapy on gait in patients undergoing rehabilitation not only in the early post-stroke phase but also several years after stroke onset. The finding that mobility and independence in daily activities can still be improved in chronic stroke survivors may serve as an important motivational factor for continued rehabilitation efforts.

Conclusions

The present study highlights the potential of BTL WALK training in mitigating drop foot in post-stroke patients. The observed improvements in walking speed, distance covered, and stair-climbing ability contributed to enhanced independence in daily activities, which may serve as a crucial motivational factor for continued rehabilitation, particularly for individuals undergoing therapy several years post-stroke. The therapy is an effective intervention for rehabilitating patients with limited mobility and gait impairments resulting from brain damage, promoting functional recovery and improved movement patterns.

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