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Therapeutic effect of functional electrical stimulation-triggered gait training corresponding gait cycle for stroke

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ABSTRACT

The purpose of this study was to determine the therapeutic effects of functional electrical stimulation (FES) applied to the gluteus medius and tibialis anterior muscles during the gait cycle in individuals with hemiparetic stroke. Eighteen patients who had suffered a stroke were enrolled in this study. The participants were divided into either the gluteus medius and tibialis anterior (GM + TA) training group ($n = 9$) or the control group ($n = 9$). The GM + TA group received FES-triggered gait training to the gluteus medius (GM) in the stance phase and the tibialis anterior (TA) in the swing phase for 30 min, 5 session a week over a 6-week period, and control group who received only gait training without FES-triggered for the same duration of time. A foot-switch sensor was used to trigger the device in the stance (GM) and swing (TA) phases of the gait cycle reciprocally. This study measured three types of outcome measures, including spatiotemporal gait parameters, muscles activities, and balance function. After 6 weeks training, there was a significant improvement in gait velocity, cadence and stride length in the GM + TA training group compared to the control group. Dynamic balance function was significantly improved in the GM + TA training group compared to the control group. The mean changeable values of the GM was significantly greater strength in the GM + TA training group than the control group. These findings suggest that FES-triggered gait training of the GM in the stance phase and TA in the swing phase may improve the spatiotemporal parameters of gait in persons with hemiparetic stroke.

1. Introduction

Gait training following stroke is the most important component of clinical rehabilitation for improving active, independent, functional activities for daily living, community-dwelling, and social environments [1]. Functional reeducation or relearning is dependent upon the amount of practice. Therefore, gait training is one of the important components in improving quality of life in stroke survivors. Within the clinical setting, common and popular approaches to gait training are range of motion exercises, intensive gait training, strength training, proprioceptive neuromuscular facilitation, and neurodevelopmental approach [2–4]. These approaches are more effective in the acute or subacute stages than in chronic stages of stroke because focus is directed towards the feasibility of independent walking rather than on characteristics of gait disorders [5].

It is important for chronic stroke patients to focus on the intervening factors of their gait performance, and not solely on gait itself. As such, functional electrical stimulation (FES) has some benefits for gait training in chronic stroke patients. FES can be used for improving muscle strength and performance, increasing range of motion, decreasing atrophy and spasticity, as well as suppressing pain. FES has also been used extensively to relearn the recruitment and timing of muscles activation in the paretic limb to produce a more normal gait and to create the lower limb muscle activation sequence needed during gait performance [6–8].

Generally, FES facilitates ankle dorsiflexion during the swing phase of gait in hemiparetic stroke patients within clinical fields [9,10]. Stroke patients do not generate sufficient foot clearance during walking, which can lead to falls and other secondary injuries, such as fracture. Also, they cannot proceed in front due to insufficient foot clearance during the swing phase of gait [11]. Therefore, FES was used to focus these impairments during the swing phase within the clinical settings. As though the swing phase is impaired with an inability to get the foot in front and an insufficient foot clearance during walking, the stance phase has

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difficulties in performing weight bearing and weight shifting on the paretic limb in stroke patients [2,3]. However, FES applications may correct the impairments in the swing phase during gait but not the difficulties in the stance phase, such as abnormal weight bearing and weight shifting, for hemiparetic stroke patients.

This study applied FES in the attempt to improve functional gait performance in the swing phase as well as stance phase for hemiparetic stroke patients. This study applied FES on the hip abductors to activate the pelvic stabilizers in the stance phase and on the ankle dorsiflexors to activate the ankle dorsiflexors in the swing phase during gait simultaneously. When hip abductors activate sufficiently during initial double limb stance and the initial half of single limb support in the stance phase, stroke patients can perform more normal weight bearing on their stance limb as well as propel their swing limb forward. The purpose of this study was to investigate the effect of FES applied on the gluteus medius (GM) during stance phase and the tibialis anterior (TA) during swing phase of gait performance in chronic hemiparetic stroke patients.

2. Methods

2.1. Subjects

Eighteen patients with chronic hemiparetic stroke were enrolled for this study, and were allocated randomly either to the gait training with FES (GM + TA) group or the control group. This study was approved by the Human Research Ethics Committee from all participating institutions. All participants recruited by brochure of this study in rehabilitation units, and were inpatient. All participants signed a consent form to participate in this study.

The inclusion criteria were as follows: (1) first stroke and no other neurological diseases; (2) manual muscle test (MMT) grade below 2 (full range of motion in gravity-eliminated position) in the gluteus medius (GM) and tibialis anterior (TA) muscles; (3) the ability to walk at least 10 m without assistance; (4) above a score of 24 in the Mini-Mental State Examination; (5) ability to communicate and follow instructions normally; and (6) no orthopedic surgery that affected gait performance. Patients with vestibular or cerebellar disease or with visual or auditory difficulties were excluded. Table 1 lists the general characteristics of the subjects.

2.2. Equipment and data collection

Surface FES (EMG–FES 3000, Cyber Medic Inc.) was used to trigger muscle activations in the GM during stance phase and TA during swing phase in this study. The electrodes were attached to the GM and TA muscles. The FES used an symmetric biphasic wave with a frequency of 40 Hz and a pulse width of 200 μs on the GM and TA muscles.

Table 1
General characteristics of the participants ($n = 18$).

Variables	GM + TA training group ($n = 9$)	Control group ($n = 9$)
Sex (male/female)	7/2[a]	7/2
Age (year)	60.0(7.5)[b]	56.6(7.6)
Post-stroke duration (months)	25.4(3.2)	24.9(3.1)
Mini-mental state examination	24.9(2.5)	23.8(3.0)
Etiology (ischemic/hemorrhage)	5/4	4/5
Paretic side (right/left)	4/5	2/7
Brunnstrom stage (4/5)	6/3	7/2

GM + TA, Gluteus medius + tibialis anterior.
[a] Number.
[b] Mean (standard deviation).

GAITRite (GAITRite, CIR system Inc., Havertown, Pensylvania, USA) was used to measure the spatiotemporal parameters, including gait velocity, stride length and double support period. GAITRite is a validated gait analysis system and an electronic gait-analyzing board consisting of a 192 in (488 cm) electrical walkway that contains six sensor pads encapsulated in a roll-up carpet to produce an active area, 24 in (61 cm) wide and 0.6 cm high. The active area was a grid (48 sensors by 384 sensors placed on 0.5 in (1.27) centers) totaling up to 16,128 sensors. The device measured the loading of the subject's feet with a sample rate of 80 Hz when the subject walks on it. The data was transmitted to the computer through a serial interface cable. The spatiotemporal data collected was processed using GAITRite GOLD, version 3.2b Software. For this study, the subjects were instructed to stand in front of the gait board, and then walk on it in a self-selected comfortable speed until they reached the end of the board.

The dynamometer (Model 01163, Lafayette Inc., IN, USA) is a hand-held device for objectively quantifying eccentric muscle strength, and is designed for one hand operation. The dynamometer measure the peak force required to break an isometric contraction as the examiner applies force against the participant. The dynamometer was used to measure isometric strength of the gluteus medius and tibialis anterior. Gluteus medius force was measured in supine with the knee extended and the hip joint in neutral relative to extension, abduction, and rotation, and was measured at the lateral surface of the thigh just proximal to the lateral condyle of the femur. Tibialis anterior force was measured in sitting with the hip joint flexed to 90° and the knee joint flexed 30°, while the foot hung freely over the edge of the table, and was measured at the perpendicular to the sole of the foot under the metatarsals's head. Participant performed three trials of each muscle with five second holds as the measure of muscular strength. The mean values were used for statistical analysis.

The Berg Balance Scale (BBS), developed by Katherine Berg, is a widely used clinical measurement of static and dynamic balance function and is generally considered to be the gold standard. The test consists a set of 14 different items, scoring from 0 (the lowest level of function) to 4 (the highest level of function), with a maximum score of 56. The score is interpreted as follows: 0–20, wheelchair bound; 21–40, walking with assistance; 41–56, independent. A score of 45 points is the relative risk and an appropriate cut-off for safe independent walking. The BBS has been shown to have excellent inter-rater (ICC = 0.98) and intra-rater reliability (ICC = 0.98) in individuals with hemiparetic stroke. The BBS is considered a sound measure of balance impairment for stroke rehabilitation [12,13].

This study measured four spatiotemporal parameters, gait velocity, cadence and double support percentage. A manual muscle test was used to measure the muscle strength of both hip abductor and dorsiflexor muscles using a dynamometer. Balance performance and gait performance (velocity, cadence, stride length) (step length ratio) were measured before commencing the training programs, and again after 6 weeks.

2.3. Procedures and intervention

All participants were trained with and without walking aids according to their gait performance, and were worn FES electrodes on GM and TA muscles. Prior to training, FES electrodes were applied and set at a predetermined intensity. FES electrodes were placed on the GM (over a line connecting the highest point of the iliac crest and the greater trochanter of the femur; 5 cm below the highest point of the iliac crest and 3 cm above the greater trochanter) and TA (over the lateral to the medial shaft of the tibia,