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Effect of functional electrical stimulation on the effort and walking speed, surface electromyography activity, and metabolic responses in stroke subjects

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ABSTRACT

Objective: To investigate the effects of functional electrical stimulation (FES) combined with conventional rehabilitation program on the effort and speed of walking, the surface electromyographic (sEMG) activity and metabolic responses in the management of drop foot in stroke subjects.
Methods: Fifteen patients with a drop foot resulting from stroke at least 3 months prior to the start of the trial took part in this study. All subjects were treated 1 h a day, 5 days a week, for 12 weeks, including conventional stroke rehabilitation program and received 30 min of FES to the tibialis anterior (TA) muscle of the paretic leg in clinical settings. Baseline and post-treatment measurements were made for temporal and spectral EMG parameters of TA muscle, walking speed, the effort of walking as measured by physiological cost index (PCI) and metabolic responses.
Results: The experimental results showed a significant improvement in mean-absolute-value (21.7%), root-mean-square (66.3%) and median frequency (10.6%) of TA muscle EMG signal, which reflects increased muscle strength. Mean increase in walking speed was 38.7%, and a reduction in PCI of 34.6% between the beginning and at end of the trial. Improvements were also found in cardiorespiratory responses with reduction in oxygen consumption (24.3%), carbon dioxide production (19.9%), heart rate (7.8%) and energy cost (22.5%) while walking with FES device.
Conclusions: The results indicate that the FES may be a useful therapeutic tool combined with conventional rehabilitation program to improve the muscle strength, walking ability and metabolic responses in the management of drop foot with stroke patients.

1. Introduction

After a stroke, people will have resulting motor deficits including decreases in muscle activation, increases in muscle stiffness, and changes in gait patterns (Lamontagne et al., 2002; Woolley, 2001). Motor weakness, poor motor control, and spasticity result in an altered gait pattern, and increased energy expenditure during walking (De Quervain et al., 1996; Tyson, 1999). Ineffective ankle dorsiflexion during swing (drop foot) and failure to achieve heel strike at initial contact are common problems that disturb gait pattern after stroke (Burridge et al., 2001).

Functional electrical stimulation is the clinical application of electric current to activate upper motoneurons, in order to generate a muscle contraction. This contraction is then incorporated into a functional activity, for example, walking. The FES is used to correct drop foot by stimulating the peroneal nerve during the swing phase of gait cycle (Lyons et al., 2002). Libersion and colleagues were the first investigators who reported that some patients with stroke continued to dorsiflex the foot while walking after stimulation was stopped (Liberson et al., 1961). FES refers to the regular use of electric stimulation to achieve overall functional improvement for the patient (Kottink et al., 2004). Thompson and Stein (2004) reported that increased activation of the tibialis anterior muscle during FES-aided walking increased afferent inputs to the central nervous system and thereby influenced plasticity in healthy subjects. It is possible that more benefit could be gained by applying neuromuscular electric stimulation (NMES) early after stroke (Chae et al., 1998).

Many treatments are prescribed to increase gait efficiency of chronic stroke patients who cannot perform voluntary ankle dorsiflexion, such as 1- or 2-channel peroneal nerve stimulators (Burridge et al., 1997), functional electric stimulation (FES) (Kottink et al., 2004), and solid ankle–foot orthosis (Gok et al., 2003). Descriptive review by Burridge et al. examined both the orthotic and therapeutic effects of surface electrodes using single or dual channels of stimulation as an intervention for drop foot (Burridge et al., 1998). Taylor et al. (1999a,b) reported significant improvements in device-free walking speed of 27% and reduction in PCI of 31% in a more recent retrospective review of 151 stroke survivors treated with the

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Odstock Dropped Foot Stimulator (ODFS), for an average of 4.5 months. Studies of subjects late after stroke (>6 month) have shown that FES has a positive orthotic effect on walking ability (Burridge et al., 1997; Kottink et al., 2004; Kenney et al., 2002). Meta-analyses studies have been conducted to evaluate the effectiveness of electric stimulation in post stroke rehabilitation (Glanz et al., 1996; Robbins et al., 2006). They concluded that electric stimulation significantly improved muscle strength, and gait speed, thus it can be used as an orthosis in post stroke subjects. In a recent study by Kottink et al. (2004), had shown a significant orthotic effect on walking speed was found in subjects who received FES, both when measured with a 6-min walk test and when measured on a 10-m walkway. As a rehabilitation therapy, FES exercise may increase whole body activity of patients so that they may gain general health and fitness benefits (Davis et al., 2008). Principal disturbances among hemiparetic patients are affecting gait, which impose excessive energy expenditures during walking (Wade and Hewer, 1987). None of these studies experimented with multi parameters nor correlated the walking speed with RMSmax value of TA muscle EMG signal and walking speed with energy expenditure.

In this study, we hypothesize that the increased RMSmax of the TA muscle would result in increased walking speed when FES was not used because of the repetitive stimulation was applied to this muscle directly. The purpose of this study was to investigate the effect of FES therapy to the tibialis anterior muscle combined with conventional rehabilitation program on improving the multi parameters such as muscle strength, speed of walking, effort of walking and metabolic responses in stroke patients. In addition, RMSmax of the TA muscle and walking speed were correlated to investigate a positive relationship between both the outcomes. We also attempted to find a correlation between walking speed and energy cost with FES device.

2. Materials and methods

2.1. Study design

The study was approved by the institute ethical committee and written informed consents were obtained from all participants. Subjects who met entry criteria were assigned to the experiment, which includes walking with FES system for 30 min combined with conventional stroke rehabilitation program, 5 days a week, 1 h a day, for 12 weeks. The conventional rehabilitation program consists of physical therapy exercises for neurodevelopmental facilitation as well as motor relearning and occupational therapy for activities of daily living. The following outcome measurements were taken at baseline and at post-treatment: temporal and spectral parameters of TA EMG signal, walking speed, effort of walking as measured by PCI, and metabolic responses e.g. volume oxygen consumption (VO_2), volume of carbon dioxide production (VCO_2), expiratory minute ventilation (V_E), energy cost (EC) and heart rate (HR) to the FES based therapy.

2.2. Subjects

Fifteen hemiplegic patients (Table 1) having drop foot due to stroke participated in the study with aged 40–65 years. Patients were required to meet the following criteria for inclusion in the study: (1) history of unilateral stroke with hemiparesis; (2) had stroke at least 3 months before study entry; (3) were medically stable; (5) ability to walk at least 10 m independently; (6) no medical contraindication to walking or to electric stimulation; and (7) ability to understand procedure of test. Exclusion criteria included: active implants (like pacemaker); peripheral neuropathy; pregnancy, absent proprioception; and acute diagnosis (e.g., cancer).

Table 1
Characteristics of all participated subjects at baseline.

Number of subjects	15
Sex (male/female)	12/3
Mean age (years)	51.4 ± 17.6
Mean body weight (kg)	56.3 ± 7.2
Mean body height (cm)	161.3 ± 9.5
Mean time since stroke (mo)	17.46
Affected side (left/right)	12/3
Mean walking speed (m/s)	0.39 ± 0.17
Mean PCI (beats/m)	0.43 ± 0.22
Mean Fugl-Meyer score (lower-extremity)	18.8 ± 4.8

Values reported in mean ± standard deviation.
Abbreviation: PCI, physiological cost index.

2.3. Electrical stimulation system

The single-channel stimulator (EMS, CyberMedic Corp., Korea) was used to provide electrical stimulation through surface electrodes over the common peroneal nerve and the motor point of tibialis anterior or slightly lateral to this to elicit dorsiflexion and eversion of the foot. The stimulation was initiated and terminated to synchronise with the swing phase of walking using a foot switch placed under the heel of the foot on affected lower extremity. The components of the movement may be varied by adjusting the electrode position and stimulation amplitude. The stimulation was delivered a bi-phasic rectangular pulse at 300 μs with intensity of 0–80 mA at a frequency of 40 Hz to produce desired movement as close to "normal" as possible at the ankle during gait (Taylor, 2002). At beginning of the each FES treatment session, the intensity of stimulation and the electrode positions were adjusted for required movement of the foot to clear the ground in the swing phase more easily.

2.4. Measurements

2.4.1. Recording and processing of sEMG signal

The sEMG provides valuable information that can be utilized as an important outcome assessment tool in the treatment process (Ebenbichler, 2001). The sEMG data can be used to study the physiological mechanism of changes in muscle strength (Moritani and DeVries, 1979). The most common two measures of the amplitude of the EMG signal, root-mean-square (RMS) and mean absolute value (MAV), and two measures of the dominating signal frequency, the mean frequency (MNF) or median frequency (MDF), were used to estimate the muscle activation (Pattichis and Elia, 1999). The latter two frequency parameters are extracted from the power spectral density (PSD) estimation of sEMG signals. These parameters have been widely used in identification of muscle impairment, assessment of rehabilitation, and monitoring of muscle fatigability. For instance, during a high-intensity maximum voluntary contraction (MVC), the RMS of sEMG usually increases, while MNF and MDF decrease (Georgakis et al., 2003; Knaflitz and Bonato, 1999; Stulen and De Luca, 1981).

Surface EMG signals from the TA muscle of the affected leg were recorded using a multichannel data acquisition system (PowerLab system, AD Instruments, Castle Hill, NSW, Australia). First, the subjects were asked to sit in a chair with the knee flexed at 90° and ankle at neutral position. Paired bipolar surface electromyographic recordings (Ag–AgCl) electrodes; 1 cm^2 recording area, 2 cm between poles were placed over the TA muscle of the affected leg of the subject. A reference electrode was placed on the hand. This placement and preparation conforms to the SENIAM guidelines. The EMG was recorded for 10 s by encouraging the maximum voluntary contractions (MVCs) of ankle dorsiflexors. Data analysis was performed off-line using MATLAB with the Signal Processing toolbox (The MathWorks Inc., Natick, MA, USA). The raw EMG signals were sampled at 1 kHz per channel and the stored digitized raw EMG signal was initially band-pass filtered between 20 and 400 Hz to remove low frequency motion artefact and high frequency noise. The signal was full wave rectified using an absolute function to produce a linear envelope representation of the data.

The EMG signals were analyzed for temporal parameters such as MAV and RMSmax to determine a possible therapeutic effect of FES on amplitude of the EMG signal. A customized software program was used to determine the MAV and RMSmax of the TA, muscles for finding clinical benefits with FES therapy. The power spectral estimation is the distribution (over frequency) of the power contained in a signal was also carried out for TA EMG signals. The estimation of power spectral density (PSD) is useful in a variety of applications in clinical practice. The EMG signal suffers morphologic and spectral changes in according to the changes in the conditions of registry and the recruited motor units. These changes can be seen in peak amplitude, and in the mean and median of the power spectrum of the sEMG signal (Merletti et al., 1990). The AR-model-based PSD estimator was used to extract the median frequency of the recorded signal. The increase in the conduction velocity, results in a shift of the power spectrum towards the higher frequencies (Brody et al., 1991).

2.4.2. Assessment of walking speed and PCI

Walking speed and PCI, which is an indication of the amount of effort in walking, were obtained at each assessment (Nene, 1993). The physiological cost index has been used as an indirect measure of energy cost during exercise to find energy-efficient gait with stroke survivors (MacGregor, 1979). The patients were instructed to walk at a comfortable walking speed in the gait laboratory on a 10-m walkway without the use of FES device. To exclude the influence of acceleration and deceleration at the beginning and end of the walk, 1.5 m was allowed at the start and finish of the test. The amount of time to cover the distance was measured using a stopwatch and the heart rate was measured using a polar heart rate monitor consisting of an electrocardiogram detector strapped to the chest and a receiver with a display unit that was worn on the wrist, in the manner of a wrist watch. The six-minute of walk test was used to estimate the walking heart rate. The PCI (beats/m) was calculated as (HRW–HRR) divided by walking speed (m/min), where HRW = heart rate at the end point of each 6-min walking trial; HRR = heart rate resting, both in beats per minute. The mean walking speed and PCI was calculated from the measured parameters. Exertion was assessed using the physiological cost index. We expected that the increased strength of the TA muscle would result in increased walking speed when FES was switched off while walking due to carry over effect.

2.4.3. Assessment of metabolic parameters

As a rehabilitation exercise, FES therapy can increase whole body activity of patients so that they may gain general and localised health and fitness benefits. Previous studies has reported abnormally elevated oxygen consumption (VO_2, mL/kg/m) in chronic stroke survivors compared to normal individuals walking at matched speeds (Potempa et al., 1995; Macko et al., 1997). Oxygen cost has been used successfully to evaluate gait training methods and to assess response to treatment in chronic stroke survivors (Guyton and Hall, 2006). The oxygen cost as the amount of oxygen consumed per kilogram body mass per unit distance (mL/kg/m), which reflects efficiency of walking (Mattsson, 1989).

The cardiorespiratory variables were measured with a CosMed K4b^2 (Cosmed, Rome, Italy) metabolic system and Polar™ heart rate monitor. The CosMed K4b^2 system was calibrated prior to each individual test according to the manufacturer's guidelines. The subject asked to sit at rest for a period of 3 min and at the end of this period the test commenced. Subjects walked for 30 m length on two occasions at their preferred walking speed (PWS); once using stimulator and once without stimulation. Before beginning the testing procedure, the clinical therapist checked each subjects' FES equipment to ensure it was in working order.

2.4.4. Correlation between RMSmax of the TA muscle and walking speed and between walking speed and energy cost

Drop foot prevents the patient from effectively swinging the leg when walking; causing an abnormal gait thus increased effort is required means that walking is slow, tiring and unsafe (Burridge et al., 1997).The RMSmax of the TA muscle and measurements of walking speed were correlated to investigate a positive relationship between both outcomes. Increased maximal muscle activity was expected in the TA muscle after prolonged use of FES. Thus a positive relationship in the FES group was hypothesized between maximal TA muscle activity trained by FES and walking speed, since this is the muscle that was primarily stimulated. We also expected a higher correlation between energy cost and walking speed while using the FES device compared to not using the device.

2.4.5. Data analysis

Baseline measurements were compared with those obtained at the 12-week after treatment phases and paired *t*-tests were used to investigate the significant of the treatment. Data's were analyzed using SPSS for windows and changes were considered as statistical significant if *P* values were less than 0.05.

3. Results

3.1. Evaluation of EMG signal

During the trial, the temporal parameters MAV and RMSmax values of EMG signal for the TA muscle showed a significant improvement after treated with FES therapy as represented in Fig. 1. The MAV value increased from 23 ± 6 to 28 ± 5 μV of 21.7% ($p < 0.01$) and mean RMSmax value increased from 86 ± 58 to 143 ± 85 μV of 66.3% ($p < 0.01$) at the baseline and post-treatment assessment. These results suggested that an improvement in maximum voluntary control of TA muscle which indicates an increase in muscle strength after treated with FES therapy. An example of raw EMG signal from a subject with its RMS is represented in Fig. 2.

The power spectral estimation of EMG signal improved significantly in average median frequency shifted from 63.9 to 70.7 Hz ($p < 0.05$), a shift toward higher frequencies and mean amplitude increased from 0.013 (±0.02) V^2 to 0.028 (±0.04) V^2 ($p < 0.05$) at

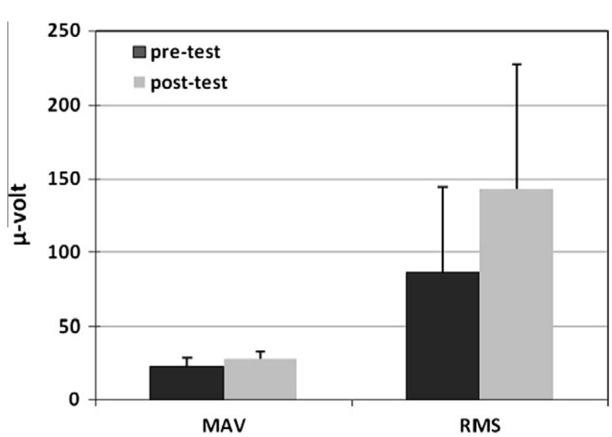

Fig. 1. Mean value of the MAV and RMS of the tibialis anterior (TA), as measured by maximal voluntary contraction.

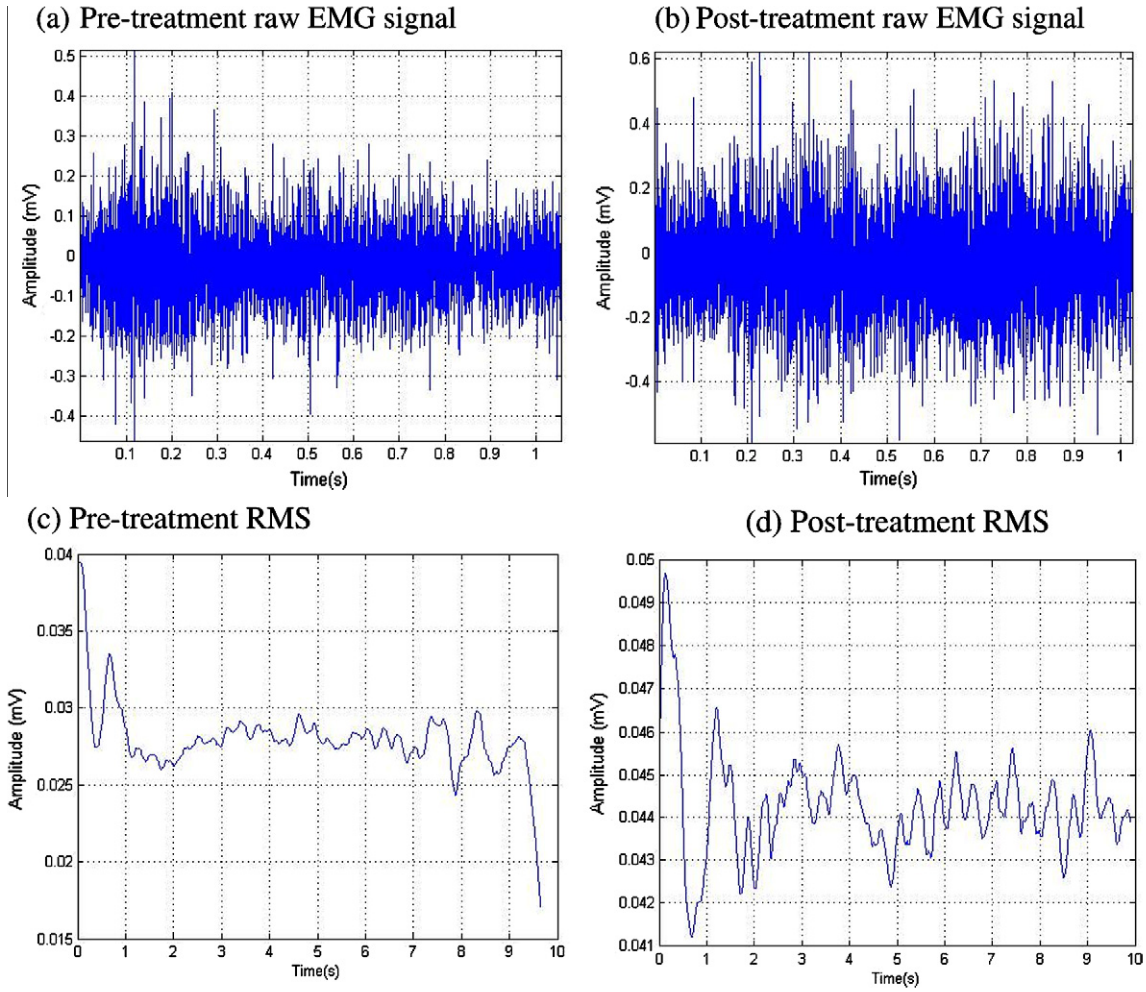

Fig. 2. An example of synthesized RMS of sEMG of tibialis anterior from a single subject.

pre- and post-treatment to FES therapy, respectively. The analyzed recorded EMG signal showed an improvement in both amplitude and frequency spectrum, which indicates an improvement in muscle power treated with FES therapy. An example of synthesized sEMG signal from a subject, together with its fast Fourier transform (FFT) spectrum and autoregressive-based PSD was shown in Fig. 3. The frequency content of the EMG as evident from the FFT spectrum was different from pre- to post-treatment as shown in Fig. 3c–d. A relatively low amplitude activity was observed at frequencies between 20 and 150 Hz in pre-test and a high amplitude activity spectrum was observed at frequencies between 30 and 200 Hz in post-treatment. The median frequency of power spectrum changed from 94 to 102 Hz, a shift toward higher frequencies. The amplitude of EMG spectrum had also increase from 0.011 V^2 to 0.034 V^2 at post-treatment recording of the signal as shown in Fig. 3e–f.

3.2. Walking speed and PCI

The stroke patients showed a statistically significant improvement in both walking speed and PCI from baseline to the post-treatment values is shown in Fig. 4. The mean walking speed improved from 0.39 ± 0.17 to 0.53 ± 0.21 m/s with an increase of 38.7% ($p < 0.001$) and a reduction in PCI of 34.6% ($p < 0.05$), reduced from 0.43 ± 0.22 to 0.27 ± 0.13 beats/m at pre- and post-treatment with FES therapy. The stroke patients have improved both the walking speed and the energy-efficient gait with FES therapy. This indicates that the FES may have a therapeutic as well as an orthotic effect for correction of drop foot in stroke subjects.

3.3. Correlation between RMSmax of the TA muscle and walking speed

The FES therapy seemed to have the positive effect on maximal muscle activity produced by the TA muscle and walking speed. When one considers that the prime function of the TA muscle to lift the foot during the swing phase of gait, which will require an amount of activity and is likely to be linearly related to the walking speed. Fig. 5 shows the Pearson correlation coefficients found for the TA muscle voluntary activity and walking speed. There was a moderate correlation coefficients were shown by the stroke subjects between RMSmax of the TA muscle and walking speed ($r = .783$, $P < 0.001$). The high correlation coefficients suggest that relationship does exist between TA muscle activity and walking speed. An interesting finding of this study was that the seated isometric MVC strongly correlated with increased walking speed.

3.4. Evaluation of metabolic parameters

The walking with FES system showed improved in general cardiopulmonary health. Table 2 shows the changes in respiratory parameters for the subjects walked with and without FES device. Significant improvements were seen in all measured parameters. A mean decrease in VO_2 of 24.31% ($p < 0.05$) from 8.7 ± 2.2 to 6.6 ± 2.1 (mL/min/kg) and reduction in VCO_2 of 19.94% from

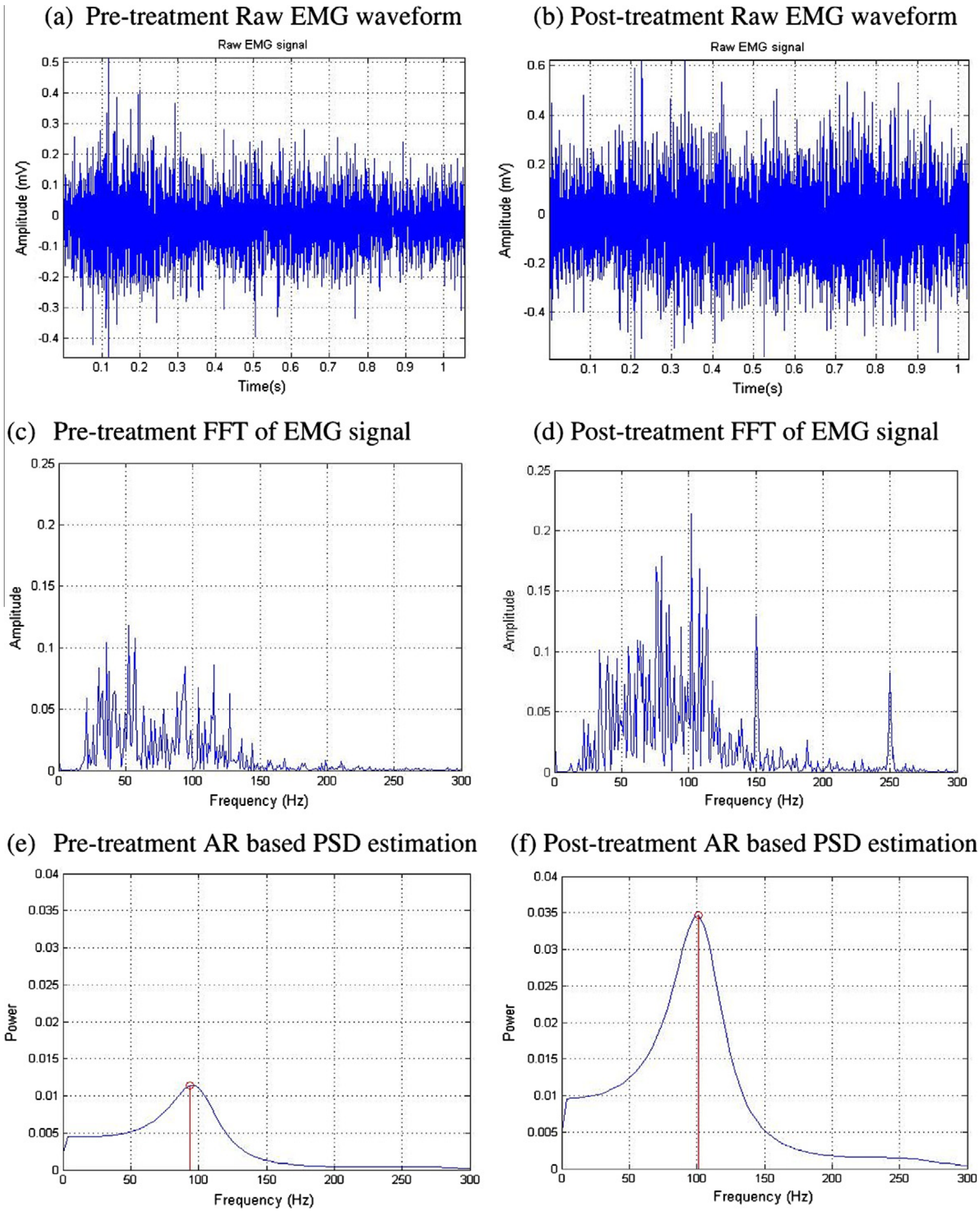

Fig. 3. An example of synthesized sEMG signals pre- versus post-test from a single subject.

6.4 ± 1.7 to 4.1 ± 1.6 (mL/min/kg) was measured. Similarly improvements were also found in HR (7.8%), V_E (16.8%) and EC (22.5%) while walking with FES device.

3.5. Correlation between energy cost (EC) and walking speed

As expected, there was a low degree of correlation coefficients for the energy cost (kcal/min/kg) and speed (m/s) during walking without stimulation ($r = .103$, $P < 0.05$) and a moderate degree of correlation coefficients walking with stimulation at a chosen speed with FES ($r = .375$, $P < 0.05$) by the stroke subjects are shown in Fig. 6. This correlation coefficient indicates that a positive relationship exists between walking speed and energy-efficient gait while using the FES device.

4. Discussion

This study determined the therapeutic effect of FES to the tibialis anterior muscle in stroke patients on improving the muscle strength, on the effort and speed of walking and metabolic responses. The results of this study showed that more than one measure may be useful for a more comprehensive evaluation of a patient.

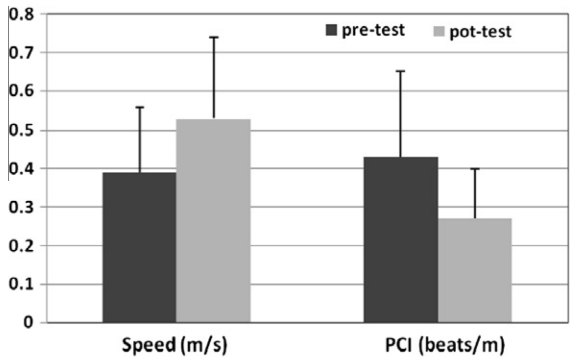

Fig. 4. Mean walking speed and PCI values at pre- and post-treatment.

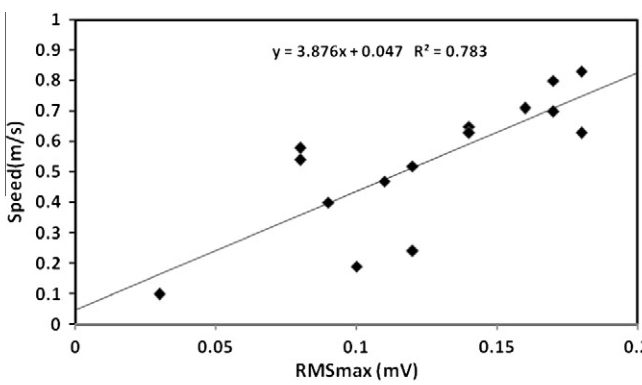

Fig. 5. Pearson correlation coefficients between RMSmax of the TA muscle and walking speed.

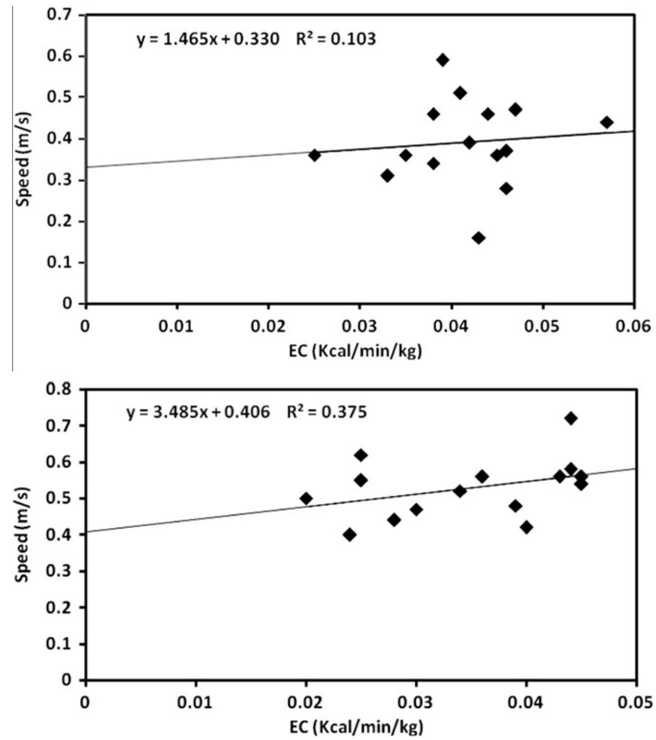

Fig. 6. Pearson correlation coefficients between energy cost and walking speed when FES device was not used (top) and when FES device was used (bottom).

Table 2
Comparison of cardiorespiratory measurements.

Parameters	Without stimulation	Stimulation	% Change	*p*-Value
Heart rate (beats/min)	100.1 ± 15.9	92.3 ± 16.5	7.8	0.019
VO_2 (mL/min/kg)	8.7 ± 2.2	6.6 ± 2.1	24.3	0.004
VCO_2 (mL/min/kg)	6.4 ± 1.7	4.1 ± 1.6	19.9	0.013
VE (L/min/kg)	0.3 ± 0.05	0.25 ± 0.04	16.8	0.019
Energy cost (kcal/min/kg)	0.04 ± 0.005	0.031 ± 0.004	22.5	0.003

Values are mean ± standard deviation.

The timing of the intervention is important. Natural recovery of walking function occurs within the first 11 weeks after stroke, hence early and intensive treatment significantly improves motor and functional outcome (Jorgensen et al., 1995). Although most of the overall improvement in motor functions occurs within the first month after stroke, modulation of motor networks may still be possible in some patients up to 6 months later. The reliability of outcome studies of specific treatments during the early post stroke rehabilitation is, however, limited by the variables of spontaneous recovery (Ring and Rosenthal, 2005). Thus, we included patients more than 3 months after stroke in order to avoid the variability of spontaneous recovery.

Yan et al. (2005), reported that 15 sessions of FES on quadriceps, tibialis anterior and medial gastrocnemius along with standard rehabilitation improved motor recovery and functional mobility in acute stroke subjects, more than did placebo stimulation and standard rehabilitation, or standard rehabilitation alone. They found increase in maximum MVC torque and integrated electromyographic signals of the FES group were significantly larger than those of the control group. An explanation for the increased TA muscle activity (Miller and Light, 1997), who described that increased muscle activity, can be accomplished in several ways, such as increasing the number of activated motor units, increasing the rate of activation, or increasing the synchronization of activation. In this study, we applied electric stimulation only to the tibialis anterior muscle for 12-weeks. From increased voluntary muscle output of the TA muscle, we concluded that the increased in muscle activity was caused by a local training effect of the stimulated muscle with change in motor control, suggesting an orthotic effect of FES. The RMSmax of the tibialis anterior muscles reflects the capacity of the muscle output in a static test condition. The spectral analysis of EMG signal shown the improvements in both amplitude and median frequency at post-treatment experiment. A higher positive relationship was also found between maximal TA muscle activity and walking speed. The RMSmax of the TA muscle was increased; hence the FES seemed to have the largest positive effect on maximal muscle activity produced by the TA muscle.

The gait of a patient with hemiparesis is markedly slower than that of a normal person (Turnbull et al., 1995). Walking speed is an important factor when we consider assessing the patient's ability to walk (Mizrahi et al., 1982). Previous studies reported a mean increase in walking speed of 14% after using FES for 18 weeks in stroke subjects (Taylor et al., 1999a,b). Burridge et al. investigated the effect of FES use over 1 year in stroke survivors and suggested an average reduction of 24.9% in PCI (Burridge et al., 1997). Some studies reported a reduction in the PCI of 31% after the use of stimulator therapy for 4½ months measured during a 10-m walk before and after training with a peroneal stimulator in chronic stroke patients (Taylor et al., 1999a,b). In the present study, we found that the mean walking speed has increased significantly by 38.7% and the PCI has reduced by 34.6% between the beginning and end of the trial, which would be indicative of orthotic benefits of FES therapy. More effectively walking with FES, reduces the need for compensatory mechanisms such as hip hitching and circumduction, and thus reduces the biomechanical impairment, energy expenditure and increases the speed of walking. A 10% increase in walking speed represents a positive result, while a 10% decrease in PCI represents a positive outcome in carry-over effect to make a noticeable difference to mobility (Taylor et al., 1999a,b). The effect of carry-over may be in part due to the effect on spasticity of using the device. This study indicates that the FES may have a therapeutic as well as an orthotic effect for correction of drop foot in stroke subjects.

Gains in cardiovascular function were indicated by decreased working heart rate, signifying that walking in particular had become more energy efficient. The novel result from this investigation was found that the energy cost of walking was significantly reduced while using the FES device. The heart rate was decreased by 7.8% with using the FES device. Considering the main physiological variables, the V_E (L/min), VO_2 (mL/min), VCO_2 and energy cost (EC) were significantly decreased with stimulation compared to no stimulation while walking. A better relationship was also found between energy expenditure and walking speed with the use of FES device compared to no device.

Previous research results on FES to stroke subjects have shown that FES can improve the short-term therapeutic and functional outcomes by demonstrating participant's improvements in walking speed and PCI (Robbins et al., 2006; Burridge et al., 1997). This study supplements these data by documenting additional therapeutic and functional gains, such as improvement in muscle strength, speed and effort of walking, and metabolic responses to FES therapy. This was a preliminary observation with limited number of subjects treated with FES therapy. The limitation of this study design was the absence of a control group. Hence further detailed studies have to be carried out on larger number of stroke survivors with compared group to quantify the rehabilitative effects of FES therapy on improvement of functions and quality of life.

5. Conclusion

This study demonstrated that the FES therapy has a potential as a therapeutic intervention to correct drop foot in stroke subjects. FES resulted in therapeutic benefits on increasing the walking speed and reducing the effort of walking measured as PCI on a 10-m walkway. In addition, patients who have had a stroke experience a short term "carry-over" effect when they are not using the stimulator, after treated with FES for 12-weeks. The study results also reveal that of FES treatment has clinically relevant in voluntary activity of the TA muscle to improve the walking speed and energy-efficient gait in stroke patients.

We concluded that the FES therapy is a clinically effective treatment option combined with conventional rehabilitation program for hemiplegics who present with difficulty walking because of drop foot. We assume that within normal rehabilitation conditions, it would be necessary for patients to continue FES therapy along with conventional rehabilitation program in their daily lives.

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