Concurrent impact of bilateral multiple joint functional electrical stimulation and treadmill walking on gait and spasticity in post-stroke survivors: A Pilot Study

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ABSTRACT

Background: Stroke causes multi-joint gait deficits, so a major objective of post-stroke rehabilitation is to regain normal gait function. **Design and Setting:** A case series completed at a neuroscience institute. **Aim:** The aim of the study was to determine the concurrent impact of functional electrical stimulation (FES) during treadmill walking on gait speed, knee extensors spasticity and ankle plantar flexors spasticity in post-stroke survivors. **Participants:** Six post-stroke survivors with altered gait patterns and ankle plantar flexors spasticity (4=male; age 56.8 ± 4.8 years; Body Mass Index (BMI) 26.2 ±4.3; since onset of stroke: 30.8 ±10.4 months; side of hemiplegia [L/R]: 3:3) were recruited. **Intervention:** Nine treatment sessions using FES bilaterally while walking on a treadmill. **Main Outcome Measures:** Primary outcome measures included the Modified Modified Ashworth Scale (MMAS), Timed Up and Go test (TUG), 10-m walking test, gait speed, and Functional ambulation category (FAC). Secondary outcome measures included the Step Length Test (SLT), and active range of motion (ROM) of the affected ankle and the knee. Measurements were taken at baseline (T0), at the end of last treatment (T1), and one month after the final treatment session (T2). **Results:** The TUG, 10-m walking test, gait speed, FAC, active ROM, and SLT all significantly improved following treatment (P<0.05), while ankle plantar flexors spasticity (P=0. 135), and knee extensors spasticity (P=0.368) did not show any significant decrease. **Conclusions:** A short duration of bilateral FES in conjugation with treadmill walking contributed to significant improvement in gait speed, functional mobility, functional ambulation, range of motion and step length in post-stroke survivors. In contrast, no significant decrease were identified in the spasticity of the ankle plantar flexors and knee extensors muscles.

Keywords: functional electrical stimulation; gait; neurorehabilitation; stroke

INTRODUCTION

Stroke is one of the main contributors of death and disability (Feigin et al, 2015). In developing countries, the incidence of stroke and its associated disabilities, continues to increase annually (Feigin et al, 2015). In Iran, stroke is the second highest cause of death and disability (Forouzanfar et al, 2014), and physical complications include spasticity, that negatively affect walking ability and gait patterns (Watkins et al, 2002).

One of the major objectives of post-stroke rehabilitation is to regain normal gait function (Noma et al, 2012). Stroke causes multi-joint gait deficits (Kesar et al, 2009), consequently, treadmill training has received special attention in post-stroke rehabilitation (Kesar et al, 2009). As speed and gradient are fully controllable, the treadmill may allow patients to train gait function without some of the challenges faced with walking on a regular surface (Barbeau and Visintin, 2003).

Functional electrical stimulation (FES) may be an effective treatment for reducing muscle spasticity and improving movement in post-stroke survivors (Howlett, Lannin, Ada, and McKinstry, 2015). Previous rehabilitation studies have shown that FES is effective for increasing muscle activation (Kafri and Laufer, 2014; Shariat et al, 2018). In addition, FES appears to engage the sensorimotor cortex of the brain by stimulating Type 1 afferent nerve endings in post-stroke survivors. The process of these repetitive sensory inputs may provide sensory and visual feedback to the brain, aiding the rehabilitation process (Howlett, Lannin, Ada, and McKinstry, 2015). The effectiveness of a single channel of FES for increasing gait velocity and reducing energy expenditure has been previously reported (Kafri and Laufer, 2014). A single channel of FES has also been shown to help improve the swing phase of the gait cycle in 20% of post-stroke survivors (Kafri and Laufer, 2014; Kesar et al, 2009). However, in patients where multiple joints are affected by paralysis this method may not be effective (Kesar et al, 2009). Therefore, FES should be used to target multiple muscle groups, for example, dorsiflexors and plantar flexors during gait training as part of the rehabilitation process. Previous studies have shown that FES may help patients improve ankle and knee impairment during the swing and stance phases of the gait cycle (Kesar et al, 2009), and a dose response relationship appears to be evident between the number of muscle groups stimulated and the improvement observed in the gait cycle (Daly et al, 1996).

Bilateral stimulation of the affected and unaffected limb (either the upper or lower extremities) has not often been studied in the rehabilitation setting. Chan, Tong, and Chung (2009) have suggested that bilateral upper limb training with FES could be an effective method for upper limb rehabilitation of stroke patients. A study conducted by Cauraugh and Kim (2002) using 2 coupled motor recovery protocols with electromyography (EMG)-triggered neuromuscular stimulation and bilateral movements, showed that the motor improvement of the bilateral group for upper extremity function was better than the improved motor function of the unilateral group. However, they noted that the unilateral group did improve significantly compared to the control group. One study examined bilateral (versus unilateral) TENS combined with task-oriented training (e.g. stepping up and down, squatting, standing up from a chair and walking short distances) on lower extremity function (Kwong, Ng, Chung, and Ng, 2018). Kwong, Ng, Chung, and Ng (2018) found that bilateral electrical stimulation was better for improving ankle dorsiflexion strength and the timed up and go test, but balance and motor coordination were not improved. No studies were found to indicate if lower extremity bilateral stimulation (compared to unilateral stimulation of the involved limb) would improve gait function in individuals with stroke. No studies combining bilateral lower extremity FES and treadmill training were found.

There is emerging evidence that FES may be more beneficial than skeletal muscle training alone following stroke (Howlett, Lannin, Ada, and McKinstry, 2015). A decrease in plantar flexors spasticity and increased ankle active dorsiflexion following FES training has been previously reported (Wang et al, 2016). Further, in patients with spinal-cord-injury, FES may reduce quadriceps tone, increase voluntary muscle strength, and increase stride length (Granat, Ferguson, Andrews, and Delargy, 1993). The aim of the study was to determine the concurrent impact of bilateral multiple joint functional electrical stimulation (FES) during treadmill walking on gait parameters and ankle plantar flexors and knee extensors muscle spasticity in post-stroke survivors. It was hypothesized that the involvement of multi-channel bilateral FES during treadmill walking would decrease muscle spasticity and increase gait speed in post-stroke survivors.

METHODOLOGY

Design

A pilot study was performed based on a single group (pre-test, post-test design; STROBE guidelines). The study protocol was approved by the ethical committee of (REMOVED FOR REVIEW) and all participants signed an informed consent form prior to the study.

Participants

Thirty-six patients were screened as potential subjects to participate in this study. Twenty-one were excluded based on the exclusion criteria of the study; and among the fifteen patients who met all inclusion criteria, nine agreed to participate in this study (Figure 1). The inclusion criteria were: 1) no past history of electrical stimulation; 2) only one episode of stroke; 3) patients with 30-65 years of age 4) ability to sit supported for 40 minutes; 5) sufficient communication skills to indicate yes/no verbally or via gestures; 6) ability to walk without any support for at least 10 meters; 7) Ambulation ability ≥

3 based on functional ambulation classification; 8) stroke onset > 6 months, and < 5 years prior to study recruitment; and 9) unilateral hemiplegia.

FIGURE 1 ABOUT HERE

The exclusion criteria were: 1) pregnancy; 2) patients with aphasia with inability to follow instructions; 3) contractures of the lower extremities; 4) arrhythmias during resting EKG, and/or implanted cardiac pacemaker; 5) major circulatory disturbances; 6) severe osteoporosis or arthritis; 7) metallic implants in the upper legs; 8) open wounds in the lower extremities; 9) allergic to electrode gel; 10) history of deep coma (coma recovery scale <12); 11) peripheral neuropathy; and 12) cognitive impairment.

A physiotherapist, who was blinded to group assignments performed, all measurements. Research was performed at the Sports Medicine Research Center, Neuroscience Institute, under the supervision of a neurorehabilitation specialist, and a specialist in sports medicine.

Outcome Measurements

Outcome measurements included plantar flexors and knee extensors spasticity assessment using Modified Modified Ashworth Scale (MMAS), functional mobility assessed by Timed Up and go test (TUG), gait speed assessed by the 10-m walking test and Functional ambulation category (FAC). Step length and active range of motion in the ankle and knee joints was also assessed. Each measurement was performed at baseline, immediately after the final treatment session, and one month following the final treatment session.

Spasticity Assessment

The Modified Modified Ashworth Scale (MMAS) was used to assess the spasticity of the ankle plantar flexors and knee extensors (Ansari, Naghdi, Younesian, and Shayeghan, 2008; Ghotbi, Ansari, Naghdi, and Hasson, 2011). The MMAS assesses the level of spasticity on an ordinal scale from 0 to 4 based on the level of resistance in response to a passive movement. According to the MMAS scale, 0 represents no increase in muscle tone, and 4 represents rigidity of the affected part in flexion or extension (Ansari, Naghdi, Moammeri, and Jalaie, 2006). The MMAS has been shown to be a reliable tool in post-stroke survivors: inter-rater reliability for plantar flexors was good (*Kappa* = 0.74); knee extensors was very good (*Kappa* = 0.81) (Ghotbi et al, 2009); and kappa values were very good for intra-rater in ankle plantar flexors (*Kappa* = 0.85 and knee extensors (*Kappa* = 0.82) (Ghotbi, Ansari, Naghdi, and Hasson, 2011). All the tests were performed in the same position, lying in a supine position with knees in flexed (soleus) and extended (gastrocnemius) position for ankle plantar flexors movement, and lying on the side for knee extensors movement by same rater.

10-m Walk Test and Gait Speed

To test changes in ambulation ability we used the 10-meter walk to measure walk time and calculated gait speed (Alon and Ring, 2003). Patients were asked to walk as fast as possible over a straight, level 10m surface. Patients performed one trial, and the time (seconds) was recorded. Time was measured for the intermediate 6 meters and gait speed was determined. Start and stop the timing of procedure was synchronized by passing the 2 meter and 8 meter mark on the toes of the leading foot (Scivoletto et al, 2011). Scivoletto et al showed inter- and intra-rater reliabilities were between 0.97 and 0.99 intra-class correlation coefficient (ICC) for 10-m Walk Test and Gait Speed.

Timed Up and Go Test (TUG)

TUG was used to evaluate functional mobility. The patient sat in a chair (seat height 46 cm, arm height 67 cm), and following a command from the assessor, would stand up (the patient was allowed to use the chair arms), walk 3 meters in a straight line, turn around, walk back to the chair, and re-seat themselves. This test was performed in one practice trial, followed by a timed trial, and the time (seconds) was recorded. The test showed to be a reliable tool (ICC > 0.95) for quantifying functional mobility after a stroke (Ng and Hui-Chan, 2005).

Functional Ambulation Category (FAC)

The FAC is a common clinical assessment scale which has high test-retest reliability (Cohen *Kappa*=0.950) and inter-rater reliability (*Kappa*=0.905) in patients with stroke (Mehrholz et al, 2007). FAC includes 6 functional levels: “0” (nonfunctional ambulator) indicates a patient who is not able to walk at all or needs the help of 2 therapists. Level of “1” (ambulator, dependent on physical assistance [level II]) indicates a patient who requires continuous manual contact to support body weight as well as to maintain balance or to assist coordination. “2” (ambulator, dependent on physical assistance [level I]) indicates a patient who requires intermittent or continuous light touch to assist balance or coordination. “3” (ambulator, dependent on supervision) indicates a patient who can ambulate on level surface without manual contact of another person but requires stand by guarding of one person either for safety or for verbal cueing. “4” (ambulator, independent, level surface only) indicates a patient who can ambulate independently on level surface but requires supervision to negotiate (e.g. stairs, inclines, nonlevel surfaces). “5” (ambulator, independent) indicates a patient who can walk everywhere independently, including stairs (Holden et al, 1984).

Step Length

A spatial characteristic of the gait cycle was measured using an ink footprint record. Patients were asked to walk 10 meters at a self-selected and comfortable speed while wearing non-permanent ink patches on their footwear. A perpendicular distance (meters) from foot contact to the contact of the opposite foot was recorded for each step taken during the 10-meter walk. The first and final two meters of the walk were not calculated due to changes in walking gait/velocity. The test was performed on two trials, and mean step length was recorded; both sound and affected side were assessed for each participants. The validity of the test has been previously demonstrated in patients with hemiparesis (Graham et al, 2008), Inter-rater and test-retest reliability has been showed in patients with hemiparesis (Holden et al, 1984).

Range of Motion- Ankle and Knee

Active range of motion was measured by standard manual goniometer (Youdas, Bogard, and Suman, 1993). Active range of motion of the ankle plantar flexion was measured with patients in a supine position, with knees extended to 20 degrees of flexion. Patients were asked to perform active dorsiflexion of the ankles. Knee range of motion was evaluated in the supine position with the hip in neutral as starting position , patients were encouraged to bend their knees without losing heel contact from the table. Each measurement was repeated on three times and the highest score was reported.

Intervention

The treatment intervention involved 10 sessions of concurrent FES during treadmill walking. However, the first session acted as a familiarization, and the following nine sessions were provided over a 3-week period. We used a current-controlled 8-channel stimulator (FES, Hasomed, Germany), with surface electrodes (rectangular auto-adhesive gel electrodes, Flextrode, Krauth + Timmermann Ltd. Hamburg, Germany, size 4.5 x 9.5 cm) in a bipolar configuration situated on the quadriceps, hamstrings, peroneals, and plantar flexors muscle groups. The pulse width was 350 μs, stimulation frequency was 35 Hz, and amplitude was set to achieve motor responses as determined by contractions produced under the electrode. Intensity in the first session was variable from 20mA to 34mA between subjects, the amplitude was increased for each participant based on the acceptable personal tolerance during next sessions and reached ultimately to 40-45 mA (Figure 2). In the first week, the intervention consisted of ten minutes of treadmill walking and FES was utilized in two, 5-minute bouts. In the second and third weeks, treadmill walking increased to 15-20 minutes, with FES introduced in three and four, 5-minute bouts, respectively. Between any therapeutic treatments, a rest period of one to two minutes was incorporated. Before each treatment session, patients performed a two-minute warm up on the treadmill. Likewise, a two-minute cool-down session was incorporated at the end of each treatment session when no FES was performed. During each session, treadmill speed was set to a minimum speed in the warm-up phase, and gradually increased based on individual gait limitations. The inclination of the treadmill was set to zero in all sessions.

FIGURE 2 ABOUT HERE

Statistical Analysis

Statistical analysis was performed using SPSS version 21 for Windows. Values are presented as mean ± SD or 95% confidence intervals unless otherwise specified. Data normality was checked for all variables with the Shapiro-Wilk test. One-way repeated measure analysis of variance (ANOVA) was applied to test the effects of the treatment on primary and secondary outcome measures over time (pre, post, and follow up). A Bonferroni post-hoc adjustment was used for multiple comparisons. The Friedman test was performed for non-normally distributed, as well as ordinal variables (i.e. FAC), followed by the Wilcoxon Signed Ranks Test (WSRT) for pairwise comparisons of dependent variables measured on three occasions. Partial eta^2 (η_p^2), effect sizes were also calculated, with 0.25, 0.40, and > 0.40 representing small, medium, and large effect sizes, respectively (Richardson, 2011).

For ordinal variables Kendall's W (Coefficient of concordance) was calculated to determine effect size (Schmidt, 1997). An alpha level of $P < 0.05$ was used as a threshold for statistical significance.

RESULTS

Initially 15 participants were eligible for the study, however only nine consented to participate. Of the nine individuals three participants dropped out for the reasons unrelated to the study (transportation issues) (Figure 1). After exclusions six patients (4=male; age 56.8 ± 4.8 years; body mass index (BMI) 26.2 ±4.3; since onset of stroke: 30.8 ±10.4 months; side of hemiplegia [L/R]: 3:3) completed the intervention.

<u>Ankle Plantar Flexors MMAS</u>

There was no statistically significant difference in ankle plantar flexors spasticity after the FES intervention, χ^2 (2)=4.000, P = 0.135. Post hoc analysis showed no significant changes at T0 compared to T1 (Z=-1.41, P = 0.157), and T1 compared to T2 (Z=0.00, P = 1.000) (Table 2).

<u>Knee Extensors MMAS</u>

There was no statistically significant difference in knee extensors spasticity, χ^2 (2) = 2.000, P = 0.368 following the intervention. Post hoc analysis showed no significant changes at T0 compared to T1 (Z=1.00, P = 0.317), and T1 compared to T2 (Z=1.00, P = 0.317) (Table 2).

<u>Timed Up and Go</u>

A statistically significant improvement in TUG was evident ($F_{(1.076, 5.382)} = 14.347$, $P = 0.011$, $\eta^2_{p=}0.742$). Post hoc testing revealed that FES training during treadmill walking elicited a mean improvement of 2.89 seconds (between T0 and T1), but was not maintained one month later (T1 to T2).

10-Meter Walk Test

A significant improvement in 10-meter walk test performance was evident following the intervention [$F_{(1.045, 5.227)}$= 8.598, P = 0.031, η_p^2=0.632]. Post hoc testing with Bonferroni correction revealed that mean time improved by 2.98 seconds between T0 and T1 (p = 0.032). The improvement remained consistent between T1 and T2 (P = 0.307).

Gait Speed

A significant change in gait speed was reported after intervention ($F_{(2, 10)}$= 13.456, P < 0.001, η_p^2=0.729) . Post hoc testing with Bonferroni correction revealed that walking improved by .345 meter/ seconds between T0 and T1 (P < 0.001). The improvement remained consistent between T1 and T2 (P = 0.460).

Functional Ambulation Category (FAC)

There was statistically significant difference in FAC, χ^2 (2) = 2.000, P = 0.039 following the intervention. Post hoc analysis showed significant changes at T0 compared to T1 (Z=2.00, P = 0.046), while T1 compared to T2 showed no evident change (Z=1.00, P = 0.317) (Table 3). Kendall's W (Coefficient of concordance) for FAC was 0.542.

Active Range of Motion: Ankle

Improvements in active range of motion of the ankle were evident following the intervention between time points ($F_{(2, 10)}$ = 10.588, *P* = 0.003, η_p^2=0.679). Post hoc testing with Bonferroni correction revealed that ankle range of motion increased by 4 degrees between T0 and T1 (*P* = 049). The improvement remained consistent between T1 and T2 (*P* = 0.123).

Active Range of Motion: Knee

Active range of motion of the knee significantly improved between time points following the intervention ($F_{(1.067, 5.241)}$ = 12.045, *P* = 0.015, η_p^2=0.707). A mean improvement of 27.2° was evident between T0 and T1 (*P* = 0.044) Improvements remained between T1 and T2 with (*P* = 0.064).

Step Length – Sound Side

Step length (sound side) improved significantly between time points following the intervention ($F_{(1.010, 5.051)}$ = 13.294, *P* = 0.014, η_p^2=0.727). A mean improvement of 17.6 cm was evident between T0 and T1 (*P* = 0.042). The improvement remained from T1 to T2 (*P* = 0.807).

Step Length - Affected Side

Step length on the affected side improved significantly following the intervention ($F_{(1.086, 5.429)}$ = 20.845, *P* = 0.005, η_p^2=0.807). A mean improvement of 11.6 cm was evident between T0 and T1 (*P* = 0.018), this improvement did remain consistent at T2 assessment (*P* = 0.152).

TABLES 1, 2 and 3 ABOUT HERE

DISCUSSION

The study examined the effect of FES with treadmill walking on gait parameters and spasticity in post-stroke survivors. To our knowledge, this is the first study which has investigated the impact of a bilateral FES application in conjunction with gait training. Each patient reported no adverse events while undertaking the intervention. One ultimate goal of therapy for lower-limb motor impairment is to improve the function of walking (Hatem et al, 2016), and our novel intervention showed that a short duration of bilateral FES combined with treadmill walking training contributed to significant improvements in gait speed, functional ambulation, and step length.

Increased gait speed is the most common effect reported after FES application (Kafri and Laufer, 2014). FES has been demonstrated to improve gait through repetitive practice during retraining by restoring the motor program of a more normal gait performance in stroke (Kim, Chung, Kim, and Hwang, 2012). In this study we reported a significant gait speed improvement of 0.345 m/s difference after intervention and this progression maintained by 0.223 m/s from T0 to T2 assessment with a large effect (η_p^2=0.729) exceeding the meaningful change of walking speed which has been reported as 0.10 m/s in stroke (Howelt et al, 2015) suggesting that the improvement made by the participants in gait speed is considered clinically important. A gait speed improvement of 0.18 m/s has been reported based on a meta-analysis of three control trials (Robbins, Houghton, Woodbury, and Brown, 2006), while another systematic review reported 0.08 m/s difference after FES during walking (Howlett, Lannin, Ada, and McKinstry, 2015). Differences reported in gait speed improvement can be influenced by patients characteristics (i.e. severity, age and initial gait speed) (Peurala, Tarkka, Pitkänen, and Sivenius, 2005). Another reason for significant improvement in gait speed in our study could relate to bilateral and multiple muscle stimulation; the more muscles stimulated the better gait improvement expected (Daly et al, 1996). We reported evident improvement in FAC score with Kendall's W=0.542 (indicating moderate effect size). However, no minimal clinically important difference (MCID) and minimal detectable change (MDC) data are available for the FAC (Louie and Eng, 2016); it seems that FAC which classifies walking ability both indoors and outdoors (Holden, Gil, and Magliozzi, 1986) are associated with improvements in gait performance (Holden et al, 1984; Holden, Gil, and Magliozzi, 1986). It has been suggested that FAC scores correlate significantly with walking speed and step length (Mehrholz et al, 2007). In this study, only 5.6% of subjects had level 5 based on FAC scores at baseline while after 3 weeks of intervention this value reached 16.7% among participants and maintained by 11.1% after one month. It seems that bilateral FES with treadmill training not only improved gait speed in stroke survivor, it might also change their functional category.

We found significant improvement after 3 weeks of intervention in TUG score; however, the improvement did not last after 1 month. Therapeutic effect of FES on TUG has not demonstrated any clear effects (Kafri and Laufer, 2014). Yan, Hui-Chan, and Li (2005) did not demonstrate any significant changes after FES application on 4 muscle groups, 5 days per week, after 3 weeks of intervention. Since TUG does include walking, it is expected to have a strong relationship with gait speed. However it should be noted that TUG test is not a simple walking task, it includes a series of motor tasks requiring rising from a chair, walking and turning; thus balance control in addition to muscle strength, coordination and walking endurance could impact the score (Ng and Hui-Chan, 2005).

Correlation between slower gait speed and decreased propulsive force generation has been shown after stroke (Bowden, Balasubramanian, Neptune, and Kautz, 2006). It has been reported that FES to the ankle plantar flexors and dorsiflexors muscles during gait while on a treadmill can correct mechanics resulting in an increase in knee flexion swing phase, greater plantar flexion at toe-off and better forward propulsion (Kesar et al, 2009). Another investigation by Patterson, Rodgers, Macko, and Forrester (2008) also demonstrated an increase in step length after combined treadmill walking and

FES. The authors concluded that improvement in non-paretic step length resulted from increased propulsion. Conversely, increased paretic step length may be due to an increased range of motion in the paretic leg joints allowing the limb to swing farther forward. Previous studies have shown a positive impact of FES on muscle strength and active range of motion (Daly et al, 2011; Peurala, Tarkka, Pitkänen, and Sivenius, 2005). In our study, significant improvement in active range of motion of the ankle and the knee demonstrating large effects for the affected limb, respectively (η_p^2= 0.679 and 0.707); and significant improvement in step length for both the sound and affected limb (again with large effects, respectively η_p^2= 0.727 and 0.807) occurred. Minimal detectable changes were 6.0 degrees for ankle dorsiflextion (Krause et al, 2011) and 6.3 degrees for knee flexion (Mehta et al, 2017). Our results demonstrated 27.2˚ increase in knee active ROM after 3 weeks of intervention and these changes maintained by 22˚ after one month; therefore these improvements not only exceeded the minimal detectable changes but also showed over 15% change which is considered clinically important (Albright et al, 2001). For the ankle we did not meet the above value with 4˚ improvement after treatment (though large effect size). In regards to step length, it has been suggested a clinical meaningful improvement would be > 15% change (Albright et al, 2001) . Step length in the affected limb improved by approximately 20% and the sound limb by approximately 40% and these percent improvements maintained in follow-up (again with large effect size).

We did not find any significant decrease in muscle spasticity which was similar to the Peurala, Tarkka, Pitkänen, and Sivenius (2005) findings. They did not find any decrease in ankle, knee, and hip spasticity after three weeks of over-ground walking with FES. In addition, another study suggested that unchanged spasticity after FES applications on two antagonist muscles like plantar flexors and dorsi flexors may represent positive messages to clinicians (Embrey et al, 2010) disallowing clinical concerns about stimulating antagonist muscle groups for fear of increasing spasticity.

Study Limitation

The study included a relatively small number of participants. Future studies with larger sample sizes, over a longer period, are needed to support or refute our findings. We did not test lower extremity muscle strength which might have been improved from the intervention and may be an important factor for improvement of step length and gait speed. The knee and ankle spasticity of our participants was not severe, therefore, generalization of our results to patients with progressed stages is unwarranted. Also, we did not separate out the impact of multiple joint stimulation and bilateral stimulation in this study as we used these concurrently.

CONCLUSION

In conclusion, a short duration (ten sessions) of bilateral FES combined with treadmill walking training contributed to significant improvements in gait speed, functional mobility, functional ambulation, range of motion and step length in post-stroke survivors while no significant decrease were identified in the spasticity of the ankle plantar flexors and knee extensors muscles.

Declaration of Interest

The authors declare no conflict of interest.

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