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The Effects of Functional Electrical Stimulation on Balance of Stroke Patients in the Standing Posture

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Abstract. [Purpose] The present study was designed to evaluate the effect of functional electrical stimulation (FES) according to the treatment position (standing and supine) on patients after stroke. [Subjects] Nine (men=6, women=3) patients who had suffered from stroke were recruited. They were all in their subacute stage. [Methods] Participants were divided into 2 groups according to the position for treatment by FES (standing group and supine group). The duration of FES in both groups was 30 minutes, 6 times a week for 8 weeks. The subjects were evaluated every 2 weeks for 8 weeks using the timed up-and-go test (TUG), Berg balance test (BBT) and FES intensity to induce maximum muscle contraction. [Results] The standing group showed greater improvements in balance ability than the supine group as assessed by TUG and BBT. The time of TUG was significantly reduced from 30.25 ± 5.0 to 20.73 ± 3.9 in the standing group and from 31.99 ± 3.6 to 26.40 ± 4.5 in the supine group after 8 weeks. The scores of BBT significantly increased from 28.0 ± 8.8 to 45.6 ± 5.9 in the standing group and from 26.25 ± 5.9 to 37.5 ± 3.7 in the supine group after 8 weeks. The FES intensity significantly changed from 48.4 ± 12.4 mA to 36.8 ± 11.9 mA in the standing group and from 48.8 ± 13.5 mA to 43.75 ± 11.8 mA in the supine group after 8 weeks. [Conclusion] These results suggest that the standing position is more beneficial to the recovery of balance ability after stroke than the supine position.

Key words: Functional electrical stimulation, Stroke patients, Standing posture

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INTRODUCTION

Regaining walking ability is a major goal of rehabilitation programs after stroke, though gait patterns of stroke patients may vary greatly[1)]. Walking of stroke patients is characterized by slow velocity, excessive energy expenditure, and asymmetry[2,3)]. Energy expenditure of stroke patients is known to increase by 3–4 times compared to stable gait[4)]. The recovery of walking ability is important for restoring functional independence and directly influences patients' quality of life[3)]. In this respect, normal pattern and effective walking by physical therapists should be achieved rather than simple walking in patient with stroke[5)]. Considering the efficiency of walking, it is essential to strengthen muscles and coordinate muscle activity in the lower extremities (LE). In the case of patients who have a problem in producing muscle strength in standing, they should be needed to facilitate extensors in the lower extremities for supporting their body weight[6)]. To improve the efficiency of walking, ankle foot orthosis (AFO) and functional electrical stimulation (FES) are widely used to prevent dropped foot on the paretic side. AFO restrains not only dropped foot but active plantarflexion in the ankle joint and hinders coordination of the LE[7)]. FES is known to be beneficial for muscle strengthening, preventing atrophy, improving range of motion, and assists muscle reeducation without peripheral neuron impairment[8–12)]. Gait training on a treadmill wearing a harness (or suspension equipment) is also generally used during rehabilitation after stroke to improve gait ability and its efficacy has been investigated in previous studies. However, during treadmill training, it is necessary that a physical therapist or care-giver keeps watch or assists a user for safety. Using FES, patients can walk with minimal or no additional help. In this aspect, it may be said that FES is more efficient and convenient than treadmill exercise because it does not require supervision after attaching electrical pads to a patient's skin[13)]. When stroke patients are treated with FES, the stimulation intensity is varied according to the individual's sensory threshold. It is determined by the electricity flow through the electrode, and it is set in proportion to the power of muscle contraction required ? That is, the stronger the required muscle contraction is, the higher the stimulation intensity is[14)]. A previous study showed that appropriate FES intensities were 13.25 ± 6.29 in hemiplegic patients with an average age of 70, 4.72 ± 0.91 in age-matched controls, and 3.41 ±

0.50 in controls with an average age of 30[15]. This implies that lower intensities are appropriate for younger and healthier population. Walking is a complex process involving multi-systemic cooperation in the nervous and musculoskeletal systems. It is a continuous repetition of body actions which move the body forward through swinging a leg while the other leg maintains a stable stance[16]. Also, walking is a fundamental factor for many activities of daily living (ADL). To regain walking ability and to facilitate muscle activation in LE, FES in the standing position would be more beneficial than in the sitting or supine positions because standing is a basic prerequisite of walking. However, most previous studies have applied FES in the supine position. There have been few studies of FES in standing. Therefore, we investigated the effect of FES, applied to the dorsiflexor on the paretic side in the standing position, on walking of stroke patients.

SUBJECTS AND METHODS

Nine participants (men=6, women=3) were recruited from G hospital located in Seoul, Korea. Participants had previously been diagnosed with cerebral infarction or cerebral hemorrhage according to established criteria. They were treated in the physical therapy room of the hospital from December 17th in 2010 to February 11th in 2011. Inclusion criteria were as following: a scored of more than 24 on the Korean Mini Mental State Examination, ability to stand independently without an assistive device, and passive ankle dorsiflexion range of motion of more than 5° beyond neutral on the paretic side. Exclusion criteria were: cognitive deficits, peripheral nerve damage affecting the common peroneal nerve of the paretic side, and allergic reaction to FES application. All participants provided their written informed consent prior to participation in the study. Microstim (Medel Gmbh, inc., German) is an FES device and its frequency, muscle contraction-relaxation time, and pulse duration are adjustable. It is used to increase dorsiflexion. To enhance ankle dorsiflexion, the active electrode was attached 1 cm inferior to the fibular head, where the deep peroneal nerve can be stimulated selectively, and the reference electrode was placed 10 cm anterior and inferior to the fibular head between the peroneus longus and tibialis anterior, where the ankle and foot muscles are innervated by the deep peroneal nerve and can be stimulated. The device was programmed to deliver biphasic rectangular waves at a pulse rate of 35 pps, pulse amplitude of 250 μV, pulse duration of 8 seconds, and off-pulse duration of 11 seconds. Carbon rubber surface electrodes were used in this study. These electrodes are noninvasive, inexpensive, and convenient[17]. The stimulation intensity was increased until visible maximal contraction occurred while the patient was carefully observed to be in a stable state[18–20]. At the intensity of maximal muscle contraction, FES was applied for 30 minutes 6 times a week for 8 weeks. The timed up-and-go test is a method commonly used to evaluate functional mobility, ambulation, and balance. TUG measures, in seconds, the time taken by an individual to stand up from a chair, walk a distance of 3 m, turn, walk back to the chair, and sit down again without physical assistance. Subjects performed 1 practice trial and then 3 actual trials. The times of the three actual trials were averaged. We measured TUG every 2 weeks during the 8-week intervention. Berg balance test (BBT) measures balance of older people with impairments in balance function by assessing the performance of functional tasks[21]. It is a valid instrument for the evaluation of the effectiveness of interventions and for quantitative descriptions of functions in clinical practice and research. It assesses 3 areas, sitting, standing, and changing between positions, and each of 14 items is scored from 0 to 4, with a maximum possible score of 56. The scores from three trials were averaged. A higher score means a higher balance ability (Table 1). To evaluate participants' balance, BBT was measured every 2 weeks during the 8-week intervention. Upper motor neuron impairment such as stroke generally requires a stronger FES intensity for the paretic leg than for the nonparetic side or for healthy controls[22]. We expected FES intensity would reduce with motor recovery. We measured the FES intensity needed to induce a visual maximal contraction of the ankle dorsiflexor at every 2 weeks during the 8-week intervention. We analyzed the data using Friedman's test to evaluate the changes according to time in both the standing group and the supine group. Correlations between TUG, BBT, and FES intensity were determined using Pearson's correlation coefficient. SPSS for Windows (version 12.0) was used for the analysis in this study.

Table 1. Items measured in the Berg Balance Test

Item	List
1	Sitting to standing
2	Standing unsupported
3	Sitting unsupported
4	Standing to sitting
5	Transfers
6	Standing with eyes closed
7	Standing with feet together
8	Reaching forward with out stretched arm
9	Retrieving object from floor
10	Turning to look behind
11	Turning 360 degrees
12	Placing alternate foot on stool
13	Standing with one foot in floor
14	Standing on one foot

Table 2. General characteristics of participants

Group	Standing	Supine
Age [a]	52.80 ± 6.47	65.50 ± 2.18
Sex ratio (M/F)	4/1	2/2
Onset [a] (month)	3.80 ± 0.37	3.75 ± 0.48
Paretic side	L=2, R=3	L=2, R=2

[a], mean ± standard deviation; M, male; F, female; L, left; R, right.

Table 3. A comparison of the standing and supine groups

		Time (weeks)				
		0	2	4	6	8
TUG (sec)	Standing	30.25 ± 2.23	27.48 ± 2.04	25.78 ± 2.63	22.80 ± 2.33	20.73 ± 1.73
	Supine	31.99 ± 1.78	30.28 ± 2.42	28.76 ± 2.28	26.35 ± 1.79	26.40 ± 2.27
BBT (score)	Standing	28.00 ± 3.94	32.40 ± 3.31	38.40 ± 4.18	42.20 ± 3.81	45.60 ± 2.66
	Supine	26.25 ± 2.95	30.50 ± 0.87	34.00 ± 1.78	36.50 ± 1.55	37.50 ± 1.85
FES (mA)	Standing	48.40 ± 5.54	46.60 ± 5.87	41.60 ± 4.93	40.20 ± 4.81	36.80 ± 5.33
	Supine	48.75 ± 6.73	50.75 ± 6.25	45.50 ± 5.19	45.25 ± 6.26	43.75 ± 5.88

Mean ± Standard error; *p<0.05; **p<0.01; ***p<0.001. TUG: timed up and go test; BBT: Berg balance test; FES: FES intensity for maximal contraction; Asymp. Sig.: asymptotic significance.

RESULTS

We enrolled 9 stroke patients in our study. Demographic data of the patients are given in Table 2 (men=6, women=3). Participants had an average age of 52.8 ± 4.5 and they were all in the subacute stage after stroke onset. Participants in the standing group showed significant decreases in the TUG performance time (30.25 ± 2.23 at baseline, 25.78 ± 2.63 four weeks later, and 20.73 ± 1.73 eight weeks later). Those in the supine group also showed significant decreases in the TUG performance time (31.99 ± 1.78 at baseline, 28.76 ± 2.28 four weeks later, and 26.40 ± 2.27 eight weeks later). The decrease in the standing group (p=0.001) was greater than that in the supine group (p=0.006) (Table 3). Participants in the standing group showed significant increases in the BBT score (28.0 ± 3.94 at baseline, 38.40 ± 4.18 four weeks later, and 45.60 ± 2.66 eight weeks later). Those in the supine group also showed significant improvements in the BBT score (26.25 ± 2.95 at baseline, 34.00 ± 1.78 four weeks later, and 37.50 ± 1.85 eight weeks later). The change in the standing group (p=0.000) was greater than that in the supine group (p=0.005) (Table 3). Participants in the standing group showed significant decreases of FES intensity (48.40 ± 5.54 mA at baseline, 41.60 ± 4.93 mA four weeks later, and 36.80 ± 5.33 mA eight weeks later). Those in the supine group also showed significant decreases of intensity (48.75 ± 6.73 mA at baseline, 45.50 ± 5.19 mA four weeks later, and 43.75 ± 5.88 mA eight weeks later). The change in the standing group (p=0.002) was greater than that in the supine group (p=0.043) (Table 3). The two balance ability test used in the present study, TUG and BBT, were closely correlated with each other (ρ=–0.439, p=0.003). FES intensity was also correlated with TUG (ρ=0.361, p=0.015) and BBT (ρ= –0.461, p=0.001) (Table 4).

Table 4. Correlations among TUG, BBT, and FES intensity

TUG	BBT	FES
TUG	–0.439** (0.003)	0.361* (0.015)
BBT		–0.461** (0.001)
FES		

*p<0.05; *p<0.01

DISCUSSION

There is a growing concern that not only primary impairments but secondary complications after stroke greatly affect the lives of the patients and their families, and eventually increase the social burden. As the elderly population has become ever larger, the social costs of senile diseases such as stroke have grown rapidly. Lots of patients with stroke have complications that prevent them from regaining social status and an active role in society. Stroke also shows a high prevalence rate and mortality. FES has been widely used to treat patients with lesions in the central nervous system arising from stroke and spinal cord injury in order to improve motor control[23]. A previous study of 45 hemiplegic patients in their acute stage reported greater reduced muscle rigidity and increased dorsiflexion after FES than after conventional treatment. The same study also revealed that patients treated with FES walked and turned faster than those treated conventionally in the TUG test after 8 weeks treatment[24]. Though all participants in the present study showed reduced performance times in the TUG test after 8 weeks treatment, the standing group showed a greater decrease in time than the supine group. Considering the time since stroke onset, all participants were in the subacute stage, when it is known that natural recovery processes are taking place, and this may have contributed to the overall improvement seen in both groups in our study. However, it is still noticeable that the change was greater in the standing group than in the supine group. This may imply that FES in the standing position is more beneficial than FES in the supine position. According to our BBT results, all participants showed improved balance ability after 8 weeks of the intervention. However, the changes were greater in the standing group. In a previous study comparing TUG and BBT scores of 15 hemiplegic patients before and after 4 weeks FES treatment, the TUG results improved from 18.9 ± 7.8 to 18.2 ± 6.7 seconds and those of BBT from 46.7 ± 6.3 to 47.9 ± 5.4 scores. On both measures, patients showed slight improvements after FES treatment[25]. Our results in the standing group showed greater improvement in both BBT (+10 scores) and TUG (–4.2 seconds) after 4 weeks than the previous study and the improvement continued until 8 weeks (BBT: +17 scores; TUG:–10 seconds). TUG and BBT are well-known for evaluating the balance ability of stroke patients and the continuous improvements in both TUG and BBT scores demonstrate that FES treatment in the standing position is helpful for recovering balance ability. Previous studies of FES have mainly focused on the effect of therapeutic exercise with or without FES. Peurala et al.[18] reported that an exercise group with FES for 20 minutes showed greater improvements in motor performance than an exercise group without FES. ROM of limitation, muscle weakness, and functional movements of restraint can predict the walking ability of stroke patients. Especially, ankle dorsiflexion is a critical predictor of falls[26]. In a previous study, 14 subjects who performed ankle strengthening and walking exercises, showed reduced fear of falls as well as improved ankle strength and walking ability[27]. In the present study, ankle dorsiflexors were trained with FES resulting in improved balance and walking ability. This may imply that FES applied to ankle dorsiflexor may reduce the fear of falls. According to Hakansson and colleagues[28], stroke patients walked faster than at the baseline (0.4 m/s vs. 0.7 m/s) after FES treatment for 12 weeks. FES applied to ankle dorsiflexors during walking increased knee flexion in the swing phase in this study. Kesar et al.[29] studied the ground reaction force (GRF) and the degree of knee flexion of 9 stroke patients during walking with or without FES on a treadmill. They also found increased knee flexion when FES was applied. Increased knee movement during the swing phase may yield an inefficient gait pattern in respect of energy expenditure. Therefore, we applied FES in the stable standing position and it led to selective isometric muscle contraction without knee flexion movement. It can be said that the application of FES during movements such as walking should be controlled carefully not to induce excessive joint movement. Kesar et al.[29] reported that fast walking produced greater GRF than self-selected natural walking regardless of FES. This suggests that FES acts on the control of the gait pattern by stimulating specific muscle contraction rather than on force production. Actually, in this study, patients' patterns were more stable after 8 weeks of FES treatment. The standing position is best for retaining motor function according to Tojo et al[30]. They evaluated and compared functional abilities both in the sitting and standing positions. They found participants performed functional tasks better in the standing position than in the sitting position. They noted that performance speed was reduced more in the standing position than in the sitting position. Ankle movement is more critically involved in upright positions such as steady standing, walking, and running than in other ADLs in the sitting or supine positions. Standing could be recommended as an appropriate position for FES application to maximize the functional restoration. Our results show there was faster walking and better balance in the standing group than in the supine group. Nevertheless, FES has been commonly used in the sitting or supine positions in clinical practice. The intensity of FES in stroke patients varies among individuals and changes as the recovery progresses. FES intensity is directly proportional to an individual's muscle contraction. That is, the higher the intensity is, the stronger the induced muscle contraction is[14]. In addition, the paretic side after stroke is in need of higher FES intensity than the nonparetic side. This greater need is due to reduction of type I and II a muscle fibers, changes in the ratio of capillary distribution of muscle fibers, decrease of contractile protein including myofibrillar ATPase and succinate dehydronase, muscle atrophy, weakness, reduction of muscle contraction, and increase of fatigue[22]. The threshold of a single FES is likely to get smaller as a subject's condition approaches a normal, healthy state[15]. That is, the intensity of FES needed to induce muscle contraction can be decreased as a patient recovers. According to Meador et al.[15], hemiplegic patients with an average age of 70, and controls with average ages of 68 and 30 showed single stimulation at the intensities of 13.25 ± 6.29 mA, 4.72 ± 0.91 mA, and 3.41 ± 0.50 mA, respectively. In the present study, we measured FES intensity at the time the strongest muscle contraction was shown. All subjects showed a decrease in FES intensity as time went by. Especially, FES in the standing group showed significant differences. The continuous decrease of FES intensity in the standing group can be explained if there were gradual and continuous motor recovery, and if the standing position enhanced the recovery more than in the supine position. The improvement in BBT and TUG in both groups and the greater changes in the standing position than in the supine position strongly support this hypothesis.

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