

## The Effects of Dynamic Functional Electrical Stimulation With Treadmill Gait Training on Functional Ability, Balance Confidence and Gait in Chronic Stroke Patients

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### Abstract

The aim of this study was to evaluate the effects of walking on a treadmill while using dynamic functional electrical stimulation (Dynamic FES) on functional ability and gait in chronic stroke patients. This was a prospective, randomized controlled study. Twelve patients with chronic stroke (>24 months) who were under grade 3 in dorsiflexor strength with manual muscle test were included and randomized into intervention (Dynamic FES) ( $n_1=7$ ) and control (FES) ( $n_2=5$ ). Both the Dynamic FES group and FES group were given a neuromuscular development treatment. The Dynamic FES group has implemented a total of 60 minutes of exercise treatment and gait training with Dynamic FES application. The FES group, with the addition of applying FES while sitting, has also implemented a total of 90 minutes of gait training on treadmill after the exercise treatment. Both two groups accomplished the program, twice a week, for a total of 24 times in a 12-week period. Exercise treatment, gait training on treadmill, and both Dynamic FES and FES were implemented for 30 minutes each. Korean version activities-specific balance confidence scale (K-ABC) was measured to determine self-efficacy in balance function. Timed up and go (TUG) test was performed to evaluate the physical performance. K-ABC, TUG, Berg balance scale (BBS), modified physical performance test (mPPT) and G-walk were evaluated at baseline and at 12 weeks. After 12 weeks, statistically significant differences ( $p<.05$ ) were apparent in the Dynamic FES group in the changes in K-ABC and BBS. mPPT, TUG, gait speed, stride length and stance phase duration (%) were compared with the FES group. K-ABC had higher correlation to BBS, along with mPPT to TUG. Our results suggest that walking with Dynamic FES in chronic stroke patients may be beneficial for improving their balance confidence, functional ability and gait.

**Key Words:** Balance confidence; Chronic stroke patients; Dynamic functional electrical stimulation; Gait.

### Introduction

Regaining the ability to walk independently is a major goal during the neurological rehabilitation of patients with stroke. Furthermore, an efficient gait is one of the major goals of patients with stroke (Duncan et al, 2007). Stroke patients have motor

control problems such as muscle weakness, abnormal muscle tone and movement pattern, disability of weight shifting, and loss of fine motor skills (Bobath, 1990; Carr et al, 1985). Also, Perry (1992) has reported that hemiplegic patients often shows abnormal gait pattern, especially equinus (an excessive ankle plantarflexion and pronation) and foot drop (an ex-

cessive ankle plantarflexion) pattern due to impairment in the selective control of foot. This gait pattern allows the great toe and lateral toe to contact the ground leading patients to a continuous ankle sprain and a risk of other ankle injuries. Ankle foot orthosis (AFO) and functional electrical stimulation (FES) have been suggested as alternatives to minimize these risks (Cozean et al, 1988; Lehmann et al, 1987).

FES is one of methods to help denervated muscle to do functional activation by electrical stimulation (Gracanin et al, 1967), dividing its action mechanism into peripheral mechanism and central mechanism. The peripheral mechanism involves the improvement of muscle power and endurance, elongation of muscle length and soft tissue, and decrease of spasticity, with the central mechanism being the cortical and segmental reorganization of supraspinal portion involving the cerebral cortex (Shimada et al, 2005). Liberson et al (1961) who applied the FES system to hemiplegia first reported that the FES system used electrical signs to activate peripheral nerves and control functional movements. Also, Bogataj et al (1989) reported that there was an increase of lower extremity muscle activation and an improvement of gait performance in patients who couldn't walk by an intervention using multi-channel electrical stimulation for 3 weeks. Furthermore, van Swigchem et al (2012) reported that FES applied group had more increase in ability to avoid falling obstacles on the treadmill than the AFO applied group. These results show that there was more freedom of ankle movement in the FES applied group than in the AFO.

Recently, task-specific repetitive approach with treadmill gait training and FES application studies were being accomplished. Activation of the dorsiflexors during swing is typically triggered by a foot switch placed under the heel of the paretic leg. A foot switch determines the on-and-off switching of the stimulation. Hesse et al (1995a) reported gait speed and increase of gait linear var-

iable of hemiparesis patient using partial weight support treadmill training with several FES channels. Liepert et al (2000) reported that task-specific repetitive approach using FES for hemiplegic patient has influenced cortical plasticity. This study reported that the standard sensory input was the most important factor of inducing plasticity in the spinal circuit for reciprocal inhibition (Perez et al, 2003). Daly et al (2006) reported the improvement of gait and knee flexion coordination in a stroke patient group applied with FES on the neuromuscular system. However, Prado-Mederios et al (2011) reported that there were no significant differences in motor function, gait linear variation, and kinematic variation in comparison between FES and non-FES application in 12 chronic stroke patients who performed gait training with partial weight support through harness. They reported that 41.7 months of disease period patients were in a chronic recovery stage where their gait patterns were already too late to change. Also, The Korean Health Insurance Review and Assessment Service (2012) also notified that FES, in approval standards of professional rehabilitation enforced for a long time to patients with brain damage (stroke, traumatic brain injury etc.), was a rehabilitation treatment for functional improvement approved 2 times a day for two years after the onset but approved FES 2 times a day only for 6 months with patients showing no increase in muscle power and functional improvement, progressing to once a day after 6 months and to not approving FES treatment at all after 2 years. However, there are few studies related to the effect of FES on patients with stroke after 24 months of onset. The purpose of this study were as follows: First, to determine the effects of Dynamic FES application on the functional ability of achievement, balance confidence and gait of patients with stroke after 24 months of onset. Second, to compare the effect of Dynamic FES and FES application.

## Methods

### Subjects

Twelve university-affiliated hospital out-patient department patients with chronic stroke (>24 months) were studied. The inclusion criteria were considered in the selection of the subjects. Dorsiflexor strength was classified above grade 2 (trace) and under grade 3 (fair) in muscle manual test (MMT); spasticity was classified under level 3 according to the Modified Ashworth Spasticity Scale and an interval of greater than 24 months after stroke. Patients who were able to gait over 10 m without any support of assistive devices, who understood and followed instruction and those whose educational standard average was above 24 points in the Mini Mental Examination (Korean version) were also considered in the selection of the subjects. The exclusion criteria were those with low cognitive function (scoring below 23 in the Mini Mental State Examination), severe visual and perception disturbance, high-risk cardiovascular disorders and severe medical disease, and orthopedic diseases in lower extremities. In addition, patients unable to get treatment for 3 consecutive sessions or unable to receive 80% of the treatment were excluded in the study. 20 patients were enrolled. 8 participants discontinued due to exclusion or them being declined caused by distance to the hospital. 12 patients were randomized. After being given a thorough explanation of the study, participants gave their informed consent prior to participating in the study.

### Measurement tool

Assessors were composed of three physical therapists with more than 10 years' experience for all measurements, and all measurements were done under the same evaluator in all pre- and post-measurements. Thorough explanations of the evaluation were given to the participants prior to the measurement. The evaluation was carried out in a separate space excluded from all noises and external

disturbances with a fatigue-reduced state after an adequate amount of rest. The assessment was stopped immediately if the patient appealed dizziness or fatigue during the evaluation.

### Korean version activities-specific balance confidence (K-ABC)

An activities-specific balance confidence is an assessment tool that evaluates self-effectiveness through a direct interview with the examiner which is composed of 16 specific activities. Activities-specific balance confidence holds a high reliability by assessing how much of a difficulty is felt in activities of daily living such as changing positions or movements by marking on a number ranging from zero (no confidence) to a hundred (very confident) (ICC=.86) (Powell and Myers, 1995). This study used K-ABC translated by the research of Hwang et al (2007). They had high reliability (ICC=.90) and used an average of 16 tasks in their analysis.

### Berg balance scale (BBS)

This Berg balance scale test, which takes in consideration 3 sides-postural maintenance, postural control on volitional movement, and external disturbance-were used for dynamic balance control of high risk fall adults and central nervous system patients. The task was comprised of a set of 14 simple balance and easy activities of daily living-related tasks. The score added up to a total of 56, comprised of a five-point scale ranging from zero to four in three-domains of sitting, standing, and postural change. The balance degree was assessed as good as the BBS score rose. A score above 45 was needed for independent and safe transfer (Bogle Thorbahn and Newton, 1996). The inter-rater reliability was .98 and the intra-rater reliability was .97 on a stroke patient basis (Berg et al, 1995).

### Modified physical performance test (mPPT)

Modified physical performance test is a functional

assessment test method for adults with diseases such as stroke, Parkinson's, etc., which evaluates various domains of body functions by observing diverse activities of daily living. This test is comprised of a total of nine items consisting of a five-point scale ranging from zero to four which adds up to a total of 36. The higher score shows better physical function. The inter-rater reliability of mPPT is .99 and its intra-rater reliability is .90 (Paschal et al, 2006; Reuben and Siu, 1990).

### Timed up and go (TUG) test

Timed up and go test is a test method of basic motility and locomotion which measures the time of one starting from a sitting position to stand up and walking 3 meters forward and passing the halfway point to come back and sit to the starting position (Podsiadlo and Richardson, 1991). This study instructed patients to pass the halfway point with their uninvolved side. The evaluator used a stopwatch to measure three times and record its average. The inter-rater and intra-rater reliability of TUG were both .99 (Morris et al, 2001).

### G-walk

G-walk (BTS G-walk<sup>®</sup>, BTS Bioengineering, Garbagnate Milanese, Italy) uses a wireless system, G-sensor, equipped with triaxial accelerometer, magnetic sensor, and triaxial gyroscope that makes it possible to easily measure spatio-temporal gait parameters, which is required to diagnose a patient and determine exercise strategy. G-walk can be attached on a waist (L5) area, where functional gait analysis is possible, using a belt which then analyzes the patient's ambulation using a wireless software program (Figure 1). This study only used gait speed, affected limb's stride length and stance phase duration (%) values out of various measurable parameters (Figure 1) (Figure 2). A single wireless inertial sensing device is easy to use and does not interrupt natural walking. And these devices are no statistically significant differences with generally used gait analysis

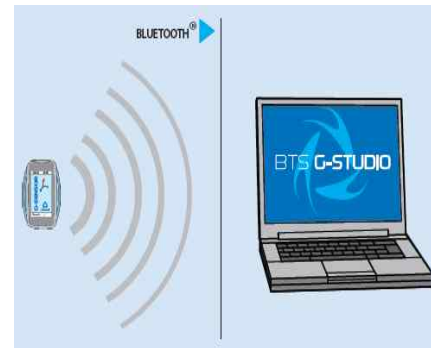


Figure 1. G-walk.



Figure 2. Dynamic FES (WalkAide2).

methods (Bugane et al, 2012; Pau et al, 2014).

### Dynamic functional electrical stimulation (Dynamic FES): WalkAide2

WalkAide2 (Innovative Neurotronics, Austin, USA) is a FES device designed to minimize foot drop by stimulating dorsiflexor muscles through the peroneal nerve. This device can be connected through the use of Velcro cuff in the infra patellar area. The stimulation can be triggered by the change of pressure on the heel or a vertical orientation on the leg. However, this study only uses the spark on the vertical orientation of all participants, instructing to walk on the speed the participant thinks is most comfortable above the treadmill. The device is programmed to start stimulating, transferring 25 Hz and 100 sec pulse width asymmetric biphasic wave on the time when the foot is lifted up the floor and maintaining it throughout the swing phase in any circumstances (Figure 2).

### Functional electrical stimulation (FES)

FES (Microstim, MEDEL Medizinische Elektronik Handelsgesellschaft mbH, Hamburg, Germany) has provided a stimulus with the intensity that allows ankle dorsiflexion by attaching two electrode pads on the tibialis anterior muscle of the patient sitting down before gait training. The patients were told to purposely contract tibialis anterior to make ankle dorsiflexion when they received FES electric current. We have instructed the patient to observe the movement of the foot in order for them to get visual feedback.

### Application methods and procedures of FES

Both the Dynamic FES group and FES group were given an general exercise treatment that includes neuromuscular developmental therapy. Dynamic FES group each has implemented 30 minutes, for a total of 60 minutes of gait training in a day with the application of Dynamic FES on the tibialis anterior after general exercise treatment. The FES group has implemented gait training on treadmill after the general exercise treatment, which was also given to the Dynamic FES group, and additionally applying FES on tibialis anterior muscle while sitting on a chair. A total of 90 minutes, 30 minutes each, was implemented on a day. Both two groups accomplished the program, twice a week, for a total of 24 times in a 12-week period. The gait speed on treadmill was set to the speed where the participant felt most comfortable. Physical therapists with professional

knowledge supervised all the programs including treatment and gait training in order for participants to participate in the experiment with the right posture and movement.

### Data analysis

All data analysis was performed using SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA) to examine the general features of the Dynamic FES and FES group by analyzing the mean and standard deviation. Spearman coefficient applied correlation analysis was used to know correlations between clinical scales. The Kolmogorov-Smirnov Z-test was performed to investigate whether continuous data approximated a normal distribution. Paired t-test was implemented to find out comparisons between pre- and post-test to find out the significance on each of the groups' exercise. The changes of pre- and post-test were compared between the two groups using independent t-test and the statistical significance level was set to  $p < .05$ .

## Results

### Descriptive characteristics of participants

The descriptive characteristics of participants are shown in Table 1. The average age of the Dynamic FES group was 59.0 and that of the FES group was 58.4. The Dynamic FES group consisted of 4 men and 3 women, and 2 men and 3 women were in FES group. The average height in the Dynamic FES

**Table 1.** Descriptive characteristics of participants

(N=12)

Characteristics	Dynamic FES group (n <sub>1</sub> =7)	FES group (n <sub>2</sub> =5)
Age (year)	59.0±15.9 <sup>a</sup>	58.4±10.7
Sex (male/female)	4 (57.1%)/3 (42.9%)	2 (40%)/3 (60%)
Height (cm)	166.4±9.0	159.4±6.2
Weight (kg)	63.4±12.7	58.2±10.8
Stroke duration (month)	62.3±42.9	70.8±29.7
Paretic side (right/left)	5 (71.4%)/2 (28.6%)	4 (80%)/1 (20%)

<sup>a</sup>mean±standard deviation.

group was 166.4 cm, and the FES group's was 159.4 cm. The average weight in the Dynamic FES group was 62.3 kg, and the FES group's was 58.2 kg, with the stroke duration on the Dynamic FES group being 62.3 months and the FES group being 70.9 months. The paretic side of the Dynamic FES group was 5 on right and 2 on left, while that of the FES group was 4 on right and 1 on left.

### **Correlation between each clinical scales**

The comparison result of each clinical scale showed a highly significant correlation in the correlation analysis between the K-ABC, BBS, mPPT and TUG ( $R=.772$ ,  $R=.782$ ,  $R=-7.798$ ,  $p<.005$ ).

### **Comparison of K-ABC, BBS, mPPT, TUG, gait speed, cadence, stride length, and stance duration between the Dynamic FES group and FES group**

There were no significant differences in K-ABC, BBS, mPPT, TUG, all linear parameters such as gait speed, cadence, stride length, and stance duration before the intervention was given on the Dynamic FES group and FES group. The Dynamic FES group showed significant changes in K-ABC, BBS, mPPT, TUG, gait speed, cadence, stride length, and stance duration after the intervention was given ( $p=.000$ ,  $p=.001$ ,  $p=.000$ ,  $p=.004$ ,  $p=.001$ ,  $p=.005$ ,  $p=.029$ ,  $p=.003$ ); however, the FES group did not show significant difference ( $p>.05$ ) except in cadence ( $p=.020$ ) in the comparison of pre- and post-intervention. The variation of the change in the difference of average in K-ABC, BBS, mPPT, TUG, gait speed, stride length, and stance duration showed a statistically significant difference ( $p=.000$ ,  $p=.015$ ,  $p=.032$ ,  $p=.019$ ,  $p=.007$ ,  $p=.025$ ,  $p=.031$ ) except in cadence ( $p=.118$ ) between the two groups after intervention (Table 2).

## **Discussion**

This study focused on the effects of Dynamic FES

on balance control, balance confidence, functional ability and gait to chronic stroke patients passing 24 months after onset of illness. The results showed that the Dynamic FES group showed a significant increase over the FES group in functional ability, dynamic balance control, and balance confidence. These results may be seen as increase in trunk control capability through increase in ankle stability. Bobath (1990) stated that increase in trunk control capability is an important key to increase dynamic balance control. Robertson et al (2010) reported physical enhancement and increase in balance control after applying FES on the tibialis anterior of stroke patients, while Lyons et al (2002) reported that FES application on ankle dorsiflexor enhance ankle stability which increases trunk control capability and balance control.

This study shows that higher scores in K-ABC showed greater score in BBS. This accorded with the research findings which reported that BBS balance control and balance confidence had a positive correlation (Botner et al, 2005). In the study of walking with an AFO, the BBS showed significant relationship with gait speed, step length of the affected side, and stride length in patients with chronic stroke (Kobayashi et al, 2014). The correlation between self-efficacy and physical capacity has been regarded. Therefore, low ability levels may lead to low self-efficacy, and low self-efficacy may result in less activities (Gecas, 1989). Furthermore, since FES was reported to re-educate normal movement on a paralyzed area due to upper motor neuron damage like stroke which helps functional recovery by decreasing rigidity causing abnormal movements (Shimada et al, 2005). Further, Dynamic FES application according to various therapeutic environments is necessary for effective motor system stimulation.

This study showed a significant increase in gait speed, affected limb's stride length and stance phase duration (%) more on the Dynamic FES group compared to the FES group. FES helps ambulation with ankle dorsiflexion by blocking foot drop during swing

**Table 2.** Comparison of K-ABC, BBS, mPPT, TUG, gait speed, cadence, stride length, stance duration between Dynamic FES group and FES group (N=12)

		Baseline	After 12 weeks	Difference of average	T	p
K-ABC <sup>a</sup>	DFG <sup>b</sup>	894.29±275.01 <sup>c</sup>	1015.71±292.34	121.42±41.80	-7.685 <sup>d</sup>	.000*
	FG <sup>e</sup>	658.00±428.45	678.00±441.66	12.00±13.04	-2.108	.103
	T	1.171 <sup>f</sup>	.246	.241		
	p	.269	.140	.000*		
BBS <sup>g</sup>	DFG	44.14±6.23	49.10±2.22	8.28±3.40	-6.444	.001**
	FG	37.00±7.38	37.81±11.94	3.20±2.16	-.375	.726
	T	1.821	.052	.379		
	p	.099	.028***	.015***		
mPPT <sup>h</sup>	DFG	22.34±5.41	25.14±4.77	2.85±1.06	-7.071	.000*
	FG	14.80±7.69	17.00±8.51	1.40±.89	-2.557	.063
	T	1.996	.216	.968		
	p	.074	.059	.032*		
TUG <sup>i</sup>	DFG	20.98±10.89	15.50±8.01	-5.48±3.21	4.509	.004**
	FG	28.46±20.96	26.07±23.18	-1.62±.59	1.718	.161
	T	.813	.093	.038		
	p	.435	.284	.019***		
Gait speed (m/s)	DFG	45.27±20.96	69.54±21.72	24.27±11.00	-5.839	.001**
	FG	46.98±25.73	49.68±23.74	2.70±10.76	-.561	.605
	T	-.127	1.504	.814		
	p	.902	.163	.007***		
Cadence (number of steps/min)	DFG	29.88±13.88	44.50±13.04	14.61±9.04	-4.274	.005***
	FG	33.28±13.57	40.38±15.97	7.10±4.22	-3.796	.020***
	T	-.421	.493	.062		
	p	.683	.633	.118		
Stride length (m)	DFG	1.37±.18	1.55±.22	.17±.16	-2.864	.029***
	FG	1.30±.25	1.19±.18	-.11±.21	1.135	.320
	T	.581	.181	.300		
	p	.574	.015***	.025***		
Stance duration (%)	DFG	65.16±3.16	69.75±2.53	4.60±2.56	-4.753	.003**
	FG	69.26±7.03	67.02±4.62	-2.24±6.67	.751	.494
	T	-.914	.173	.121		
	p	.382	.213	.031***		

<sup>a</sup>Korean version activities-specific balance confidence scale, <sup>b</sup>dynamic functional electrical stimulation group, <sup>c</sup>mean±standard deviation, <sup>d</sup>paired t-test, <sup>e</sup>functional electrical stimulation group, <sup>f</sup>independent t-test, <sup>g</sup>Berg balance scale, <sup>h</sup>modified physical performance test, <sup>i</sup>timed up and go, \*p<.001, \*\*p<.005, \*\*\*p<.05.

phase in the gait cycle of hemiplegic stroke patients showed significant increase in stride length had a greater influence that significant increase in gait (Shimada et al, 2005). We conclude that this study

speed when in comparison of two experiments. There were no significant difference in cadence due to Dynamic FES group showing more increase in dynamic balance, stance duration and stride length than in FES group. In addition, it is reported that FES application during gait training provides functional benefit to stroke patients by increasing walking speed (Hakansson et al, 2011). Furthermore, task specific repetitive approaches such as treadmill training focused on ambulation after stroke enhances functional performance capability and ambulatory ability among patients with neurological deficits (Hesse et al, 1995b; Richards et al, 1993; Visintin et al, 1998), improves damaged movements through repetitive motion, and provides positive influence on increased endurance (Hesse, 2008). Perhaps it is believed that the simultaneous application of Dynamic FES has helped improve ambulatory ability during treadmill training on the Dynamic FES group.

Laufer et al (2001) reported hemiplegic stroke patients lack balance control, and are vulnerable to fear of falling. Hemiplegic stroke patients, with addition to their weak muscles, cause the patient and therapist to face difficulties in stroke rehabilitation when enforcing treadmill gait training without proper support (Laufer et al, 2001).

Even if weakened muscle strength in chronic stroke patients is one of the factors limiting functional performance, psychological factors may have a greater effect on their ability. As a psychological factor, patient's self-confidence, in particular, can lead to a fall due to a limitation in daily activities. It is credited to a loss of balance and decrease of functional independence (Whitney et al, 1998). Thus, in the aspect of improving confidence, psychological factor contributes to an increase in physical performance.

Treadmill training with Dynamic FES is perhaps believed to block foot drop which contributes to an increase in balance confidence through decreased abnormal gait pattern and fear of falling with ankle stability. Also, conducting a task-specific repetitive approach is believed to bring improvement in balance

confidence through motivation towards training and achievement of goals.

South Korea is not clinically implementing FES to hemiplegic stroke patients after 2 years of onset. This study has showed an improvement of balance control, balance confidence, functional performance and gait in the Dynamic FES group than in the FES group. Therefore, it is necessary to develop and enforce various gait training programs in the clinical field where it applies Dynamic FES during gait training on patients who have experienced chronic stroke since the last two years.

The limitation of this study was that it was hard to create a generalization due to the small number of participants. Also, there were some difficulties in explaining ankle stability and trunk control capability due to lack of measurements in ankle movements. Moreover, this study was not able to have a follow-up after 3 months on FES effects which limits our knowing whether Dynamic FES aided motor learning transfer. Thus, further studies are needed, with a larger sample size, a longer duration, and more diverse gait training program on patients with chronic stroke, which can be determine the optimal treatment protocol.

## Conclusion

Walking with Dynamic FES training for chronic stroke patients improves balance, balance confidence, functional ability and gait after 3 months. In the group comparison, the group of Dynamic FES improves in K-ABC, mPPT, BBS, TUG, gait speed, stance phase duration (%), stride length.

Our results demonstrate that K-ABC and mPPT have higher correlation to BBS and TUG, respectively. Our results suggest that Dynamic FES in chronic stroke patients may be beneficial for improving balance, balance confidence, functional ability and gait. More long term follow-up studies and various type of walking studies are needed to determine the opti-



mal treatment protocol. A large sample study may also clarify our findings. However, we expected that these results may contribute in the application of Dynamic FES for chronic stroke patients in the future.

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