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Review Article

Effect of Functional Electrical Stimulation on Gait Restoration After Stroke - A Review

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Abstract: Stroke is one of the leading cause of disability and death throughout the world. Among the hospitalized neurological patients, 60% acquire gait disturbance. Functional electrical stimulation (FES) is a form of electrical current which helps to contract the weak muscles in the patient with stroke. Several studies were conducted to identify the effectiveness of FES on gait performance. Therefore the purpose of the article was to identify the good quality RCTs and find their results regarding the effectiveness of FES on gait performance of stroke patient. 5 randomized control trials were identified from the Physiotherapy Evidence Database (PEDro) and their score was 5 and above. A careful analysis was performed to make synopsis of those articles and presented in table with description. The first 4 studies found that a combination approach such as Mirror Therapy, Action Observational Training, Brain-computer interface and standard rehabilitation along with FES is effective in gait performance than the FES alone. One study compared the effectiveness of dual and four channels FES where they found 4 channels FES is more effective than dual channel. Therefore the review concluded that FES combined with other treatment modalities is beneficial to restore gait performance of patient with stroke.

Keywords: Functional Electrical Stimulation (FES), Stroke, Gait, Abnormality

1. Introduction

The World Health Organization defined stroke as ‘rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours leading to death, with no apparent cause other than of vascular origin’. [1] The classic definition of stroke mainly clinical which is not completely account for advance science and technology, therefore the American heart Association/American stroke association assigned a group of experts to develop consensus regarding the updated definition of stroke for 21st century. They define the CNS infraction as, “CNS infarction is brain, spinal cord, or retinal cell death attributable to ischemia, based on pathological, imaging, or other objective evidence of cerebral, spinal cord, or retinal focal ischemic injury in a defined vascular distribution". They also define intra-cerebral hemorrhage as, "Rapidly developing clinical signs of neurological dysfunction attributable to a focal collection of blood within the brain parenchyma or ventricular system that is not caused by trauma. [2] Sudden weakness or numbness of the face, arm or leg, most often on one side of the body, confusion, difficulty speaking or understanding speech, vision, gait, dizziness, loss of balance or coordination, severe headache, fainting or unconsciousness are the usual symptoms which might vary according to the area and severity of the brain involvement. Sudden death of patient might occur following a severe stroke. [3] The three alarming signs of stroke include-slurred speech, facial droop and arm weakness. [4] If we look different part of the world, it is found that Stroke affects the urban area of Latin America 6%, China 9%, India 1.

9% and rural India 1.1%, China1.6%, and Peru 2.7%. The proportion of stroke survivors who need medical care varied between 20% and 39% in Latin America but was higher in rural China 44%, urban China 54% and rural India73%. [5] As we know that after stroke there are many physical limitation arises and among the several physical involvements one of the major problems that usually encounters by the stroke survivors is gait disturbance. It causes loss of independence therefore imposes a great strain on patient and the caregivers. It was found in one study that among the hospitalized neurological patients, 60% acquire gait disturbance and Stroke was the most prevalent condition along with the other neurological conditions. [6] The biomechanical pattern changes due to reduction of walking speed and longer stance phases; especially in the unaffected side. There are variations in joint movements in stance and swing phase. Therefore the deviation occurs either due to particular impairment or adaption to the impairment. [7] In another study it was found that asymmetry in gait is common in chronic stage of stroke than the velocity and speed of the gait. [8] Among the several treatment options Functional electrical Stimulation (FES) is a form management where electrical current is used to contract the paralyzed muscle in the patient with neurological impairment. Aiming to improve the voluntary activity of muscle by changing the physiology it is applied. As it is the substitute for the neurological impairments often termed Neuro-prosthesis. Both sensory and motor function can be improved by functional electrical stimulation. The intact lower motor neurons are activated by the placement of several electrodes, near or over the nerve fibers which initiates the action potential and propagate along the nerve axon and terminates at the neuromuscular junction which cause muscle fiber to contract. [9] The following study was an attempt to find out the evidence of effectiveness of FES to treat gait problem of stroke patient from the scholarly articles.

2. Methods

The study is a Review in nature where five different scholarly articles regarding the effect of Functional Electrical Stimulation on gait restoration for the stroke patient were reviewed. An electronic search strategy was used based on Physiotherapy Evidence Database (PEDro), Google scholar, Pub Med, Google. The following key words were used to find out the desired literatures:"FES","Stroke Rehabilitation", "functional electrical stimulation for stroke patient". Five randomized control trials were selected from Physiotherapy Evidence Database (PEDro) which had PEDro score 5 or above. The study participants were both in acute and chronic stage of stroke. Only hemiplegic cases were included, aged from 45 to 85. A careful analysis was performed to make synopsis of those articles and presented in table with description.

3. Result

A Randomized Placebo-Controlled Trial which was conducted aimed to find out, whether FES in acute stroke was more effective in promoting motor recovery of the lower extremity and walking ability than standard rehabilitation.46 participants were randomly allocated into 3 groups where all subjects received the same standard rehabilitation including 60 minutes neuro development facilitation. Experimental group additionally received FES and placebo group received placebo FES for 60 minutes; 5 days per week for 3 weeks. Descriptive statistics and repeated ANOVA were used by SPSS(version10.0) to compare the main effects before, during, and after treatment, followed by post-hoc to compare treatment effects among the 3 groups. The level of significance was set at 5%. The result found no significant differences in the baseline measurements. After 3 weeks of treatment, there was a significant reduction in the percentage of composite spasticity score, and a significant improvement in the ankle dorsiflexion torque, accompanied by an increase in agonist electromyogram. Furthermore, reduction in electromyogram co-contraction ratio in the FES group was noted, when compared with the other 2 groups (P0.05). All subjects in the FES group were able to walk after treatment and 84.6% of them returned home, in comparison with the placebo (53.3%) and control (46.2%) groups. The study concludes that FES with standard rehabilitation improves motor and walking ability. [10]

A RCT was conducted aiming to find out the 'Effect of Mirror Therapy Integrating Functional Electrical Stimulation on the Gait of Stroke Patients'. 30 subjects were included who were randomly divided into 3 groups (10ineach). Among 2 experimental groups (I and II), Group-I received mirror therapy conjunction with FES, while Group-II received mirror therapy; however, Group-III which was the control group got Sham treatment. The mirror was set in such a way that the affected foot was behind and patient can see the movement of unaffected lower limb. For FES, a pair of surface electrodes, a stimulator and a foot switch was attached at the base of the affected foot. The patient was instructed to perform simultaneous foot dorsiflexion in the affected side with 10 seconds hold followed by 5 seconds rest while watching the unaffected side dorsiflexion at the mirror. Group-II performed same training without FES while the control group performed the same training without mirror and FES. Each group performed additional exercise for 20 minutes. The analysis was performed using a three-dimensional motion capture system. Every subject was instructed to walk inside a 7m capture area, three times at a comfortable speed. The average of the measurement values were taken on Velocity, Cadence, Step Length, Stride Length were recorded by three-dimensional motion capture system. Paired t-test was performed to find out the statistical significance. Between groups, analysis was done by one-way ANOVA. Post hoc test was performed using Fisher's Least Significance Difference (LSD) test. The statistical significance level was set at α=0.05. There was a significant difference in gait velocity between groups and post hoc analysis found significant differences between experimental Group-I and the control group; and also, between experimental group II and the control group. The statistical significant differences also found in step length and stride length between the groups after the experiment, and post hoc

analysis revealed the significant differences between experimental Group-I and control group. This showed that mirror therapy in conjunction with FES is more effective for improving gait ability than mirror therapy alone. [11]

Another study was conducted to find the effects of Additional Action Observational Training for Functional Electrical Stimulation Treatment on Weight Bearing, Stability and Gait Velocity of Hemiplegic Patients. 20 participants who were 6 months post stroke were randomly divided into two groups. Both groups received FES and experimental group additionally got action observational training. Along with the FES, the experimental group participants were asked to watch a video which showed walking in flat, slope, and stairs for 5 times a week, for 6 weeks. FES was used to stimulate the deep peroneal nerve. The control group received only functional electrical stimulation. SPSS version 12.0 used for statistical analysis. Paired t-test calculated within group and the independent t-test for inter-group comparison. The level of statistical significance was chosen as α=0.05. The experimental group showed statistically significant changes in front and rear foot weight bearing, left and right foot weight bearing, stability index and gait velocity($p<0.05$). The control group only showed a significant difference in anterior and posterior weight bearing ($p<0.05$). Therefore, the study revealed that functional electrical stimulation (FES) is effective in conjunction with action observational training than the FES alone to improve weight bearing, stability and gait velocity of stroke patients. [12]

This study "Effects of brain-computer interface-based functional electrical stimulation on balance and gait function in patients with stroke: preliminary results, was conducted and aimed to find out the effects of brain-computer interface (BCI) based functional electrical stimulation (FES) on balance and gait function inpatients with stroke. BCI is the technology which analyzes brain waves, in real-time, as the brain attempts to control equipments.10 participants were randomly assigned into two groups equally. BCI-FES group (n=5) and a FES group (n=5). Participants were included who suffered from at least 6 months old ischemic, hemorrhagic and hemi paretic stroke; more than 24 points on the Mini-Mental State Examination and able to walk independently for more than 10 m. According to a BCI-based program for 30 minutes per day for 5days, the BCI-FES group received ankle dorsiflexion training with FES. The FES group received ankle dorsiflexion training with FES for the same duration. Timed Up and Go (TUG) test and the Berg Balance Scale (BBS) was used to assess the balance ability. Gait function such as gait velocity, cadence, step length, and stride length was measured by GAITRite system. SPSS version12.0 was used for all statistical analysis. Wilcoxon test was used as a non parametric statistical method within group because the number of research subjects was 5 only. Mann-Whitney test was performed to compare the 2 groups before and after training. The p value of<0.05 was considered as significant. The result revealed that BCI-FES group improved significantly on TUG test, cadence and step length where the FES only group didn't revealed any significant change and eventually there were no significant differences between the 2 groups. Finally the author suggested further similar study with bigger sample and longer period of time investigation for generalization. [13]

A study named "The Effectiveness of Functional Electrical Stimulation Based on a Normal Gait Pattern on Subjects with Early Stroke: A Randomized Controlled Trial "was conducted aimed to find out the effectiveness of four channels FES based on a normal gait pattern on improving functional ability in early stroke patient. The study included participants who were diagnosed as ischemic stroke at first by either computed tomography or magnetic resonance imaging, unilateral hemi paralysis, ages 45 to 80 years old, within 3 months post onset, and a Brainstorm stage of I, II, or IV. The study was a single-blinded, stratified, randomized, controlled trial accommodate 45 subjects who were divided into 3 groups–Four channels FES group (n=16), a placebo group (n=15) and a dual-channel group (n=14) respectively. The stimulation provided for 30 minutes, 1 session/day, 5 days a week for 3 weeks. All subjects were assessed at baseline, at 3weeks of treatment, and at 3 months after the treatment. Fugl-Meyer Assessment (FMA), the Postural Assessment Scale for Stroke Patients (PASS), Berg Balance Scale (BBS), Functional Ambulation Category (FAC), and the Modified Barthel Index (MBI) were used. For statistical analysis descriptive, one way ANOVA followed by post hoc test was used by version 16.0 SPSS software. FMA lower extremity showed no significant differences among the 3 groups at baseline. After 3 weeks of treatment, there was a significant difference in FMA scores between the four channel and dual-channel groups (P=0.024), but no significant difference between the four-channel and placebo groups (P=0.062) was found. There were no significant differences in PASS and BBS scores among the 3 groups at baseline, and after 3 weeks of treatment. But further comparison demonstrated that the difference between the four-channel and placebo groups in PASS (P=0.031) and BBS (P=0.022) scores reached significance. Therefore the study conclude that Four Channel FES is effective in the improvement of Function, walking ability and performance activities of daily living in early ischemic stroke. [14]

The following tables will give an 'at glance idea' about the articles.

Table 1. *Article basic information.*

Article no	Author	Name of Journal	Design and no of participants	Inclusion criteria	Pedro score
1	Yan et al.,(2005)	Stroke	RCT,46 subjects 3groups	Unilateral stroke within the carotid artery system according to computerized tomography. Aged 45 to 85years old, and were independent in daily	6

Article no	Author	Name of Journal	Design and no of participants	Inclusion criteria	Pedro score
				activities before stroke.	
2	Jiet.,(2014)	Journal of Physical Therapy Science	RCT,30subjects, 3groups (10 in each group)	Hemi paresis due to stroke	5
3	Park and Kang.,(2013)	Journal of Physical Therapy Science	RCT, 20 subjects, 2 groups (10 in each group)	The subjects were hemiplegic patients more than 6 months from stroke onset who, scored over 25 points on the K-MMSE6) and were capable of gait over15m.	5
4	Chung et al.,(2015)	Journal of Physical Therapy Science	RCT,10 subjects, 2 groups (5 in each group)	More than 6 months after clinical diagnosis of ischemic or hemorrhagic hemi paretic stroke. More than 24 points on the Mini-Mental State Examination, and able to walk independently for more than 10 m.	5
5	Tan et al.,(2014)	Biomedical Research International	RCT, 45 subjects, (16,15,14 respectively)	First ischemic stroke diagnosed by either computed tomography or magnetic resonance imaging. Unilateral hemi-paralysis, ages 45 to 80 years old, Within 3months post onset, and a Brunnstrom stage of I, II, or IV.	6

Table 2. *Article findings.*

Article no	Treatment as per group allocation	Outcome measure tool	Result	Duration
1	Experimental group-received the standard rehabilitation including 60 minutes neurodevelopment facilitation approach and occupational therapy focused on activities of daily living, given, 5days per week for 3 weeks and FES for 30 minutes. Placebo group-standard rehabilitation with 60 minutes placebo FES, 5days per week for 3weeks. Control group-Only FES, 5days per week for3weeks.	Joint torque and surface EMG. Timed "Up & Go"(TUG) test.	FES with standard rehabilitation improve lower extremity motor function and walking ability in stroke patient.	3weeks
2	Experimental group I-mirror therapy in conjunction with FES Experimental group II received mirror therapy and, The control received a sham therapy. All subjects performed PNF neurodevelopment technique for 30 minutes a day, 5 times a week for 6 weeks.	Three-dimensional motion capture system-A gait Analysis tool with a real-time tracking device (The Eva Real-Time-EvaRT)	Mirror therapy in conjunction with FES is more effective for improving gait ability than mirror therapy alone.	6weeks
3	The experimental group received functional electrical stimulation treatment and they were asked to watch a video on gait for 15 minutes (action observational training). The video on gait showed walking on flat ground, slopes, and stairs, and was watched 5times a week for 6 weeks. The control group received only functional electrical stimulation treatment.	Tetrax, device to evaluate subjects' weight bearing and stability. The stability index	Functional electrical stimulation (FES) is effective in conjunction with action observational training then the FES alone to improve weight bearing, stability, and gait velocity of stroke patients.	6weeks
4	The subjects in both the BCI-FES and FES groups participated in the program according to a designated schedule. The BCI-FES group received ankle dorsiflexion training with FES as per the BCI-based program for 30 minutes per day, for 5days. The FES group received ankle dorsiflexion training with FES for the same duration.	Timed Up and Go (TUG) test Berg Balance Scale (BBS) GAITRite system.	BCI-FES training Increases balance and gait function in patients with stroke.	5days
5	All subjects received conventional stroke rehabilitation program including 30 minutes of physical therapy daily based on the neurodevelopment facilitation approach and 30 minutes of daily occupational therapy focused on ADL training, given 1session each day, 5days a week for 3weeks. Subjects in the four-channel group received four-channel FES therapy stimulating the affected lower extremity. Placebo group were also given the four channel FES therapy, but only the indicator light was working and no current was output. The dual-channel group received dual-channel FES therapy. In both programmes FES was delivered at a frequency of 30Hz with a pulse width of 200μs. The current amplitude was adjusted to each patient's maximum tolerable intensity.	Fugl-Meyer Assessment (FMA), the Postural Assessment Scale for Stroke Patients (PASS), Berg Balance Scale (BBS), Functional Ambulation Category (FAC), and the Modified Barthel Index(MBI)	Four Channel FES is effective in the improvement of Function, balance, walking ability and performance activities of daily living in early ischemic stroke.	3weeks

4. Discussion

This article was aimed to accumulate and present the information regarding the effectiveness of Functional Electrical stimulation (FES) for restoration of gait in the patient with stroke. Five scholarly articles were searched from the Physiotherapy Evidence based database (PEDro).

Almost all the articles revealed that FES combine with other methods is effective for stroke patient's gait restoration as well as some other parameters. The first 4 studies found that a combination approach such as Mirror Therapy, Action Observational Training, brain-computer interface and standard rehabilitation along with FES is effective in gait performance than the FES alone. One study compared the effectiveness of dual and four channels FES where they found 4 channels FES is more effective than dual channel. Therefore FES with Mirror therapy for 30 minutes a day, 5 times a week for 6 weeks. FES combine with action observation training for15 minutes, 5 times a week for 6 weeks; BCI with FES, 30 minutes per day, for 5days, FES with standard rehabilitation for 30 minutes in15 sessions and 4 channel FES with conventional rehabilitation for 30 minutes, 5 days per week for 3 weeks could be effective in restoration of gait after stroke. Similarly FES with exercise was found to be effective to modify poor prognosis of stroke and compensate severe motor loss especially with upper extremity. [15]. A systematic review found that FES has an orthotic effect on walking in stroke patients with a dropped foot [16]. According to Canadian stroke Rehabilitation Practice Guideline 2015 "FES should be used to improve strength and function (gait) in selected patients". [17] It was found that FES is effective to treat Hemi spatial neglect in stroke patient. [18]. It was also found that FES is effective to treat the balance problem of stroke patient. [19] Functional electrical stimulation is an advanced technology where a physiotherapist needs to have specific training. It might also be an expensive procedure as most of the studies suggested other types of technological involvement along with this. A study showed the use of FES is low among the physiotherapists during the rehabilitation of stroke patients. However many of them (52.6%) want to increase the use of FES,40% had doubt in evidence. The physical therapists with postgraduate FES training were more likely to use FES. Several barriers were identified such as time constraint, lack of access to equipment, training. [20]

5. Conclusion

Several studies have been conducted so far to find out the combined effectiveness of FES. As this is a relatively new treatment approach which has evidence of combined effectiveness therefore clinical application of this approach in local context is crucial. It is also important to find out the isolated effectiveness of FES. So more studies needed to be carried out in future with the intention to find out the isolated effectiveness of FES or combination within expensive, convenient treatment protocols. Initially some difficulties were faced by the article writer regarding search strategy. Many of the full articles were not available for free. However those were over came effectively by using different key words for search, searching through Hinary, expert help and soon. Few technical difficulties were faced during writing which were solved by the advice of the respected supervisor.

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