
Assessment of the Efficacy of Functional Electrical Stimulation in Patients with Hemiplegia

The purpose of this review is to summarize recent findings relevant to the efficacy of functional electrical stimulation (FES) in the rehabilitation of patients with hemiplegia. Most clinicians still view this modality as an experimental tool. Recent controlled clinical studies have shown that FES has the potential for improving the gait pattern of hemiplegic patients and for reducing shoulder subluxation. Controlled studies showing successful treatment of the hemiplegic hand are not presently available. Given the recent technological advances and promising clinical studies, it appears that FES may become a more common clinical tool in the treatment of the hemiplegic patient in the future. Key words: *cardiovascular accident, orthosis, physical rehabilitation, stroke*

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FUNCTIONAL ELECTRICAL stimulation (FES) is the use of electrical stimulation to produce muscle contractions that have a functional purpose (Liberson, Holmquest, Scot, & Dow, 1961; cf. Peckham, 1987). This definition of FES was introduced by Liberson and colleagues in 1961 and was used to distinguish functional applications of electrical stimulation from the more classical applications of electrotherapy. The more traditional applications of electrical stimulation to skeletal muscle, such as muscle strengthening and edema reduction, are designed to have therapeutic effects that persist after the treatment is terminated. In contrast, FES produces effects at the time of stimulation. While it may not be the primary objective, many applications of FES are associated with long-term therapeutic effects, such as improved motor control, diminished spasticity, maintenance of range of motion (ROM), and muscle

This work was supported in part by grants from the National Institutes of Health (AR41264) to Dr. Binder-Macleod and from the American Physical Therapy Association and Foundation for Physical Therapy to Mr. Lee.

Top Stroke Rehabil 1997;3(4):88-98
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strengthening. This review, however, will focus on the effects produced at the time of stimulation, that is, to produce movement or maintain functional postural alignment.

FES has most commonly been used with patients who have damaged central nervous systems (e.g., stroke and spinal cord injury [SCI]). Since the initial reports outlining the potential uses for the application of FES in patients with hemiplegia, the expectations have been high for this modality. However, due to a dearth of well-controlled studies documenting the optimal training parameters and the clinical efficacy of this modality, FES is still viewed by most clinicians as an experimental procedure. Thus, although FES has been an area of active research for the past 35 years, most of its use remains confined to a limited number of research centers around the world. However, continued encouraging clinical reports and recent technological advances suggest that many stroke patients may potentially benefit from the use of this modality. The purpose of this review is to summarize recent findings relevant to the efficacy of FES in the rehabilitation of patients with hemiplegia to help clinicians to determine better if this modality may be of potential benefit to their patients.

HISTORICAL OVERVIEW

In 1961, Liberson and colleagues reported the first clinical application of FES. In this report of a series of case studies, they used a simple, portable, single-channel stimulator to activate the ankle dorsiflexors during ambulation in patients with hemiplegia. Following Liberson and colleagues' seminal work, numerous reports began appearing in the middle 1960s both for dorsiflexion assistance in the lower extremities of patients with

hemiplegia (Vodovnik, Dimitrijević, Prevec, & Logar, 1966; for reviews, see Gračanin, 1984; Kralj, Ačimović, & Stanič, 1993; Stanič et al., 1991) and finger and wrist extension in the upper extremities of patients with SCIs (Long & Masciarelli, 1963). Throughout the 1970s, additional reports about the use of FES with patients with hemiplegia appeared. However, most of these reports were technical in nature (i.e., evaluating the FES technology), and none of them utilized experimental designs to test the efficacy of the modality. Improvements in technology resulted in the development of equipment that allowed the more complex correction of the abnormal gait patterns of patients with hemiplegia through the use of multichannel stimulators (up to six channels) and the programming of complex activation sequences to accommodate individual gait patterns (Stanič et al., 1978; for review see Kralj & Vodovnik, 1977). In 1973, the first commercially available FES unit for finger extension in hemiplegic patients became available (Rebersek & Vodovnik, 1973). Interestingly, in the late 1970s, reports of the use of FES to produce ambulation in patients with SCI began to appear (Brindley, Polkey, & Rushton, 1978). Over the following decade, tremendous interest and optimism were attached to the use of FES in patients with SCIs to allow functional ambulation. Unfortunately, during this time, research reports for the use of FES in hemiplegia waned.

Virtually all of the technological improvements in FES during the 1980s were the result of work in patients with SCIs. By the end of the 1980s, due to continued technological problems and limited clinical success, enthusiasm for the use of FES to allow patients with SCIs to ambulate began to decline, and more realistic expectations for the

use of this modality (e.g., standing, lower extremity exercise) were beginning to be adopted (Kralj et al., 1993). During this time, significant progress was made in the rehabilitation of grasping hand movement in patients with quadriplegia.

The 1990s has seen increased interest in the use of FES in patients with hemiplegia. Interestingly, although the microprocessor-controlled equipment that is presently available to perform FES is very different from the relatively simple stimulator used by Liberson and colleagues, the current goals and approaches to the use of FES have remained relatively unchanged (Kralj et al., 1993). Dorsiflexion assistance during ambulation remains the most common lower extremity FES application (Kralj et al., 1993; Stanič et al., 1991). FES for improved shoulder and hand function in stroke patients has also recently been demonstrated (Faghri et al., 1994).

CLINICAL EFFICACY

Ambulation

Only recently have clinical studies that use experimental designs begun to appear in the literature identifying the benefits of using FES to improve the gait pattern of patients with hemiplegia (Bogataj, Gros, Klajajić, Aćimović, & Maležič, 1995). Throughout the previous decades, all of the clinical studies have been case reports that have touted the potential for the use of this modality. In 1961, Liberson and colleagues reported on the use of a single-channel peroneal stimulator with patients with hemiplegia and pronounced gait difficulties due to accompanying foot drop and prominent inversion of the foot (equinovarus). Portable electric simulators were used to deliver 20 μ s to 250 μ s pulses at frequencies of 30 to 100 pulses per second (pps) to the peroneal nerve of the

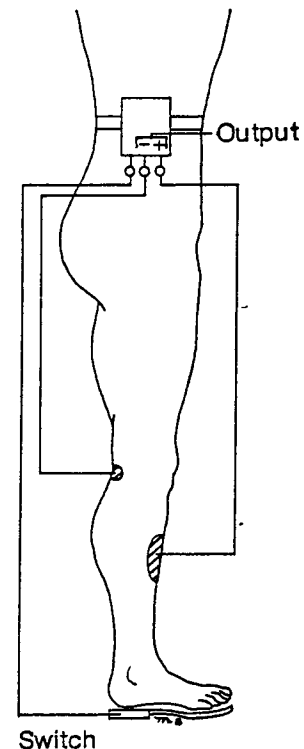


Figure 1. Single-channel dorsiflexion-assist FES unit. A portable stimulator is secured to a waist belt worn by the patient. The smaller active electrode is placed over the common peroneal nerve near the head of the fibula, and the larger electrode is placed over the muscle bellies of the ankle dorsiflexors. During stance, the heel-switch placed under the foot is closed, and the stimulator is inactivated. During swing, the heel-switch is open, and the dorsiflexor muscles are activated. *Source:* Adapted with permission from Liberson, W.T., Holmquest, H.J., Scot, D., & Dow, M. Functional electrotherapy: Stimulation of the peroneal nerve synchronized with the swing phase of the gait of hemiplegic patients, *Archives of Physical Medicine and Rehabilitation*, 42, 101-105, © 1961.

affected lower extremity (see Figure 1). The active electrode (conductive rubber) was placed over the peroneal nerve near the head of the fibula. Stimulation was synchronized

with the swing phase of gait by using a foot switch that allowed activation when the foot was lifted off the ground. The authors reported qualitative improvements for all 7 subjects in ankle dorsiflexion and eversion during the swing phase of gait. Additionally, the authors reported transitory periods of spontaneous recovery of dorsiflexion. Although a qualitative report, it provided the impetus for the development of FES and the potential carryover of therapeutic effects from its application.

Soon after its introduction, the limitations in the use of FES began to appear. Problems with FES included the incomplete correction of many of the patients' gait abnormalities (Stanič et al., 1978; Takebe, Kukulka, Narayan, Milner, & Basmajian, 1975), poor patient acceptance due to discomfort and difficulty of use (Takebe et al., 1975), and rapid muscle fatigue (Stanič et al., 1978). The limitations to the use of FES in stroke patients were such that in a 1975 article, Takebe and colleagues, using a commercially available, single-channel stimulator to improve dorsiflexion, noted only 3 of 9 patients were able to complete a 5-week course of peroneal nerve stimulation. Surface electrodes were used, with a larger electrode placed over the tibialis anterior muscle and a smaller electrode placed behind the head of the fibula to stimulate the peroneal nerve (frequency 50 pps, 0 to 00 V at 6 mA). Primary reasons for attrition include pain and discomfort with the electrical stimulation, difficulty and time involved in placing the electrodes over the motor point, and problems with shifting of the electrodes. This study highlights the importance of attention to the electrode-skin interface. As noted by Stanič and colleagues (1978), the interface problem between the electrodes and the patient's skin produces the marked variability in the motor response and pain at high excitation amplitude. These

problems markedly limit the applicability of this modality. Also, because stimulation is performed by surface electrodes, superficial muscle groups are primarily stimulated (Stanič et al., 1978), and lower muscle forces and limited selectivity of movements are achieved.

Waters, McNeal, and Perry (1975) attempted to solve some of the problems with surface electrodes by developing an implantable nerve stimulator. Their device consisted of an external stimulator and antenna that generated and transmitted a radio-frequency signal through the skin, a heel switch transmitter that triggered the stimulator (eliminating wires running from the stimulator to the heel switch), a surgically implanted receiver, and a surgically implanted electrode. The implanted receiver received the signal from the stimulator transmitter and converted it into a train of electrical pulses (200 μ s pulse duration, 33 pps, 0.4 to 0.8 V) delivered to a bipolar electrode wrapped around the deep peroneal nerve. Waters and colleagues reported the results from the use of this implantable stimulator with 16 patients. Stringent criteria were used for acceptance into the study. All patients were at least six months after the onset of stroke, were mentally and physically able to operate the equipment, displayed footdrop during walking, had sufficient ankle plantarflexor strength to raise their heels off the ground with their involved extremity, had $\leq 5^\circ$ of fixed plantarflexion while standing, had intact proprioception of the ankle and big toe, and had intact peroneal nerve and ankle dorsiflexor muscles. Footdrop was corrected in 13/16 patients (1 died of unrelated causes, 1 developed a wound infection, 1 developed peroneal nerve palsy requiring revision of electrode placement). Gait velocity, stride length, and cadence were measured before

surgery and 6 months after surgery for the 13 patients with successful results. After surgery, gait measurements were made both with and without FES stimulation to compare the effect of FES on gait. Significant increases were seen in walking velocity, stride length, and step frequency. Improvements were significant both when the patients were tested with and without stimulation but were greater with stimulation. The authors speculated that the improvement without the use of the stimulator may have been due to some type of carryover effect because the testing was performed immediately after walking with stimulation. However, this study did not attempt to determine if the improvements were caused by some short-term, central nervous system (CNS) changes (i.e., reduced spasticity or improved motor control) or due to muscle hypertrophy resulting from the stimulation. The authors also noted that at a 3-year follow-up, subjects showed encapsulation of the electrodes without any apparent tissue damage. Although this study did not utilize an experimental design, it did demonstrate the feasibility of an implantable system and quantified the improvements in the patients' walking.

Early during the development of FES, researchers recognized that more than just dorsiflexion assistance during the swing phase of gait was needed to correct the complex gait abnormalities seen in patients with hemiplegia. During the 1970s, reports began to appear from the Slovenian research group describing multi-channel stimulation to correct the gait abnormalities in patients with hemiplegia (Kralj & Vodovnik, 1977; Stanič et al., 1978; for a review, see Stanič et al., 1991).

In 1978, Stanič and colleagues reported the application of a six-channel system that used surface electrodes to stimulate the ankle dorsiflexors, evertors, and plantarflexors;

knee flexors and extensors; and hip extensors and abductors. Stimulus trains contained voltage-regulated, rectangular, 150 to 300 μ s pulses at 30 to 40 pps. Typical stimulation voltages were 20 to 80 V with a maximum voltage of 150 V. Inclusion criteria for subjects in this study were similar to those outlined above for the study by Waters and colleagues (1975). This study, however, did not require that patients have active ankle plantarflexion. The patients were in the "later phases of rehabilitation" (range 4 to 48 months since their stroke) and thus "capable of walking." The selection of appropriate muscle groups for stimulation and the determination of the optimal sequence of muscle activation was made individually for each patient based on a clinical analysis of the patient's gait. After the optimal stimulation sequence was determined, the patients were trained three times per week for 1 month, sent home for 1 month with no FES or other therapy, and then returned for another month of therapy. Training with the FES was provided in addition to the patient's regular physical therapy.

Using a *qualitative* kinesiological analysis of gait, the authors reported that FES produced marked improvement in many of the patients' gait. In general, there was greater correction of gait abnormalities during the swing phase than during the stance phase. As an example, FES was able to correct the equinovarus and the landing on the lateral border of the foot in all patients. In contrast, FES did not completely correct the inadequate weight shift during the stance phase for any of the patients. The authors suggested that the poorer correction during the stance phase was due to greater lower extremity muscle forces needed during this phase to support the weight of the body, which cannot be generated during surface stimulation. The

two *quantitative* measurements that were made of the gait cycle—changes in step time and stance time—also showed significant improvements. The authors noted that, despite these promising results, the benefits were only demonstrated during the period of stimulation. That is, no long-term or therapeutic results were tested. Finally, the authors noted that, although there was no control group, the use of multichannel stimulation appeared to shorten the period of rehabilitation and produce a more complete rehabilitation of the patient.

Several recent reports have suggested that short-term intensive therapy using multichannel FES may be of benefit to severely involved, nonambulatory stroke patients. Bogataj and colleagues studied the effects of multichannel FES in a group of 20 hemiplegic patients with severe motor deficits (Bogataj et al., 1989). Sixteen patients were hemiplegic secondary to stroke, and 4 were hemiplegic secondary to head injury. Treatments were begun on average 9.5 months postonset of the injury (range = 1.5 to 72 months). At the beginning of treatment, none of the subjects could walk independently. A six-channel microprocessor-controlled stimulator was used to activate the appropriate muscles with 200 μ s pulses and a pulse frequency of 30 pps. In most cases, stimulation was applied to the common peroneal nerve for ankle dorsiflexion, to the soleus muscle for plantarflexion, to the quadriceps femoris muscle for knee extension, to the hamstring muscles for knee flexion, to the gluteus maximus for hip extension, and to the triceps brachii for reciprocal arm swing during the swing phase of the ipsilateral leg. For stimulation over the target muscles, silicon rubber electrodes with karaya pads were used. To stimulate the peroneal nerve, a gauze button electrode was used. Subjects were treated

with 1 session per day, 5 days per week. Treatment lasted 2 to 3 weeks, depending on the patients' response to treatment (i.e., as long as the patients' gait improved). During this time, patients continued with their prescribed rehabilitation program. Changes in the patients' gait patterns before and after the 2 to 3 weeks of training were made both during the application of FES and without the FES. During testing both with the application of FES and without FES, objective measurements of gait showed improvement following training. All subjects showed some improvement of their gait, endurance, and posture. The authors concluded that patients who previously had been unable to walk, were able to walk again and live more independent lives after just 2 or 3 weeks of therapy. It is unclear from the study how patient independence was assessed. Nevertheless, based on the rate of recovery by the patients receiving multichannel FES, a considerable reduction in the cost of rehabilitation may be possible with the use of FES (Bogataj et al., 1989), or patients may achieve a higher level of function for almost the same personnel cost (Kralj et al., 1993).

A more recent study by this same Slovenian group (Bogataj et al., 1995) reported the results of the first clinical study of FES for improving gait that has utilized an experimental design to attempt to evaluate the effects of FES. Twenty patients with severe hemiplegia secondary to a recent stroke (< 1 year) were studied. As in the previous study, patients were nonambulatory. Patients were randomly assigned to one of two groups. One group ($n = 10$) started with conventional therapy for 3 weeks then switched to multichannel FES for 3 weeks in addition to continued conventional therapy. The other group received FES and conventional therapy first and then discontinued the

use of FES. Conventional therapy included "passive techniques" to reduce reflex activity, increase or preserve the range of motion in the joints, and enhance sensory input; "active techniques" to achieve functional movement (Bobath technique, proprioceptive neuromuscular facilitation, and biofeedback exercises); and gait training using a passive ankle-foot orthosis or knee-ankle-foot orthosis. Six-channel FES consisted of electrical stimulation applied to the same muscle groups as those previously described (Bogataj et al., 1989) using the sequence of activation of the muscles determined to be optimal for each subject. Gait performance (gait speed, stride length, gait cadence) was assessed by a ground reaction measuring system at the beginning of treatment, after 3 weeks of treatment (the switchover point for the two treatment groups), and after 6 weeks of treatment. The general physical status of the patient was also tested with the Fugl-Meyer evaluation. Mean values of performance showed greater improvements when the patients received FES combined with conventional therapy than when the patients received conventional therapy alone. This study provides considerable support to the argument that FES may accelerate the rehabilitation of patients with severe motor problems following a stroke and may thus help to reduce the cost of rehabilitation.

Although these previous studies demonstrate the feasibility of incorporating sophisticated FES techniques into conventional therapy settings, many questions remain unanswered. Uncertainty exists about which patients respond best to FES and when FES should be introduced. Similarly, whether all patients require complex, six-channel, microprocessor-based stimulators is unclear. For patients who ambulate independently, a

single-channel peroneal stimulator may be all that is needed to markedly improve their gaits (Stanič et al., 1991). Maležič and colleagues (1992) have recently reported the use of a two-channel system (constant current symmetrical biphasic or monophasic pulses ranging from 0 to 50 mA) designed for both clinical rehabilitation and for subsequent daily use as an orthotic aid. The device was used with 11 stroke patients and 10 traumatic brain-injured patients. Improved muscle force; joint angle; and stride time, length, and velocity during gait were observed with the use of the stimulator. Thus, some patients can use relatively simple devices to improve their walking patterns.

Another concern is determining the most appropriate electrode to use during FES. From the studies previously cited, both surface and implanted electrodes have been used successfully. When applying FES for short-term therapeutic benefits, the use of surface stimulation may be the most appropriate. Though the application of surface electrodes remains time consuming, improvements in the electrode materials and coupling have made stimulation with surface electrodes more comfortable and acceptable for most patients. We recently demonstrated for a group of 20 healthy volunteers that surface stimulation using 600 μ s, monophasic, rectangular pulses could be used to produce 80% of the maximum isometric voluntary contraction from a large muscle like the quadriceps femoris muscle from all subjects (Binder-Macleod, Halden, & Jungles, 1995). Thus, while surface electrodes are restricted to the selective stimulation of superficial muscle groups, they can produce sufficient forces from even large muscles. However, for long-term orthotic use, implanted electrodes appear to be the choice for the majority

of patients (Stanič et al., 1991). Implanted electrodes markedly reduce the time for donning the orthosis, allow for more selective stimulation (particularly of deep muscles), and require much lower currents than surface stimulators. Difficulties with implanted electrodes include the need for surgical reimplantations following electrode displacement and the inability to modify the electrode placement should alterations in electrode position occur over time (Stanič et al., 1991). Continued improvement in electrode materials and design will undoubtedly result in more predictable and reliable stimulation of muscles.

Upper extremity applications

Far fewer clinical advances have been made in the use of FES for the upper extremities of patients with hemiplegia than for the treatment of their lower extremities. This fact is not surprising. Although restoration of upper extremity function is an important and challenging goal, the application of FES to do so is much more difficult for the upper extremity than the lower extremity (Rebersek & Vodovnik, 1973). Because functional movements of the upper extremity are much more complex and variable than for the lower extremity, and because greater precision in the timing and finer gradations of the force and specificity of the muscles that are recruited is required for the upper extremity, a complex control signal is required. That is, the stimulation intensity, selection of muscles to be activated, and sequence of activation of the muscles must all be able to be modified by the patient.

In the 1970s, two studies reported the progress being made in the development of FES units for upper extremity applications (Merletti et al., 1975; Rebersek & Vodovnik, 1973; also see Kralj & Vodovnik, 1977).

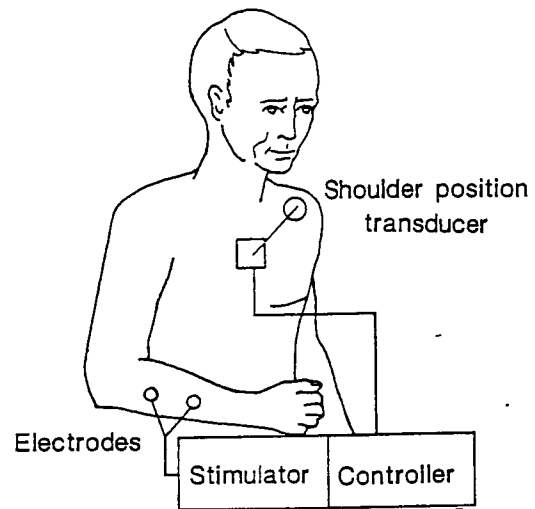


Figure 2. Proportionally controlled, single-channel FES unit for hand opening. A chest-mounted shoulder position sensor is used to voluntarily control stimulation of the wrist and finger extensors of the affected upper extremity. Protraction-retraction of the contralateral shoulder proportionally controls stimulator intensities for hand opening and closing. Shoulder elevation-depression is used for logic signals such as maintaining a set level of stimulation (i.e., "hold"). *Source:* Adapted with permission from Keith, M.W., Peckham, P.H., Thorpe, G.B., Buckett, J.R., Stroh, K.C., & Menger, V., Functional neuromuscular stimulation neuroprostheses for the tetraplegic hand, *Clinical Orthopaedics and Related Research*, 233(8), 25-32, © 1988.

Rebersek and Vodovnik (1973) reported the development of a proportionally controlled, single-channel FES unit that used elevation of the contralateral shoulder to control the intensity of stimulation to the extensor digitorum communis, abductor pollicis longus, and extensor pollicis longus muscles (see Figure 2).

A two-channel stimulator developed by Merletti and colleagues (1975) used contralat-

eral shoulder elevation and protraction to control the timing and amplitude of the stimulation (300 μ s, monopolar rectangular pulses at 30 pps) delivered to muscles that produced hand opening and elbow extension. Both of these studies provided results from several pilot subjects that showed improvements in the performance of functional tasks (e.g., moving an object to a defined point on a table) with the use of the stimulators.

Two other studies that appeared in the late 1970s provided additional encouragement for the use of FES in stroke patients (Baker, Yeh, Wilson, & Waters, 1979; Bowman, Baker, & Waters, 1979). These studies, using cyclic isotonic electrical stimulation of the wrist and finger flexors, showed that stimulation could be used to maintain or improve range of motion of the wrist and finger extensors. Interestingly, since the 1970s, there have been few new clinical studies reporting the use of FES for the treatment of the hand in patients with hemiplegia (cf., Gračanin, 1984).

Over the past 20 years, almost all of the technological improvements and clinical studies reporting the use of FES for improving hand function have been made using patients with spinal cord injuries. For both SCI and stroke patients, movements of the contralateral shoulder have generally been used to control the stimulation. However, because of marked differences in the motor problems presented by these two groups of patients, very different patterns of stimulation are used. As an example, in contrast to hand-opening movements typically elicited with stroke patients, FES with SCI patients attempts to produce grasping movements (Keith et al., 1988). Thus, although it is hoped that many of the technological advances made in FES for use with SCI patients

will become applicable to stroke patients, unique training and control strategies will ultimately need to be developed for the treatment of stroke patients.

An exciting recent application of FES in the upper extremity in patients with hemiplegia is the treatment of shoulder subluxation. In 1986, Baker and Parker used FES-induced contractions of flaccid shoulder muscles to reduce the degree of subluxation of the glenohumeral joint. Sixty-three patients with hemiplegia and shoulder subluxation were randomly assigned either to a control group ($n = 32$) using conventional "hemi-slings" or wheelchair arm supports or to an experimental group receiving 6 weeks of FES to the posterior deltoid and supraspinatus muscles and using conventional hemi-slings or wheelchair arm supports when not receiving FES. Treatments using compensated monophasic waveforms to produce tetanic contractions (12 to 25 pps) were gradually increased from 3-half-hr sessions each day to a single 6- to 7-hr session. Treatments were received 5 days a week. A significant decrease in shoulder subluxation was observed in the experimental group from an initial mean of 14.8 mm to a mean of 8.6 mm at the end of 6 weeks. No change was observed in the control group (mean 13.3 mm). This study suggests that functional electrical stimulation for the reduction of shoulder subluxation not only may prevent further joint separation but also can provide normal glenohumeral alignment by serving as an orthotic assist. As a result, it is suggested that this normal alignment of the shoulder complex creates a stable platform from which the patient may be able to develop more usable distal motor control (Baker & Parker, 1986). This study, however, did not involve any

functional outcome measures.

In a similar study, Faghri and colleagues (1994) examined the prophylactic application of FES in the acute phase of recovery from stroke to prevent shoulder subluxation. Twenty-six stroke patients with shoulder muscle flaccidity were randomly assigned to either a control group receiving conventional therapy ($n = 13$, 17 +/- 4 days poststroke) or an experimental group receiving conventional therapy and FES ($n = 13$, 16 +/- 5 days poststroke). FES intensity was set to obtain humeral elevation with some abduction and extension to pull the head of the humerus into the glenoid cavity using tetanic stimulation (35 pps). After treatment, the experimental group showed greater increases in arm abduction, improvements in arm muscle stretch reflexes and tone, and posterior deltoid surface electromyogram (EMG) activity when compared to the control group. Additionally, for the experimental group, there was a decrease in shoulder subluxation from 6.0 mm initially to 2.46 mm following the treatment program. In contrast, the control group showed increased shoulder subluxation from 4.0 mm initially to 9.85 mm following the treatment program. The results of this study suggest that FES intervention can be used to decrease shoulder subluxation and associated pain, maintain joint stability, and speed recovery of arm function in hemiplegic

stroke patients. As suggested by the authors, FES treatment may have resulted in faster recovery of shoulder function by preventing the disuse atrophy that may occur during the flaccid stage of recovery. The authors also noted that further studies are needed to optimize treatment protocols for further reducing shoulder subluxation and improving arm function. Nevertheless, this study suggests that FES of hemiplegic patients' shoulder may be a useful clinical tool.

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Although FES for the treatment of hemiplegia was first introduced 35 years ago, most clinicians still view this modality as an experimental tool. Much of the original excitement and enthusiasm has been replaced by more realistic expectations. Recent studies have suggested that FES may have the potential for improving the gait pattern of hemiplegic patients and for reducing shoulder subluxation. Additional clinical studies are needed to replicate these previous studies and to identify optimal treatment parameters. Controlled studies showing successful treatment of the hemiplegic hand are not presently available. Given the recent technological advances and promising clinical studies, it appears that FES may become a more common clinical tool in the treatment of the hemiplegic patient in the future.

REFERENCES

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- Baker, L.L., & Parker, K. (1986). Neuromuscular electrical stimulation of the muscles surrounding the shoulder. *Physical Therapy*, 66(12), 1,930-1,937.
- Baker, L.L., Yeh, C., Wilson, D., & Waters, R.L. (1979). Electrical stimulation of wrist and fingers for hemiplegic patients. *Physical Therapy*, 59(12), 1,495-1,499.
- Binder-Macleod, S.A., Halden, E.E., & Jungles, K.A. (1995). Effects of stimulation intensity on the physiological responses of human motor units. *Medicine and Science in Sports and Exercise*, 27(4), 556-565.
- Bogataj, U., Gros, N., Kljajić, M., Ačimović, R., & Maležič, M. (1995). The rehabilitation of gait in patients with

- hemiplegia: A comparison between conventional therapy and multichannel functional electrical stimulation therapy. *Physical Therapy*, 76(6), 490-502.
- Bogataj, U., Gros, N., Maležič, M., Kelih, B., Kljajić, M., & Ačimović, R. (1989). Restoration of gait during two to three weeks of therapy with multichannel electrical stimulation. *Physical Therapy*, 69(5), 319-327.
- Bowman, B.R., Baker, L.L., & Waters, R.L. (1979). Positional feedback and electrical stimulation: an automated treatment for the hemiplegic wrist. *Archives of Physical Medicine and Rehabilitation*, 60(11), 497-502.
- Brindley, G.S., Polkey, C.E., & Rushton, D.N. (1978). Electrical splinting of the knee in paraplegia. *Paraplegia*, 16, 428-435.
- Faghri, P.D., Rodgers, M.M., Glaser, R.M., Bors, J.G., Ho, C., & Akuthota, P. (1994). The effects of functional electrical stimulation on shoulder subluxation, arm function recovery, and shoulder pain in hemiplegic stroke patients. *Archives of Physical Medicine and Rehabilitation*, 75, 73-79.
- Gračanin, F. (1984). Functional electrical stimulation in external control of motor activity and movements of paralysed extremities. *International Journal of Rehabilitation Medicine*, 6, 25-30.
- Keith, M.W., Peckham, P.H., Thorpe, G.B., Buckett, J.R., Stroh, K.C., & Menger, V. (1988). Functional neuromuscular stimulation neuroprostheses for the tetraplegic hand. *Clinical Orthopaedics and Related Research*, 233(8), 25-32.
- Kralj, A., Ačimović, R., & Stanič, U. (1993). Enhancement of hemiplegic patient rehabilitation by means of functional electrical stimulation. *Prosthetics and Orthotics International*, 17, 107-114.
- Kralj, A., & Vodovnik, L. (1977). Functional electrical stimulation of the extremities. *Medical Engineering and Technology*, 1(1), 12-15, 75-78.
- Liberson, W.T., Holmquest, H.J., Scot, D., & Dow, M. (1961). Functional electrotherapy: Stimulation of the peroneal nerve synchronized with the swing phase of the gait of hemiplegic patients. *Archives of Physical Medicine and Rehabilitation*, 42, 101-105.
- Long, C., & Masciarelli, V.D. (1963). An electrophysiologic splint for the hand. *Archives of Physical Medicine and Rehabilitation*, 44, 499-503.
- Maležič, M., Bogataj, U., Gros, N., Dečman, I., Vrtačnik, P., Kljajić, M., & Ačimović-Janežič, R. (1992). Application of a programmable dual-channel adaptive electrical stimulation system for the control and analysis of gait. *Journal of Rehabilitation Research and Development*, 29, 41-53.
- Merletti, R., Ačimović, R., Grobelnik, S., & Cvilak, G. (1975). Electrophysiological orthosis for the upper extremity in hemiplegia: Feasibility study. *Archives of Physical Medicine and Rehabilitation*, 56, 507-513.
- Peckham, P.H. (1987). Functional electrical stimulation: Current status and future prospects of application to the neuromuscular system in spinal cord injury. *Paraplegia*, 24, 279-288.
- Rebersek, S., & Vodovnik, L. (1973). Proportionally controlled functional electrical stimulation of hand. *Archives of Physical Medicine and Rehabilitation*, 54, 378-382.
- Stanič, U., Ačimović-Janežič, R., Gros, N., Kljajić, M., Maležič, M., Bogataj, U., & Rozman, J. (1991). Functional electrical stimulation in lower extremity orthoses in hemiplegia. *Journal of Neurologic Rehabilitation*, 5, 23-35.
- Stanič, U., Ačimović-Janežič, R., Gros, N., Trnkoczy, A., Bajd, T., & Kljajić, M. (1978). Multichannel electrical stimulation for correction of hemiplegic gait. *Scandinavian Journal of Rehabilitation Medicine*, 10, 75-92.
- Takebe, K., Kukulka, C., Narayan, M.G., Milner, M., & Basmajian, J.V. (1975). Peroneal nerve stimulator in rehabilitation of hemiplegic patients. *Archives of Physical Medicine and Rehabilitation*, 56, 237-240.
- Vodovnik, L., Dimitrijević, M.R., Prevec, T., & Logar, M. (1966). Electronic walking aids for patients with peroneal palsy. *World Electronic Instruments*, 4(2), 58-61.
- Waters, R.L., McNeal, D., & Perry, J. (1975). Experimental correction of foot drop by electrical stimulation of the peroneal nerve. *Journal of Bone and Joint Surgery*, 57A(8), 1,047-1,054.