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Effects of Functional Electrical Stimulation on Wrist Function and Spasticity in Stroke: A Randomized Controlled Study

İnmede Fonksiyonel Elektrik Stimülasyonunun El Bileği Fonksiyonları ve Spastisiteye Etkisi: Randomize Kontrollü Bir Çalışma

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Summary

Objective: To investigate the effect of functional electrical stimulation on wrist function and spasticity in individuals with subacute/chronic stroke.
Materials and Methods: Randomized, controlled and prospective study. Twenty-eight patients with a mean age of 58.9±12.3 years and with a mean stroke duration of 100±62 days were randomly assigned to a functional electrical stimulation group or a control group. A standard rehabilitation program was applied to control group (n=14), and a standard rehabilitation program plus functional electrical stimulation of wrist and finger extensors were applied to the other group (n=14). Upper limb function was assessed by the Motricity index and spasticity was assessed by the Ashworth scale at the beginning and two weeks after the treatment. Resistance to passive wrist flexion and extension at 60, 90 and 120 degrees/sec velocities were measured by using an isokinetic dynamometer.
Results: Total upper extremity Motricity index scores were not different between the groups at the beginning (p=0.142). Intragroup analyses of the Motricity index showed that there was a statistically significant improvement in total Motricity index score in functional electrical stimulation group (n=14) (p=0.027), however, other studied parameters did not improve significantly (p>0.05). None of the studied parameters statistically significantly improved in the standard rehabilitation group (n=14) (p>0.05).
Conclusion: Adding functional electrical stimulation to standard rehabilitation program has a positive improving effect on the upper limb motor function in patients with post-stroke hemiplegia. *Turk J Phys Med Rehab 2013;59:97-102.*
Key Words: Stroke, functional electrical stimulation, spasticity

Özet

Amaç: Subakut/ kronik inmelilerde fonksiyonel elektrik stimülasyonunun el bileği fonksiyonları ve spastisitesine etkisini araştırmak.
Gereç ve Yöntem: Randomize, kontrollü, prospektif çalışma. Yaş ortalaması 58,9±12,3 yıl, ortalama inme süresi 100±62 gün olan 28 hasta, rastgele fonksiyonel elektrik stimülasyonu veya kontrol grubuna alındı. Kontrol grubunda bulunan hastalara (n=14) standart rehabilitasyon programı, diğer grup hastalara (n=14) standart rehabilitasyon programına ek olarak el bileği ve parmak ekstansörlerine fonksiyonel elektrik stimülasyon uygulandı. Üst ekstremite fonksiyonları Motricity indeksi, spatisite Ashworth skalası ile tedavi öncesi ve 2 hafta sonrası değerlendirildi. El bileği fleksiyon ve ekstansiyonunda pasif direnç izokinetik dinamometre ile 60, 90 ve 120 derece/sn açısal hızlarda ölçüldü.
Bulgular: Total üst ekstremite Motricity indeks skoru tedavi öncesi gruplar arasında benzerdi (p=0,142). Grup içi Motricity indeks analizlerinde, total Motricity indeks skoru fonksiyonel elektrik stimülasyonu grubunda düzelme gösterirken (n=14) (p=0,027), diğer parametrelerde anlamlı düzelme görülmedi (p>0,05). Fonksiyonel elektrik stimülasyon grubunda araştırılan diğer parametrelerde de düzelme görülmedi (p>0,05).
Sonuç: İnme sonrası gelişen hemiplejide standart rehabilitasyon programına eklenen fonksiyonel elektrik stimülasyon üst ekstremite motor fonksiyonlarını olumlu yönde etkilemektedir. *Türk Fiz Tıp Rehab Derg 2013;59:97-102.*
Anahtar Kelimeler: İnme, fonksiyonel elektrik stimülasyon, spastisite

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Introduction

Upper extremity impairment is one of the main factors that cause functional disability in stroke patients (1). Stroke causes alterations in the muscle tone and motor functions, and the rate of regaining isolated active movement and functional abilities is lower in the upper extremities when compared to the lower extremities (2,3). Approximately half of stroke patients have loss of movement and functions in their upper extremities, i.e. hands and arms, which results in major functional problems (4).

Most of the improvement in the upper extremity functions occurs in the first three months after stroke, however, the improvement may continue up to six months (5,6). After the stroke related to middle cerebral artery occlusion, complete or near-complete recovery of the upper extremity functions is only 11.6% in the first six months (7). There is no definitive therapy that accelerates the recovery process and increases the level of neurologic improvement. In this period, neurophysiologic exercises, sensorimotor integration, proprioceptive neuromuscular facilitation, biofeedback, and functional electrical stimulation are the techniques that are believed to improve motor recovery (8,9). Improving posture through physical management (nurse care, physiotherapy, occupational therapy), preservation of joint range of motion, reinforcement, splinting, and pain control are the main points of spasticity management. The aim of the therapy is to reduce increased and uncontrolled motor nerve activity in order to decrease abnormal sensory input in all patients. All pharmacological interventions are the elements of a physical therapy program, and botulinum toxin treatment is a good example for it. Botulinum toxin treatment is used in company with physiotherapy, alone or together with functional electrical stimulation. However, there are discrepancies on the combination of these therapies, the treatment period (acute, subacute, chronic), optimal length of the therapy, application method and the motor deficit level required for their use (8-15).

Functional electrical stimulation is a neuromuscular electrical stimulation method used for stimulating task-specific and functional activities. A number of studies reported that functional electrical stimulation was effective for improving upper extremity functions, such as holding, grasping, moving and releasing the objects (7). Functional electrical stimulation is thought to show its effects through accelerating motor healing, decreasing spasticity, strengthening the muscles, and increasing articular range of motion (4,16). In the literature, various studies report that afferent stimulation obtained by functional electrical stimulation increases nerve excitability arising from the paretic area and provides neuroplasticity (17,18). Various electrical stimulation methods were found to be effective, however, treatment longer than 90 minutes/session or 36 sessions/12 weeks did not provide an additional benefit (5,19). Still, there is no agreement on the duration of an effective treatment that shows its effect within the shortest time. Although some studies aim regaining upper extremity functions, there are no standardized methods to evaluate the results. A Cochrane review investigated the efficacy of electrical stimulation methods for enhancing upper limb motor recovery. However, numerous methodological limitations make the interpretation of the results difficult (20,21).

The aim of our study was to quantify the effect of short-term functional electrical stimulation on motor improvement, functional gain and spasticity of the upper extremity in patients with subacute/chronic stroke.

Materials and Methods

Twenty-eight subacute/chronic stroke patients were investigated in a randomized, controlled and prospective study. The inclusion criteria were as follows: presence of the first and unilateral attack, stroke duration less than 6 months - more than 1 month, conserved communicative and cognitive skills, age >18 years and absence of a medical contraindication for functional electrical stimulation. Patients with implanted electronic pacemakers, severe cardiac arrhythmia, articular range of motion limitation in the wrist, shoulder pain, complex regional pain syndrome, negligence and lower motor neuron lesions were excluded from the study. During the treatment period, the patients went on using medications and splints they used before for antispasticity. The age, gender, height, weight, dominant side, hemiplegic side, the etiology of the cerebrovascular accident (ischemic, hemorrhagic) and the duration of the stroke were noted, and Brunnstrom stage of the upper extremity and degree of the spasticity of the upper extremity were evaluated qualitatively and quantitatively. Upper extremity functions were evaluated using the Motricity index (pinch-grasp, elbow flexion, shoulder abduction and upper extremity total Motricity score), clinical evaluation of the elbow, wrist and the fingers, and the spasticity was evaluated using the Ashworth scale (22,23). Computerized isokinetic dynamometer (Biodex, Biodex Corp., Shirley, NY) was used for the evaluation of the wrist spasticity. The resistance of the wrist during flexion and extension was measured at 60°, 90° and 120°/second angular velocities. All measurements were performed before and after 2 weeks of the treatment.

An assessor-blind, randomized controlled design was used. The patient group was divided into two groups via the sealed envelope method, as the standard rehabilitation program group and the standard rehabilitation program plus functional electrical stimulation group. The physician who performed the assessments was blinded to the spasticity, motor power and isokinetic measurements, however, neither the patients nor the therapists who delivered the intervention were blinded, because it was impossible to do so. The randomization flowchart is shown in Figure 1. The standard rehabilitation program was applied to 14 patients, and other 14 patients had the standard rehabilitation program plus functional electrical stimulation (Samms® Professional) of wrist and finger extensors (30-minute sessions/5 days/week, for 2 weeks). Extensor digitorum communis, extensor carpi ulnaris and extensor carpi radialis were stimulated through surface electrodes in the treatment group. The stimulation current intensity was set to produce full wrist and finger extension with a duty cycle of 10 seconds on and 12 seconds off. The stimulus pulse was a biphasic rectangular waveform with a pulse width of 250 µsn, frequency of 36 Hz, and ramp up and down time of 3 seconds each. The current intensity was adjusted to subject comfort.

Statistical Analysis

Statistical analyses were performed with SPSS version 11.0 for Windows (Chicago, USA). All data were entered into a database to be analyzed later. Chi-square statistics were calculated to analyze the differences in frequencies for the categorical variables. Demographic and clinical data were compared between the groups with the use of the Mann-Whitney U test. Independent sample Wilcoxon Signed-Rank test was used for the evaluation of the improvement within the groups. A "p" value of less than 0.05 was considered statistically significant. All patients gave their written informed consent to participate in the study.

Results

The mean age of 28 stroke patients fulfilling the inclusion criteria was 58.9±12.3 years (23-76). The mean disease duration was 100±62 (28-224) days. The demographic and clinical characteristics (age, gender, type of the cerebrovascular accident, duration of the disease, and hemiplegic side) of 28 subacute/chronic stroke patients (divided into standard rehabilitation program and standard rehabilitation program + functional electrical stimulation groups) are shown in Table 1. There were no statistically significant differences between the groups for these characteristics.

Total Motricity index scores used for the evaluation of the upper extremity function were not different between the groups at the beginning (p=0.142). There were no differences between the two groups for elbow, wrist or finger flexor spasticity when Ashworth scale scores, a scale that was used for evaluation of the spasticity level, were taken into consideration (p=0.513, p=0.119, p=0.655, respectively).

There were no differences between the groups for passive resistance measurements during wrist flexion-extension at 60º, 90º and 120º angular velocities (Table 2).

Although there was no statistically significant difference between the groups for total Motricity index scores after the treatment, there was an improvement that was close to statistical significance in the standard treatment+functional electrical stimulation group when compared to standard treatment group (p=0.073). There were no differences between the groups for elbow, wrist and finger flexor spasticity when Ashworth scale scores were taken into consideration (p=0.875, p=0.736, p=0.233, respectively). There were no differences between the groups for passive resistance measurements during wrist flexion-extension at 60º, 90º and 120º angular velocities (Table 3).

The difference between the scores before and after treatment was defined as delta gain. Delta gain was calculated for all measurements (Brunnstrom, Motricity index, Ashworth, isokinetic measurements) in both groups. The delta gains for upper extremity Brunnstrom and Motricity total scores were statistically significantly different between the groups (p=0.008, p=0.027, respectively). Hand Brunnstrom and elbow spasticity Ashworth values indicated a statistically insignificant gain in standard treatment + functional electrical stimulation group, however, it could still be regarded as an improvement (p=0.083, p=0.059, respectively). There were no differences between the groups in the delta gain differences for quantitative wrist spasticity evaluated as passive resistance measurements during wrist flexion - extension at 60º, 90º and 120º angular velocities (Table 4).

Discussion

In this study, we investigated the effect of functional electrical stimulation on hand-wrist functions and spasticity in patients with subacute/chronic stroke, and we found that functional electrical stimulation added to a 2-week standard rehabilitation program was effective on the motor functions.

Table 1. Demographic characteristics of the patients in standard rehabilitation program group (SRP) and SRP +FES group.

	SRP (n=14)	SRP+FES (n=14)	p value
Gender (Male/Female)	8/6	7/7	0.710
Side of paresis (Right/Left)	6/8	7/7	0.710
Type of stroke (Hemorrhagic/Ishemic)	3/11	1/13	0.289
Age (years) (mean±SD) (min-max)	62.3 ±9.6 (43-76)	55.6±14.1 (23-73)	0.152
Time from onset (days) (mean±SD) (min-max)	88.4±59.9 (28-204)	112±64.0 (56-224)	0.324

Table 2. Clinical characteristics of the patients in standard rehabilitation program group (SRP) and SRP+FES group at the beginning of the study.

	SRP (n=14)	SRP + FES (n=14)	p value
Brunnstrom upper extremity stage			
2	11 (78.6 %)	8 (57.1 %)	
3	3 (21.4 %)	4 (28.6 %)	0.179
4		2 (14.3 %)	
Brunnstrom hand stage			
2	11 (78.6 %)	10 (71.4 %)	
3	3 (21.4 %)	2 (14.3 %)	0.544
4		2 (14.3 %)	
Total Motricity index (median)	9 (0-25)	14 (0-60)	0.142
Flexion peak torque of wrist (Nm), (mean±SD)			
60º/sn	3.20±0.7	3.95±1.7	0.150
90º/sn	3.03±0.7	3.95±1.5	0.057
120º/sn	3.10±0.6	3.85±1.2	0.052
Extension peak torque of wrist (Nm), (mean±SD)			
60º/sn	3.64±0.7	4.42±1.9	0.165
90º/sn	3.47±0.7	4.37±1.7	0.080
120º/sn	3.57±0.6	4.24±1.3	0.113

* SRP: Standard rehabilitation program; FES: Functional electric stimulation.

Table 3. Clinical characteristics of the patients in standard rehabilitation program group (SRP) and SRP +FES group after the treatment.

	SRP (n=14)	SRP + FES (n=14)	p value
Brunnstrom upper extremity stage			
2	9 (64.3%)	4 (28.6 %)	
3	4 (28.6 %)	6 (42.9 %)	
4	1 (7.1 %)	3 (21.4 %)	0.044
5		1 (7.1 %)	
Brunnstrom hand stage			
2	10 (71.4%)	9 (64.3%)	
3	3 (21.4 %)	2 (14.3 %)	0.540
4	1 (7.1 %)	2 (14.3 %)	
5		1 (7.1 %)	
Total Motricity index (median)	11.5 (0-33)	19.5 (0-68)	.073
Flexion peak torque of wrist (Nm), (mean±SD)			
60º/sec	3.26±0.9	3.69±0.7	0.194
90º/sec	3.22±1.0	3.55±0.8	0.344
120º/sec	3.30±0.9	3.50±0.7	0.500
Extension peak torque of wrist (Nm) (mean±SD),			
60º/sec	3.62±0.9	4.04±0.8	0.215
90º/sec	3.68±1.0	3.97±0.9	0.427
120º/sec	3.60±1.0	3.97±0.8	0.269

* SRP: Standard rehabilitation program; FES: Functional electric stimulation.

Table 4. Change from baseline in standard rehabilitation program group (SRP) and SRP+FES group.

	SRP (n=14)	SRP +FES Group (n=14)	p value
Flexion peak torque of wrist (mean±SD), (Nm)			
60º/sn	-0.06±1.16	0.26±1.43	0.963
90º/sn	-0.19±1.17	0.00±1.25	0.434
120º/sn	-0.20±1.03	0.35±1.04	0.289
Extension peak torque of wrist (mean±SD), (Nm)			
60º/sn	0.21±0.98	0.38±1.5	0.818
90º/sn	-0.21±1.01	0.40±1.3	0.240
120º/sn	-0.02±0.92	0.27±1.1	0.645

* SRP: Standard rehabilitation program; FES: Functional electric stimulation.

Our study was limited by several issues. First, the number of patients in our study was small, that is why explorative subgroup analysis (between Brunnstrom stages, Ashworth levels) could not be performed. Second, the patients could not be divided into two groups as subacute and chronic because of small number of patients. Another limitation was our single-blind study design. For a double-blind study, either the patient or the therapist had to be blinded for the type of the therapy, however, since this blinding was not possible, this limitation could not be overcome in our study.

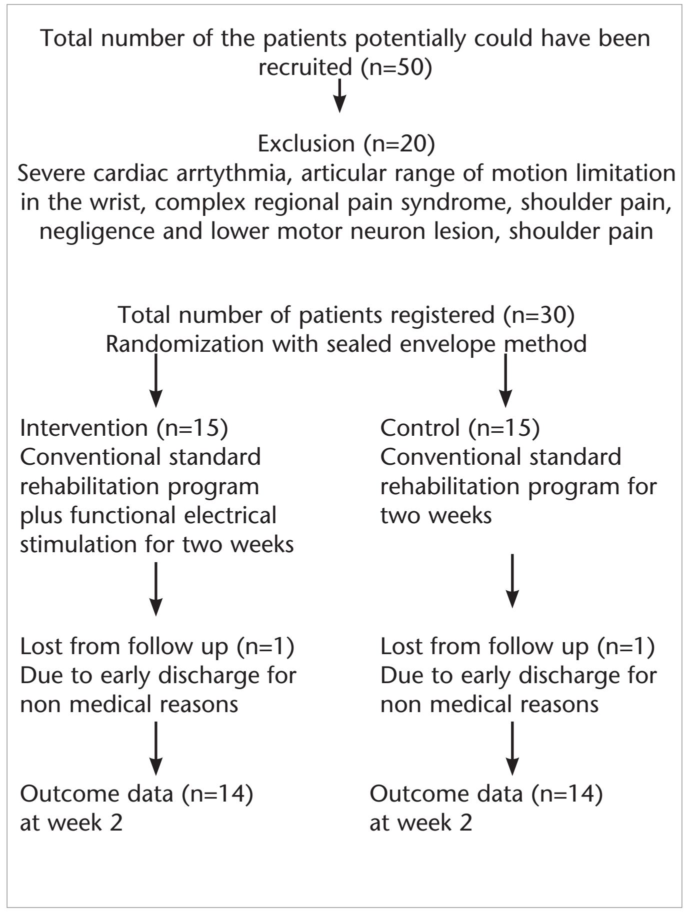

Figure 1. Flowchart for randomized subject assignment in this study.

We used the Ashworth scale to evaluate spasticity. The Ashworth scale is developed to evaluate spasticity, and it is an easy-to-use, valid and widely used scale to evaluate the treatment outcome (24,25). The Motricity index was a good choice since it was defined as a valid test to assess motor impairment in stroke patients. The valuable determinant of this test is to measure task-specific skills of the affected (unilateral) extremity (26). We used the isokinetic evaluation method to quantify spasticity. This method was previously used in other studies to quantify spasticity, however, it was not used before to show the effectiveness of electrical stimulation on the spasticity, what we did in our study (27).

Electrical stimulation is roughly divided into two as functional and therapeutic electrical stimulation. Therapeutic electrical stimulation is divided into four as neuromuscular electrical stimulation, electromyography triggered electrical stimulation, positional feedback stimulation training, and transcutaneous electrical stimulation (28). The basic difference between functional electrical stimulation and therapeutic electrical stimulation is arrangement of the present movement by facilitation, and by this way, making it functional (29).

Use of neuromuscular electric stimulation in the upper extremity for reorganization of active movement following hemiplegia involves the movements of the wrist in addition to the shoulder region (30,31). Vuagnat et al. (32) reported that, in addition to shoulder pain, functional electrical stimulation helped functional restoration and motor development in the acute period. Similarly, Mangold et al. (33) stressed the efficiency of functional electrical stimulation on both the shoulder and the wrist in the early phase, and reported that it helped functional improvement. Electrical stimulation applications were performed in the forms of electrical stimulation subgroups in the chronic period for therapeutic purposes (34).

Certain studies investigated the efficiency of therapeutic electrical stimulation in subacute/chronic period (28,35). We included patients in subacute/chronic period in our study and aimed to show the efficiency of functional electrical stimulation. The return of motor function in the upper extremity starts within the first two weeks and usually finalizes within two months. This process may extend up to six months. The use of neural pathways in the affected areas helps reorganization and healing process not only in the acute period, but also in the subacute/chronic period (36-38). The positive changes observed in motor levels and motor impairment outcome showed that functional electrical stimulation could be effective in the neurologic healing process in this period. Our results confirm that subacute/chronic effect of functional electrical stimulation is observed especially in upper extremity motor and functional gains. Although these positive effects were not statistically reflected on the hand Brunnstrom level, there were improvements when these parameters were concerned. We supposed that positive effects concentrated on the proximal region were related to functional electrical stimulation-mediated motor relearning in our study. In addition to that, the effect of functional electrical stimulation on spasticity was not as pronounced as its effect on the motor level. There were no statistically significant differences between the treatment groups for the effect of spasticity on wrist and finger extensors, however, the elbow spasticity lessened in the functional electrical stimulation group. We supposed that this difference was related to concentration of motor healing, especially in the proximal region, and as hemiplegic synergies, which were originally described by Twitchell (39), to the negative relation between the motor gain and spasticity in the upper extremity (5,40). In addition to all of these positive progresses, the presence of some parameters that did not exhibit any differences between the treatment groups (hand Brunnstrom, spasticity level in the wrist and finger flexors, quantitative wrist spasticity measurement) may be related to short-term (2 weeks/5 days a week/30 minutes) application of functional electrical stimulation.

There is no consensus on the time of appearance of the optimal effects of electrical stimulation in stroke patients (41). Maximum treatment period is reported to be 12 weeks/36 sessions/90 minutes (19). Kroon et al. (28) performed a systematic review of electrical stimulation in stroke patients and mentioned the study by Bowman et al. in which a treatment of 2x30 min a day was performed 5 days of a week, for 4 weeks. Various authors performed functional electrical stimulation in the chronic period as did Cauraugh et al. (30), who defined the treatment as 2x30 trials a day/3 days a week/2 weeks. Our treatment duration was shorter when compared to the other studies, however, it was more intense. Although our treatment period was not similar to other studies, we supposed that intensive treatment program resulted in positive results. We did not investigate the long-term effects of functional electrical stimulation which appeared as a limitation of our study, but long-lasting therapeutic effects of functional electrical stimulation have been reported in a previous study on patient groups including stroke individuals (42).

Decreased spasticity, increased muscle strength, increased awareness, increased range of motion in joints, and induced neuroplasticity are some of the possible mechanisms that can explain the improvement observed in Brunnstrom stage and total Motricity index score in our study.

We believe that this rapid improvement observed in our patients decreased spasticity, increased awareness and muscle strength. Additionally, increased range of motion of the joints played an important role for neuroplasticity, for which a longer time period was needed. Whatever are the mechanisms, standard rehabilitation program combined with functional electrical stimulation appeared as an effective treatment option in subacute and chronic stroke patients.

Conclusion

Adding functional electrical stimulation to standard rehabilitation program has a positive effect on improving upper limb motor recovery and function in patients with post-stroke hemiplegia. New studies with larger sample sizes and with different functional electrical stimulation parameters may help determination of the most effective program.

Conflict of Interest
Authors reported no conflicts of interest.

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