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Fatih BAYGUTALP
Kazım ŞENEL

RESEARCH

EFFECT OF NEUROMUSCULAR ELECTRICAL STIMULATION IN HEMIPLEGIC UPPER EXTREMITY REHABILITATION

ABSTRACT

Introduction: In this study, it was aimed to investigate the efficacy of the combined application of conventional physical therapy and neuromuscular electrical stimulation applied to the shoulder, arm, elbow and wrist of the hemiplegic side in the rehabilitation of hemiplegic patients.

Materials and Method: The study group received conventional physical therapy modalities plus neuromuscular electrical stimulation (n=15) whereas the control group received conventional therapy alone (n=15). Neuromuscular electrical stimulation was applied to the shoulder, arm, elbow, and wrist of the hemiplegic side. Groups were evaluated by active joint range of motion, the Modified Ashworth Scale, Brunnstrom's upper extremity and hand staging, Visual Analog Scale, and the Barthel index at four time points: before the therapy (T1), after the first week of therapy (T2), at discharge (T3), and two months after discharge (T4).

Results: In the study group, significantly better improvements were observed in the active external rotation of the shoulder for the period "before the therapy until the discharge" ($p<0.05$), in Modified Ashworth Scale values of the wrist for the period "before the therapy and after the first week of the therapy" ($p<0.05$), and in Visual Analog Scale values of the hemiplegic upper extremity for all comparisons ($p<0.05$).

Conclusion: The combination of conventional physical therapy modalities, with neuromuscular electrical stimulation applied to the whole upper extremity, seems to be more effective and convenient in hemiplegic upper extremity rehabilitation.

Key Words: Hemiplegia; Upper Extremity; Rehabilitation.

ARAŞTIRMA

HEMİPLEJİK ÜST EKSTREMİTE REHABİLİTASYONUNDA NÖROMÜSKÜLER ELEKTRİKSEL STİMÜLASYONUN ETKİSİ

ÖZ

Giriş: Bu araştırmada hemiplejik hastalarda konvansiyonel rehabilitasyona ilaveten nöromüsküler elektriksel stimülasyon uygulamasının omuz, kol, dirsek ve el bileğine kombine uygulanmasının rehabilitasyondaki etkinliğinin araştırılması amaçlanmıştır.

Gereç ve Yöntem: Çalışma grubuna (n=15) konvansiyonel fizik tedavi modaliteleri ve nöromüsküler elektriksel stimülasyon, kontrol grubuna (n=15) yalnız konvansiyonel fizik tedavi modaliteleri uygulandı. Nöromüsküler elektriksel stimülasyon, inmeli taraftaki omuz, kol, dirsek ve el bileğine uygulandı. Gruplar tedavi öncesi, tedavinin birinci haftası, taburculuk ve iki ay sonra aktif eklem hareket açıklığı, Modifiye Ashworth Skalası, Brunnstrom'un üst ekstremite ve el evrelemesi, Vizuel Analog Skala ve Barthel indeksi ile değerlendirildi.

Bulgular: Nöromüsküler elektriksel stimülasyon grubunda; tedavi öncesi ve taburculuk dönemi aralığında omuz aktif dış rotasyonunda anlamlı artış ($p<0,05$), tedavi öncesi ve tedavinin birinci haftası aralığında el bileği Modifiye Ashworth Skalası değerlerinde anlamlı azalma ($p<0,05$) ve hemiplejik üst ekstremite ağrısı Vizuel Analog Skala değerlerinde tüm karşılaştırmalarda anlamlı azalma ($p<0,05$) saptandı.

Sonuç: Hemiplejik üst ekstremite rehabilitasyonunda konvansiyonel fizik tedavi modaliteleri ve NMES kombinasyonunun daha faydalı olduğunu ayrıca nöromüsküler elektriksel stimülasyonun tüm üst ekstremiteye uygulanmasının daha etkili olduğu düşünülmüştür.

Anahtar Sözcükler: Hemipleji; Üst Ekstremite; Rehabilitasyon.

İletişim *(Correspondance)*

Fatih BAYGUTALP
Atatürk Üniversitesi Tıp Fakültesi Fiziksel Tıp ve Rehabilitasyon Anabilim Dalı ERZURUM

Tlf: 0442 344 66 66
e-posta: drbaygutalp@gmail.com

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Atatürk Üniversitesi Tıp Fakültesi Fiziksel Tıp ve Rehabilitasyon Anabilim Dalı ERZURUM

INTRODUCTION

Stroke represents the most common and most important neurological condition in adult populations. Hemiplegia developing after stroke involves the upper extremities more commonly than the lower extremities. Unfortunately, stroke affecting the upper extremity is associated with a slower and less complete motor and functional recovery. Specific treatments aimed at strengthening motor functions and improving functional recovery are important elements of hemiplegia rehabilitation (1,2). In this regard, neuromuscular electrical stimulation (NMES) is a commonly used as a therapeutic modality in the treatment of spasticity to accelerate functional recovery and protect or increase range of active movement (ROM) and muscular strength in hemiplegic upper extremities (3).

We aimed to investigate the effect of NMES applied to the whole upper extremity (shoulder, arm, forearm, and hand), in addition to conventional physical therapy, on the rehabilitation of hemiplegic patients.

MATERIALS AND METHOD

This prospective randomized study involved 30 patients with stroke-related hemiplegia who were admitted to Ataturk University, Faculty of Medicine, Department of Physical Therapy and Rehabilitation between May 2009 and December 2009. Patients were randomized into two groups. The study group received conventional physiotherapy plus NMES and the controls received conventional physiotherapy alone. Exclusion criteria included the following: history of the stroke episode > 1 year ago; unconsciousness; presence of bilateral hemiplegia; presence of neglect syndrome, history of another episode of stroke or accompanying neurological condition; decompensated cardiac disease; cardiac pacemaker; active infection; neoplasia; and skin lesions at the site of application. Four assessment points were defined for the study: before therapy (T1); at completion of the first week of therapy (T2); at discharge (T3); and two months after discharge (T4). Clinical assessments included the measurement of active ROM of the shoulder in all directions and active flexion in the elbow, wrist, and 2nd, 3rd, and 4th metacarpophalangeal (MCP) joints, using a standard goniometer. Upper extremity tonus was measured using Modified Ashworth Scale (MAS) (4). Visual analog scale (VAS) was used to score the pain in the hemiplegic upper extremity (5); Brunnstrom's upper extremity and hand scales were used for evaluation of the upper extremity and hand, respectively (6). Turkish validity and reliability studies of MAS, VAS and Brunnstrom's scales have not be reported yet. Thus, Turkish translation of these scales were performed to patients. Functional status was measured using the Turkish version (7) of original Barthel Index (8). Information was provided to all patients regarding the study procedures and informed consent was obtained. The study was approved by the Local Ethics Committee and was conducted in accordance with the 2002 version of the Declaration of Helsinki, 1975. The study was conducted within the rules of the Good Medical Practice Guidelines and Good Laboratories Practice Guidelines.

A conventional rehabilitation program was taught to all patients, which included the correct positioning of extremities; passive/active assisted movement exercises, active/resisted ROM exercises and stretching exercises 3 times daily, adjusted according to the level of muscular strength. In addition; endurance, standing, posture and balance training were performed.

A low-frequency current (frequency: 20-50 Hz) for 30 min per session was applied to the dorsal shoulder and wrist, and for 60 min per session to the arm and elbow once daily, 5 times per week, for 3 weeks. All patients and controls were discharged after 3-week rehabilitation. The NMES group consisted of 15 patients and NMES was applied superficially with a combined dual output device (Intelect Advanced, Chattanooga Inc.) with two electrodes at each output. NMES was initially applied to the shoulder, arm, and elbow of the hemiplegic side, and then to the dorsal wrist along with the arm and elbow. In addition, a low-frequency current was applied to the antagonist muscle groups using a tonic muscular strengthening protocol. In the first 30-minute period, 4 electrodes were attached as described below: the positive electrode was attached to the supraspinatus fossa where the suprascapular nerve innervating the supraspinatus muscle follows a superficial course; and the negative electrode was attached to the superoposterior side of the deltoid muscle. On the arm, a positive electrode was attached posterolaterally to the proximal third of the arm close to the radial nerve innervating the triceps muscle, and on the elbow the positive electrode was attached to the lateral epicondyle where the radial nerve follows its most superficial course and the extensor muscles of the forearm originate; the negative electrode was attached to the posteromedial elbow in the olecranon where the triceps muscle terminates. In the next 30-minute session, 4 electrodes were attached to the same regions as above on the arm; on the elbow the positive electrode was attached to the lateral epicondyle where the radial nerve follows its most superficial course and the extensor muscles of the forearm originate; the negative electrode was attached to the dorsal surface of the wrist. Current intensity was increased as needed to obtain maximum extension in the elbow, wrist, and 2nd, 3rd, 4th MCP joints without causing significant discomfort for the patient.

Within- and between-group comparisons were performed for each set of variables recorded during the pre-treatment and follow-up phase of the study. All data were analyzed using the SPSS/PC statistical software package (SPSS, v.18.0 for Windows, SPSS Inc. Chicago). Statistical comparisons of the scores were performed using the non-parametric Wilcoxon test (within group comparisons) or Mann Whitney U test (between group comparisons). For the comparison of categorical variables, the chi-square test and Fisher exact test were used. A p value less than 0.5 was considered statistically significant, for a 95% confidence interval.

RESULTS

No significant differences were found between patient and control groups in terms of clinical and demographic characteristics such as age, disease duration, etiology, hemiplegic and dominant sides (p>0.05) (Table 1).

When NMES group was compared to controls with regard to goniometric measurements of active ROM of the shoulder, the change in external rotation was significantly higher in the T1-T3 period (p=0.03); however, no significant differences were found in other directions during this time interval. In addition, no significant differences were observed during the T1-T2 and T1-T4 periods in any direction (p>0.05).

No significant changes occurred in the goniometric measurements for active flexion of the elbow, wrist, and 2nd, 3rd, and 4th MCP joints during the T1-T2, T1-T3, and T1-T4 intervals (p>0.05).

The changes in MAS scores for the shoulder and elbow during the T1-T2 period did not differ significantly (p>0.05). However, the change in wrist MAS was significantly lower among NMES patients (p=0.02). The changes in shoulder, elbow and wrist MAS scores were not significantly different between the groups for the T1-T3 and T1-T4 periods (p>0.05) (Table 2).

In the NMES group, a greater improvement in VAS scores was found for upper extremity pain on the hemiplegic side during the T1-T2, T1-T3, and T1-T4 periods, compared to the control group (p=0.02, p=0.04, p=0.04 respectively) (Table 3). There were no statistically significant differences in the changes in upper extremity scores, hand Brunnstrom stages and BI (p>0.05) (Table 4 and 5).

DISCUSSION

Upper extremity involvement is more common in hemiplegia that develops after an episode of stroke. In addition, motor healing is slower and less complete in hemiplegia involving this site as compared to the lower extremities. Unfortunately, functional disability in the upper extremity occurring after stroke is not only very common, but is also extremely debilitating for the patient. For this reason, specific treatments complementary to the conventional therapeutic approaches aiming to improve motor abilities and functional status are of clinical importance (1,2).

Table 1— Distribution of Groups By Age, Disease Duration, Etiology, Hemiplegic and Dominant Sides.

		NMES Group (n:15)	Control Group (n:15)	Chi Square, p
Age (year) mean±sd (min/max)		56.07±11.61 (42/79)	60.27±6.375 (42/69)	p:0.228
Disease duration (month) mean±SD (min/max)		6.50±6.16 (1/11.50)	3.65±4.00 (0.53/11.16)	p:0.119
Etiology n (%)	Ischemia	11 (73.3%)	8 (53.3%)	Chi square:1.292 p:0.256
	Hemorrhage	4 (26.6%)	7 (46.6%)	
Hemiplegic side n (%)	Right	4 (26.6%)	4 (26.6%)	Chi square:1.292 p:0.256
	Left	11 (73.3%)	11 (73.3%)	
Dominant side n (%)	Right	14 (93.3%)	15 (100%)	Chi square:0.0 p: 1.0
	Left	1 (6.6%)	– (–)	

NMES: Neuromuscular Electrical Stimulation.

Table 2— Comparison of the Changes in Shoulder, Elbow and Wrist MAS Scores.

	ΔT1-T2			ΔT1-T3			ΔT1-T4		
	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p
Shoulder MAS	0.0±0.845 (-2/2)	0.13±0.352 (-1/0)	0.476	-0.5±1.1 (-3/1)	-0.3±0.617 (-2/0)	0.904	-0.33±1.175 (-2/2)	-0.3±1.496 (-3/2)	0.904
Elbow MAS	-0.13±0.51 (-1/1)	-0.1±0.352 (-1/0)	0.952	-0.6±0.737 (-2/0)	-0.4±0.9 (-2/1)	0.513	-0.6±1.4 (-2/3)	-0.7±1.3 (-3/1)	0.513
Wrist MAS	0.12±0.15 (0/1)	-0.1±0.15 (-1/0)	0.02	-0.4±0.828 (-3/0)	-0.3±0.61 (-2/0)	0.979	0.0±1.134 (-3/2)	-0.47±1 (-3/1)	0.979

NMES: Neuromuscular Electrical Stimulation.
MAS: Modified Ashworth Scale.
Δ: Changes between, T1:Before therapy, T2: at completion of the first week of therapy, T3: at discharge, T4: two months after discharge.

Table 3— Comparison of the Changes in Hemiplegic Upper Extremity VAS Scores.

	ΔT1-T2			ΔT1-T3			ΔT1-T4		
	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NNMES Group v (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p
VAS	-1.8±1.885 (-5/0)	-0.4±0.632 (-2/0)	0.02	-3.4±2.1 (-7/0)	-1.2±1.1 (-4/0)	0.04	-4±2.07 (-7/0)	-2.4±1.8 (-5/0)	0.04

NMES: Neuromuscular Electrical Stimulation.
VAS: Visual Analog Scale
Δ: Changes between, T1:Before therapy, T2: at completion of the first week of therapy, T3: at discharge, T4: two months after discharge.

Table 4— Comparison of the Changes Between Upper Extremity and Hand Brunnstrom Scores.

	ΔT1-T2			ΔT1-T3			ΔT1-T4		
	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p
Upper extremity Brunnstrom	0.33±0.488 (0/1)	0.20±0.414 (0/1)	0.417	0.93±0.594 (0/2)	0.53±0.743 (0/2)	0.076	1.20±0.676 (0/2)	1.07±1.033 (0/3)	0.630
Hand Brunnstrom	0.07±0.258 (0/1)	0.13±0.352 (0/1)	0.550	0.67±0.816 (0/3)	0.47±0.516 (0/1)	0.604	0.73±0.884 (0/3)	1.07±1.223 (0/4)	0.504

NMES: Neuromuscular Electrical Stimulation.
Δ: Changes between, T1: Before therapy, T2: at completion of the first week of therapy, T3: at discharge, T4: two months after discharge.

Table 5— Comparison of the Changes in BI Scores.

	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p	NMES Group mean±sd (min/max)	Control Group mean±sd (min/max)	p
BI	7.33 ±12.938 (0/40)	4.33 ±12.228 (-10/40)	0.313	11.67 ±12.344 (0/40)	7.00 ±13.862 (-10/40)	0.086	14.33 ±14.500 (0/45)	16.67 ±20.500 (-5/50)	0.967

NMES: Neuromuscular Electrical Stimulation.
BI: Barthel Index.

Conventional therapy, neurophysiological therapy, constraint-induced movement therapy, NMES, functional electrical stimulation (FES), bio-feedback, EMG bio-feedback, and orthosis are some examples of the therapeutic modalities have been used in hemiplegia rehabilitation (1). The aim of our study was to examine the effect of NMES, given in combination with conventional physical therapy, on the upper extremity function of stroke-related hemiplegia patients. For study purposes, NMES was applied to the shoulder, arm, elbow, and wrist. Our results suggest that NMES combined with conventional physical therapy is more effective in improving the ROM of the upper extremity, spasticity and pain, compared to conventional therapy alone.

In addition, electromyography (EMG)-triggered NMES (active NMES) has been using in enhancing the upper extremity motor and functional recovery of stroke patients. In a randomized, controlled trial performed on thirty-one hemiplegic patients, the authors did not report significant difference between the efficiency of active NMES and NMES without EMG (passive NMES) groups. It is concluded that both active and passive NMES can be used as adjuvant therapy in the neurophysiologic exercise programs to enhance the upper extremity motor and functional recovery of stroke survivors (9).

The primary use of NMES in stroke rehabilitation is to protect or increase muscular strength, to reduce spasticity, and to improve motor abilities and functional status (10). It is also useful in the prevention of the joint contracture and muscular atrophy that develop due to immobility. NMES has been shown to improve passive ROM (11,12) and active ROM (12,13) and it is commonly used for the rehabilitation of hemiplegic shoulders and hands.

However, the most effective application site, time, method, and duration of NMES in patients with stroke have not been clearly defined (14). Our literature search has not revealed any studies examining the efficacy of combined treatment with conventional rehabilitation and whole upper body extremity NMES involving shoulder, arm, elbow, and wrist. Most of the studies of NMES applied this modality separately to the shoulder (14,15), to the arm and forearm (16), only to the forearm (11,12), or to the forearm and hand muscles (13,17). In hemiplegic patients, NMES is generally used within the first year after stroke. In our study, the average duration of the disease was 6.50±6.16 months in the NMES group and 3.65±4 months in the control group, with no significant difference between groups. Also, the timing of NMES in our patients was in accordance with the literature data (13,17).

Although the reported duration of NMES targeting muscular strength usually varies between 3 and 6 weeks, treatment protocols as short as 2 weeks have also been reported (18). According to Hakkien, increase of strength begins in 2 weeks, but no hypertrophic response occurs during this period (19). The literature suggests that a total of 12 to 25 sessions may be adequate for strength training (20). Although most of the studies adopted a 30 min/session schedule on a daily basis, some studies used 3 to 6 hour sessions per day (15). In this regard, we adopted the prevailing method described in the literature and administered NMES sessions for 5 days a week for a total duration of 3 weeks. The session duration was 30 min/day, 60 min/day, and 30 min/day for the shoulder, arm, and the wrist, respectively.

NMES has long been used for the treatment of spasticity in hemiplegic upper extremities, and can be particularly useful in mild to moderate spasticity. Despite some controversy, NMES can be given to agonist or antagonist muscles separately, or to both groups in spasticity. As antagonist muscles can be stimulated to decrease spasticity through reciprocal inhibition, agonist muscles can also be stimulated in order to inhibit or over-fatigue muscles. In recent years, low-intensity current has been applied to antagonist muscles to resolve spasticity (21). Similarly, we applied a low-frequency symmetric biphasic current for this purpose. As in the current format, the more appropriate mode CV (constant voltage) was used. The threshold value required to reveal action potential in neural fibers is 100-1000 times lesser than that of in muscle fibers. Therefore, clinical NMES systems are applied directly to the innervation zone of muscle (22).

Since spasticity develops in the adductor and internal rotator muscles in the shoulder in stroke, the arm remains in adduction and internal rotation. Therefore, antagonist muscles (the supraspinatus muscle and the posterior part of the deltoid muscle) in the shoulder have been targeted during therapy. The positive electrode was attached to the supraspinatus fossa by targeting the supraspinatus muscle and its nerve (suprascapular nerve) during abduction and external rotation of the arm to overcome spasticity in the shoulder. Since the posterior part of the deltoid muscle pulls the arm posteriorly and externally (external rotation), the negative electrode was attached to the upper part of the deltoid muscle. The current intensity was increased until marked contractions could be achieved without discomfort.

In stroke patients, flexor and pronator muscles of the elbow are more severely affected, leading to flexor spasticity. Thus, the triceps muscle, the strongest extensor of the elbow (forearm), was targeted through the antagonist muscles in the arm. The electrodes were attached to the regions where the highest degree of extension could be obtained with the minimum current in the arm. The positive electrode was attached to the posterolateral surface of the proximal third of the arm (where the radial nerve innervating the triceps muscle is closest to the surface), the negative electrode was attached to the posteromedial part of the elbow (olecranon process of the ulna where the triceps muscle ends). The current intensity was increased as long as elbow extension could be maintained without discomfort. In stroke patients, flexor spasticity is observed in the wrist and hand. Finger flexor and adductors are more severely affected in hands (23). Many studies have established that NMES of wrist extensors can accelerate motor and functional recovery of the hand (13). Therefore, in our study electrodes were placed at the region where maximal extension in the wrist and 2nd,3rd, and 4th MCP joints could be achieved with the minimum current, through targeting antagonist muscles in the wrist (i.e., extensor digitorum communis muscle). The positive electrode was attached to the lateral epicondyle, where the radial nerve follows a superficial course and the forearm extensors originate, and the negative electrode to the dorsal surface of the wrist. The current intensity was increased as long as extension could be maintained in the wrist and 2nd, 3rd, and 4th MCP joints without causing marked discomfort.

Generally, the most prominent site of pain is shoulder and the incidence of hemiplegic shoulder pain is between 38% and 84%, starting within the first week of stroke and lasting up to one year. NMES has been successfully used in the treatment of hemiplegic shoulder and shoulder subluxation, and it helps muscular re-education after stroke and prevents atrophy. Therefore, NMES can be regarded as an orthotic assistant in early stroke rehabilitation. By closing the distance between the humeral head and glenoid fossa, NMES contracts shoulder muscles and reduces the degree of subluxation. Protection of shoulder muscles through NMES therapy in the early period improves the functional status of the upper extremity in stroke patients. In addition, psychological benefits of the therapy and treatment compliance are important determinants of the success of the treatment of shoulder pain, as observed in our patients. We believe that, within the context of an all-encompassing therapy program (positioning, orthotics, steroid injections, etc.) NMES is able to provide significant benefits in terms of the reduction in shoulder pain and prevention of shoulder subluxation. In literature, there is limited data on the effect of NMES on motor improvements in the upper extremity. In a placebo-controlled study conducted by Chae et al. on 46 patients with acute stroke, combined exercise therapy with NMES was shown to be more effective due to motor healing of the upper extremity after stroke (13). Although we have beneficial results of NMES, our study has a limitation that control group did not received a sham stimulation and thus the possible placebo effect of NMES might be ignored.

The results of the studies show that maintaining the activity of muscles may provide neuromuscular and motor benefits. However, further studies are required to determine whether such benefits can be transformed into physical improvements in daily living activities (24).

In conclusion, for patients with stroke related hemiplegia, a combination of NMES and conventional rehabilitation showed more beneficial effects than conventional rehabilitation alone in terms of improvements in upper extremity ROM, spasticity, and hemiplegic pain. Furthermore, using NMES on the whole upper extremity (shoulder, arm, forearm, and wrist) might offer additional therapeutic advantages in hemiplegic upper extremity rehabilitation.

Conflict of Interest

The authors declare that there is no conflict of interest.

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