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ORIGINAL REPORT

LONG-TERM EFFECTIVENESS OF NEUROMUSCULAR ELECTRICAL STIMULATION FOR PROMOTING MOTOR RECOVERY OF THE UPPER EXTREMITY AFTER STROKE

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Objective: **To investigate the long-term efficacy of neuromuscular electrical stimulation in enhancing motor recovery in the upper extremities of stroke patients.**

Methods: **A total of 46 patients with stroke were assigned to a neuromuscular electrical stimulation group or a control group. All patients received a standard rehabilitation programme. Patients in the neuromuscular electrical stimulation group received neuromuscular electrical stimulation for 30 min, 5 days a week for 3 weeks. Measurements were recorded before treatment, at the 2nd and 3rd week of treatment and 1, 3 and 6 months after treatment ended. The Modified Ashworth Scale for spasticity, the upper extremity section of the Fugl-Meyer motor assessment, and the Modified Barthel Index were used to assess the results.**

Results: **Significant improvements were found in both groups in terms of Fugl-Meyer motor assessment, and Modified Ashworth Scale scores after the 3rd week of treatment. The significant improvements persisted 1 month after treatment had been discontinued. At 3 and 6 months after treatment was discontinued the average scores in the neuromuscular electrical stimulation group were significantly better than those in the control group.**

Conclusion: **Three weeks of neuromuscular electrical stimulation to the affected upper extremity of patients with stroke improves motor recovery. The effect persists for at least 6 months.**

Key words: stroke; neuromuscular electrical stimulation; arm; rehabilitation.

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INTRODUCTION

Stroke is caused by an acute onset of neurological deficit (reduction in function) that persists for at least 24 h, reflecting impairment of the central nervous system resulting from a circulation disorder in the brain (1). Stroke is the third largest cause of death and one of the main causes of disability in China and worldwide. In China, the annual incidence of stroke between 1980 and 1990 was 215 per 100,000 (2), and this has progressively increased in recent years (3). Neuromuscular outcomes for survivors with severe hemi-paresis are poor. Approximately 75% of survivors have some sort of impairment (1), the upper extremities being one of the most frequently affected areas. In the initial stage of stroke, 69–80% of patients have affected upper extremities (2). Only 5% of patients with complete paralysis recover full arm function, and 30–66% can never use the affected arm properly again (3). Of those who regain purposeful upper-limb movement, fine motor control or dexterity often remains impaired due to sensory loss and impairments in sensorimotor integration (4). Shoulder subluxation and shoulder-hand syndrome are common after stroke, and recovery of the upper extremities is much slower than that of the lower extremities. Stroke thus has a great impact on activities of daily living and entails a large burden to survivors' families and to society (5).

There are many clinical modalities that can help to improve the functioning of stroke survivors (5, 6). Interventions focused on upper extremity recovery include exercise, task-specific training and surface neuromuscular electrical stimulation (7–9). The clinical efficacy of such measures, as well as a number of difficulties inherent in using them to treat general and upper extremity paralysis or paresis have been reviewed (9, 10). Many clinical studies have demonstrated that electrical stimulation after stroke greatly improves motor function and performance in activities of daily living and reduces long-term disability (4, 8, 11–13). Intense and task-oriented training has been found to yield better upper extremity control, particularly in patients who demonstrate at least modest motor control prior to treatment (11, 14). Indeed, several researchers have reported that task-specific, repetitive training with or without restraining the non-paretic extremity results in significantly faster improvement in upper extremity function among both chronic and subacute stroke survivors (15, 16).

Clinical research has shown that neuromuscular electrical stimulation (NES) can improve motor function in the upper extremities and performance in activities of daily living (17, 18). However, evidence from a Chinese population has seldom been reported in the English-language literature (2, 3, 19). The objective of this study was to investigate to what extent the effects of NES on motor recovery of the upper extremity after stroke persist after treatment ends. The investigation involved stroke survivors in a Chinese population.

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METHODS

Study design

This was a randomized, single-blinded, controlled trial. The sample size was calculated prior to recruiting the participants. The study was approved by the ethics committee of Sun Yat-sen Memorial Hospital.

Recruitment and group allocation

Patients were recruited if they met the following inclusion criteria: first stroke; within 3 months post-onset; admitted to the Neurology or Rehabilitation Department of the 5th Affiliated Hospital of Sun Yat-sen University between January and August 2008; diagnosed with either cerebral infarction or cerebral haemorrhage using either computed tomography (CT) or magnetic resonance (MR) imaging; fulfilling the diagnostic and classification criteria for stroke established by the Chinese Neuroscience and Neurosurgery Institute. All the subjects were in the age range 44–80 years, with hemiplegia of one upper limb. Their shoulder flexor strength before treatment was grade 3 or less (out of 5). They were also required to have no severe cognitive dysfunction (with a score of 7 or better on the abbreviated mental test (19)) and to be willing to sign an informed consent form.

Patients were excluded if they had progressive stroke; subarachnoid haemorrhage; shoulder muscle strength ≥ grade 3; severe heart, liver, kidney or infectious disease; head injury; tumour; a score < 7 on the abbreviated mental test; or if they were younger than 44 years, older than 80 years, or were not willing to sign the consent form.

The patients recruited were randomly divided into an NES group or a control group after stratification using Minimizing software (20).

Treatment

All patients received the same standard treatment, including physical therapy and occupational therapy, for 30 min on 5 days each week for 3 weeks, respectively. The patients in the NES group were given neuromuscular electrical stimulation. The 2-channel Respond Select II stimulator (Texas, USA) was used (19). This stimulator has 5 programmable protocols. The pre-set protocols can be modified. In this study, the protocols were fixed and they were run automatically, not trigged by electromyography (EMG), when the stimulator was on, in order to mimic the function of the upper limb, such as the activity of drinking or eating. The surface electrodes were applied over the motor points near the middle of the supraspinatus muscle and the deltoid muscle on the paretic side, as well as over the wrist extensor (between one-third and half-way from the proximal end of the dorsal forearm). The stimulation was at a frequency of 30 Hz, with a pulse width of 300 μs, and ramp up and down times of 1 s each. The stimulus pulse was a symmetrical biphasic waveform. The amplitude of the current was adjusted to the maximal tolerance of the patient, in a range up to 90 mA, and to produce shoulder abduction of approximately 30–50 degrees and full wrist extension with a duty cycle of 5 s on and 5 s off. The total stimuli were 180 cycles during 1 treatment session. Patients were focusing on the movement induced by NES during the treatment. Treatment lasted for 30 min, 5 days per week for 3 weeks. The control group did not receive any electrical stimulation during the study period.

Outcome measurements

The Modified Ashworth Scale (MAS) was used to evaluate shoulder spasticity (19), along with the upper limb section of the Fugl-Meyer Assessment (FMA-U) (19). The Modified Barthel Index (MBI) was applied to rate performance in activities of daily living (22). Each of these measurements was made before treatment and after the 2nd and 3rd week of treatment. All treatment was then discontinued for both groups, and the assessments were repeated 1, 3 and 6 months later. The outcome measurements were assessed by the physiotherapists, who did not know to which group each patient belonged. A flow-chart of the study is shown in Fig. 1.

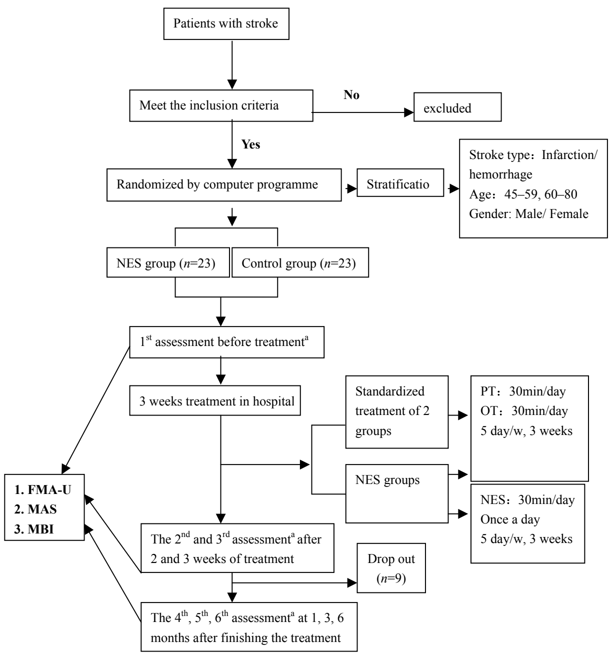

Fig. 1. Study flow-chart. All assessments were performed with Fugl-Meyer motor assessment (upper limb). Modified Ashworth Scale for spasticity and Modified Barthel Index. [a]assesments made by FMA-U, MAS and MBI. NES: neuromuscular electrical stimulation; PT: physical therapy; OT: occupational therapy.

Statistical analysis

The data were analysed with SPSS software (version 15.0). The normality of the data's distribution and the homogeneity of its variance were tested. Multiple analysis of variance (ANOVA) was used to compare the outcomes for the 2 groups before treatment and after the 2nd and 3rd week, then after 1, 3 and 6 months. χ^2 and Kruskal-Wallis tests were used to identify significant differences in age, gender, or nature of stroke between the 2 groups. The threshold for statistical significance was set at the 5% level.

RESULTS

Demographics

Of the 46 patients initially included, 37 completed the study. Seven patients were dropped due to early discharge, including

Table I. *Demographic data for the 2 study groups*

Group	Age, years Mean (SD)	Gender Male/female *n*	Stroke type Infarction/haemorrhage *n*	Hemiparesis Right/left *n*	Right-handed/ Left-handed *n*	Time post-stroke, days, Mean (SD)
NES (*n* = 19)	62.2 (8.7)	11/8	13/6	8/11	16/3	43.5 (25.2)
Controls (*n* = 18)	66.0 (9.6)	11/7	12/6	7/11	16/2	41.3 (26.5)

No significant difference was found between groups before treatment. NES: neuromuscular electrical stimulation; SD: standard deviation.

Table II. *Comparison of Fugl-Meyer motor assessment (FMA-U) scores between groups*

Group	Before treatment Mean (SD)	2 weeks Mean (SD)	3 weeks Mean (SD)	1 month Mean (SD)	3 months Mean (SD)	6 months Mean (SD)
NES ($n=19$)						
Total	8.4 (2.5)	15.9 (4.9)*,**	20.3 (5.4)*,**	22.6 (5.7)*,**	26.0 (5.1)*,**	29.8 (3.6)*,**
Proximal arm	4.0 (2.8)	7.2 (3.6)*	11.4 (4.4)*	13.1 (5.0)*,**	14.6 (4.3)*,**	15.0 (5.1)*,**
Wrist	0.7 (0.3)	1.2 (1.4)*	1.8 (1.9)*,**	2.2 (1.8)*,**	3.0 (2.1)*,**	3.7 (2.4)*,**
Hand	2.3 (1.2)	2.8 (2.0)*,**	3.6 (3.8)*,**	4.0 (3.2)*,**	4.8 (3.7)*,**	5.3 (4.0)*,**
Controls ($n=18$)						
Total	8.2 (3.4)	12.5 (5.0)*	14.5 (5.8)*	17.7 (6.2)*	18.5 (6.7)*	20.3 (12.3)*
Proximal arm	4.3 (2.9)	6.2 (3.4)*	9.4 (3.5)*	10.1 (5.5)*	10.6 (4.3)*	12.0 (5.0)*
Wrist	0.8 (0.5)	1.0 (1.2)	1.3 (1.7)*	1.6 (1.8)*	2.2 (2.1)*	2.5 (2.2)*
Hand	2.0 (1.3)	2.1 (2.5)	3.2 (3.2)*	3.0 (3.6)*	4.1 (3.6)*	4.3 (4.1)*

*Significant difference between the scores of the NES group and those of the control group.
**Significant difference between the scores before treatment and those after treatment within the group.
NES: neuromuscular electrical stimulation; SD: standard deviation.

3 in the NES group, and 4 in the control group. Two subjects could not finish the study due to illness. The demographics have been summarized in Table I. There were no significant differences in age, gender or stroke type (cerebral infarction or cerebral haemorrhage) between the two groups.

Changes in upper limb function

There were no significant differences in mean FMA-U, MBI scores between the two groups before treatment. After 2 weeks of treatment, all patients showed significant improvement in upper limb function ($p<0.05$), and at least some of the improvement persisted for the entire 6 months in every case.

FMA-U scores

In this study, FMA scores for both groups were significantly improved after 3 weeks' treatment. Most patients showed a significant improvement in flexion function of the wrist and fingers, as well as in extension activities of the fingers. However, the FMA scores of patients in NES group were higher than in the control group ($p<0.05$). The patients in the NES group, on average, showed significant enhancement in shoulder retrusion, put-up, outreach, external rotation and flexion, as well as improved flexion and extension of the wrist and fingers. These were consistently better than the mean improvements in the control group over the entire 6 months. The results in terms of FMA-U scores are shown in Table II. Table II clearly shows the relative efficacy of NES for such patients during treatment and beyond.

MAS scores

No significant difference in mean MAS scores between the 2 groups was observed during the first 2 weeks. The NES group showed significantly better progress at the 3rd week and 1 month later ($p<0.05$), but at the 3- and 6-month evaluations their advantage had disappeared. The mean MAS score in the control group improved slowly over the whole period of the study (Table III).

MBI scores

The MBI scores of both groups in this study were significantly improved at the 1st, 3rd and 6th months after treatment compared with those before treatment ($p<0.05$). Moreover, the difference between the two groups was statistically significant ($p<0.05$). The patients in the NES group showed greater improvement in their ability in activities of daily living than the control group. The significant differences after 1, 3 and 6 months are shown in Table IV.

DISCUSSION

Upper limb paresis is one of stroke's primary functional impairments. A wide range of treatment techniques for hemiplegic patients have been studied in recent decades (10, 16, 17). The mechanical approach, however, has gradually been abandoned and has been replaced by forms of treatment that emphasize the reorganization of motor activities (11). Many clinical studies have proven that electrical stimulation can significantly improve physical function after stroke, and improve the lives

Table III. *Comparison of Modified Ashworth Scale for spasticity scores between groups*

Group	Before treatment Mean (SD)	2 weeks Mean (SD)	3 weeks Mean (SD)	1 month Mean (SD)	3 months Mean (SD)	6 months Mean (SD)
NES ($n=19$)	0.53 (0.5)	0.60 (0.58)	1.16 (0.50)*,**	1.42 (0.51)*,**	1.56 (0.53)*	1.67 (0.52)*
Controls ($n=18$)	0.5 (0.51)	0.67 (0.59)	0.78 (0.55)*	1.11 (0.32)*	1.50 (0.53)*	1.86 (0.38)*

*Significant difference between the scores of the NES group and those of the control group.
**Significant difference between the scores before treatment and those after treatment within the group.
NES: neuromuscular electrical stimulation; SD: standard deviation.

Table IV. *Comparison of Modified Barthel Index scores between groups*

Group	Before treatment Mean (SD)	2 weeks Mean (SD)	3 weeks Mean (SD)	1 month Mean (SD)	3month Mean (SD)	6 month Mean (SD)
NES (n=19)	31 (10.1)	46.3 (10.6)*	57.0 (10.7)*	64.5 (10.4)*, **	72.4 (8.5)*, **	79.2 (5.2)*, **
Controls (n=18)	30.3 (8.7)	45.8 (10.1)*	49.7 (11.4)*	55.7 (12.1)*	59.3 (12.0)*	66.1 (11.3)*

*Significant difference between the scores of the NES group and those of the control group.
**Significant difference between the scores before treatment and those after treatment within the group.
NES: neuromuscular electrical stimulation; SD: standard deviation.

of patients through increased self-care ability and decreased disability (18, 19, 21, 23).

Many studies have demonstrated improved upper extremity function after NES (3, 19), but the long-term efficacy of NES has seldom been reported. This study found that NES treatment during early rehabilitation not only significantly improved motor function in the hemiplegic upper extremities of stroke patients and then indirectly enhanced their ability in activities of daily living due to their improvement in motor function in the affected upper extremity, but also that its effects persist for at least 6 months after the treatment has been discontinued.

Shoulder joint function

Numerous studies have shown that NES can prevent or reduce shoulder subluxation and shoulder pain, expanding the range of joint activity, improving motor function, and reducing upper limb spasticity (2, 3, 5, 6, 22). Vuagnat and Chantraine (24) used NES to treat stroke patients with shoulder subluxation and found that NES therapy not only eased their shoulder pain and facilitated the joint's resetting, but also significantly improved motor function in the shoulder.

In the present study, NES induced shoulder abduction by stimulating the deltoid and supraspinatus muscles. FMA-U scores had significantly increased in both groups at the end of the 2nd and 3rd weeks of treatment, suggesting that either rehabilitation training alone or rehabilitation training in combination with NES can improve motor function in the shoulder. However, comparison between the two groups demonstrated that the NES group achieved greater improvement in shoulder function than the control group, indicating that NES adds some effects to the routine stroke treatment.

Hand function

It has often been reported that NES can significantly improve the functioning of a hemiplegic hand after stroke (21, 23). A group led by Alon (25) conducted a double-blind study with stroke patients in whom the electrodes were applied on the hand extensor, flexor pollicis longus, extensor pollicis brevis, and superficial flexor muscles. Stimulation produced gripping and opening responses. The FMA-U scores they report suggest that NES treatment requires at least 3 weeks to improve wrist function. After that, however, the FMA-U in their NES group was significantly better than those in their control group, suggesting that the NES was useful in improving hand function. In this study, wrist flexion and extension were both improved in patients in the NES group after treatment, although the electrodes were applied on the wrist extensors. One possible reason was that, due to the improvement in wrist extension, the patients were more willing and more able to use the paretic hand actively, including flexion and extension in activities of daily living. This is consistent with the findings of Alon et al. (25).

Ability in activities of daily living

Ability in activities of daily living is one of the most important goals of rehabilitation after stroke (9–12). This study found that NES treatment during early rehabilitation significantly improved motor function in the hemiplegic upper extremities of stroke patients and indirectly enhanced their ability in activities of daily living due to the improvement in motor function in the affected upper extremity.

A possible mechanism

At present, the mechanism of functional recovery after stroke is unclear (4). There are many different theories (4, 13, 15). Among them, brain plasticity is the most widely accepted, and there is a lot of evidence from laboratory and clinical research in its favour (7, 8). It has been shown that the adult animal brain can demonstrate plasticity, including nerve sprouting and synaptic activation, under experimental conditions (16). It is currently thought that deficits in organization, due to loss of dominance, can cause a significant sprouting response provided the nervous system is mature (17). Synapses are activated by repetitive training when the nervous system is damaged (18). Patients with stroke-limited plasticity contribute to functional recovery (12–14). In any case, basic and clinical research has shown that adding NES treatment to traditional therapy improves the nerve function over what can be achieved by traditional rehabilitation alone (16, 26–28).

In stroke rehabilitation, specific training or repetitive exercise is also well known to increase cortico-spinal excitability and improve function in the paretic hand. NES, when applied to the peripheral muscles of normal volunteers, seems to have a direct effect on the cerebral cortex (24, 25). Task-specific physiotherapy, involving repetitive practice of meaningful daily activities, is more effective than traditional approaches to rehabilitation of the upper limb and can lead to increased activation of the affected sensorimotor cortex (29).

In the present study, the NES produced repetitive exercise and meaningful movement of the affected upper limb, significantly improving its motor function. This should be closely related to brain plasticity. The effect persists for at least 6 months after treatment has been discontinued. This may be due to the long-term effectiveness of early application of NES, leading to improved function of the upper extremities and resulting in increased ability of patients to move their affected upper limb and increased willingness to use it in their daily activities.

Study limitation

One limitation of this study was the absence of a sham stimulation group. This was due to the limited time and the complications of recruiting an adequate sample. However, in a previous randomized controlled study in our laboratory on the affected lower extremities of stroke patients, we did find that sham stimulation had some placebo effect. In this study, the treatment effects induced by NES appeared more quickly and obviously, with earlier significant differences between the NES group and the controls, but not between the sham stimulation group and the control group (19). Future studies, using similar stimulation protocols with a larger sample, are needed to gain further insight into the potential to induce functionally beneficial neuroplasticity in stroke patients.

In conclusion, NES combined with standard rehabilitation treatment promotes muscle strength and motor function in the upper extremities, and thus improves ability in activities of daily living of patients after a first stroke. Its effects persist for at least 6 months.

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