J. Phys. Ther. Sci.
27: 2767–2770, 2015

Original Article

Effects of neuromuscular electrical stimulation on masticatory muscles in elderly stroke patients

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Abstract. [Purpose] This study aimed to examine the effects of neuromuscular electrical stimulation on masticatory muscle activation in elderly stroke patients. [Subjects and Methods] The subjects included 20 elderly patients diagnosed with stroke and 10 healthy elderly individuals. The neuromuscular electrical stimulation group received stimulation on the masseter muscle in the affected side for 30 min each day, 3 times per week for 8 weeks. In all the subjects, surface electromyography was used to measure activity of the masseter and temporal muscles in both sides under resting and clenching conditions. [Results] In the neuromuscular electrical stimulation group, after the intervention, an increase in the activity of all of the masticatory muscles was observed during clenching, with a significant increase in the activity of the masseter muscle in the affected side. Significant differences between the groups were not observed after the interventions. [Conclusion] The results of this study suggest that application of neuromuscular electrical stimulation effectively improves muscle activity in elderly stroke patients during clenching, and that this technique can be applied particularly for the improvement of the clenching activity of the masseter muscle in the affected side.

Key words: Stroke, Masticatory muscle, Neuromuscular electrical stimulation

(This article was submitted Mar. 24, 2015, and was accepted Jun. 3, 2015)

INTRODUCTION

Stroke is a cause for reduction in the masticatory movement[1–3)]. Mastication, which is controlled by the nervous system, is closely related to quality of life. The sensory, motor, and pre-motor cortexes and the cerebellum of the brain are activated during the clenching action[4)]. Mastication movements are under highly accurate control of the nervous system. The complex control of mastication is disrupted by a neurological injury that prohibits the interactions of the central and peripheral mechanisms[1)]. The bite force of the masticatory muscles in the affected and the unaffected side in stroke patients, as compared to that in healthy individuals, decreases an approximately 20–30%[3)]. Moreover, in stroke patients, the masticatory muscles are asymmetrically stimulated, resulting in the thickening of the muscles in one side[5)]. Consequently, masticatory function is impaired. Therefore, a longer oral phase and a greater number of chews are required in stroke patients than in healthy individuals[2)].

The masticatory function also decreases because of aging[6)], and in cases of accompanying stroke, the negative impact of the neurological impairment on the masticatory function is heightened. In a few previous studies, electrotherapy was used to stimulate the masticatory muscles in elderly stroke patients. Regarding the treatment method for increasing the muscle strength in stroke patients, neuromuscular electrical stimulation (NMES) is considered effective[7, 8)]. NMES is used for the recruitment of motor units or for increasing the muscle strength[9)]. The oxygen levels of tissues increase and the intrinsic characteristics of paralyzed muscles are altered as a result of NMES application[10)]. Recently, NMES application for stroke patients was reported to effectively reduce lower-extremity impairment and improve the functional locomotion ability[11)]; moreover, it improved isometric finger-extension strength and increased cortical intensity in the somatosensory cortex[12)]. Therefore, NMES is currently successfully applied in clinical practice for muscle re-education, prevention of muscle atrophy, and recovery of functions in stroke patients. However, few studies have been conducted on electrotherapy for the management of the masticatory muscles in elderly stroke patients.

In this study, NMES was applied to the masticatory muscles in the affected side in elderly stroke patients, and the results were evaluated using objective measuring equipment. Furthermore, the mechanism by which NMES caused changes in muscle activation during rest and during clenching was examined. Thus, a treatment method that is clinically effective in improving the masticatory functions in elderly stroke patients was proposed.

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Table 1. General characteristics of the subjects

Characteristics		NMES Group (n = 10)	Control Group (n = 10)	Normal Group (n = 10)
Gender	Male	6	6	5
	Female	4	4	5
Age (years)		66.5 ± 0.3	66.7 ± 0.4	67.3 ± 0.5
Weight (kg)		64.8 ± 2.7	61.0 ± 2.9	60.3 ± 2.2
Height (cm)		163.1 ± 2.7	162.4 ± 2.6	163.1 ± 1.9
Paretic side (Left/Right)		5/5	5/5	
K-MMSE		26.5 ± 0.6	26.4 ± 0.4	27.7 ± 0.3
After-stroke duration (months)		24.2 ± 3.5	22.3 ± 2.9	

Values are means ± SE
K-MMSE: Korean Version of Mini-Mental State Examination

SUBJECTS AND METHODS

For this study, 20 chronic stroke patients among those hospitalized in a geriatric hospital located in Gyeonggi-do Province in Korea were selected. They were diagnosed with stroke by using computed tomography (CT) or magnetic resonance imaging (MRI); the patients showed hemiplegia that persisted over a year. This study also included 10 healthy elderly individuals (normal group). The research was performed from October to December 2014. The elderly stroke patients were randomly assigned to the NMES group consisting of 10 patients who underwent NMES treatment, and the control group consisting of 10 patients who did not undergo NMES treatment. All of the subjects satisfied the following inclusion criteria: no missing teeth, no history of trauma to the face or to the temporomandibular joint over the past year, a score of 24 on the Korean version of a mini-mental state exam[13)], teeth preservation including implants, and characteristics of unassisted gait better than those of cane-assisted gait. All of the 30 participants gave their consent to participate in this study. This study was approved by the Ethics Committee of Namseoul University in Korea. The institutional review board (IRB) approval number is 1041479-201409-HR-006. The general characteristics of the participants are shown in Table 1.

Electromyography (EMG) signal of the masticatory muscles was measured using TeleMyo 2400T G2 (Noraxon Inc., USA). Surface electrodes were placed on the right masseter (RM), left masseter, right temporal, and left temporal muscles, and the interelectrode distance was maintained at 20 mm. The location of the electrodes was based on the anatomical landmarks[14)]. A ground electrode was attached to the forehead. Before the electrode was attached, the part in contact with the forehead was lightly wiped with a 70% alcohol solution to reduce resistance of the skin under the electrode. Thereafter, an Ag–AgCl surface electrode with a diameter of 10 mm (Noraxon Inc., USA) was attached to the skin. The sampling rate of the EMG signal was set at 1,000 Hz, and the signal was filtered at 10–500 Hz using a band-pass filter with a 60-Hz notch filter. The EMG signals recorded were converted into digital signals by using TeleMyo 2400T G2; the digital signals were subsequently analyzed using Myoresearch-XP 107 software (Noraxon Inc., USA).

The measurements were recorded with the participants in a sitting position, with their hips and knee joints in 90° flexion, lower limbs in alignment, the back of the chair at the height of the shoulders, and both hands placed on the thighs. The head was positioned parallel with the ground, with the eyes in a straight-ahead position of gaze.

For the measurement of muscle activation in the resting condition, the subjects were shown a screen display at 200-ms intervals of the root mean squared (RMS) value of their EMG activity while they maintained a comfortable posture with eyes closed. For the measurement of muscle activation during clenching, maximal voluntary contraction (MVC) was recorded. The subjects were instructed to maintain a comfortable posture, ensuring that the upper teeth were not in contact with the lower teeth and that the mandible was in the center. The muscle activity in the resting condition was measured twice with a 15-s interval. Regarding measurements during clenching, the subjects performed 5-s maximal clenching voluntarily for 3 times in total with a 5-min interval. RMS and MVC were measured in 4 muscles. The subjects were verbally encouraged during the MVC test.

The subjects in the NMES group underwent 3 treatment sessions per week for 8 weeks. Each treatment session lasted 30 min. For NMES, an adhesive electrode with a diameter of 1.25 inch (Neurostimulation Electrodes, ValuTrode, USA) was attached to the affected masseter muscle by using a 2-channel portable electrical stimulator (Microstim, Medel, Germany).

The parameters of the electrical stimulation were as follows: symmetric biphasic waves, a pulse width of 250 μs, a frequency of 20–40 Hz, a pulse rate of 50 pps, and on-off time ratio of 1:3[15)]. The stimulation intensity was controlled so that the subjects did not feel discomfort during current conduction. The subjects were instructed to close their mouths slightly with voluntary contractions during NMES. The posture maintained during the treatment was identical to the one maintained during EMG activity measurement. The control group and the normal group did not receive NMES.

All of the data were encoded and analyzed using statistical analysis software (SPSS 19.0/PC, USA). The differences in the activities of the masticatory muscles between the affected side and unaffected side before and after the NMES application were tested using a Wilcoxon signed-rank test.

Table 2. Changes in the activity of the masticatory muscles under resting conditions

Region	NMES Group (n = 10)		Control Group (n = 10)		Normal Group (n = 10)	
	Before	After	Before	After	Before	After
AT (μV)	1.60 ± 0.11	1.61 ± 0.11	1.70 ± 0.22	1.69 ± 0.37		
UT (μV)	1.73 ± 0.23	1.73 ± 0.10	1.75 ± 0.18	1.72 ± 0.22	2.09 ± 0.21	2.28 ± 0.16
AM (μV)	0.93 ± 0.08	1.06 ± 0.09	1.10 ± 0.06	1.05 ± 0.09		
UM (μV)	0.99 ± 0.06	1.01 ± 0.08	1.15 ± 0.09	1.17 ± 0.12	1.38 ± 0.11	1.33 ± 0.10

Values are mean ± SE
AM: affected masseter; UM: unaffected masseter; AT: affected temporal; UT: unaffected temporal
*Significant difference between values before and those after the intervention in each group

Table 3. Changes in the activity of the masticatory muscles under clenching conditions

Region	NMES Group (n = 10)		Control Group (n = 10)		Normal Group (n = 10)	
	Before	After	Before	After	Before	After
AT (μV)	50.57 ± 4.35	54.99 ± 4.23	54.74 ± 5.11	52.12 ± 5.44		
UT (μV)	60.65 ± 4.19	60.96 ± 4.08	61.22 ± 3.20	60.29 ± 4.25	63.92 ± 4.51	62.06 ± 3.80
AM (μV)	42.98 ± 4.76	53.44 ± 4.24*	45.38 ± 5.79	44.49 ± 5.56		
UM (μV)	55.01 ± 6.38	57.67 ± 5.70	56.72 ± 4.28	56.24 ± 5.28	66.57 ± 3.66	65.75 ± 3.89

Values are mean ± SE
AM: affected masseter; UM: unaffected masseter; AT: affected temporal; UT: unaffected temporal
*Significant difference between values before and those after the intervention in each group

Moreover, a Kruskal-Wallis H test was performed to compare the values obtained before NMES application to those obtained after NMES application. The significance level for all the tests was set at $p < 0.05$.

RESULTS

The masticatory muscle activity under the resting condition did not differ significantly among the study groups for the affected masseter (AM), unaffected masseter (UM), and affected temporal (AT) muscles. Moreover, the activity of the unaffected temporal (UT) muscles did not differ significantly among the groups ($p > 0.05$). The activities of all of the AM, UM, AT, and UT muscles did not differ significantly within the groups before and after the intervention ($p > 0.05$) (Table 2). A significant difference in the activity of the masticatory muscles—AM, UM, AT, and UT muscles—during clenching was not observed among the study groups ($p > 0.05$). Regarding the within-group differences in the activity of the muscles before and after the intervention, statistically significant improvement was observed in the activity of only the AM muscles in the NMES group ($p < 0.05$) (Table 3).

DISCUSSION

In this study, the extent of activation of the masticatory muscles under the resting condition did not change significantly after NMES application in any of the study groups. However, the extent of activation of these muscles was lesser in stroke patients in the NMES group and the control group than in the healthy individuals in the normal group.

A previous study in rats examined the impact of masticatory muscle paralysis on the masticatory function. In that study, botulinum toxin type A injected in both the right and left temporal muscles (TM) and masseter muscles (MM) caused a remarkable decrease in the TM and MM weight and muscle fiber size. These observations supported the argument that a decrease in masticatory function affects the masticatory muscle fibers[16]. In the case of humans, decreased masticatory function caused by paralysis also decreases the thickness of the MM fibers[16]; furthermore, in the case of stroke patients, the extent of decrease in MM thickness is greater in the affected than in the unaffected side under both relaxation and contraction[5]. The results of the previous studies are consistent with those of the present study: the muscle activity decreased in the NMES group and the control group, as compared to the muscle activity in the normal group.

Iwatsuki et al. reported that the application of a deep-friction massage on the masticatory muscles resulted in an increase in the bite force of approximately 10–15%[3]. Kawanishi et al. suggested that mastication of solid food after permanent middle cerebral artery occlusion in rats was effective in the rehabilitation of sensorimotor and learning/memory dysfunction[17]. These report implying that management of the masticatory muscles in stroke patients enhances the clenching ability.

In this study, the extent of masticatory muscle activation at the early clenching stage was lesser in the elderly stroke patients than in the healthy individuals. Furthermore, the muscle activation was weaker in the affected side than in the unaffected side. Even though no significant differences were observed in terms of the changes in the muscle activity among the study groups after the intervention, the activity of all of the AT, UT, AM, and UM muscles increased in the NMES group; particularly, a significant increase in the activity of the in AM muscle was observed ($p < 0.05$). NMES application not only increased AT muscle activation, but also improved muscle activation in the unaffected side, and thus probably enhanced the overall masticatory function. Moreover, an increase in the MVC of the AT and AM muscles through NMES application eased mastication of solid food, which can be effective for the resolution of the masticatory muscle dysfunction in stroke patients. Iwatsuki et al. argued that the maximum bite force in the affected side reduces to a greater extent in stroke patients than in healthy individuals[3], and this observation is consistent with the observations of the present study. However, other studies did not show a clear difference in the maximum bite force between the affected and the unaffected side[18, 19]. Thus, various factors may affect the maximum bite force in stroke patients, and diverse results can be obtained in a sample consisting of elderly people.

However, the brain activity can be increased to a greater extent through the application of both functional electrical stimulation (FES) and voluntary contraction than through the application of either voluntary contraction or FES[20]. NMES in elderly stroke patients is thought to play a positive role in motor function recovery and neuronal plasticity, because the improved masticatory muscle activity increases brain activity as well as the clenching ability. However, the study results cannot be extended to stroke patients of all ages and all levels of impairment; furthermore, they cannot be generalized to patients with teeth loss. A limitation of this study is that it did not measure muscle fatigue to avoid potential risks caused by isometric contractions for a sustained period of time in elderly stroke patients. However, importantly, this study show that masticatory muscle activity in elderly stroke patients can be improved by NMES application. In particular, NMES is an effective intervention to improve clenching ability of AM.

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