Japanese Journal of Comprehensive Rehabilitation Science (2014)

Brief Report

Electrode position and hyoid movement in surface electrical stimulation of the suprahyoid muscle group

Sayako Shimizu, MD,[1] Hiromichi Metani, MD, PhD,[1] Takashi Hiraoka, MD, PhD,[1] Sosuke Seki, MD, PhD,[1] Kozo Hanayama, MD, PhD,[1] Akio Tsubahara, MD, PhD[1]

[1]Department of Rehabilitation Medicine, Kawasaki Medical School, Kurashiki, Okayama, Japan

ABSTRACT

Shimizu S, Metani H, Hiraoka T, Seki S, Hanayama K, Tsubahara A. Electrode position and hyoid movement in surface electrical stimulation of the suprahyoid muscle group. Jpn J Compr Rehabil Sci 2014; 5: 97−101.

Objective: To determine the relationship between electrode position and hyoid movement for effective surface electrical stimulation in the treatment of dysphagia.

Methods: Surface electrode pairs targeted on the suprahyoid muscle group were placed in mesial, distal, or pervasive placement patterns on the skin anterior to the suprahyoid muscle group of five healthy subjects, and the vertical and horizontal movements of the hyoid induced by electrical stimulation in the three pattern groups were measured and compared.

Results: The mesial electrode-pair pattern induced significant anterior movement of the hyoid. The distal pattern showed a tendency to induce upward hyoid movement. The distance of hyoid movement induced by the electrical stimulation was about half of that found for actual water swallowing. No significant difference in electrical stimulus intensity was found among the electrode patterns.

Conclusion: Surface electrical stimulation with mesial electrode-pair placement anterior to the hyoid presumably induces contraction of the digastric muscle anterior belly and the geniohyoid muscle, and was found to pull the hyoid forward. This information and further elucidation of the relationship between surface electrode position and hyoid movement is expected to increase the range of clinical applications.

Correspondence: Sayako Shimizu, MD
Department of Rehabilitation Medicine, Kawasaki Medical School, 577 Matsushima, Kurashiki, Okayama 701−0192, Japan.
E-mail: s-shimizu@med.kawasaki-m.ac.jp
Accepted: August 4, 2014
Conflict of interests: There are no conflict of interests in this study.

Key words: hyoid bone, surface electrical stimulation, suprahyoid muscle group, electrode position, selective stimulation

Introduction

The use of neuromuscular electrical stimulation (NMES) in combination with traditional swallowing training has increased in recent years. Surface electrical stimulation (SES), performed with electrodes placed on the skin, is used particularly often in a wide range of clinical applications because of its ease of use and high level of safety. It is used to strengthen muscles and prevent amyotrophy in the cervical region, but selective muscle stimulation has been regarded as difficult. Humbert et al. reported that SES in the anterior cervical region lowers the hyoid and the larynx [1]. Heck et al. reported that the use of NMES in the anterior cervical region tends to lower pharyngeal pressure [2]. These reports also indicate that SES may involve a risk of aspiration and increased pharyngeal residue.

Clarification of the distance and direction of hyoid movement with SES might lead to the establishment of an effective method for the treatment of dysphagia. The relationship between SES electrode positions and induced hyoid movement for the suprahyoid muscle group, which might be relatively easy to stimulate selectively, was investigated.

Methods

1. Subjects

The subjects were five healthy volunteers (average age 24.2 ± 1.3 years; male to female ratio 3:2). Individuals with dysphagia due to laryngopharyngeal disease, neuropathy, or other causes were excluded from this study. All of the subjects received a thorough explanation of the experiments to be performed in this study and provided their written, informed consent prior to participation. The study was performed with the approval of the Kawasaki Medical Ethics

Committee (Approval No. 1053-1).

2. Electrode Positions and Stimulation Conditions

The surface electrodes were self-adhering electrode pads (major axis 32 mm). They were placed on the submental region in three patterns, as shown in Fig. 1: suprahyoid medial (Type 1), suprahyoid distal (Type 2), and suprahyoid pervasive (Type 3; 2-channel, Type 1 + Type 2). They were carefully positioned to avoid any lateral placement that might result in carotid artery stimulation.

Electrical stimulation was applied using the stimulator shown in Fig. 2 (ES-510; Ito Co., Ltd., Tokyo, Japan), with an interference wave (modulation current) setting of 5,000-Hz carrier frequency and 30-Hz interference frequency. Prior to the experimental trials, for each subject the stimulus intensity was increased in 0.5-mA increments until the subject expressed a feeling of pain or discomfort, and the intensity just below that level was defined as the maximum stimulus intensity for that subject throughout the trials.

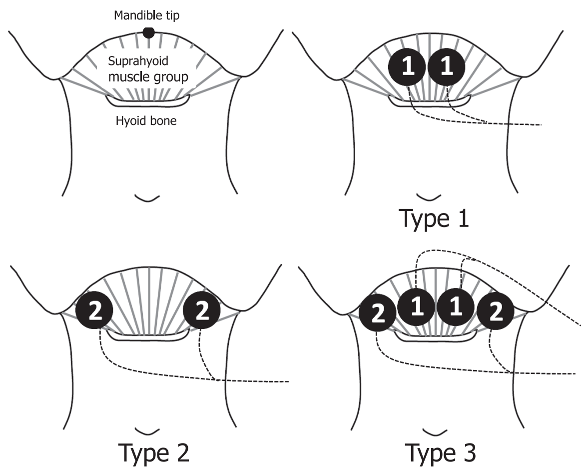

Figure 1. Surface electrode placement patterns.
Type 1: Mesial pair placement (suprahyoidal, just left and right of the center line between the mandibular tip and the hyoid center).
Type 2: Distal pair placement (suprahyoidal, just outside the Type 1 left and right positions).
Type 3: Suprahyoidal pervasion (Type 1 + Type 2).

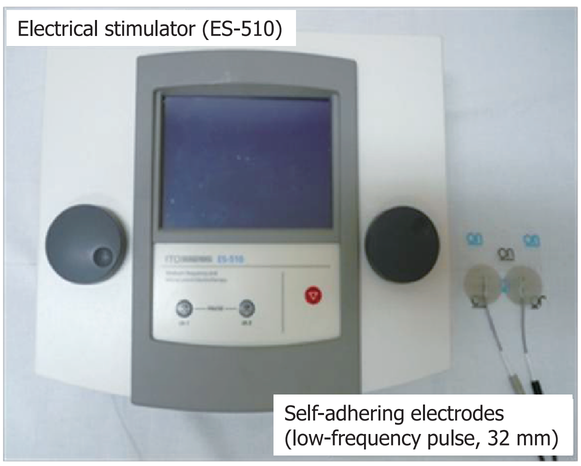

Figure 2. Electric stimulator and self-adhering electrodes.
Electrical stimulator (ES-510; Ito Co., Ltd.).
Self-adhering electrodes (low-frequency pulse, 32 mm major axis; Ito Co., Ltd.).

3. Procedure

1) Surface electrode placement

The male subjects were instructed to shave in advance. For all subjects, the submental region was wiped with alcohol cotton prior to electrode placement. Following placement, electrode position relative to the hyoid was confirmed by palpation and radioscopy, and the electrodes were then secured in close contact with the skin by applying film dressing tape.

2) Videofluoroscopy

Each subject sat in a chair with a backrest for 80-degree hip joint flexure and a pillow headrest to maintain the craniocervical position. A metal ball (11 mm diameter, 5.5 g mass) was placed on the center of the subject's neck as a marker presumably having no effect on the swallowing movement.

Lateral videofluoroscopic (VF) images were captured and recorded on a DVD. Prior to electrical stimulation, control images were obtained for each subject performing free swallowing of 10 mL of water from a cup in two iterations. Submental SES at the defined maximum stimulus intensity was then performed without food or water ingestion, with Type 1, Type 2, and Type 3 electrode placement in that order and VF imaging of each iteration. The subjects were instructed not to perform voluntary swallowing during the trial.

4. Measurement of Hyoid Movement

The VF images were played back at 1/30 sec per frame, and the frames showing the hyoid at its original position and at its maximum elevation and anterior displacement during water deglutition and during SES iteration were identified. The distances of hyoid elevation and anterior movement were measured with reference to the method of Humbert et al. [1], with the line connecting the first and third cervical vertebrae as the Y-axis and the perpendicular posteroanterior line as the X-axis (Fig. 3). Image analysis was performed with ImageJ processing software developed at the US NIH (Bethesda, MD).

5. Statistical Analysis

The Friedman test was applied to the differences in induced hyoid anterior, upward, and straight-line movement distances and maximum stimulus intensities among the three types of surface electrode placement. The Bonferroni multiple comparison correction was then applied in those cases with significant differences with the Friedman test. The level of significance was $p < 0.05$. SPSS for Windows version 16.0 was used for the analysis.

Results

None of the five subjects complained of pain or discomfort during any of the trials in this study. Table 1 shows the hyoid movement distances found for each subject during water deglutition and during the SES trials with the three electrode pattern types at maximum stimulus intensity for that subject. A significant difference (p=0.007) in hyoid anterior movement distance among the three placement patterns was found by the Friedman test. In the multiple comparison, as shown in Fig. 4, the distance of anterior hyoid movement was significantly increased with Type 1 placement and smallest with Type 3. There were no significant differences among the three placement types in the distance of hyoid elevation or straight-line movement, but both tended to be larger with Type 2 placement than with the other two types. No significant difference in the maximum stimulus intensity was found among the electrode patterns.

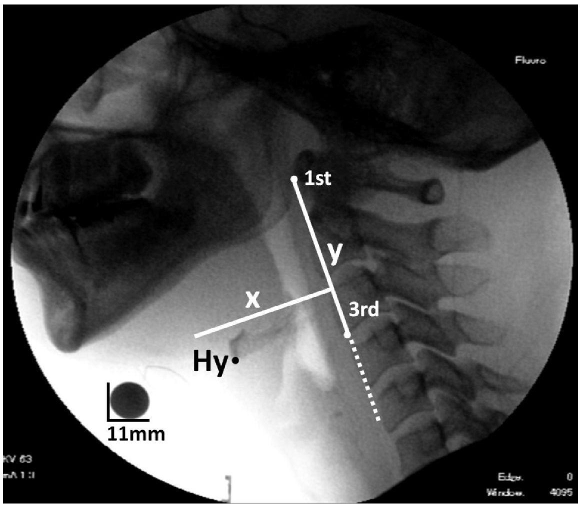

Figure 3. VF image for measurement of hyoid movement. Hy, hyoid bone; 1st, first cervical vertebra; 3rd, third cervical vertebra; y, Y-axis; x, X-axis.
In measurement of the hyoid bone, the anteroinferior point of the hyoid body is taken as the measurement point. In measurement of the distance of hyoid movement, the vertical line connecting the anteroinferior points of the first and third cervical vertebrae is taken as the vertical axis (y), and the line perpendicular to that line is taken as the other axis (x), thus forming the reference base.

Discussion

1. Selective Muscle Stimulation

Various studies have reported the difficulty of

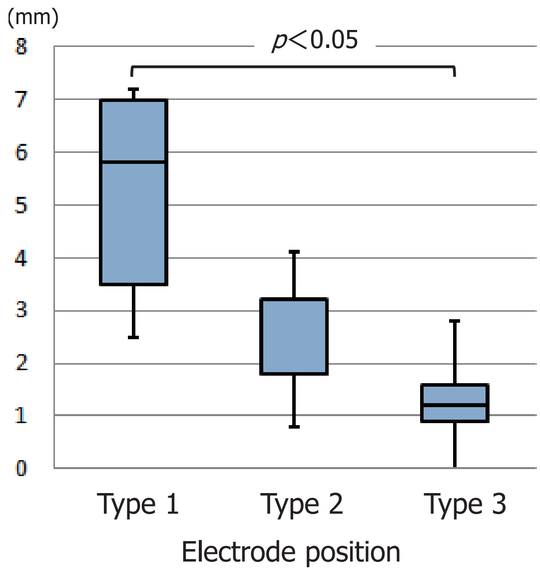

Figure 4. Distance of anterior movement of the hyoid bone.
Friedman test: p=0.007.
Bonferroni: Type 1 vs. 2, p=0.095; Type 1 vs. 3, p=0.024; Type 2 vs. 3, p=0.45.

Table 1. Hyoid movement distances and maximum stimulus intensities.

Subject	Anterior movement (mm)				Elevation (mm)				Straight-line movement (mm)			Maximum intensity (mA)		
	WS	Type 1	Type 2	Type 3	WS	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
1	17.1	3.5	3.2	2.8	16.1	2.2	8.0	5.5	4.1	8.6	6.2	23	23	23
2	10.1	7.2	4.1	1.2	12.6	4.2	3.6	3.1	8.3	5.5	3.3	22	22	22
3	7.8	5.8	0.2	0	13.2	2.9	12.7	10.0	6.5	12.7	10.0	23	20	22
4	10.7	7.0	3.2	0.9	12.1	3.1	7.9	6.5	7.7	8.5	6.6	28	28	28
5	13.9	3.4	1.8	1.6	17.8	0.6	5.6	2.4	3.5	5.9	2.9	23	18	21
Friedman test		p=0.007*				p=0.074			p=0.074			p=0.135		

*Significant, $p < 0.05$.

selective stimulation of muscles in the submental region by SES. Humbert et al. reported that SES with adhesive surface electrodes placed on the cervix in ten different placement patterns resulted in hyoid and larynx descent in nearly all cases, and that the use of suprahyoid placements alone induced only slight hyoid elevation [1]. Kagaya et al. reported that SES targeted on the thyrohyoid muscle belonging to the infrahyoid muscle group lowered the hyoid bone and the larynx as an effect of combined stimulation of the sternohyoid muscle, but they also found that targeting of the mylohyoid muscle belonging to the suprahyoid muscle group resulted in hyoid and larynx elevation [3]. In light of the reported difficulty of selectively stimulating the infrahyoid muscle group by SES, the present study focused on targeting the suprahyoid muscle group alone.

In the present comparison of three patterns of suprahyoid electrode placement, SES with placement of an electrode pair with suprahyoid median (Type 1 placement) in particular induced significant anterior movement of the hyoid. Consideration of the electrode positions and the direction of hyoid movement in this case suggests the occurrence of selective stimulation of the anterior belly of the digastric muscle, the geniohyoid muscle, or some other muscle capable of pulling the hyoid in the anterior direction. In contrast, SES with the two electrodes placed distally on opposite sides of the suprahyoid median (Type 2 placement) tended to result in observable though not statistically significant hyoid elevation, which suggests the occurrence of selective stimulation of the mylohyoid muscle, the stylohyoid muscle, the posterior belly of the digastric muscle, or some other muscle capable of elevating the hyoid. In SES with the Type 3 electrode placement pattern, comprising Types 1 and 2 in combination and thus effectively covering the entire suprahyoid region, the hyoid anterior movement was smaller than with Type 1 placement alone and its elevation was smaller than with Type 2 placement alone. This suggests that SES with this electrode pattern tends to cancel anterior, superior, and posterior hyoid movements by simultaneous contraction of all suprahyoid muscles and, more specifically, by mutually opposing effects of the actions of the anterior belly of the digastric muscle and the geniohyoid muscle on anterior hyoid movement, those of the mylohyoid muscle, the stylohyoid muscle, and the digastric muscle on hyoid elevation, and those of the stylohyoid muscle and posterior belly of the digastric muscle on posterior hyoid movement. In ordinary swallowing, the muscles of the related groups, including the suprahyoid muscle group, undergo separate, coordinated contraction. Therefore, simultaneous contraction of the entire suprahyoid muscle group as an effect of electrical stimulation may well severely constrain ordinary swallowing movements. Differences in stimulus intensity might also have an effect, but the maximum stimulus intensities did not differ significantly among the subjects.

2. Distance of Hyoid Movement

The finding in this study that hyoid movement under SES was about half that observed in water swallowing is in accordance with the findings of Kim et al. that hyoid elevation and anterior movement induced by SES of the suprahyoid muscle group were 66.8% and 45.2%, respectively, of those found in voluntary swallowing [4].

The SES-induced hyoid movements found in the present study were also smaller than those reported for electrical stimulation with implanted electrodes; thus, SES is inferior to implanted electrodes in causing contraction of muscles. Kagaya et al. found that electrical stimulation of the motor points of the suprahyoid muscle group with implanted electrodes induced about the same hyoid and larynx movements as in voluntary deglutition [3], and Burnett et al. found that electrical stimulation by hook-wire electrodes can provide effective correction of larynx elevation [5].

In clinical use, however, SES is relatively simple in technique and high in safety. Sotoyama et al., moreover, reported that they were able to obtain about the same level of hyoid movement as in voluntary swallowing by electrical stimulation in which they pressed mouse-shaped electrodes on the cervical region [6]. To approach the higher limit of possible muscle contraction by SES, it will therefore be necessary to increase surface electrode adhesion, compress the electrodes, and limit mandibular descent. We are now considering the design and fabrication of a simple brace or other device for this purpose.

3. Stimulation Conditions

Reports on cervical SES therapy generally involve the use of low frequencies. In the present study, an interference wave was used for current modulation to lower the skin resistance. The modulated current is generated in a single circuit containing just two electrodes and has the same waveform as the interference wave current. The interference wave induces little pain, such as the feeling of needle penetration which is characteristic of low-frequency wave utilization, and this may have facilitated the use of higher stimulus intensities in the present study.

4. Clinical Application

Elucidation of the relationship between the surface electrode placement pattern and hyoid movement will make it possible to plan swallowing training tailored to the dysphagia of the individual, and placement of the SES electrodes centrally in the suprahyoid region is expected to be effective in training for muscle strengthening and correction of hyoid movement in patients with insufficient hyoid anterior movement.

5. Limitations of the Present Study

With just five healthy young volunteers, the number and age range of subjects in this study were small; further study is needed with more subjects over a wider range of ages. We hope to build on the results of this study through experience at clinical facilities and further studies of effectiveness.

References

1. Humbert IA, Poletto CJ, Saxon KG, Kearney PR, Crujido L, Wright-Harp W, et al. The effect of surface electrical stimulation on hyolaryngeal movement in normal individuals at rest and during swallowing. J Appl Physiol 2006; 101: 1657−63.
2. Heck FM, Doeltgen SH, Huckabee ML. Effects of submental neuromuscular electrical stimulation on pharyngeal pressure generation. Arch Phys Med Rehabil 2012; 93: 2000−7.
3. Kagaya H, Baba M, Saitoh E, Okada S, Yokoyama M, Muraoka Y. Hyoid bone and larynx movements during electrical stimulation of motor points in laryngeal elevation muscles: a preliminary study. Neuromodulation 2011; 14: 278−83.
4. Kim SJ, Ryoon T. Effect of surface electrical stimulation of suprahyoid muscles on hyolaryngeal movement. Neuromodulation 2009; 12: 134−40.
5. Burnett TA, Mann EA, Cornell SA, Ludlow CL. Laryngeal elevation achieved by neuromuscular stimulation at rest. J Appl Physiol 2003; 94: 128−34.
6. Sotoyama K, Matsumoto S, Kurasawa M, Noma T, Shimodozono M, Kawahira K. Effect of neuromuscular electrical stimulation on hyoid bone and laryngeal movements to improve swallowing function. Sogo Rehabilitation 2011; 39: 977−85. Japanese.