Effects of surface electrical stimulation of suprahyoid muscles on the movements of the hyo-laryngeal complex

Sang Jun Kim, MD¹, Tai Ryoon Han, MD¹, Kun Jai Lee, MD², and Ho Chun Cheong, PhD³

¹Department of Physical Medicine and Rehabilitation, Seoul National University, College of Medicine, JongRo-Gu, Seoul
²Department of Physical Medicine and Rehabilitation, Kangwon National University, College of Medicine, HyoJa-Dong, Chuncheon
³Cybermedic Corp., Iksan, Cheonbuk

E-mail: guitarren@hanmail.net; guitarren@medimail.co.kr

ABSTRACT

We stimulated the suprahyoid muscles by surface electrodes and compared the movements of the hyo-laryngeal complex with those during fluid swallowing. Twelve volunteers without dysphagia were participated in this study and swallowed 5 ml barium-diluted fluid, which was also recorded by videofluoroscopic study. Then, they received electrical stimulation at the midpoints between the chin and the bilateral edges of the hyoid and this movement was also recorded. Two-dimensional motion analysis was executed and the movement degrees of the hyoid and the subglottic air-column and the rotation of the epiglottis were acquired and compared between the electrical stimulation and the fluid swallowing. Although elevation and anterior movement of the hyoid and the subglottic air-column and the rotation of the epiglottis were significantly different between the electrical stimulation and fluid swallowing (p<0.05), elevation and anterior movement of hyoid during electrical stimulation were 64% and 41% of movements during fluid swallowing respectively. This suggests possibility of development of neural orthosis to help the laryngeal elevation of a patient who complains of poor laryngeal elevation, so presents with dysphagia.

1. Introduction

Many treatment methods including pharyngeal tactile stimulation and ice cube swallowing have been challenged to improve pharyngeal dysphagia. Recently, electrical stimulation therapy has been emerged for treatment of pharyngeal dysphagia. There are two commercial products used in clinical situation; VitalStim® (Chattanooga Group, Hixson, TN) and StimPlus® (Cybermedic Cor., Iksan, Korea) and clinical studies about two products are in progress[1-4].

Elevation and anterior excursion of hyoid and larynx are important because they induce the inversion of epiglottis, so protect the airway during swallowing[5] and decreased laryngeal elevation and delayed triggering of the pharyngeal motor response are the most common causes of aspiration[6]. If the electrical stimulation can induce the elevation and anterior excursion of hyoid and larynx, so assist the swallowing of patients with decreased laryngeal elevation and delayed pharyngeal triggering as electrical stimulation synchronized with patients’ swallowing, it can reduce the aspiration risk of the patients.

Several trials have been done to elevate hyoid and larynx by electrical stimulation of submandibular muscles[7-10]. Intramuscular stimulation of mylohyoid and geniohyoid muscles induces the elevation of hyoid and larynx[10], but surface electrical stimulation around neck muscles induces significant laryngeal and hyoid descent at rest and reduces hyo-laryngeal elevation during swallowing, so may be an obstacle to pharyngeal swallowing[7]. However, we think it is possible to induce the elevation and anterior excursion of the hyoid through surface electrical stimulation if we find the optimal stimulation site and stimulus parameters.

Epiglottic downward movement to closure is important to prevent aspiration during swallowing, so it is necessary to examine the epiglottic movement during electrical stimulation for the possible treatment of dysphagia. Epiglottic downward movement to closure is known to be the biomechanical effect of hyo-laryngeal movement, downward bolus movement and tongue base retraction[11]. In normal persons, three components happen simultaneously, so in clinical situation, we cannot know the pure contribution of the hyo-laryngeal movement to the rotation of epiglottis, but we can know it if the hyo-laryngeal movement is acquired by the electrical stimulation without tongue movement.

Our hypotheses are two; one is that surface electrical stimulation of suprahyoid muscles can induce the hyo-laryngeal complex elevation like normal swallowing does, and the other is that the epiglottis will rotate according to the hyo-laryngeal movement induced by electrical stimulation without tongue movement. So, the purpose of this study is to investigate the movement pattern of hyo-laryngeal structures and to find the contribution of the hyoid movement to the epiglottic movement during surface electrical stimulation compared with during normal pharyngeal swallowing.

2. Methods

2.1 Subjects

Twelve young male volunteers without any neurological disorder participated in this study and received written or verbal consent. The protocol of this study was approved by Institutional Review Board of the National University Hospital. Subjects were 28.6±3.0 years old and 172.2±5.8 cm.

2.2 Procedures

All subjects were clean-shaved state and wiped their neck off by alcohol sponge before the study for good attachment of electrodes. Two paired electrodes were attached to the midpoints between the chin and the bilateral edges of the hyoid and the midpoints between the chin and the bilateral mandibular angles (Figure 1), so total 4 electrodes (two channel stimulation) were attached. Two channels were synchronized, so the intensities of the electrical stimulus at two channels were always the same. To fix the electrodes to skin and reduce the skin electrical impedance, thin molded neck splint was worn on each subject and fastened by velcro strap (Figure 1). After attachment, electrical stimulus started from 3 mA. Stimulus parameter was 70 Hz frequency, 0.5 ms duration and continuous symmetric biphasic waveform. Stimulus duration was one second and enough resting interval was given after stimulus to prevent laryngospasm. If the volunteer endured it, the intensity increased by one mili ampere and repeated the procedure. When the volunteer felt discomfort but could tolerate, we repeated the intensity three times for adaptation of the electrical stimulus. When the volunteer felt discomfort after three times or complained of pain, we determined the previous stimulus intensity to the maximal tolerable intensity. All electrodes’ locations were modified inch by inch till the
maximal hyoid movement could be obtained by the maximal tolerable intensity through fluoroscopy. 

After the maximal tolerable intensity and accurate electrode placement for a subject were determined, videofluoroscopic study was performed in the lateral position. A subject sat on a comfortable chair between the fluoroscopic tube and the plate and then the position was adjusted to locate the images of the hyoid and epiglottis in the center of the monitor. The penetrating voltage of the X-ray beam was set as a 40 kV peak which allowed viewing the soft tissues of the laryngeal structures. A coin of 2.4 cm-diameter was taped under the subject’s lateral neck to serve as a reference ruler to compensate the radiographic magnification. Subjects were given 5 ml of 35% diluted barium solution using a 10 ml syringe, held it in their mouth and swallowed it at a time, which procedure was recorded. Then, subjects were attached to the electrodes at the previously acquired location, worn by neck splint and given the stimulation at the maximal tolerable intensity during a second, which procedure was recorded. All subjects clenched their teeth during electrical stimulation for suprahyoid muscles not to move the chin to the hyoid but to move the hyoid to the chin.

2.3 Motion analysis

Swallowing motion file was acquired by videofluoroscopic study and capture board and trimmed to the necessary point for analysis. The anterior margin of the hyoid, base-to-tip margin of the epiglottis, anterior margin of the subglottic air column and the anterior-inferior margins of the 2nd and 4th cervical vertebrae were digitally coordinated at each frame using a motion analysis software system (Ariel Performance Analysis System; Ariel Dynamics, Inc., Trabuco Canyon, CA, USA) (Figure 2). To acquire each point’s coordinates, we defined the ‘0’ point as the anterior-inferior margin of the 4th cervical vertebra, the y-axis as a straight line from the ‘0’ point to the anterior-inferior margin of the 2nd cervical vertebra and the x-axis as a straight line starting from the ‘0’ point perpendicular to the y-axis. Degree of the elevation and anterior excursion of the hyoid and subglottic air column was measured and transformed into the real distance (mm) through the ruler. Degree of epiglottic rotation during swallowing or stimulation was calculated. More detailed method was described in the previous study[12].

2.4 Statistics

Paired t-test was used to compare the elevation and anterior excursion of the hyoid and the subglottic air column and the rotation of the epiglottis between fluid swallowing and electrical stimulation. Multiple regression analysis was performed to show the contribution of the degree of the elevation and anterior excursion of the hyoid to the degree of the epiglottic rotation.

3. Results

Any side effect including dizziness, electrical burn, persistent pain and laryngospasm did not happen. However, four subjects complained of facial distortion and labial depression during stimulation due to the attachment of electrodes to the mandible but these were not persistent after cessation of the stimulation.

Elevation and anterior excursion of hyoid during fluid swallowing were 16.3 mm and 14.0 mm and those during electrical stimulation were 10.5 mm (64.4 % of fluid swallowing) and 5.8 mm (41.4 % of fluid swallowing). Elevation and anterior excursion of subglottic air column during fluid swallowing were 24.1 mm and 4.6 mm compared to 9.6 mm (39.8 % of fluid swallowing) and 1.9 mm (41.3 % of fluid swallowing) during electrical stimulation respectively. Rotation of epiglottis during fluid swallowing and electrical stimulation were 101.1 ° and 23.9 ° (23.6 % of fluid swallowing) respectively (Table 1). All parameters between fluid swallowing and electrical stimulation were significantly different (p<0.05). Adjusted coefficients of determination (γ²) of the degree of the hyoid and epiglottic movements during fluid swallowing and electrical stimulation were 0.742 (p<0.05) and 0.584 (p<0.05) respectively. Standardized beta coefficients of anterior and superior movements of hyoid during fluid swallowing were 0.568 (p<0.05) and 0.771 (p<0.05). Standardized beta coefficient of anterior movement of hyoid during electrical stimulation was 0.703 (p<0.05) but superior movement was 0.202 (p>0.05).

4. Discussion and Conclusions

We induced the hyoid elevation by electrical stimulation to about 64 % of the elevation during fluid swallowing and anterior excursion of the hyoid about 40 % during fluid swallowing although significant difference was found in all parameters. However, epiglottic rotation by electrical stimulation happened to only 23.6 % during fluid swallowing. Anterior excursion induced by electrical stimulation made much contribution to the epiglottic rotation like fluid swallowing but elevation by electrical stimulation did not significantly contribute to the epiglottic rotation.

We gave the electrical stimulation one second to avoid possible laryngospasm because persistent 70 Hz electrical stimulation can induce the muscle tetany. Freed insisted that during 4,500 stimulations by Vital Stim were administered, there was no occurrence of laryngospasm. According to VitalStim manufacturers, 100 microseconds interphase interval prevent the muscle tetany but there was no scientific basis or exploration[13]. So, we used the 0.5 ms duration current without interphase interval for one second at a time in this study to prevent laryngospasm and stimulate the deep muscles effectively.

Main difference between this study and other previous studies[2, 7, 14, 15] is the location of electrodes. Previous studies[2, 7, 14, 15] concentrated on the stimulation of the thyrohyoid muscle for the elevation of the hyo-laryngeal complex but they did not accomplish or could not prove it through the fluoroscopic study. Humbert et al[7] reported the hyo-laryngeal depression paradoxically when stimulating the thyrohyoid muscle by skin electrodes but this result is thought to be natural because the hyoid is a suspensory bone connected between the mandible and larynx, so is pulled by larynx, not pulls larynx during the stimulation of the thyrohyoid muscle. Although the thyrohyoid muscle is activated during fluid swallowing, larger force of suprahyoid muscle drives the hyoid to the upward direction, so the thyrohyoid muscle can pull the larynx to the upward direction. In this study, the fact that larynx was elevated (24.5 mm) more than the hyoid was (16.1 mm) during fluid swallowing means thyrohyoid muscle has an important role in elevating larynx during normal swallowing. Because we did not stimulate the thyrohyoid muscle, the larynx was moved passively, so less elevated (9.1 mm) than the hyoid (10.2 mm).

The method to find optimal stimulation site to elevate the hyo-laryngeal complex is very time-consuming and needs many trial and errors. Although we think the midpoint between the chin and the edge of the hyoid as an approximate optimal site, this location must be adjusted by many trials individually. We think this location may be the motor point of anterior belly of digastric muscle although the other electrode did not locate in it’s insertion area. Unlike the efforts to
stimulate the geniohyoid and mylohyoid muscles in other previous studies[8, 10], we selected the anterior belly of digastric muscles because this locates more superficially than the geniohyoid and mylohyoid muscles. In fact, we failed the elevation of hyo-laryngeal complex to stimulate the midpoint between the chin and the midline of the hyoid which is near the mylohyoid and geniohyoid muscles.

Another key point to elevate the hyo-laryngeal complex by the electrical stimulation is to give some pressure of to the electrodes attached to the skin. We used the Steri-Drape® (3M™ USA) for the firm attachment of electrodes but this is not enough to give enough electrical current to elevate the hyoid. So, we used the thin molded neck splint and gave some pressure as fastening by the velcro. However, this technique is not applicable in view of swallow assistance by synchronized stimulation because the splint is solid, so hinders voluntary swallowing during wearing on it. In order to assist the swallowing of patients with decreased laryngeal elevation as electrical stimulation synchronized with patients’ swallowing as we commented at the introduction, it is necessary to develop a new method to give some pressure to the electrodes and not to hinder voluntary swallowing.

In this study, we could make an elevation and anterior excursion of the hyoid about 64% and 40% of fluid swallowing. This data do not fall behind those by the electrical stimulation using the hooked wire in the Burnett’s study[10] and have an advantage over it in the aspect of noninvasiveness. However, surface electrical stimulation only made a rotation of the epiglottis about 24% and this may be due to the poor movement of the thyroid cartilage. Logemann et al[11] suggested the biomechanical effects of vertical and anterior laryngeal movement are likely created by the ligamentous attachments of the epiglottis to the thyroid cartilage. In fluid swallowing, thyrohyoid muscle contraction moves the thyroid cartilage in the anterior and superior direction but in the electrical stimulation of the suprahyoid muscles, no thyrohyoid muscle contraction occurs. However, if we attach the electrodes at the thyrohyoid muscle belly and stimulate it, the thyrohyoid muscle contract and pull the hyoid in the downward direction, not the larynx in the upward direction.

Pure contribution of the hyoid movement to the rotation of the epiglottis during fluid swallowing and electrical stimulation is 74.2% and 58.4% respectively but the rotation of the epiglottis is too small to prove the significant contribution of the hyoid. Further study will be necessary to acquire enough rotation of the epiglottis.

As we mentioned at the introduction, in order to assist the swallowing function of a patient who complains of poor laryngeal elevation, so presents with dysphagia, it is necessary to reveal the augmentation of the laryngeal elevation with synchronized stimulation of suprahypoid muscles. Later study will be focused in this aspect, so develop a neural orthosis to help the swallowing function of a patient with dysphagia.

This study suggest the electrical stimulation of suprahypoid muscles by surface electrodes can induce the elevation and the anterior excursion of the hyoid to some degree but it is not enough to induce the epiglottic rotation and laryngeal movement, so closure of laryngeal vestibule. Further study will be necessary to reveal the effect of synchronized electrical stimulation on the laryngeal elevation at a patient who complains of poor laryngeal elevation, so presents with dysphagia.

**References**


**Acknowledgements**

This study was funded by Korea Institute of Industrial Technology. (registration number : S1011657)