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Effects of Surface Electrical Stimulation Both at Rest and During Swallowing in Chronic Pharyngeal Dysphagia[§]

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Abstract

We tested two hypotheses using surface electrical stimulation in chronic pharyngeal dysphagia: that stimulation 1) lowered the hyoid bone and/or larynx when applied at rest, and 2) increased aspiration, penetration or pharyngeal pooling during swallowing. Bipolar surface electrodes were placed on the skin overlying the submandibular and laryngeal regions. Maximum tolerated levels of stimulation were applied while patients held their mouth closed at rest. Videofluoroscopic recordings were used to measure hyoid movements in the superior-inferior (s-i) and anterior-posterior (a-p) dimensions and the subglottic air column (s-i) position while stimulation was on and off. Patients swallowed 5 ml liquid when stimulation was off, at low sensory stimulation levels, and at maximum tolerated levels (motor). Speech pathologists blinded to condition, tallied the frequency of aspiration, penetration, pooling and esophageal entry from videofluorographic recordings of swallows. Only significant ($p=0.0175$) hyoid depression occurred during stimulation at rest. Aspiration and pooling were significantly reduced only with low sensory threshold levels of stimulation ($p=0.025$) and not during maximum levels of surface electrical stimulation. Those patients who had reduced aspiration and penetration during swallowing with stimulation had greater hyoid depression during stimulation at rest ($p=0.006$). Stimulation may have acted to resist patients' hyoid elevation during swallowing.

Keywords

deglutition; deglutition disorders; hyo-laryngeal movement; aspiration; penetration; sensory stimulation; resistance; transcutaneous neuromuscular stimulation

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Introduction

Although surface electrical stimulation has received increased attention as an adjunct to swallowing therapy in dysphagia in recent years [1-4], little is known about the effects of transcutaneous stimulation on swallowing physiology. It has been hypothesized that electrical stimulation may assist swallowing either by augmenting hyo-laryngeal elevation [1,2] or by increasing sensory input to the central nervous system to enhance the elicitation of swallowing [3,4].

When electrical stimulation is applied to the skin or oral mucosa at low current levels it activates the sensory nerve endings in the surface layers providing sensory feedback to the central nervous system. With increased current amplitude, the electric field may depolarize nerve endings in muscles lying beneath the skin surface [5] and may spread with diminishing density to produce muscle contraction.

When electrodes are placed in the submental region, therefore, the current density is greatest at the skin surface, and diminishes with depth through the platysma underlying the skin and subcutaneous fat [6]. Accordingly, as the current is increased in amplitude, increasingly deeper muscles may be recruited, albeit with less efficiency. Such muscles include the anterior belly of the digastric, which can either lower the mandible or pull the hyoid upward depending upon whether the mouth is held closed. Deeper still are the mylohyoid and geniohyoid muscles, which pull the hyoid bone upward and toward the mandible, respectively. These muscles are much less likely to be activated by surface stimulation, however, because of their greater depth.

Similarly when electrodes are placed on the skin overlying the thyroid cartilage in the neck, the current will be greater at the skin with less intensity to the underlying platysma muscle with further reduction to the underlying sternohyoid and omohyoid muscles [6], which pull the hyoid downward and backward towards the sternum. The electrical field strength would be even further diminished if it reaches the deeper thyrohyoid muscle, which brings the larynx and hyoid together and the sternothyroid muscle, which lowers the larynx towards the sternum. Given that the sternohyoid muscle is larger and overlies the thyrohyoid and sternothyroid, we expect that high levels of surface electrical stimulation on the neck could pull the hyoid downward due to stimulation of either the sternohyoid or the underlying sternothyroid but would be much less likely to raise the larynx toward the hyoid bone as occurs in normal swallowing.

In VitalStim®Therapy [7] electrodes are simultaneously activated over the submental and laryngeal regions on the throat, with the aim of producing a simultaneous contraction of the mylohyoid in the submental region (to elevate the hyoid bone) and the thyrohyoid in the neck (to elevate the larynx to the hyoid bone). However, because these muscles lie deep beneath the anterior belly of the digastric, sternohyoid and omohyoid muscles, we hypothesized that simultaneous transcutaneous stimulation with two pairs of electrodes at rest would cause: 1) the hyoid bone to descend in the neck (due to sternohyoid muscle action); 2) the hyoid bone to move posteriorly (due to the omohyoid muscle activity); and, 3) the larynx to descend (if current activates either the sternohyoid or stenothyroid muscles). Further, we hypothesized that in severe chronic dysphagia: 4) when the same array is used at low levels of stimulation just above the sensory threshold, sufficient for sensation but without muscle activation, patients' swallowing might improve due to sensory facilitation; while 5) at higher levels required for motor stimulation, the descent of the hyoid might interfere with swallowing causing increased penetration and aspiration.

METHODS

Participant Selection

The protocol for the study was approved by the Institutional Review Board prior to initiating the research. Participant selection criteria included: chronic stable pharyngeal dysphagia, at risk for aspiration for 6 months or more, a score of 21 or greater on the Mini-Mental State Examination [8], a severely restricted diet and/or receiving nutrition through enteric feeding, and medically stable at the time of the study. To be included for study, all participants had to demonstrate a risk of aspiration for liquids on videofluoroscopy during the screening portion of the study.

Procedures

Participants were administered informed consent, and had to correctly answer 10 questions to demonstrate that they understood the content of the consent before participating. VitalStim® electrodes (Chattanooga Group, Hixson, TN, #59000) and the VitalStim® Dual Channel Unit were used for the study. Two sets of electrodes were used, the top set was placed horizontally in the submental region over the region of the mylohyoid muscle above the hyoid bone (Figure 1). The bottom set was placed on the skin over the thyroid cartilage on either side of the midline over the region of the thyrohyoid muscle medial to the sternocleidomastoid muscle. This electrode array was recommended as effective during certification training of the first two authors [7]. A ball bearing with a diameter of 19 mm was taped to the side of the neck for measurement calibration.

After familiarizing the participant with the device, we identified the sensory threshold as the lowest current level at which the participant reported a “tingling” sensation on the skin. Stimulation at the sensory threshold level did not produce movement on videofluoroscopic recordings and was the lowest level at which participants sensed the stimulation on the skin. Movement was first observed when participants first reported a “tugging” sensation, usually around 7 or 8 mA. The maximum motor level was the highest current level a participant could tolerate without discomfort during stimulation on the neck. We determined the sensory and motor levels independently for each set of electrodes. The VitalStim® device cycles automatically from “on” to “off” to “on” again for 1 second every minute. Because the change in stimulation is ramped, this cycling process takes up to 4 s. For the stimulation at rest trials, the participant was told to keep their teeth clenched to prevent jaw opening and the stimulation was simultaneously set at the maximum tolerated levels for both sets of electrodes. When the stimulation duration reached 55 s, videofluoroscopy was turned on and we recorded the fluoroscopic image on S-VHS videotape while the participant was in the resting position and the device automatically cycled from “on”, to “off” and then “on” again. The examiner pressed a button at the time of stimulation offset to place a visible marker on the videotape.

During the videofluoroscopic screening examination, we determined which volume, either a 5 or 10 ml of liquid barium bolus, was more challenging and put a participant at risk of aspiration for use during testing. During testing, between one and three swallows were recorded in each of the following conditions in random order: 1) with no stimulation, 2) with both electrode sets on at the sensory threshold level and 3) with both sets at the maximum tolerated stimulation level. Stimulation remained on before, during and after the stimulated swallows. The videotaped recordings included an auditory channel for documentation and a frame counter display for identifying when stimulation changed.

Because radiation exposure during this study was administered for research purposes only and was not for necessary medical care, the Radiation Safety Committee limited us to a short exposure time per participant for the total study. Therefore, depending on radiation exposure

time in each part of the study, we were only able to conduct between one and three trials per condition in addition to stimulation at rest for each of the participants.

Movement Analysis

The video of each trial was captured off-line using Peak Motus 8, a 2D motion measurement system (ViconPeak, Centennial, CO 80112). The system was equipped with a video capture board at ~60 fields/s (~30 frames/s) and a frame size of 608 X 456 pixels. The radius of the ball bearing (9.5 mm) was used for all measurement calibrations in the horizontal and vertical directions. An investigator used a cursor to identify the points on the most anterior-inferior corner of the second and fourth vertebra on each video frame and a straight line was drawn between these two points to define the y axis. When either the second or fourth vertebra was not visible, the bottom anterior-inferior corner of the first and third vertebrae were used in the same fashion. A line perpendicular to the y axis at the anterior-inferior corner of the lower vertebra served as the x axis. The x and y coordinates for all points were determined in mm relative to the anterior-inferior corner of the second vertebra serving as the origin with anterior and superior points being positive and posterior and inferior points being negative for direction of movement of the hyoid. Four points were marked for each frame, the anterior-inferior points of the two interspersed vertebrae, the anterior inferior point of the hyoid bone and the most posterior and superior point in the subglottal air column (to track the position of the larynx).

The time series plots of the x and y points of the hyoid bone and the y coordinate of the larynx were exported from Peak Modus into Microsoft Excel and then into Systat 11 (Systat Software, Inc., Richmond, CA) for analysis. The frame when the stimulation cycled from “on” to “off” was added to the file and used to sort measures into stimulation “on” and stimulation “off”. All of the position data were then corrected to place the starting position at zero on both the x and y axes for each subject and then the mean hyoid (x,y) and larynx (y) positions were computed for the stimulation “on” and stimulation “off” conditions for each subject.

Dysphagia Ratings

Four experienced certified speech pathologists initially examined the screening videotapes of randomly selected subjects to decide on a rating system. After assessing several swallows with the Rosenbek Penetration-Aspiration Scale [9](Pen-Asp) it was noted that many of the participants who were on enteric feeding because of their risk of aspiration could score within the normal range, a score of 1 on this scale. This occurred when no penetration or aspiration occurred even though there was severe residual pooling in the pyriform sinuses and none of the bolus entered the esophagus. These participants regurgitated any residual material back into the mouth after a trial, not swallowing any of the liquid but scoring as normal because no material entered the airway. Because scores of 1 on the Pen-Asp scale were at ceiling (normal) and would not allow measurement of improvement, this scale could only measure a worsening in swallowing in these patients. Therefore, another scale was developed that did not have a ceiling effect. The NIH Swallowing Safety Scale (SSS) captured the abnormalities seen in this patient group, which involved pooling and a lack of esophageal entry with and without penetration and aspiration. When scoring a swallow, a score of 1 was assigned for the occurrence of each the following abnormalities: pooling in the vallecula, penetration into the vestibule from the hypopharynx, pooling in the pyriform, and back up penetration from the pyriform into the laryngeal vestibule. The amount of the bolus material entering and clearing from the upper esophagus was rated as 3 if none entered, 2 if a minimal amount entered, 1 if a moderate amount entered and 0 if all of the bolus was cleared through the upper esophagus. In addition, the total number of aspirations in each swallowing sample were counted. Only normal swallows received a total of 0 on this scale and the maximum score could reach as high as 13 depending upon the number of aspirations or other abnormalities in bolus flow that occurred in a single swallow.

All four speech pathologists viewed each videofluoroscopic recording without knowledge of condition and came to a consensus on all noted behaviors and the Pen-Asp rating before assigning the scores. After repeating ratings on 21 trials to establish reliability, differences in ratings of the same swallow were noted and a set of uniform rules were developed to be followed in assigning scores. These rules were subsequently used to assign ratings to each of the trials in this study. Another set of 18 trials was then repeated to determine the measurement reliability.

Statistical Analyses

To determine the reliability of the position measures, two examiners measured the position for the hyoid on the x and y axes and larynx on the y axis on each frame and then computed means for each during both the stimulated and non-stimulated conditions on 4 of the 10 subjects. The output of the General Linear Model Systat 11 (Systat Software, Inc., Richmond, CA) was used to calculate the mean square differences for the within and between subject factors. The Intraclass Correlation Coefficient (ICC) was computed by taking the mean square difference between subjects and subtracting the mean square difference within subjects and then dividing the result by the sum of the mean square difference between subjects and the mean square difference within subjects [10].

To determine the reliability of the ratings made using the Pen-Asp Scale and the NIH-SSS, ICCs were computed between the two sets of ratings on each scale from the first 21 trials that were reanalyzed. To identify the items that were unreliable, Cohen's Kappa was computed for the two sets of ratings of each component item of the NIH-SSS using Systat 11 (Systat Software, Inc., Richmond, CA). After developing rules for scoring those items that had low reliability, ICCs were computed on the second set of repeated ratings for both the Pen-Asp Scale and the NIH-SSS.

To address the first hypothesis that the hyoid bone would descend in the neck with maximal levels of stimulation at rest, a one-sample directional t-test was used to test for a lowering of the hyoid bone on the y axis between "off" and "on" stimulation. To address the second hypothesis that the hyoid bone would move posteriorly, a one-sample directional t-test was used to test for a retraction of the hyoid bone on the x axis in the "off" and "on" stimulation conditions within subjects. To determine if the larynx descended during stimulation, a one-sample directional t-test was used to test for a lowering of the subglottal air column between the two conditions.

To determine if swallowing improved due to sensory levels of stimulation, one-sample directional t-tests were used to test participants' mean changes in ratings between non-stimulated swallows and stimulated swallows within participants on the Pen-Asp scale and the NIH-SSS with a Bonferroni corrected p value of $0.05/2 = 0.025$. Finally, to determine if swallowing worsened during maximum levels of motor stimulation, one-sample directional t-tests were used to test participants' mean changes in ratings between non-stimulated swallows and stimulated swallows within participants on the Pen-Asp Scale and the NIH-SSS with a Bonferroni corrected p value of $0.05/2 = 0.025$.

Pearson correlation coefficients using a Bonferroni corrected p value of 0.025 for statistical significance were computed between both the participant's mean initial severity on the Pen-Asp scale and the NIH-SSS and changes in mean ratings during the sensory stimulation to determine if participant characteristics predicted the degree of benefit. Similarly, Pearson correlation coefficients were computed between the extent to which the hyoid was pulled down in the neck during stimulation at rest and the change in participants' mean ratings for swallowing on the Pen-Asp scale and the NIH-SSS using a Bonferroni corrected p value of 0.025 for statistical significance.

RESULTS

Participants

All 11 participants had chronic long-standing dysphagia (Table 1). Their disorder was either subsequent to a CVA in six (> 6 months post), post craniotomy for a benign tumor in two (2 and 4 years post) or post traumatic brain injury in two (2 and 3 years post). Only one patient had a chronic progressive neurological disease, Parkinson disease of > 20 years with dysphagia for more than 2 years duration.

Ten of the 11 participants participated in the stimulation at rest trials; one did not because of time constraints. During swallow stimulation trials, one of the participants had severe aspiration on an initial swallowing trial and for safety reasons the study was discontinued for that participant. Therefore, we were able to include ten participants in the motor stimulation swallow trials. Because of time constraints, two of the participants did not participate in the low sensory levels of stimulation, leaving 8 participants in the study.

Measurement Reliability

The ICC for the movement of the hyoid bone on the y axis in the on and off stimulation conditions were 0.99 and 0.94 respectively and for hyoid movement on the x axis were 0.94 and 0.87. The ICCs for the larynx on the y axis in the stimulation “on” and “off” positions were 0.58 and 0.66 respectively indicating much less reliability on these measures. Because the movement of the larynx was extremely small, ranging from a mean position of 0.4 mm in the stimulation “on” to 0.18 mm in the “off” condition, measurement variability contributed to the variance on this measure.

Movement Induced by Stimulation at Rest

To address the first hypotheses, a one-tailed directional t-test comparing the mean position between “off” and “on” stimulation conditions demonstrated a significant lowering of the hyoid position on the y axis ($t=-2.523$, $df=9$, $p=0.016$) (Figures 2A and 2B). To address the second hypothesis that the hyoid bone would move posteriorly with stimulation at rest, a directional t-test comparing the mean positions in the “off” and “on” stimulation conditions within subjects was not significant ($t=-0.102$, $df=9$, $p=0.460$) (Figure 2C). Similarly, a directional t-test found no descent in laryngeal position on the y axis during stimulation ($t=0.696$, $df=9$, $p=0.748$) (Figure 2D).

Reliability of Ratings on the Pen-Asp and NIH SSS After the first set of 21 repeated ratings, the ICC was 0.965 on the PenAsp scale and 0.764 on the NIH-SSS. Because of concerns about the reliability of the NIH-SSS, we implemented more detailed judging rules for each item where disagreement occurred. A second set of 18 reliability measures using the new judging rules resulted in an ICC for the NIH-SSS that was 0.925, demonstrating adequate reliability when using the scale once the judging rules were developed and implemented.

Effects of Low Sensory Stimulation Levels During Swallowing

Due to time constraints only eight of the ten participants completed the sensory condition. To address the fourth hypothesis that swallowing improved with sensory levels of stimulation, one-sample directional t-tests were computed to compare mean change in ratings between non-stimulated swallows and stimulated swallows within participants. The results were not significant on the Pen-Asp Scale ($t=0.336$, $df=7$, $p=0.373$) but were significant on the NIH-SSS ($t=2.355$, $df=7$, $p=.025$) using a Bonferroni corrected p value of $0.05/2 = 0.025$. Six of the eight of the participants showed a reduction on the NIH-SSS with sensory stimulation during swallowing (Figure 3A) while five of the eight participants showed a reduction on the Pen-Asp scale (Figure 3B).

Effects of Motor Stimulation Levels During Swallowing

To address the fifth hypothesis that the risk for aspiration and swallowing safety worsened during stimulation, one-sample directional t-tests were computed to examine mean change in ratings between non-stimulated swallows and stimulated swallows within participants. The result was not significant on either the Pen-Asp Scale ($t=0.363$, $df=9$, $p=0.637$) or on the NIH-SSS ($t=-0.881$, $df=9$, $p=0.201$) at a Bonferroni corrected p value of $0.05/2=0.025$. On the NIH-SSS scale, five of the ten participants had increased risk with motor levels of stimulation (Figure 4A), while on the Pen-Asp equal numbers of participants increased or decreased with motor levels of stimulation (Figure 4B).

Relationship Between Severity of Dysphagia and Changes in Swallowing with Stimulation

The Pearson correlation coefficient between participants' initial severity on the Pen-Asp scale and change in swallowing with sensory stimulation was not significant ($r=0.142$, $p=0.737$). Similarly, participants' initial severity and change in swallowing with sensory stimulation on the NIH-SSS ($r=0.701$, $p=0.053$) was not significant using a Bonferroni corrected α value of 0.025 for statistical significance. A Pearson correlation coefficient between both the participants' initial severity on the Pen-Asp scale and change in swallowing with motor stimulation was not significant ($r=-0.501$, $p=0.140$), nor was the correlation between participants' initial severity on the NIH-SSS and change in swallowing with motor stimulation ($r=-0.190$, $p=0.599$), using a Bonferroni corrected α value of 0.025 for statistical significance.

Relationship of Movement during Stimulation at Rest with Changes in Swallowing with Stimulation

Pearson correlation coefficients were computed between the extent to which the hyoid was pulled down in the neck during stimulation at rest and the change in swallowing on the Pen-Asp and the NIH-SSS using a Bonferroni corrected α value of 0.025 for statistical significance. No significant relationship was found between the degree of improvement on the NIH-SSS and the degree to which the hyoid bone was depressed during motor levels of stimulation at rest ($r=-.388$, $n=9$, $p=0.302$) (Figure 5A). The improvement in the Pen-Asp scale during motor stimulation was significantly inversely related to the degree to which the hyoid bone was depressed during motor levels of stimulation at rest ($r=-0.828$, $n=9$, $p=0.006$) (Figure 5B). The relationship demonstrated that those with the greatest hyoid depression at rest had the greatest reduction on the Pen-Asp scale during motor levels of stimulation while swallowing.

DISCUSSION

The first purpose of this study was to determine the physiological effects of surface electrical stimulation on the position of the hyoid and larynx in the neck. We had predicted that when both the submental and laryngeal electrode pairs were stimulating at the participants' maximal tolerated levels, that the hyoid bone would be pulled downward, most likely due to stimulation of the sternohyoid muscle. The data supported this hypothesis; all but two of the participants had depression of the hyoid bone by as much as 5 to 10 mm during stimulation at rest (Figures 2A and 2B). We also predicted that the hyoid bone might be pulled posteriorly, however, limited anterior-posterior movement occurred in the hyoid bone. Three participants had hyoid anterior movement, by as much as 5 mm in one case, while the others had minimal movement in the posterior direction. Whereas minimal ascending movement (2-3 mm) occurred in the larynx in two participants, none of the other participants experienced any appreciable laryngeal movement (Figure 2D) and the 2-3 mm changes were potentially due to measurement variation. To summarize these findings, the only appreciable motoric effects of surface electrical stimulation was to cause the hyoid bone to descend in the neck, producing movement in the opposite direction from that required for swallowing.

These results suggest that when surface stimulation was applied to the neck at rest, stimulation was either too weak or not deep enough to stimulate axons innervating the muscles that produce hyoid and laryngeal elevation such as the mylohyoid and the thyrohyoid muscles respectively. No change in laryngeal position was observed with surface stimulation at rest.

The second purpose of this study was to determine the immediate effects of surface stimulation on swallowing in participants with chronic pharyngeal dysphagia. Based on previous use of sensory stimulation in the oral and pharyngeal cavities to augment patients' volitional control of swallowing [3,11], we compared sensory levels of electrical stimulation just above the participants' sensory threshold for detecting a tingling sensation on the skin, and found a significant improvement during swallowing on the NIH-SSS scale but no change on the Pen-Asp scale (Figure 3). The improvement on the NIH-SSS tended to be related to higher initial scores; that is the more severely affected patients were those who had the greatest improvement with stimulation. Because the NIH-SSS captures pharyngeal pooling and failed esophageal entry in contrast with the Pen-Asp scale, which only measures aspiration and penetration, sensory stimulation may be somewhat helpful in those patients who have reduced ability to clear the bolus from the airway.

Based on the expected lowering of the hyoid with motor levels of stimulation, we hypothesized that the group would have increased penetration and aspiration during swallowing with motor stimulation. No group change in aspiration was noted on either scale with motor levels of stimulation. When the degree of improvement on the Pen-Asp scale with motor levels of stimulation was examined relative to the degree of hyoid depression, we found an unexpected relationship indicating that patients with the greatest hyoid depression during motor levels of stimulation at rest had the greatest improvement during swallowing with the same levels of stimulation. When the hyoid was depressed with stimulation, a patient probably experienced a greater resistance to hyo-laryngeal elevation during swallowing. Perhaps those patients who felt a greater downward pull on the hyoid, when stimulation was turned on at maximal levels, made a greater effort to elevate the hyo-laryngeal complex when swallowing in an attempt to overcome the effects of the stimulation. It could also be the case that those patients who had greater residual power in their hyo-laryngeal muscles would have not only experienced greater hyoid descent with stimulation but could also have greater residual power that they could recruit for hyo-laryngeal elevation to counteract the stimulation induced descent during swallowing.

This study did not address whether or not surface electrical stimulation aids dysphagia therapy in patients' at risk of aspiration. A controlled clinical trial with random assignment to two groups with equal contact time to compare traditional therapy techniques and therapy using surface electrical stimulation with blinded outcome ratings is needed to answer this question. This study addressed the immediate physiological effects of the use of surface electrical stimulation at rest and during swallowing. However, this study suggests that electrical stimulation should be used judiciously dependent upon a patient's type and degree of difficulty with swallowing. In those patients who already have some ability to raise the hyo-laryngeal complex, hyoid depression with stimulation may serve as "resistance" during therapy. On the other hand, if a patient is unable to produce any hyo-laryngeal elevation, and therefore would not be able to resist the hyoid depression induced by stimulation, stimulation might put such a patient at greater risk of aspiration as the hyo-laryngeal complex is held down during swallowing. This may have occurred in some of the more severely affected patients who increased in severity on the Pen-Asp and NIH-SSS with motor levels of stimulation, while those less impaired did not change (Figure 4A and B).

In this study both submental and laryngeal pairs of electrodes were used simultaneously as is recommended for VitalStim® Therapy. It is likely that the simultaneous stimulation resulted in hyoid lowering because the stronger stimulation to the more superficial and larger

sternohyoid and sternothyroid muscles overcame any action that might have been induced by stimulation of the mylohyoid muscle in the submental region or the thyrohyoid muscle beneath the sternohyoid in the throat region. Some have proposed using submental stimulation alone to activate the anterior belly of the digastric and the mylohyoid muscles to pull the hyoid bone upward. However, elevation of the hyoid bone without simultaneous stimulation of the thyrohyoid to raise the larynx would leave the larynx down resulting in further opening of the vestibule and increased risk of aspiration. Only if the mylohyoid and thyrohyoid muscles are activated together, without contraction of the sternohyoid, would both the hyoid and larynx be raised together as has previously been shown with intramuscular stimulation [12]. This cannot be achieved using surface stimulation, because the larger sternohyoid muscle overlies the thyrohyoid and pulls the hyoid downward.

The finding that the group as a whole improved with sensory levels of stimulation alone on the Pen-Asp scale was somewhat unexpected. Previous research has shown that stimulation of the anterior and posterior faucial pillars was most effective stimulation for eliciting a swallow reflex in normal persons[13]. Although not studied physiologically, stroking the throat region is known to assist with the spontaneous elicitation of swallowing in infants and some mammals. Stimulation of either the glossopharyngeal or the superior laryngeal nerves has been shown to elicit swallowing in animals [14] and bilateral chemical blockade of the superior laryngeal nerves disrupts swallowing in normal humans [15]. It has not been observed that sensory stimulation to the surface of the throat would reflexively trigger a swallow in adults; however, sensory levels of electrical stimulation on the skin in the throat may facilitate volitional triggering of swallowing in dysphagia. These preliminary results suggest that low levels of electrical stimulation on the skin might be beneficial in some patients. Because such low levels of electrical stimulation were not observed to induce hyoid depression, we posit that none of the patients would be put at increased risk for aspiration using lower sensory levels of stimulation. Careful systematic study is needed, however, before such low levels of stimulation could be considered as an additional tool for dysphagia therapy.

This study has several limitations. Only one or two trials were evaluated in each patient in each condition because of the need to limit radiation exposure for research purposes in patients who were already receiving radiation exposure for clinical purposes. In addition, the NIH-SSS had limited reliability when first used. This tool improved once rules for judging each of the categories were developed; however, further assessment of the individual items on this scale is needed. The results differed when using the Pen Asp scale and the NIH-SSS. Further research is needed to examine how these scales differ and what they reflect. However, the NIH-SSS scale was more useful for the particular group of severely affected patients with chronic pharyngeal dysphagia who were studied here. The assessment of pooling and esophageal entry was useful for assessing the particular deficits of patients who were on enteric feeding and had not ingested food for six months or more.

In spite of these limitations the results presented here may be helpful as a first step in developing physiological understanding of the immediate effects of surface electrical stimulation in dysphagia. Before such a tool is used in therapy, improved understanding of its immediate effects should be gained in the presence of specific types of swallowing difficulties before it is applied widely to a variety of patients regardless of their risk of aspiration with hyoid lowering.

Before surface electrical stimulation is used, the patients should be carefully screened to determine whether they would be placed at increased risk of aspiration with a procedure that lowers the hyoid. Our results indicate that in some patients with dysphagia this form of stimulation could interfere with hyo-laryngeal elevation required for airway protection during swallowing.

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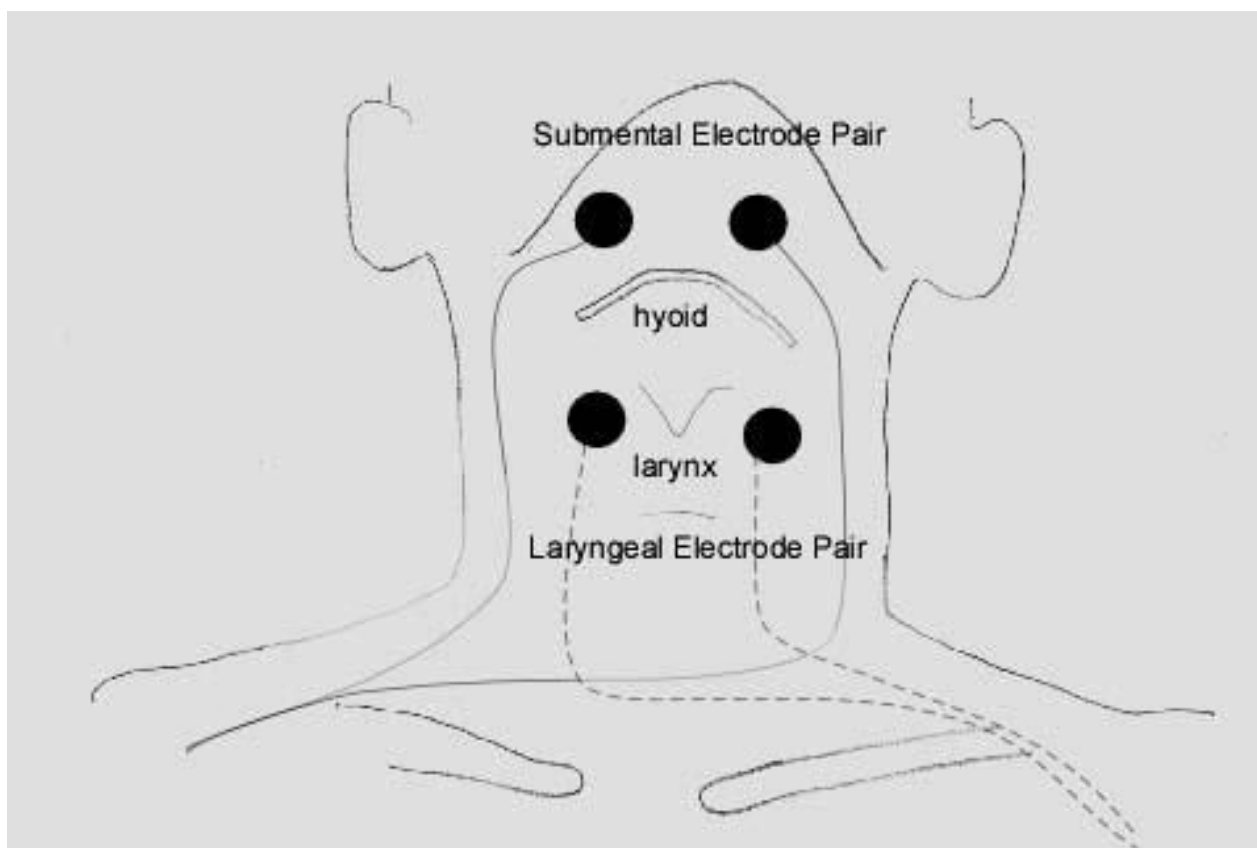


Figure 1. A schematic drawing of the placement of the surface electrodes over the submental region and the laryngeal region relative to palpation of the hyoid bone and the thyroid cartilage in the neck.

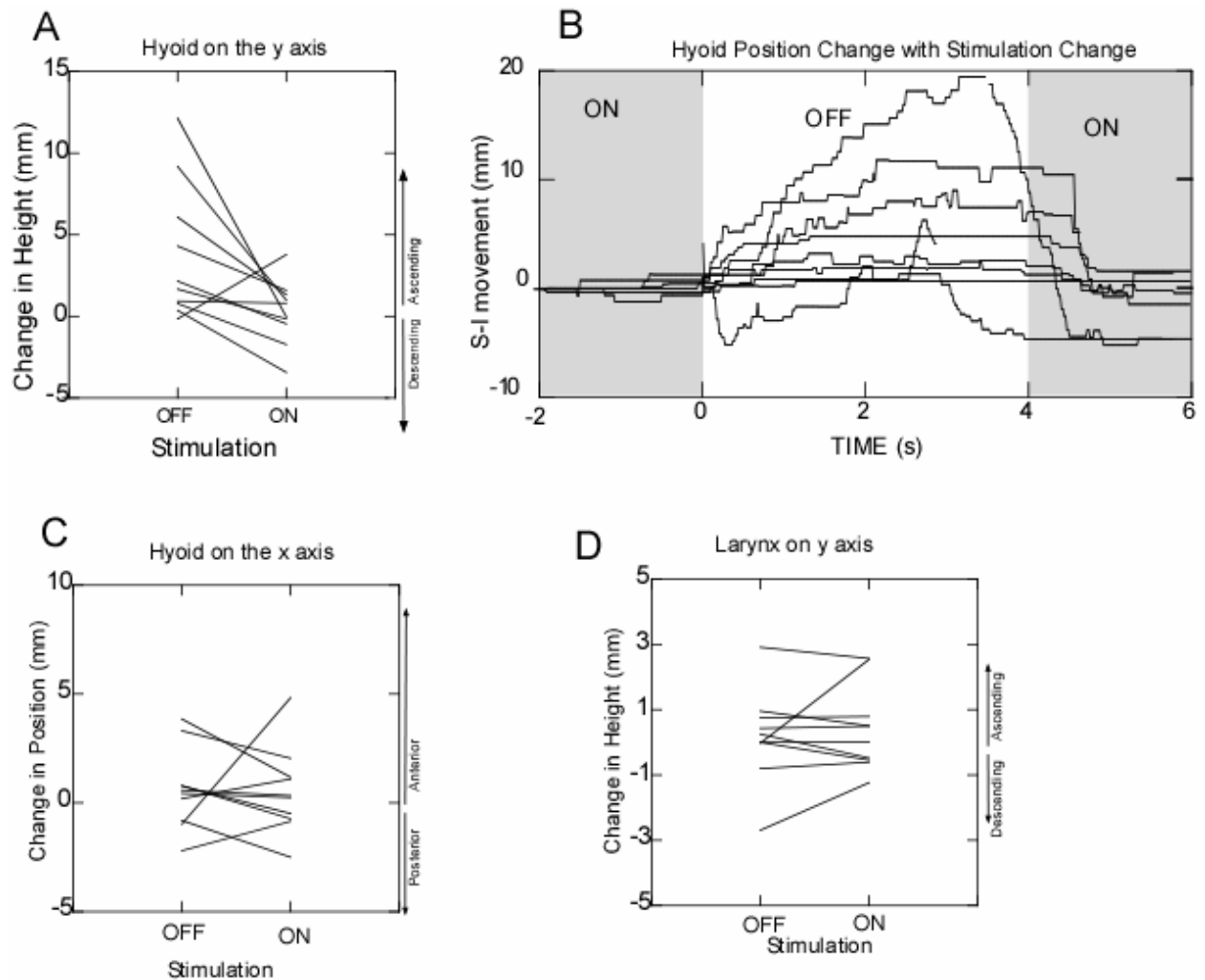


Figure 2.

Line graphs showing the mean values for each participant during the off and on stimulation conditions for (A) the hyoid position on the y axis. In (B) the traces of hyoid position during stimulation “on”, stimulation “off” followed by stimulation “on” are shown for each of the participants in the study. Line graphs also show the mean values for each participant during the “off” and “on” stimulation conditions for (C) the hyoid position on the x axis and (D) the larynx position on the y axis.

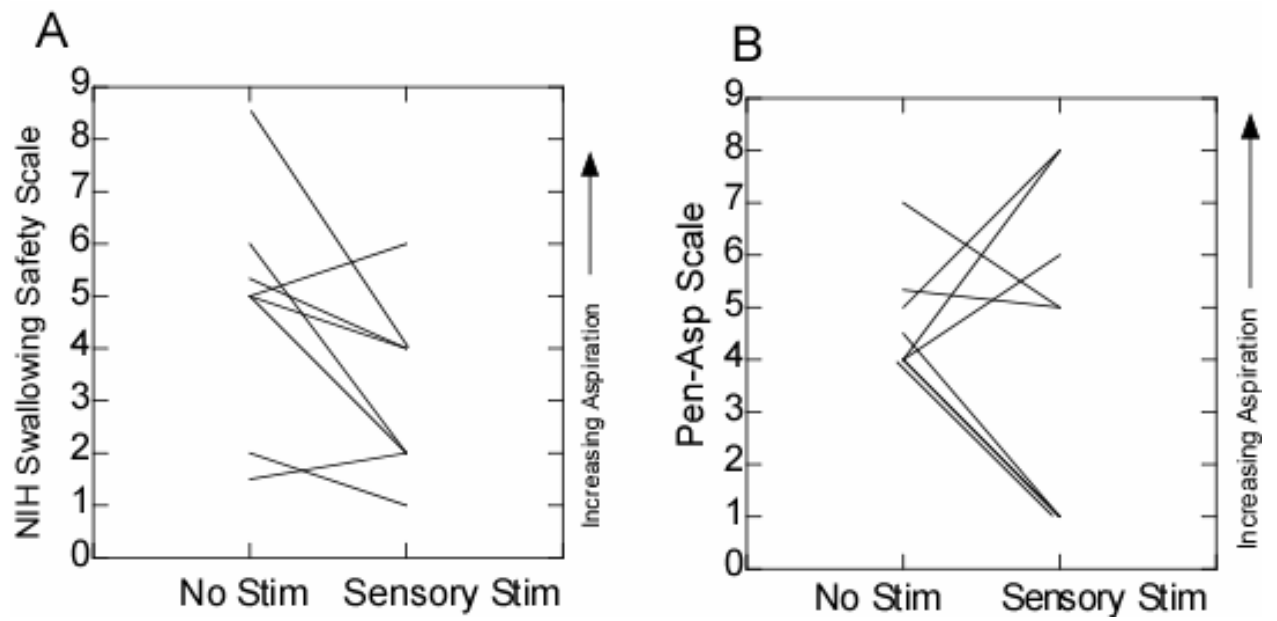


Figure 3.

Line graphs showing individual participants rating during the stimulated and non-stimulated swallows at sensory levels of stimulation on the NIH Swallowing Safety Scale (A) and the Penetration-Aspiration scale (B).

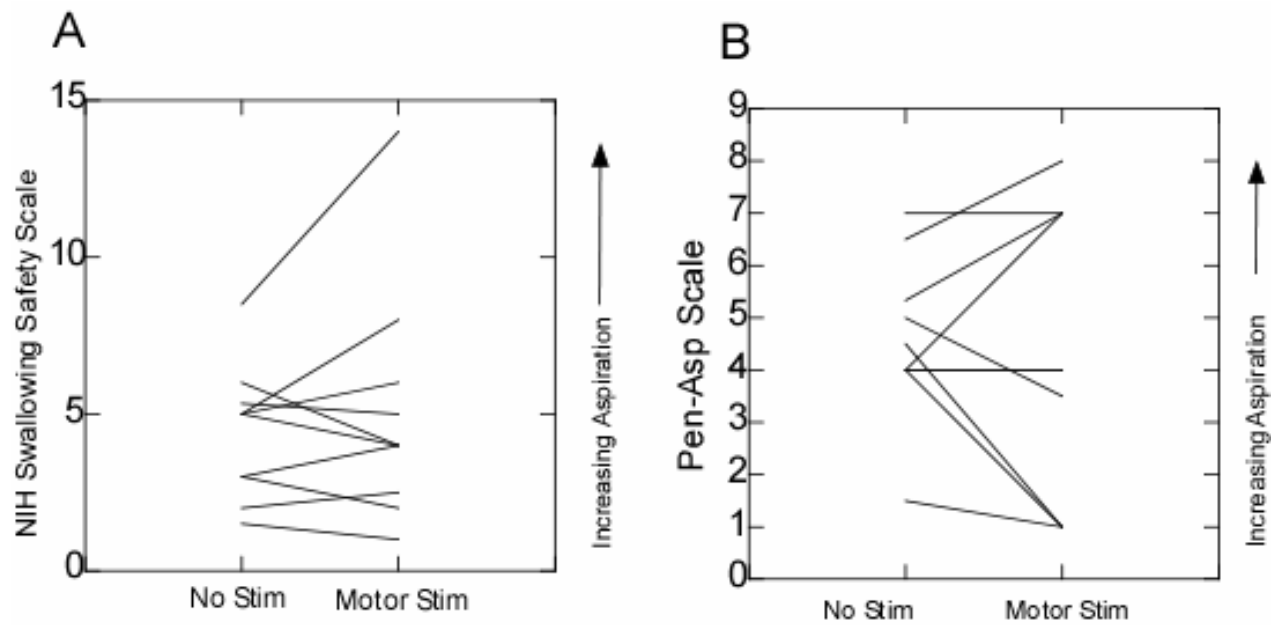


Figure 4.

Line graphs showing individual participants rating during the stimulated and non-stimulated swallows at motor levels of stimulation on the NIH Swallowing Safety Scale (A) and the Penetration-Aspiration scale (B). These graphs are autoscaled to the range of the data in the two conditions, therefore the (A) is on a larger scale than (B).

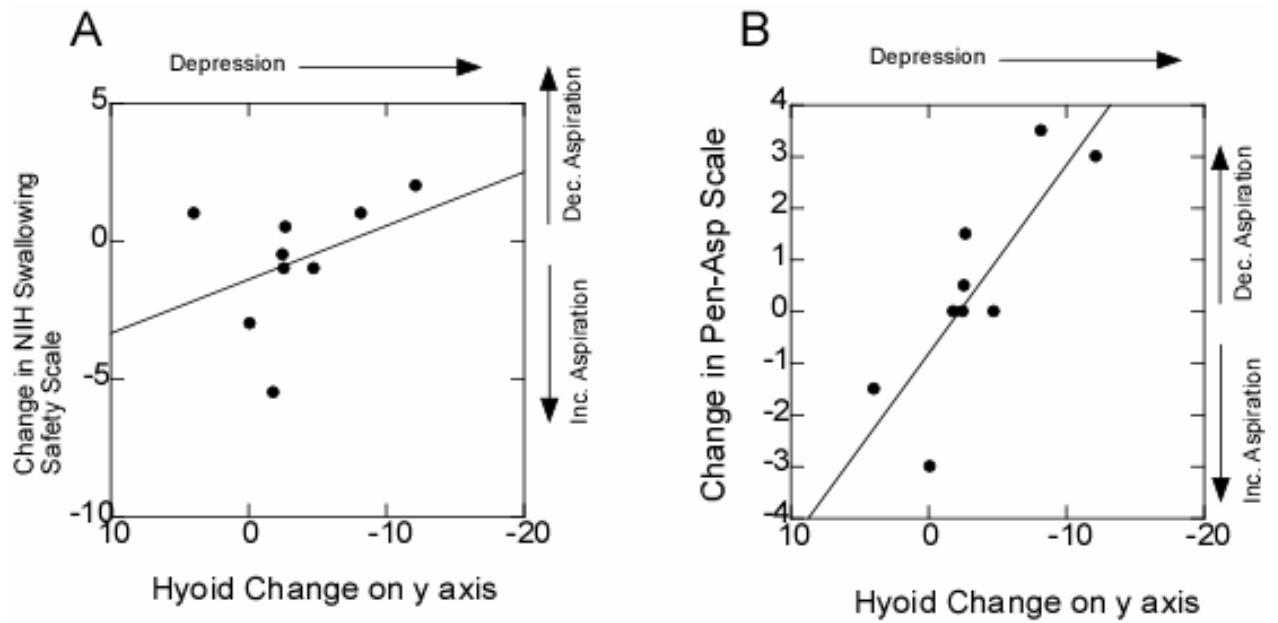


Figure 5. Scatterplots with linear trend showing the relationship between improvements on the swallowing and the extent of hyoid depression during stimulation at rest for the NIH Swallowing Safety Scale (A) and the Penetration-Aspiration scale (B).

Table 1
Participant Characteristics and Surface Electrical Stimulation levels

Subject	Sex	Age	Etiology	Time post onset (years)	Status	Sensory Threshold Upper/Lower electrode (mA)	Motor Threshold Upper/Lower Electrode (mA)
1.	M	66	hemorrhage in vetebro-basilar circulation	2.5	PEG, bilateral sensory loss, pooling, previous aspiration pneumonia	3.5/2.0	8.0/8.0
2.	M	66	Parkinson disease	20 years duration, severe dysphagia	PEG for 2 years, swallowed own secretions	6.0/2.5	10.0/10.0
3.	M	76	Stroke	2+ years	Recurrent pneumonias	4.0/2.0	14/7.0
4.	M	78	Brain stem stroke	1	PEG unable to handle secretions		
5.	F	47	Left occipital and brain stem stroke	5	Aspiration pneumonia X 3, normal sensation	7.0/7.0	14/14
6.	M	25	closed brain injury	3	PEG, frequent aspiration pneumonias, severe reduction in UES relaxation, normal sensation	3.0/4.0	10/10
7.	M	48	Cerebellar hemorrhage with craniotomy	2	PEG, unable to handle secretions, Bilateral sensory loss	3.5/6.0	16.6/13.0
8.	F	44	subarchnoid hemorrhage left vertebral artery	2	Aspiration on liquids, bilateral sensory loss	3.0/2.5	18.0/18.0
9.	M	45	Traumatic brain injury	2	PEG, Unable to handle secretions, aspiration pneumonia, pooling, Normal sensation	4.0/2.0	12.5/9.5
10.	M	61	Left hemisphere sstroke	3	Tracheostomy PEG tube Normal sensation bilateral Pooling of secretions	3.0/4.0	18.0/16.0
11.	M	47	Craniotomy for brain stem tumor	0.5	Chokes on saliva, eats soft foods, drooling Bilateral sensory loss	1.5/4.0	13.0/13.0
				4	PEG, unable to handle secretions, Normal sensation on left, pooling, BOTOX@in UES Severe aspiration, multiple aspiration pneumonias bilateral sensory loss	1.5/1.5*	14/18

• Couldn't study effects of either sensory or motor stimulation during swallowing due to severe aspiration