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ORIGINAL ARTICLE

Measurement of Hyolaryngeal Muscle Activation Using Surface Electromyography for Comparison of Two Rehabilitative Dysphagia Exercises

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Abstract

Objective: To investigate the effects of a resistance-based chin-to-chest (CtC) exercise on measures of hyolaryngeal muscle activation compared with a head-lift exercise.

Design: Within-subject, repeated-measures design.

Setting: Academic research laboratory.

Participants: Healthy young women (N=20) without a history of dysphagia, cervical spine conditions, neurologic disease, or head/neck cancer (mean age, 22.5y).

Interventions: All participants performed an isometric jaw-opening exercise against resistance (CtC) and an isometric head-lift exercise, both targeting activation in the hyolaryngeal (suprahyoid) muscles. The CtC exercise required jaw opening into a chin brace secured against the upper torso for a duration of 10 seconds. The isometric head-lift exercise required lifting and holding the head from a supine position for 10 seconds. The degree to which each exercise activated the suprahyoid muscles was measured using surface electromyography (sEMG).

Main Outcome Measures: Microvolts as measured from sEMG sensors placed on the skin surface above the hyolaryngeal muscles (surface of skin above geniohyoid, mylohyoid, and anterior digastric). Dependent variables included the peak microvolts during 10 seconds of sustained contraction and the difference in microvolts from rest to peak contraction for each exercise.

Results: Activation in the hyolaryngeal musculature as measured via sEMG was significantly greater when participants performed the CtC exercise compared with the head-lift exercise. Measures of peak microvolts during contraction were significantly greater for CtC ($t=10.72$, $P<.001$) compared with the head-lift exercise, and difference measures in microvolts calculated between rest and contraction for each exercise revealed a 2-fold increase in hyolaryngeal muscular activation for CtC ($t=8.27$, $P<.001$).

Conclusions: The isometric CtC exercise resulted in greater activation of the hyolaryngeal muscles compared with an isometric head-lift exercise. Results support the need for further investigations to determine whether the CtC exercise has a positive effect as a rehabilitative exercise for clinical populations with dysphagia secondary to upper esophageal sphincter dysfunction where hyolaryngeal excursion is a physiological impairment.

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A reduction in the opening diameter of the upper esophageal sphincter (UES) during the pharyngeal stage of swallowing is a physiological impairment underlying dysphagia in both neurologic and oncologic etiologies. Mechanical and neurologic events that facilitate UES dilation during the pharyngeal swallow include central nervous system−mediated relaxation, bolus pressure at the superior UES, and traction applied to UES tissue via superior and anterior movement of the hyoid and thyroid (hereafter referred to as hyolaryngeal excursion) secondary to activation in the hyolaryngeal (mylohyoid, geniohyoid, anterior digastric, and thyrohyoid) musculature.[1-5] Reduced hyolaryngeal excursion is a common cause of aspiration in dysphagic patients.[6,7] When hyolaryngeal excursion is restricted, the diminished superior and anterior laryngeal movement fails to provide adequate traction on

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the tissue of the UES, which can inhibit bolus material from entering the esophagus.[1,2] This can put an individual at a significant risk for laryngeal penetration and aspiration of bolus material, which when chronic and unresponsive to swallowing therapy can lead to additional health risks or the necessity of feeding tube placement to meet nutritional needs, or both.[3] Therapies that target improvement of hyolaryngeal muscular function in patients with dysphagia where this impairment underlies reduced UES opening can potentially have a significant impact on a patient's swallowing physiology, swallowing safety, and quality of life.

In populations with chronic dysphagia caused by a reduced UES opening, approaches that target the hyolaryngeal muscles have demonstrated a significant clinical effect. Shaker et al[8] used an exercise protocol consisting of isometric and isotonic head-lifting exercises while lying supine to target the hyolaryngeal muscles in 27 tube-fed patients with chronic dysphagia. After 6 weeks of treatment, the exercises significantly increased the degree of UES opening, the anterior excursion of the larynx during swallowing, and in a functional outcome measure—all 27 patients were able to discontinue tube feedings and resume oral feeding after 6 weeks of exercise. The results of this study supported earlier pilot work that found that the same exercise program facilitated greater UES opening in healthy elderly subjects.[9] The activation of the hyolaryngeal elevators using the head-lift exercise has been confirmed using electromyography, and has been supported by at least 2 subsequent studies.[10-12] A recent randomized controlled trial[12] reported that the head-lift exercise significantly reduced postswallow aspiration to a greater degree than other traditional swallowing therapy approaches.

Yoshida et al[13] noted the possible limitations for using the head-lift exercise in elderly populations because of its physical requirements. Patients with ambulatory limitations may be restricted from performing the required posture (lying on the floor supine, raising head). These authors developed a tongue press exercise that also recruited activation in the hyolaryngeal elevators, validating its effect on these muscles using surface electromyography (sEMG) and suggesting its use as an effective alternative to the head-lift exercise. More recently, Wada et al[14] investigated the effects of an isometric jaw-opening exercise that targeted activation in the hyolaryngeal muscles. Individuals with chronic dysphagia were asked to maximally open their jaw and hold for 10 seconds, completing 2 sets of 5 repetitions over a 4-week treatment course. The authors reported significant effects for this exercise on hyolaryngeal excursion, UES opening width, and pharyngeal bolus clearance time, although only limited functional impacts (amount of pharyngeal residue, diet upgrades) were reported after the 4 weeks of treatment. Additional reports of the Mendelsohn maneuver (volitionally prolonging the peak height of hyolaryngeal excursion during swallowing) have also supported the use of exercises that activate hyolaryngeal elevators for improving UES dilation and further support the notion that alternatives to the head-lift exercise may allow the clinician to target the hyolaryngeal muscles in varied clinical populations.[15,16]

The geniohyoid, mylohyoid, and anterior digastric are hyolaryngeal muscles with extended fiber lengths designed for large excursions with high shortening velocities.[17] During the pharyngeal stage of swallowing, contraction of these muscles leads to hyolaryngeal excursion and UES dilation. Rehabilitative exercises targeting these muscles aim to facilitate neuromuscular adaptation (where structural and functional properties of muscles change via some form of stimulation) through principles of strength training.[18,19] Among these principles is the concept of muscle overload, which can be understood as neuromuscular adaptation occurring only if the magnitude of the training load is greater than habitual levels.[20] Increasing the level of resistive load placed on contracting muscles facilitates neuromuscular adaption (ie, if the magnitude of a load is too low, muscular performance may plateau or even decrease). One way to achieve overload during exercise is to increase the amount of resistance to isotonic or isometric contraction. Yoshida[13] used tongue pressure against the hard palate as a form of resistance and found comparable sEMG measures in the hyolaryngeal muscles compared with the head-lift exercise. Wada,[14] similar to Shaker,[8] did not incorporate added resistance into their exercise protocol, although adaptation could be indirectly observed because of increases in hyolaryngeal excursion. These results support further inquiry into the effects of increasing resistance load on the hyolaryngeal muscles during contraction with the aim of designing a rehabilitative exercise that places maximum overload on the hyolaryngeal muscles, which in theory should maximally facilitate adaption.

The purpose of the current study was to investigate the effect of a novel resistance-based chin-to-chest (CtC) exercise on hyolaryngeal musculature activation, and compare these measures to those obtained during a head-lifting exercise similar to the isometric exercise used by Shaker.[8] To incorporate a large resistance load against hyolaryngeal musculature contraction, a maximal jaw-opening posture actively pushed against a semirigid chin brace was elicited in participants who held this posture for 10 seconds. It was hypothesized that the incorporation of resistance to isometric contraction of the hyolaryngeal muscles via maximal jaw opening would result in greater sEMG activity compared with the head-lift exercise, and therefore support further investigations of its effect in clinical populations. Answers to the following research questions were sought: (1) Does the CtC exercise elicit greater peak sEMG measurements during hyolaryngeal muscular contraction than the head-lift exercise? and (2) Does the CtC exercise elicit greater differences in sEMG measures between rest and peak contraction when compared with the head-lift exercise?

List of abbreviations:

CtC	chin-to-chest
GG	genioglossus muscle
sEMG	surface electromyography
UES	upper esophageal sphincter

Methods

Participants

This study was approved by the Institutional Review Board of Texas Christian University. Participants were recruited via a convenience sample and included 20 unimpaired women (mean age, 22.5y; range, 19−33y). Each participant was measured in both experimental conditions, which were counterbalanced across the sample (10 performed CtC as first exercise, 10 performed head lift as first exercise).

Inclusion/exclusion criteria

All participants were required to have a negative history (absence) of dysphagia, cervical spine conditions, neuromuscular disease, or head/neck cancer. Before measurement, all participants who met inclusion criteria were instructed in each exercise and demonstrated both after modeling by a laboratory assistant to ensure accurate understanding and compliance. Those who reported pain or difficulty in performing either exercise were excluded from the study (all participants were able to complete the exercises without pain or difficulty).

Instrumentation

Before measurement in the experimental conditions, the submental skin of each participant was cleansed with an alcohol wipe[a] and allowed to dry for approximately 30 seconds. A pair of self-adhering surface electrodes (Restorative Posture Device electrodes[b]) were placed on the skin of each participant external to the hyolaryngeal musculature (fig 1), along with a ground electrode[c] placed on the skin of the left upper shoulder. Electrodes were triangular, measuring 3.81×4.45cm and placed within 5 to 7mm of each other (ie, not touching in the horizontal plane) bilaterally on the submental skin, for a bipolar differential mode of detection. Electrodes were connected to a dual-channel sEMG module[d] that recorded muscular electrical activity in microvolts. The raw sEMG signal was bandpass filtered at 20 to 1000Hz, then rectified and smoothed at 17ms by the internal hardware. The peak amplitude (representing peak rectified amplitude across a 10-s period) displayed on the sEMG unit was recorded for each muscular contraction. Software digitization and further signal processing were not applied to the signal.

Chin-to-chest exercise

CtC was designed to target the same hyolaryngeal muscles as those in Shaker et al.[8] CtC is intended to act on the hyolaryngeal elevators by having individuals press their maximally open jaw into a chin brace (Restorative Posture Device[b]), which is a semirigid, adjustable plastic device providing a platform against which patients can press their chin as they contract their hyolaryngeal muscles, adding resistance and potential strength-building properties to the exercise. Figure 2 illustrates the chin brace fitted to an individual at rest, while figure 3 illustrates the CtC exercise during contraction. As participants open their jaw into the brace, a chest plate at the inferior end of the brace prevents compression of the device and provides a semirigid resistance to the muscular load. Before measurement in the CtC condition, participants were fitted with the brace so that it rested under the mandible and did not elicit discomfort. Hyolaryngeal sEMG activity was then measured at rest for 10 seconds before the initiation of each CtC exercise while the participants sat upright in a chair. For these resting measurements, participants were asked to sit quietly and breathe through their nose. To initiate the CtC exercise, participants were then asked to open their mouth maximally while they pushed their chin into the brace, and hold for 10 seconds. Before each CtC repetition, participants were encouraged to open their jaw into the brace “as hard as possible” for the entire 10 seconds. After the 10 seconds, participants rested for 1 minute, followed by 4 additional CtC and rest repetitions. The CtC condition resulted in 5 paired rest and contraction measurements for each participant.

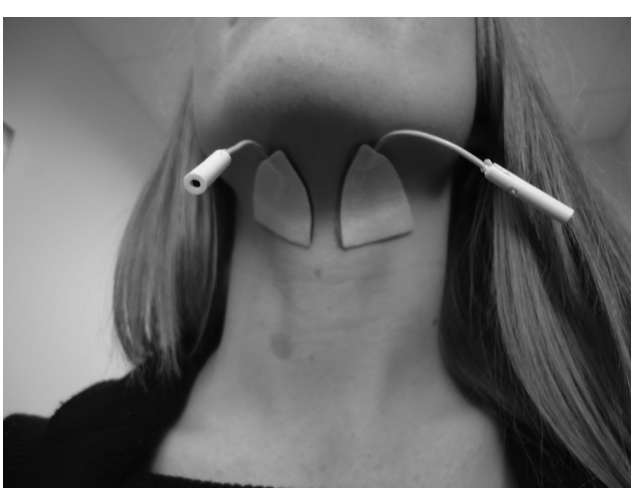

Fig 1 Placement of sEMG electrodes on the submental skin above the hyolaryngeal elevators.

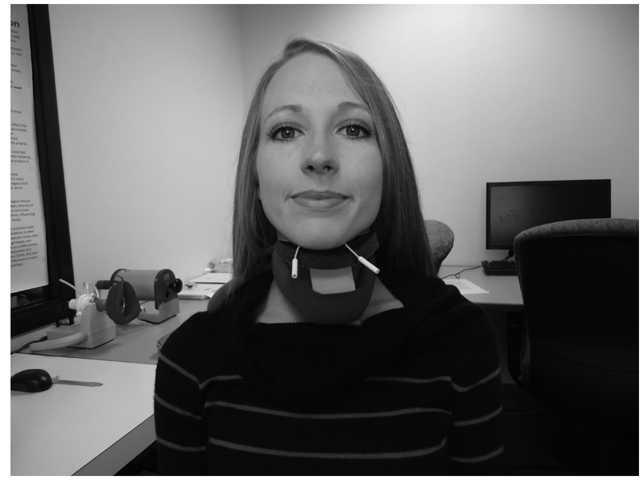

Fig 2 Positioning of the Restorative Posture Device chin brace at rest.

Head-lift exercise

The head-lift exercise performed in this study was designed to replicate the first 10 seconds of the isometric exercise (but not the isotonic component) used by Shaker[8] that is often referred to as the “Shaker exercise.”[3] Participants were asked to lie supine on

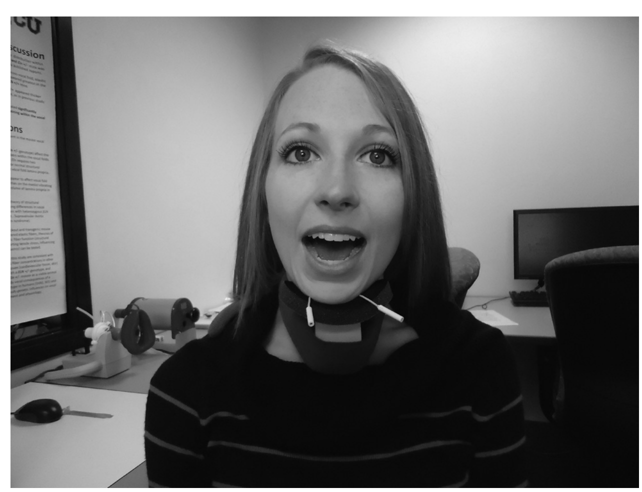

Fig 3 Contraction elicited during the CtC exercise.

a carpeted floor and raise their head so that they were looking at their toes, without lifting the shoulders. A laboratory assistant monitored each participant to ensure the exercise was completed accurately. As with the CtC condition, hyolaryngeal sEMG activity was first measured at rest for 10 seconds before the initiation of each head-lift exercise. For these resting measurements, participants were asked to lie quietly on the floor and breathe through their nose. Participants were then asked to lift their head so that they were looking at their feet, keeping their shoulders on the floor, and hold the posture for 10 seconds. After the 10 seconds, participants rested for 1 minute, followed by 4 additional head-lift and rest repetitions. The head-lift condition resulted in 5 paired rest and contraction measurements for each participant. Figure 4 illustrates the isometric contraction performed during the head-lift exercise.

Analyses

The experimental design of this study was within-subject with repeated measures on the exercise conditions (CtC and head lift). Four different measures were obtained: resting sEMG microvolts before the CtC exercise, peak sEMG microvolts during the CtC contraction, resting sEMG microvolts before the head-lift exercise, and peak sEMG microvolts during the head-lift contraction, where the amplitude values were averaged over 5 tokens (measured contractions) so that each participant's final measure to which statistical analyses were applied represented an average peak sEMG amplitude value over 10 seconds. Dependent variables to which statistical comparisons were applied consisted of the peak contraction measurement obtained during CtC and head lift, and the difference (ie, a difference score) between the rest measure and the peak contraction measure for each CtC and head-lift repetition. Measurements across the 5 repetitions of each participant were summed and averaged. Two paired-samples *t* tests were then applied to the data: one for the peak contraction (CtC vs head lift) measures and one for the difference (CtC vs head lift) measures. An a priori level of confidence was set at .05 for all statistical analyses.

Results

Figure 5 illustrates a box and whisker plot of the peak sEMG microvolts measured during the CtC and head-lift exercises. The descriptive statistics suggested that participants exhibited greater electrical activity in the hyolaryngeal muscles during the CtC exercise (mean ± SD, 60.40±16.21μV) compared with the head-lift exercise (mean ± SD, 47.95±17.36μV). Figure 6 illustrates a box and whisker plot of the difference scores (rest minus contraction) for the CtC and head-lift exercises. The descriptive statistics suggested that participants exhibited a 2-fold increase in electrical activity from rest to contraction in the hyolaryngeal muscles when performing the CtC exercise (mean ± SD, 42.85±12.16μV) compared with the head-lift exercise (mean ± SD, 21.59±11.19μV).

Results of the paired-samples *t* tests comparing peak CtC versus peak head lift, and difference scores for CtC versus head lift revealed significant differences for both comparisons. Participants exhibited significantly greater peak muscular activity during the CtC exercise compared with the head lift ($t_{19}=10.72$; $P<.001$; Cohen's $d=2.445$) and a significantly greater difference in muscular activity

Fig 4 Contraction elicited during the head-lift exercise.

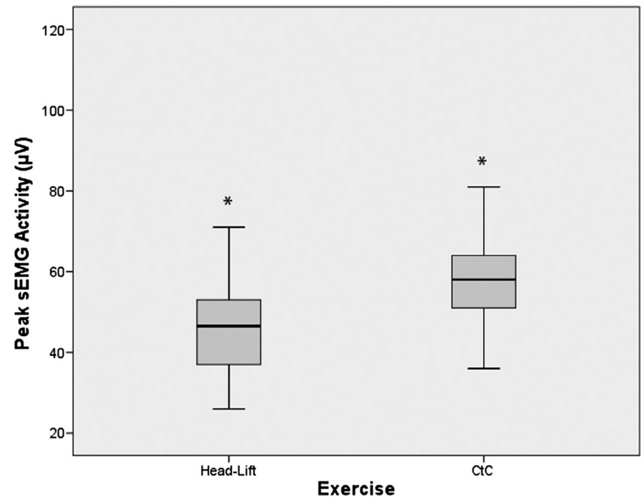

Fig 5 Peak contraction levels as measured via sEMG in the hyolaryngeal muscles during performance of the head-lift and CtC exercises. Asterisks indicate factors were significantly different at alpha of .05.

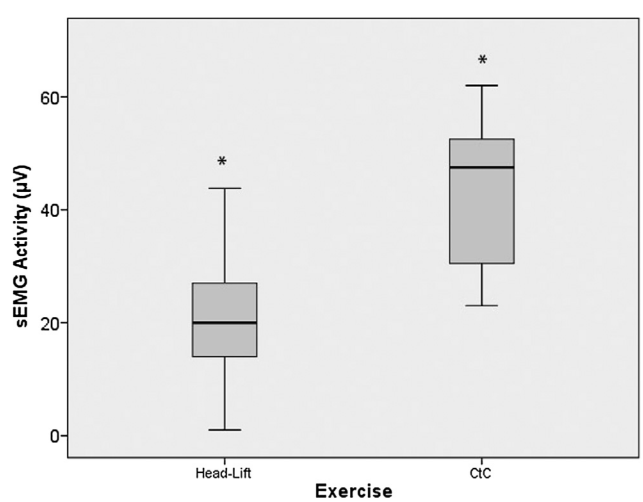

Fig 6 Difference scores (rest minus peak contraction) as measured via sEMG in the hyolaryngeal muscles during performance of the head-lift and CtC exercises. Asterisks indicate factors were significantly different at alpha of .05.

at rest versus contraction in the CtC exercise compared with the head-lift exercise ($t_{19}=8.27$; $P<.001$; Cohen's $d=1.854$). In addition to the low probability of type 1 error indicated by the statistical probability values, the large effect sizes (Cohen's d) calculated from the data suggested a high degree of practical significance.

Discussion

Muscular activation during CtC versus head-lift exercise

The purpose of this study was to investigate whether a resistance-based CtC exercise resulted in a different degree of hyolaryngeal muscular activation compared with a head-lift exercise, as measured with submental sEMG. Results revealed that sEMG measures were significantly greater at peak contraction during the CtC exercise compared with the head-lift exercise. Additionally, the difference in sEMG measures at rest versus peak contraction was significantly greater during the CtC exercise compared with the head-lift exercise. The increased muscular activity during the CtC exercise supports the need for further studies investigating the possibility of a clinical effect of the CtC exercise in dysphagic populations where decreased hyolaryngeal excursion is a physiological impairment underlying swallowing impairments.

Maximally opening the jaw and holding that posture involves the mandibular abductors/depressors, which include the mylohyoid, geniohyoid, and anterior digastric muscles.[17] Exercises developed around jaw opening have resulted in positive impacts on these muscles relative to their influence on UES function.[14] In the current study, the increased muscular activation during the CtC exercise supports the notion that the resistance incorporated during the isometric contraction of these muscles facilitated a greater degree of muscular overload compared with the head-lift exercise. This notion is supported by evidence reporting that greater resistance loads during exercise (ie, loads where fewer repetitions before failure could be achieved) facilitate remodeling of type 1 and type 2 muscle fiber types in skeletal muscle.[21] In deconditioned muscles that fatigue easily, are unable to recruit less contraction force, or have limited range of motion, increased resistance during rehabilitative exercise may facilitate muscular adaptation and more efficient functional recovery, which can be a primary goal of dysphagia rehabilitation.[18,22]

All participants in this study performed both the CtC and head-lift exercises without difficulty. Specific to the head-lift exercise, in clinical populations all patients are unlikely to be able to perform the required posture, repetitions, or both because of varying degrees of impairment caused by neuromuscular, surgical, radiation, or spinal injury. Such patients have provided the justification for the development of alternative exercises targeting the hyolaryngeal muscles.[13,14] When performing the head-lift exercise, it has been reported that the sternocleidomastoid is recruited along with the hyolaryngeal muscles, and that the sternocleidomastoid rapidly fatigues.[23] It is likely this muscle would be further challenged if a patient protruded the head as it is raised, which could cause even greater difficulty for those with cervical spine injuries or those who have undergone radical neck dissection involving the sternocleidomastoid.[24] Further research will be needed to establish the presence of a beneficial clinical effect of the CtC and whether it would be an effective option to the head-lift exercise in those patient populations.

Submandibular placement of sEMG electrodes, such as the placement used in the present study, has been used by a number of authors as a methodology to study activation in the hyolaryngeal elevator muscles. One muscle typically not addressed in these methodologies is the genioglossus muscle (GG). Fibers from the GG insert into the body of the hyoid, and contraction of this muscle is thought to influence hyoid position.[25] Although the GG forms the bulk of lingual tissue, is known to protrude the tongue, and is typically taught in the context of extrinsic tongue muscles, it has been reported that contraction of the GG can result in hyolaryngeal excursion (both superior and anterior movement).[25,26] Many individuals are able to palpate this influence by locating the hyoid body or thyroid prominence with a finger, followed by protrusion of the tongue. When the contraction for protrusion is released, hyoid movement back to the resting position (or alternatively movement of the thyroid) can be felt. Although lying deep to the anterior digastric and mylohyoid (from the surface of skin on anterior neck moving deep), the GG is a large muscle, its fibers can interdigitate with those of the geniohyoid, and it is quite possible that sEMG activity measured at the anterior neck in the submandibular region includes activity of this muscle when the CtC exercise is performed.[25,27] The contractile properties of GG have been shown to adapt to progressive resistance exercise when targeting lingual movement, and significant increases in muscular activity measured from submandibular placement of sEMG electrodes have been demonstrated during tongue press exercises.[13,28] Future studies may need to include a focus on this muscle when studying adaptation in hyolaryngeal muscles secondary to exercise because results may be in part dependent on its contractile activities.

Study limitations

A number of methodological limitations warrant caution when generalizing the results of the current study. To measure muscular activity, sEMG electrodes were used. While these were placed above the target muscles, activity in other muscles (ie, platysma) could have been recorded (ie, cross-talk) along with the hyolaryngeal elevators. Intramuscular fine-needle sEMG is a more focal method for measuring activity in individual muscles and could be considered for future studies. This study also used healthy, unimpaired participants in lieu of a clinical population. The results of this study do not permit specific recommendations for use of the CtC exercise as an approach for dysphagia rehabilitation at this time. Individuals who have decreased hyolaryngeal excursion because of neurologic, surgical, or radiation etiologies may respond differently when performing the CtC exercise. Future studies will be needed to determine whether this exercise recruits a similar degree of peak contraction levels compared with baseline in these populations. Also, although increased levels of activity in the hyolaryngeal muscles were measured during the CtC exercise, the resulting excursion of the hyoid/larynx was not measured. Although evidence from previous studies supports this assumption, future instrumental studies are needed to verify that an effect on hyolaryngeal excursion specific to the CtC exercise is present in both normal and clinical populations.

Measurement of muscular electrical activity during the CtC exercise required electrodes to be placed between the chin brace and mandible. It is possible that pressure from the chin brace could have introduced signal noise into the sEMG measures. While increased pressure on the electrodes during contraction against the brace could have possibly influenced signal noise levels and resulting sEMG measures, it is also possible that pressure from the brace influenced the gamma loop system (stretch reflex), which helped to further recruit alpha motor activity. Such a response would also influence sEMG activity but would be facilitative for exercise.

Directions for future research

This preliminary study found that peak activation in the hyolaryngeal muscles during the CtC exercise, as measured with sEMG, was significantly greater when compared with rest and also compared with the head-lift exercise. A number of important questions are in need of investigation if this exercise is to be further developed. The present study did not quantify the degree of resistance presented by the chin brace during CtC contraction. Future studies seeking to answer questions specific to what degree of resistance is applied to isometric contraction and whether additive resistance (ie, progressive resistance) maximally influences performance in the hyolaryngeal muscles are warranted. This could be accomplished with a pressure sensor added to the point of articulation between the participant's chin and the brace in addition to modifications of the chin brace that would allow the clinician to alter the resistance level of the device.

Future studies will also need to measure hyolaryngeal muscle recruitment over time as the CtC exercise is developed into a potential program of therapy. To increase strength in muscles, the dose of exercise should ideally induce fatigue.[19] Additionally, greater contraction forces over short duration typically facilitate increases in muscle strength (compared with endurance training where less contraction force over a greater amount of time is used).[19] Future studies should investigate what temporal factors (ie, duration of contraction) combined with resistance levels best facilitate adaptation in the hyolaryngeal muscles.

Conclusions

The results of this study indicate that an isometric resistance-based CtC exercise results in significantly greater peak contraction activation and a greater difference between resting activation and peak contraction activation in the hyolaryngeal elevators compared with an isometric head-lift exercise. Together these findings indicate that the activity of the hyolaryngeal muscles responsible for elevating the larynx and moving it forward during swallowing is greater when performing the CtC exercise than the isometric head-lift exercise, when the contraction is sustained for 10 seconds. These findings suggest the possibility that the CtC exercise may be useful as a rehabilitative treatment for individuals with dysphagia secondary to reduced hyolaryngeal excursion. Future studies are needed to verify this supposition.

Suppliers

a. TENS Clean-Cote; Uni-Patch, 1313 West Grant Boulevard Wabasha, MN 55981.
b. Ampcare, LLC, 3728 Arborlawn Dr, Fort Worth, TX 76109-3303. Available at: http://www.ampcarellc.com.
c. ValuTrode Lite; Axelgaard Manufacturing, 520 Industrial Way Fallbrook, CA 92028.
d. Vectra Genisys; Chattanooga Group, 2735 Kanasita Dr, Hixson, TN 37343.

Keywords

Dysphagia; Esophageal sphincter, upper; Isometric exercise; Rehabilitation; Deglutition disorders

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