ORIGINAL ARTICLE

An Analysis of Lingual Contribution to Submental Surface Electromyographic Measures and Pharyngeal Pressure During Effortful Swallow

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ABSTRACT. Huckabee M-L, Steele CM. An analysis of lingual contribution to submental surface electromyographic measures and pharyngeal pressure during effortful swallow. Arch Phys Med Rehabil 2006;87:1067-72.

Objective: To evaluate the influence of tongue-to-palate pressures on submental muscle contraction and oral and pharyngeal pressure dynamics during effortful swallowing maneuver.

Design: Comparative analysis of 2 task strategies on biomechanic measures of swallowing.

Setting: Research laboratory in a free-standing research facility.

Participants: Consecutive volunteer sample of 20 healthy participants (age range, 20–35y).

Interventions: Not applicable.

Main Outcome Measures: Peak amplitude of submental surface electromyography and orolingual and pharyngeal manometric pressure at 4 locations.

Results: General linear model analysis of variance revealed statistically significant greater amplitudes for the tongue emphasis condition of effortful swallow at all measured sensors ($P<.004$).

Conclusions: Tongue-to-palate emphasis during execution of effortful swallowing increases amplitudes of submental surface electromyography, orolingual pressure, and upper pharyngeal pressure to a greater degree than a strategy of inhibiting tongue-to-palate emphasis.

Key Words: Deglutition; Electromyography; Manometry; Pharyngeal muscles; Rehabilitation.

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THE INABILITY TO SAFELY SWALLOW, or dysphagia, is a frequent outcome of a variety of neurologic and structural disorders and contributes significantly to mortality and morbidity in the patient population.[1] It is only within recent years that focused attention has been given to management of this condition, with the establishment of clinical practice and a proliferation of research in this area. To minimize the effects of dysphagia, a variety of intervention strategies have been developed to redirect bolus flow or alter swallowing biomechanics with the ultimate goal of improving airway protection and facilitating nutritional competence.

The effortful swallow maneuver was first described by Kahrilas et al[2-4] as a compensatory technique. Research participants were instructed to "swallow hard," thus generating increased volitional contribution and muscular effort to the swallowing process. Early research by this group, using videomanometric procedures, suggested that increased effort in swallowing resulted in immediate increased pressure on the bolus and subsequently decreased pharyngeal residual. Based on this work, clinicians have readily prescribed the technique as a compensatory strategy, and more recently as a rehabilitation exercise[5-7] for patients with pharyngeal phase swallowing impairment.

More recent works by Bülow et al[8-10] have, however, raised some concerns about the biomechanic effect of effortful swallow. In the first study by this group,[8] 8 nonimpaired subjects were asked to "swallow very hard while squeezing the tongue in an upward-backward motion toward the soft palate." Videomanometric recordings documented decreased hyomandibular distance before the swallow, paired with decreased laryngeal excursion and hyoid movement during the swallow. In subsequent studies by this group, patients with moderate to severe pharyngeal phase dysphagia were evaluated. In this population, effortful swallow resulted in no change in aspiration or penetration,[9] no change in pharyngeal retention,[9] and no change in peak amplitude or duration of intrabolus pharyngeal pressures at the level of the upper esophageal sphincter (UES).[10] In summary, this research offered new and concerning possibilities that effortful swallow may have adverse effects on hyolaryngeal excursion and may not increase pharyngeal pressures as previously documented. Thus discrepancies in the literature regarding the pharyngeal effects of this technique leave the clinician with a management conundrum.

A unique contribution to the study of effortful swallow was provided by Hind et al[11] with an evaluation of orolingual pressures and videofluoroscopy in unimpaired research participants. Based on instructions to "swallow hard," research participants demonstrated increased orolingual pressure, increased duration of hyoid excursion, laryngeal vestibule closure, and UES opening as well as increased superior, but not anterior hyoid movement. Pharyngeal pressures were not evaluated in this research design; thus, this study does not contribute directly to the clarification of this issue; however the documentation of increased orolingual pressures provides a valuable contribution to understanding the effect of this technique.

In a study designed to investigate the relationship between submental surface electromyography and pharyngeal manometric pressure during 2 swallowing conditions, Huckabee et al[12] provided further information regarding effortful swallow. Dry swallows completed both without and with effort (swallow hard) were executed by healthy research participants. Data from this research confirmed the findings of Kahrilas[2-4] with effortful swallow producing increased amplitudes of pharyngeal pressure generation at both the proximal and mid-

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pharynx, and decreased pressure within the UES. Additionally, a significant increase in surface electromyographic amplitude was documented during the effortful dry swallow task. Although there is no causal link between floor of mouth and suprahyoid muscle contraction and pharyngeal pressure generation, swallowing is considered to be a synergistic behavior[13]; thus it was expected that a correlation would be observed between these 2 components of swallowing biomechanics. However, despite increases in amplitudes at all expected sensors, there was a negative correlation between surface electromyographic amplitude and pharyngeal pressure generation at the mid-pharynx and UES; this was more pronounced for the effortful swallowing condition. In other words, the more submental surface electromyographic measures increased, the less pharyngeal pressures increased. Two related explanations were proposed for this finding. First, submental electromyography is certainly not a precise measure of floor of mouth contraction because the measured amplitude also reflects lingual contribution. Taken in context with the Hind et al[11] finding of increased orolingual pressure generation during effortful swallow, it would seem quite likely that surface electromyographic amplitude could strongly reflect increased tongue effort and thus obscure the identification of a correlation between floor of mouth contraction and pharyngeal pressure generation. Second, the authors speculated that research participants might be using a variety of different biomechanic strategies to perform the effortful swallowing task. For those participants employing tongue-to-palate emphasis to increase effort, submental surface electromyographic amplitudes would be likely to increase dramatically. However, maintenance of the superior trajectory of the tongue as it moves toward the palate offers the potential to inhibit posterior lingual movement, thus limiting contribution of the tongue to pharyngeal pressure generation. This may explain the disparate findings of decreased pharyngeal pressure generation reported by Bülow et al,[8-10] who specifically instructed research participants to emphasize lingual palatal contact.

Clarification of the influence of tongue-palate approximation on pharyngeal pressure generation is of substantial clinical interest. If a strategy of tongue-palate emphasis during effortful swallow is executed, either by implicit instruction or patient adaptive behavior, it is critical to identify whether this movement contributes to or detracts from the generation of pharyngeal pressures. Does an effortful swallow, which emphasizes the tongue-to-palate contact, benefit the end goal of increased pharyngeal pressure or is it evidence of improper and maladaptive execution of this swallowing maneuver? Are there perhaps 2 "effortful swallows" that influence oral and pharyngeal mechanics differentially? If this proves to be true, it will allow clinicians greater specificity in the application of swallowing strategies and thus potentially improved treatment outcomes.

The purpose of this research was to evaluate 2 strategies of effortful swallow execution thereby evaluating the role of tongue-to-palate contact in the generation of pharyngeal pressure. Specifically, this project evaluated orolingual and pharyngeal pressure dynamics during effortful saliva swallows completed both with and without tongue-to-palate emphasis. We hypothesized that orolingual pressure would be significantly greater when tongue contribution to the performance of effortful swallow was emphasized, compared with a strategy of lingual to palatal inhibition. In addition, we hypothesized that pharyngeal pressures would be substantively smaller during the condition of inhibited tongue-palate contact, than those measured when tongue-palate contact is exaggerated.

METHODS

Participants

We recruited 20 healthy female research participants between the ages of 20 and 35 through advertisement at a university to provide data for this project. Participants reported no history of dysphagia or neurologic disease. Informed consent was obtained from all participants prior to initiating data collection; ethics approval was obtained by the appropriate regional health ethics review board.

Procedure

To avoid confusion between tasks and to minimize the potential for fatigue due to a lengthy recording session, we collected data in 2 sessions of approximately 90 minutes in duration completed within a 1-week period. Research methods for both days were identical with the exception of instruction in how swallowing maneuvers were to be executed. For both sessions, data were collected in a Swallowing Rehabilitation Research Laboratory located in a medical facility. After information was provided and questions answered, electrodes were secured to measure the activity of the anterior suprahyoid and floor of mouth muscles during swallowing. Active triode surface electrodes were positioned lengthwise to the undersurface of the chin between the spine of the mandible and the superior palpable surface of the thyroid cartilage, that is, activity of the collective floor of mouth and anterior suprahyoid muscles during swallowing. The ground electrode was positioned laterally. The resulting rectified and averaged signal was displayed on a computer monitor within view of the research participant. Before proceeding with further sensor placement or data collection, the subjects were given demonstration and directions concerning the performance of a noneffortful saliva swallow and a contrasting effortful saliva swallow. For the effortful swallow task, instructions were provided for 2 strategies of execution, which would be counterbalanced across the 2 data collection sessions. In 1 strategy condition, participants were instructed that during execution of the effortful swallow they should restrict tongue-to-palate contact and should utilize the floor of mouth and pharyngeal muscles to complete the tasks ("As you swallow, I want you to squeeze hard with the muscles of your throat, but *not* use your tongue to generate extra force"). In the alternative strategy condition, they were instructed that during execution of maneuvers they should exaggerate tongue-to-palate contact ("As you swallow, push really hard with your tongue"). Participants were allowed to practice these tasks using submental surface electromyographic output to guide performance and mastery. No participant reported difficulty with task completion at the end of the training session.

Subsequent to this instructional period for both sessions, we placed a solid state manometric catheter with 3 pressure transducers and a pair of bipolar surface electromyography electrodes[a] (diameter, 2.1mm) into an unanesthetized nares, using a lubricant gel to facilitate passage. As the catheter reached the upper pharynx, identified by resistance at the posterior pharyngeal wall, the participants were asked to rapidly ingest a glass of water through a straw. In doing so, the catheter was swallowed into the proximal esophagus. Each participant was asked to swallow until the catheter had been pulled down approximately 40cm as measured from the tip of the nose. The catheter was then slowly pulled out again until all sensors were positioned appropriately. During this procedure the subjects were asked not to swallow, not to speak and not to cough. A pull-through technique was utilized to guide catheter placement

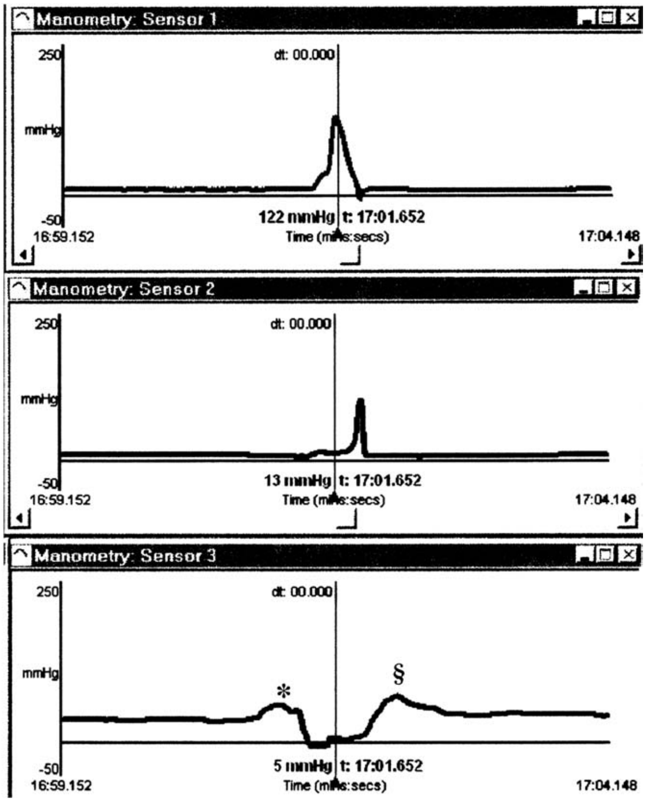

Fig 1. Sample waveform obtained from pharyngeal manometry. Location of the lowermost sensor in the UES producing high resting amplitude and a characteristic M wave with slightly increased pressure immediately preceding* and following§ the drop in pressure with UES opening.

with the third manometric sensor at the upper borders of the high pressure zone of the UES; correct placement was confirmed by clear visualization of the M wave on swallowing (fig 1).[14,15] In this resting location, the uppermost manometric sensor was positioned approximately even with the tip of the epiglottis, the second manometric sensor was placed 13mm below in mid-pharynx and the third sensor was positioned at the superior border of the UES. Manometric sensors measuring 2×5mm were oriented toward the posterior pharyngeal wall. Refer to figure 2 for a radiographic representation of catheter placement at rest. The catheter was taped securely to the external nose to limit movement of the catheter in a superior to inferior orientation. Additionally, a measurement in millimeters was taken from the tip of the nose to the end of the catheter to facilitate consistency in placement during the second recording session. Visualization of indelible orientation markers on the superior, posterior aspect of the catheter was utilized to assure continued orientation of the sensors to the posterior pharyngeal wall. Although the lowermost UES sensor was utilized to facilitate placement of the catheter, behavior of the UES was not the focus of this research and thus data from this sensor were not included in the final analysis. Finally, a strip of soft plastic incorporating 3 orolingual pressure sensors was secured to the palate using a small amount of polymer tissue adhesive.[b] The most anterior sensor was placed at the junction of the central incisors and the alveolar ridge. The middle sensor was approximately mid-palate and the most posterior sensor was approximately at the junction of the hard and soft palates. Data from the most anterior sensor were not analyzed for this study.

Data Collection

Each subject then completed 15 repetitions of 3 research tasks: noneffortful (saliva) swallows, effortful (saliva) swallows, and the Mendelsohn maneuver, as instructed during the training period. These 15 trials were completed in 3 sets of 5 repetitions to avoid within-task fatigue. The order of task completion was randomized within each research participant. Data from the Mendelsohn maneuver will not be described in this article. All data were collected and analyzed using the integrated Kay Elemetrics Digital Swallowing Workstation[c] (suprahyoid surface electromyography, orolingual manometry, pharyngeal manometry).

The manometric data (both orolingual and pharyngeal) and the submental surface electromyographic data were displayed to the researcher but not the participant during data collection and were stored on the swallowing workstation for subsequent analysis. Confidentiality was assured by assigning each participant a coded identification number. Peak amplitudes and durations of manometric and electromyographic recordings were extracted from the data files and subjected to statistical analysis.

Data Analysis

We collected data from this study over 2 sessions per participant, counterbalanced for the strategy used to perform the effortful swallow task (with or without tongue-to-palate emphasis). To account for potential intersession variability, nor-

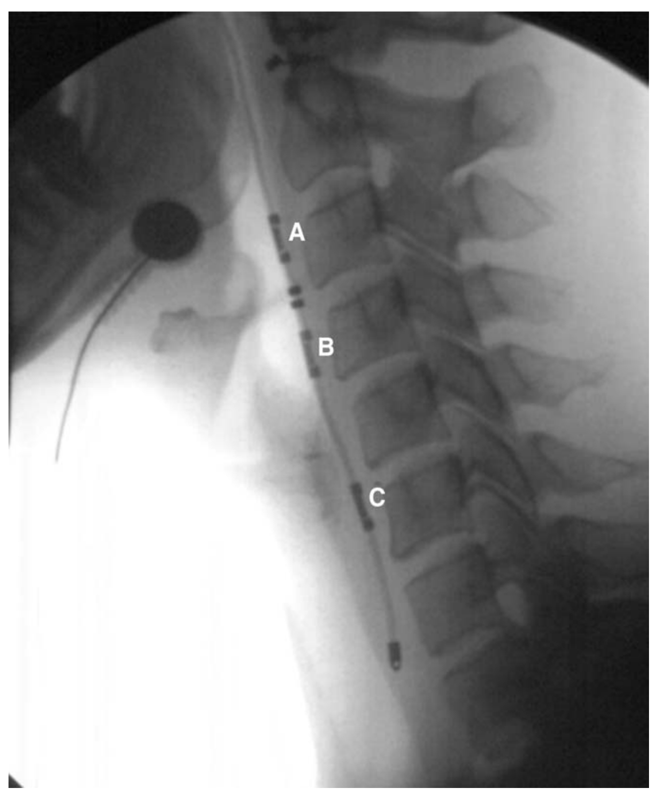

Fig 2. Lateral pharyngeal radiograph with manometric catheter in situ. Three manometric sensors are identified: (A) proximal manometric sensor, (B) mid-pharyngeal sensor, and (C) UES sensor.

malization of the data within subjects and across the 2 sessions was required. Each participant's raw data for surface electromyography and orolingual and pharyngeal pressures were transformed to a value relative to their own greatest amplitude obtained during noneffortful swallows. For example, if the raw amplitude of a participant's maximum noneffortful swallow was measured at 120μV, this value would be re-expressed as 100μV; subsequently a raw effortful swallow amplitude of 180μV would be re-expressed as 150μV. Mean transformed values for each variable were then calculated across each set of 5 repeated swallows. To appreciate the impact of manner of execution on the effortful swallow task, each effortful swallow datapoint was converted to a difference score from the mean noneffortful swallow value prior to statistical analysis. Repeated-measures analyses of variance (ANOVAs) with factors of strategy (no tongue emphasis vs tongue emphasis) and set (3 task repetitions) were performed on the effortful swallow difference score data using SPSS.[d] The α criterion for statistical significance was set at α equal to .05. Box's *M* and Mauchly tests were conducted for all ANOVA results, to identify any violations of the assumptions of homogeneity of variance, covariance matrix circularity, and compound symmetry. No violations of these assumptions were detected.

RESULTS

Noneffortful Saliva Swallows

Noneffortful saliva swallows were the reference task in this investigation, and were performed in the same manner on both data collection days. Descriptive statistics for noneffortful saliva swallows are shown in table 1, together with descriptive statistics for the effortful swallow difference scores under each condition (no tongue emphasis, tongue emphasis). Within the noneffortful swallow data, surface electromyographic amplitudes did not differ significantly across sessions ($F_{1,19}$=.138, P=.714). No statistically significant differences were found in the amplitudes of noneffortful swallow orolingual pressures across sessions at either sensor location: mid ($F_{1,19}$=0.7, P=.413) or posterior ($F_{1,19}$=.133, P=.72). Similarly, pharyngeal pressures for the noneffortful swallow task did not differ significantly across sessions at either sensor location: upper ($F_{1,19}$=.133, P=.719) or lower ($F_{1,19}$=1.003, P=.329). These analyses also confirmed the absence of any statistically significant differences across set repetitions for 4 of the 5 variables: surface electromyography ($F_{2,18}$=1.467, P=.257); mid tongue pressure ($F_{2,18}$=3.81, P=.04); posterior tongue pressure ($F_{2,18}$=.530, P=.598); upper pharyngeal pressure ($F_{2,18}$=1.173, P=.332); and lower pharyngeal pressure ($F_{2,18}$=.02, P=.980). No statistically significant set by session interactions were found. On this basis, set was removed from the model for the subsequent statistical analyses.

Effortful Swallow by Strategy

There were no significant effects of task repetition (*P* range, .48−.79) and no significant interactions between task repetition and type of swallow at any sensor, suggesting that the data were stable across multiple measures (*P* range, .11−.83). Consequently, task repetition was not included in further analysis. Statistical analyses were then performed using a general linear model ANOVA to evaluate the effect of strategy of effortful swallow execution on pressure measurements (tongue emphasis; no tongue emphasis). Results are tabulated in table 2. Statistically significant effects of strategy were observed for all five variables. In all cases, the strategy of tongue-to-palate emphasis produced a greater change from normal swallowing pressure than the strategy of tongue-to-palate inhibition.

DISCUSSION

Prior research has presented a conflicting picture regarding the biomechanic effect of the effortful swallow maneuver on

Table 1: Descriptive Statistics

Variable	Mean ± SE	95% Confidence Interval
Surface electromyography (μv)		
Noneffortful swallow	64.14±3.17	54.25 to 62.14
Effortful swallow difference scores		
No tongue emphasis	21.73±7.93	5.14 to 38.32
Tongue emphasis	120.81±26.30	65.76 to 175.86
Mid-tongue pressure		
Noneffortful swallow	51.33±2.06	47.20 to 55.46
Effortful swallow difference scores		
No tongue emphasis	−15.85±5.83	−28.06 to −3.64
Tongue emphasis	116.06±16.09	82.37 to 149.74
Posterior tongue pressure		
Noneffortful swallow	60.00±74	56.52 to 63.47
Effortful swallow difference scores		
No tongue emphasis	3.44±7.00	−11.21 to 18.10
Tongue emphasis	85.97±9.80	65.45 to 106.48
Upper pharyngeal pressure (mmHg)		
Noneffortful swallow	62.14±1.95	58.24 to 66.03
Effortful swallow difference scores		
No tongue emphasis	6.93±4.77	−3.05 to 16.92
Tongue emphasis	20.09±4.08	11.54 to 28.63
Lower pharyngeal pressure (mmHg)		
Noneffortful swallow	65.61±1.50	62.61 to 68.62
Effortful swallow difference scores		
No tongue emphasis	10.21±3.53	2.82 to 17.61
Tongue emphasis	19.62±6.02	7.03 to 32.22

Abbreviation: SE, standard error.

Table 2: General Linear Modeling ANOVA Results Comparing Strategy of Effortful Swallow Execution (tongue emphasis vs no tongue emphasis)

Source	F	*df*	*P*
Surface electromyography	38.45	1, 118	.000
Mid tongue pressure	166.51	1, 118	.000
Posterior tongue pressure	124.63	1, 118	.000
Upper pharyngeal pressure	11.37	1, 118	.001
Lower pharyngeal pressure	5.15	1, 118	.025

pharyngeal pressure generation. The purpose of this research was to evaluate the premise that the strategy used to generate increased effort would be a significant variable in pharyngeal pressure dynamics. By carefully controlling the instructions given to research participants, it was anticipated that this project would provide resolution regarding the conflicting results published in previous literature. Very specifically, it was hypothesized that increased effort that is achieved using an exaggeration of tongue-to-palate contact would result in decreased pharyngeal pressures, based on the premise that emphasis on superior tongue-to-palate trajectory of the tongue would inhibit the posterior tongue base retraction required for pharyngeal pressure generation. Support for this premise can be taken from analysis of another swallowing task. The tongue holding maneuver[16] requires patients to anchor the tongue in a forward position by holding the tongue tip between their teeth during swallowing. Although designed to elicit spontaneous exaggeration of posterior pharyngeal wall movement, increased postswallow vallecular residues were observed on videofluoroscopy; these residuals were attributed to inhibition of posterior tongue retraction associated with the maneuver.

Research participants in this project completed 2 types of effortful swallow: one that emphasized tongue-to-palate pressure and another which explicitly avoided tongue-to-palate contact. Analysis of orolingual pressure data confirm that research participants did indeed functionally differentiate between these 2 tasks. Of clinical interest in comparing these 2 tasks is the clear documentation of lingual influence on submental surface electromyographic measurement. Surface electromyographic recordings were overwhelmingly greater during the tongue-to-palate emphasis strategy. This confirms that surface electromyographic measurement is nonspecific to floor of mouth activity and includes intrinsic lingual activity. This will be of substantial clinical interest to those clinicians utilizing surface electromyographic biofeedback as a clinical rehabilitative modality and emphasizes that caution should be used in interpreting surface electromyographic data.

Based on prior work by Huckabee et al,[12] who reported a negative correlation between submental surface electromyographic and pharyngeal pressure, it was proposed that pharyngeal pressures would be reduced in a condition of tongue-to-palate emphasis. The data do not support this hypothesis. The strategy of emphasizing tongue-to-palate contact generated greater pressures not only in the oral cavity but also in the upper pharyngeal cavity, when compared with a strategy of inhibiting tongue-to-palate contact.

These data suggest that tongue-to-palate contact exaggeration during effortful swallow may serve as a type of motor system priming. Although both strategies were executed with effort, voluntary and exaggerated tongue-to-palate emphasis had a greater effect on enhancing overall motor system performance. Under normal circumstances the usual trajectory of the tongue in swallowing involves first an upward motion toward the palate, and then an anterior movement prior to the onset of the downward-posterior motion that carries the bolus into the pharynx. These patterns of movement have been documented using both electromagnetic midsagittal articulography and the x-ray microbeam system.[17,18] Furthermore, electromagnetic midsagittal articulographic studies have shown that different fleshpoints along the dorsal surface of the tongue exhibit movements that differ not only in amplitude but also in direction; this observation supports the idea that the tongue may be divided into functionally independent segments.[19] The effect, therefore, is one of relative stability in the tongue blade, while the more posterior portions of the tongue are in motion.

Given these data, it seems reasonable to suggest that the tongue-to-palate emphasis strategy involves an exaggeration of anterior tongue stability against the palate, but does not necessarily inhibit movement of the more posterior portions of the tongue. Under normal circumstances the larger movement amplitudes of the tongue dorsum compared with the tongue body have the effect of stretching and expanding the length of the tongue between those 2 segments.[17] It is unknown how the effortful swallow with tongue-to-palate emphasis might specifically affect this segmental distance, or the associated velocities of tongue movement. The current data showing higher pharyngeal pressures in the effortful swallow performed with tongue-to-palate emphasis suggest the possibility that the palatal press may actually prime the system, leading to larger movement amplitudes and/or higher movement velocities in the posterior tongue during its downward-posterior trajectory. This increased drive apparently accommodates diverse lingual postures and adapts degree of muscle contraction for biomechanic idiosyncrasies, thereby producing an effect of increased functional pressure generation. From a rehabilitative perspective this would seem promising in that the normal neurologic system is robust enough to compensate for adaptations in structural configuration. However it is possible that patients with swallowing impairment will not demonstrate similar adaptive capabilities. Thus, further research will be required before assumptions can be extended to the patient population.

A second explanation for the findings must be acknowledged. During research participant preparation for the experiment, all subjects were trained to both tasks using surface electromyographic biofeedback to facilitate mastery. The mean submental surface electromyographic amplitude during data collection was 6 times greater for the strategy of tongue-to-palate emphasis than for tongue-to-palate inhibition. It can be concluded then that research participants were indeed discriminating between tasks and that lingual muscle electromyography was contributing substantially to the collective signal measured from the submental region. However, a potential confound to interpreting the data is presented. When executing the tongue-to-palate emphasis condition, research participants would receive relatively greater positive feedback on task execution. This feedback may, in turn, guide them to greater effort in task execution that would bias toward greater strength in this condition. Although it has been documented that there is no significant correlation between submental surface electromyographic and pharyngeal pressure,[12] the influence of visual feedback on pharyngeal pressure change has not been empirically evaluated.

CONCLUSIONS

The goal for this research was to clarify discrepancies in the literature regarding the biomechanic effect of effortful swallow by investigating specific strategies for executing this technique.

The proposed hypotheses were, however, not supported as a process in healthy research participants; consequently, the disparate results offered by Bülow et al[8-10] continue to be unexplained. It can be concluded, however, that specific instruction for task execution may substantially influence the subsequent functional effect. In nonimpaired research participants, one can be confident that the effortful swallow can be maximized through a strategy of emphasizing tongue-to-palate contact during performance of the maneuver. Whether this conclusion carries over to patients with swallowing impairment will require careful evaluation.

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Suppliers

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