Title: An Analysis of Lingual Contribution to Submental sEMG Measures and Pharyngeal Biomechanics during Effortful Swallow

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Running Title: Pharyngeal Pressure in Effortful Swallow
ABSTRACT

An Analysis of Lingual Contribution to Submental sEMG Measures and Pharyngeal Biomechanics during Effortful Swallow

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

Design: Comparative analysis of two task strategies on biomechanical measures of swallowing

Setting: Research laboratory in a free standing research facility

Participants: 20 healthy participants, between the ages of 20-35 years, consecutive volunteer sample.

Interventions: not applicable

Main Outcome Measure(s): Peak amplitude of submental sEMG, oro-lingual and pharyngeal manometric pressure at four locations.

Results: Effortful swallow generated significantly greater pharyngeal pressure than normal swallow at both the upper and lower pharyngeal sensors \( p < 0.001 \). GLM ANOVA revealed statistically significant greater amplitudes for the tongue emphasis condition of effortful swallow at all measured sensors \( p < 0.004 \), with the exception of the lower pharyngeal sensor \( p = 0.03 \) after Bonferroni correction was applied for multiple comparisons.

Conclusions: Tongue to palate emphasis during execution of effortful swallowing increases amplitudes of submental semg, oro-lingual pressure and upper pharyngeal pressure greater than a strategy of inhibiting tongue to palate emphasis.

Key Words
deglutition, rehabilitation, electromyography, pharyngeal manometry
An Analysis of Lingual Contribution to Submental sEMG Measures and Pharyngeal Biomechanics during Effortful Swallow

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. 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. In an effort 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 introduced by Kahrilas and colleagues as a compensatory technique. Individuals 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 for patients with pharyngeal phase swallowing impairment.

More recent works by Bülow, et al. have, however, raised some concerns about the biomechanical effect of effortful swallow. In the first study by this group, eight non-impaired individuals were requested 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, no change in
pharyngeal retention and no change in peak amplitude or duration of intra-bolus pharyngeal
pressures at the level of the UES. Collectively, the research offered by Bülow and
colleagues suggests that effortful swallow does not positively influence pharyngeal pressures
as previously documented and may indeed have negative implications for hyolaryngeal
excursion. Thus there are conflicting views regarding the physiologic effect of effortful
swallow as a means of altering pharyngeal pressure during bolus swallows.

A unique contribution to the study of effortful swallow was provided by Hind et al. with an evaluation of oro-lingual pressures and videofluoroscopy in unimpaired research
participants. Based on instructions to “swallow hard”, research participants demonstrated
increased oro-lingual 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
oro-lingual pressures provides a valuable contribution to understanding the effect of this
technique.

In a study designed to investigate the relationship between submental surface
electromyography (sEMG) and pharyngeal manometric pressure during two swallowing
conditions, Huckabee, et al. 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 and colleagues\textsuperscript{2,3,4} with effortful swallow producing increased amplitudes of pharyngeal pressure generation at both the proximal and mid-pharynx and decreased pressure within the UES. Additionally, a significant increase in sEMG amplitude was documented during the effortful dry swallow task. Although there is no causal link between floor of mouth-suprahyoid muscle contraction and pharyngeal pressure generation, swallowing is considered to be a synergistic behavior,\textsuperscript{13} thus it was expected that a correlation would be observed between these two components of swallowing biomechanics. However, despite increases in amplitudes at all expected sensors, there was a negative correlation between sEMG 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 sEMG measures increased, the less pharyngeal pressures increased. Two related explanations were proposed for this finding. First, submental EMG 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.\textsuperscript{8} finding of increased orolingual pressure generation during effortful swallow, it would seem quite likely that sEMG 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 biomechanical strategies to perform the effortful swallowing task. For those participants employing tongue-to-palate emphasis to increase effort, submental sEMG 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., 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 behaviour, 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 two ‘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 two strategies of effortful swallow execution thereby evaluating the role of tongue-to-palate contact in the generation of pharyngeal pressure. Specifically, this project evaluated oro-lingual and pharyngeal pressure dynamics during effortful saliva swallows completed both with and without tongue-to-palate emphasis. It was hypothesized that oro-lingual pressure would be significantly greater when tongue contribution to the performance of effortful swallow was emphasized compared to a strategy of lingual to palatal inhibition. In addition, it was 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: Twenty healthy research participants (RP) between the ages of 20 and 35 provided data for this project. RPs reported no history of dysphagia or neurologic disease. Informed consent was obtained from all RPs prior to initiating data collection; ethics approval was obtained by the appropriate regional health ethics review board.

Procedure: Data were collected in two sessions of approximately 90 minutes in duration completed within a one 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. Triode surface electrodes were adhered to the under-surface of the chin to measure electromyographic activity of the collective floor of mouth and anterior suprahyoid muscles during swallowing. Specifically, the active electrodes were positioned lengthwise between the spine of the mandible and the superior palpable edge of the thyroid cartilage. 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. Two conditions of instruction were given, counterbalanced to consecutive sessions across RPs. In one condition, RPs 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 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”. RPs were allowed to practice these tasks using submental sEMG output to guide
performance and mastery.

Subsequent to this instructional period for both sessions, a solid state manometric catheter
with three pressure transducers and a pair of bipolar sEMG electrodes (Medical
Measurements Inc.; Model CT/S3+emg, 2.1 mm in diameter a) was placed transnasally. 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 40 cm 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. Correct catheter placement was confirmed using a pull-through
technique to a point just beyond high pressure in the 3rd sensor at rest; the “M” wave was
clearly observed on swallowing to assure high pressure in the 3rd sensor at rest. When
correctly placed, 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 within the tonically contracted upper esophageal
sphincter (UES). Manometric sensors measuring 2 X 5 mm were oriented toward the
posterior pharyngeal wall.14, 15 Refer to Figure 1 for a radiographic representation of catheter
placement. The catheter was then taped securely to the external nose. Finally, a strip of soft
plastic housing three oro-lingual pressure sensors was secured to the palate using a small
amount of polymer tissue adhesive (Isobutyl Cyanoacrylate 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 3 sets of five repetitions of three research tasks:
oneffortful (saliva) swallows, effortful (saliva) swallows and the Mendelsohn maneuver as
instructed during the training period. Data from the Mendelsohn maneuver will not be
described in this manuscript. The order of tasks was randomized within each research
participant. All data were collected and analysed using the integrated Kay Elemetrics Digital
Swallowing Workstation c (suprahyoid SEMG, oro-lingual manometry, pharyngeal
manometry).

The manometric data (both oro-lingual and pharyngeal) and the submental SEMG 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 RP a coded identification number. Peak amplitudes and durations of manometric and
electromyographic recordings were extracted from the data files and subjected to statistical
analysis.

Results

Data Analysis

Data from this study were collected over two sessions per participant, counterbalanced for the
strategy used to perform the effortful swallow task (with or without tongue-to-palate
emphasis). In order to allow for intra-subject comparison, normalization of the data was
required. The raw data for sEMG, oro-lingual pressure and pharyngeal manometry were
transformed to values relative to each participant’s normative amplitude range, defined as theange between zero and the highest peak value obtained during noneffortful swallows. For
example, if the raw sEMG amplitude of a participant’s maximum noneffortful swallows was
measured at 120 µVolts, this value would be re-expressed as 100 µVolts, and a raw effortful
swallow amplitude of 180 µVolts would be re-expressed as 150 µVolts. Mean transformed
values for each variable were then calculated across each set of 5 repeated swallows. In order
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 non-effortful swallow
value prior to statistical analysis. Repeated measures 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 version 13.0. The alpha criterion for
statistical significance was set at $\alpha = 0.05$. 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

**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
non-effortful 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 non-effortful swallow data, surface EMG amplitudes did not differ
significantly across sessions [$F(1,19) = 0.138, p = 0.714, d = 0.02$]. No statistically
significant differences were found in the amplitudes of non-effortful swallow oro-lingual
pressures across sessions at either sensor location: mid [$F(1,19) = 0.7, p = 0.413, d = 0.06]$;
posterior [$F(1,19) = 0.133, p = 0.72, d = 0.02$]. Similarly, pharyngeal pressures for the
noneffortful swallow task did not differ significantly across sessions at either sensor location: upper \(F(1,19) = 0.133, p = 0.719, d = 0.23\); lower \(F(1,19) = 1.003, p = 0.329, d = 0.10\).

These analyses also confirmed the absence of any statistically significant differences across set repetitions for all five variables: sEMG \(F(2,18) = 1.467, p = 0.257, d = 0.20\); mid tongue pressure \(F(2,18) = 3.81, p = 0.04, d = 0.13\); posterior tongue pressure \(F(2,18) = 0.530, p = 0.598, d = 0.09\); upper pharyngeal pressure \(F(2,18) = 1.173, p = 0.332, d = 0.19\); lower pharyngeal pressure \(F(2,18) = 0.02, p = 0.980, d = 0.17\). 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 set for any of these analyses (\(p\)-values ranging from 0.48 to 0.79) and no significant set by strategy interactions (\(p\)-values ranging from 0.11 to 0.83). Consequently, set was removed from the model. Further statistical analyses were performed using a general linear model ANOVA with a factor of strategy (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 magnitude of the difference scores from the non-effortful swallow means was greater in the tongue-to-palate emphasis condition, reflecting enhanced amplitudes of all five variables with tongue emphasis.

**Discussion**

Prior research has presented a conflicting picture regarding the biomechanical effect of the effortful swallow maneuver on 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 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 post-swallow vallecular residues were observed on videofluoroscopy; these residuals were attributed to inhibition of posterior tongue retraction associated with the maneuver.

Data from the current research support that effortful swallowing generates significantly altered pharyngeal swallowing biomechanics when compared to a condition of noneffortful swallowing. This study did not concur with the findings of Bülow, et al. who documented no increase in pharyngeal pressure generation in the lower pharynx as a function of effortful swallowing. Consistent with the results of other researchers, effortful swallow amplitudes, regardless of the strategy used, were greater than those seen during a noneffortful saliva swallow at both the upper and lower pharyngeal sensors.

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

Based on prior work by Huckabee, et al., who reported a negative correlation between submental sEMG 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 and thus hypothetically maximizing the superior trajectory of the tongue, generated greater pressures not only in the oral cavity but also in the upper pharyngeal cavity, when compared to a strategy of inhibiting tongue-to-palate contact. Although pressure in the lower pharynx was greater during effortful swallow than non-effortful swallow, there was no significant effect of strategy on pressures at this site. Lower pharyngeal pressure generation therefore appears resistant to the influence of tongue-to-palate pressure patterns.

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 and pharyngeal pressures reflected increased work in both conditions, 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 towards 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 (EMMA) and the x-ray microbeam system. Furthermore, EMMA 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 supports the idea that the tongue may be divided into functionally independent segments. 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 to the tongue body have the effect of stretching/expanding the length of the tongue between those two segments. 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 biomechanical idiosyncrasies, thereby producing an effect of increased functional pressure generation. From a rehabilitative perspective this would seem promising in that the normal neurological system is robust enough to compensate for adaptations in structural configuration.
Conclusions:

The goal for this research was to clarify discrepancies in the literature regarding the biomechanical effect of effortful swallow by investigating specific strategies for executing this technique. The proposed hypotheses were, however, not supported; consequently, the disparate results offered by Bülow and colleagues continue to be unexplained. Clinicians can, however, be confident that the effortful swallow does in fact contribute to increased pharyngeal pressure generation throughout the pharynx, and this can be maximized through a strategy of emphasizing tongue-to-palate contact during performance of the maneuver.

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References


 Suppliers

a. Medical Measurements Incorporated, 56 Linden Street, Hackensack, New Jersey 07601 USA,

b. 

c. KayPENTAX, 2 Bridgewater Lane, Lincoln Park, NJ 07035-1488
Legends

Figure 1. Lateral pharyngeal radiograph with manometric catheter in situ. Three manometric sensors are identified. A = proximal manometric sensor, B = mid-pharyngeal sensor, C = UES sensor.
Table 1. Descriptive Statistics

<table>
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<th>Variable</th>
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<td>Std. Error</td>
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Table 2. ANOVA results for Non-effortful vs. Effortful Saliva Swallows

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Table 3. Descriptive Statistics and ANOVA Results for Effortful Swallows Performed With and Without Tongue-to-Palate Emphasis

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<td>Posterior Oro-Lingual Pressure</td>
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