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Effects of effortful swallow on esophageal function in healthy adults

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Abstract

Background—Treatment for esophageal dysmotility is currently limited to primarily pharmacologic intervention, which has questionable utility and frequently associated negative side effects. A potential behavioral intervention for esophageal dysmotility is the effortful oropharyngeal swallow. A previous pilot study using water perfusion manometry found an increase in distal esophageal amplitudes during effortful vs non-effortful swallowing. The current study sought to duplicate the previous study with improvements in methodology.

Methods—The effects of swallow condition (effortful vs non-effortful), sensor site, and gender on esophageal amplitude, duration, velocity, and bolus clearance were examined for 18 adults (nine males and nine females, mean age = 29.9 years) via combined solid-state manometry and intraluminal impedance.

Key Results—The effortful swallow condition yielded significantly higher esophageal amplitudes across all sensor locations ($P < 0.05$). Further, the effortful swallowing decreased the risk of incomplete bolus clearance when compared with non-effortful swallowing (OR: 0.51; 95% CI: 0.30–0.86).

Conclusions & Inferences—With improved manometric instrumentation, larger participant numbers, and methodology that controlled for potential confounding factors, this study confirms and advances the results of the previous pilot study: Volitional manipulation of the oropharyngeal phase of swallowing using the effortful swallow indeed affects esophageal physiology. Thus, the

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DISCLOSURES

No competing interests declared.

AUTHOR CONTRIBUTION

CN conducted the research, analyzed the waveforms, and wrote the manuscript; CL analyzed the impedance waveforms and contributed to the manuscript; XL conducted statistical analyses and contributed to the manuscript; TL contributed to the design and the manuscript; SB designed the study, assisted with data collection, assisted with data analysis, and contributed to the manuscript.

effortful swallow offers a behavioral manipulation of the esophageal phase of swallowing, and future studies will determine its clinical potential for treating esophageal dysmotility in patient populations.

Keywords

effortful swallow; esophageal; impedance; manometry; pharyngeal

INTRODUCTION

Esophageal dysmotility describes a spectrum of different diseases that affect the esophagus and is a difficult problem to treat.¹ Most of the treatments are pharmaceutical and leave much to be desired as they frequently cause uncomfortable and/or harmful side effects to the patient. Improved and ideally non-pharmaceutical treatments for esophageal dysmotility are needed. Lever *et al.*² introduced the possibility that an effortful swallow (i.e., volitional manipulation of the oropharyngeal phase of swallowing) may affect esophageal peristalsis. The effortful swallow, which requires the patient to 'swallow hard', is often used as a treatment for oropharyngeal dysphagia. Although some studies have demonstrated no change in oropharyngeal mechanics under an effortful swallowing condition,³ the majority of research has shown that an effortful swallow resulted in significantly greater oropharyngeal swallow pressure, longer pharyngeal swallow duration, greater upper esophageal sphincter relaxation, and/or diminished oral residue when compared with noneffortful swallows.⁴⁻⁹

Using water perfusion manometry, Lever *et al.*² tested the effects of the effortful swallow on esophageal functioning and found increased amplitudes in the distal esophagus during the effortful vs non-effortful swallowing condition. Surprisingly, they did not find an increase in esophageal peristalsis in the striated portion of the esophagus, which is presumably most similar to the musculature of the oropharynx. The authors reported three limitations of their study and called for a duplication study. The first limitation was the slower temporal resolution associated with the water perfusion manometric system used in their study. Thus, a solid-state sensor manometric system would offer improved resolution and accuracy. Secondly, given that they found increased esophageal peristalsis only in the lower esophagus, it is possible that the effortful swallow did not directly affect esophageal peristalsis itself. Perhaps their participants recruited abdominal muscles while performing the effortful swallow, thereby increasing intraabdominal pressure and erroneously portraying an increase in distal esophageal pressures. Thirdly, impedance (i.e., bolus flow/clearance) measures were not obtained. Therefore, it is unknown whether the increase in esophageal peristaltic pressures reported by Lever *et al.* correlates with improved esophageal bolus flow. Previous studies using healthy volunteers have validated the technique of impedance measurement as a non-radiological tool for the detection of bolus transport through the pharynogo-esophageal segment and proximal esophagus^{10,11} as well as the distal esophagus.¹¹ These findings provide rationale for using intraluminal impedance to investigate the effect of an effortful swallow on esophageal bolus flow/clearance; thereby avoiding the radiation hazards associated with fluoroscopy.

The purpose of the current study was to duplicate, validate, and expand upon the original study of Lever *et al.* by using a solid-state manometric and intraluminal impedance system to test a larger number of participants while controlling for confounding recruitment of abdominal muscles during effortful swallowing. If the effortful swallow yields increased esophageal pressures and improved bolus clearance in the esophagus, potentially a new treatment may be available for patients with ineffective esophageal dysmotility. Accordingly, this study sought to examine the effect of the effortful swallow on esophageal peristaltic amplitude, duration, velocity, and bolus flow.

MATERIALS AND METHODS

Participants

Eighteen healthy adults (nine males and nine females) with a mean age of 29.9 years (range = 23–58 years) participated in this study. Participants were volunteers who reported no history of swallowing problems, speech disorders, voice problems, or pulmonary, neurologic, or otolaryngologic disease, as determined via questionnaire. Volunteers who reported the current use of medications that might alter swallowing dynamics (i.e., nitrates, calcium channel blockers, anticholinergics, prokinetic agents, and narcotics) were excluded from the study. All participants were non-smokers and did not consume alcohol on a regular basis. All participants were ambulatory and reported good health. Informed consent was obtained from all research participants prior to initiating data collection. Institutional approval was obtained from the Wake Forest University Baptist Medical Center Institutional Review Board.

Apparatus

For the first six participants (five males, one female), a 5-Channel Castell catheter (Konigsberg Instruments Inc., Pasadena, CA, USA) and supporting software (Insight Manometry System; Sandhill Scientific, Highlands, CO, USA) were utilized to collect the manometric data. The manometry catheter was a 145-cm long, round catheter, 4.6 mm in diameter, with five solid-state, circumferential sensors spaced 5 cm apart. Digital 16-bit samples were obtained with a sampling frequency of 30 Hz and displayed in a 100-mmHg display window. The Sandhill system software generated pressure waveforms as a function of time. Impedance electrodes were located 2 cm apart on this catheter, surrounding the four more proximal pressure sensors.

For the final 12 participants, the InSIGHT high-resolution manometry catheter (Sandhill Scientific) was used due to clinic upgrading of the equipment. This catheter was 145 cm long, 3.1 mm in diameter with 32 solid-state, circumferential sensors spaced 1 cm apart. The supporting software (Insight Manometry System; Sandhill Scientific) was utilized to collect the manometric data. Similarly, impedance electrode pairs (spaced 2 cm apart) centered around sensors 5, 10, 15, and 19 cm from the lower esophageal sphincter (LES) were used for the bolus transit analysis.

A KayPENTAX Digital Swallowing Workstation (KayPENTAX, Lincoln Park, NJ, USA) was used to obtain surface electromyographic (sEMG) data of the suprahyoid and abdominal

musculature. Dual-channel sEMG was acquired with 5.4-cm silver chloride electrode triode patches (Uni-Patch, Wabasha, MN, USA). Digital 12-bit samples were obtained with a sampling frequency of 500 Hz via a Bi-Link portable computer (Pentium Model MMX 166; Intel, Santa Clara, CA, USA). The system software generated electromyographic waveforms as a function of time.

Procedure

A sEMG triode patch was placed submentally between the thyroid notch and the anterior mandible, targeting the suprahyoid and floor-of-mouth muscles. A second sEMG triode patch was placed over the external oblique/rectus abdominis below the navel 1 inch and to the right 1 inch to assure no use of abdominal muscles during the performance of the effortful swallow. Participants were instructed in the differences between the non-effortful and effortful swallow conditions. For the non-effortful swallow, the participants were instructed to swallow naturally as if taking a sip of water.² For the effortful swallow trials, participants were instructed to swallow as hard as they could with all of the muscles in their mouth but to make sure they did not recruit any of their abdominal or stomach muscles. Participants used the sEMG waveform as a biofeedback modality to master the differentiation between non-effortful and effortful swallows and to assure that there was no recruitment of the abdominal muscles during either swallow condition. Effortful swallowing training took approximately 5 min.

For the manometry component of the study, manometric catheter calibrations were conducted prior to each participant's data collection using a sphygmomanometer calibration kit (Sandhill Scientific, Highlands, CO, USA, which has an accuracy of ± 0.75 mmHg. One nare of each patient was anesthetized and decongested with a combined spray of 4% lidocaine and oxymetazoline. The tip of the manometric catheter was lubricated and passed transnasally into the stomach while the participant sipped water through a straw, and the catheter was advanced to the 60-cm level marking (read at the nares) so that the distal three sensors were in the stomach. A slow pull-through technique was used until the distal-most sensor was identified in the LES. The resulting locations of the sensors in the esophagus were then 5, 10, 15, and 20 cm above the LES.

For the first six participants, the 5-Channel Castell catheter was used. This catheter has five manometric sensors spaced 5 cm apart; thus, to assess the upper and lower portions of the esophagus, two different catheter placements were used. The first catheter placement allowed for lower esophageal assessment [smooth 1 and smooth 2 (most distal) esophageal/sensor locations]. The catheter was then moved superiorly and procedures repeated to allow for upper esophageal assessment (striated and mixed esophageal/sensor locations). Specifically, the most distal sensor was identified in the LES first, then each participant was given 1 min to become familiar with the catheter before swallow trials began. The participant performed 10 non-effortful and 10 effortful 5-mL swallows of room temperature liquid saline (0.9% NaCl) and 5 non-effortful and 5 effortful 5-mL swallows of banana-flavored room temperature viscous saline (Sandhill Scientific), administered into the oral cavity via syringe. Liquid saline swallows were administered first followed by the viscous saline swallows; however, the swallow condition on liquid and viscous swallows was

alternated to control for order effects. Participants were given 30 s between swallows and cued not to reswallow during that period to avoid the inhibition of primary esophageal peristalsis when successive swallows were performed. Afterward, the catheter was moved superiorly until the most proximal sensor registered the elevated resting pressures associated with the upper esophageal sphincter. Once the upper esophageal sphincter was identified, the catheter was advanced back/inferiorly 1 cm so that all the five sensors were located in the upper esophageal body, but below the upper esophageal sphincter, to obtain measurements from the striated and transition zones of the esophagus. The participant again performed the 10 non-effortful and 10 effortful 5-mL saline liquid swallows and 5 non-effortful and 5 effortful viscous swallows. To minimize artifact in the data tracings, the participants were instructed to relax and refrain from talking, laughing, and moving their body during data acquisition. To facilitate compliance, the specific swallow task instructions and general instructions were repeated out loud to the participants immediately prior to each bolus presentation. Additional boluses were administered in cases of non-compliance (e.g., more than one swallow per bolus, or a non-effortful instead of effortful swallow) in order to obtain 10 acceptable saline and 5 acceptable viscous swallow events for each swallow condition.

For the final 12 participants, the high-resolution manometry catheter was used. This catheter had 32 solid-state sensors spaced 1 cm apart down its entire length, which permitted simultaneous evaluation of the entire esophagus (including the LES) using only 20 swallows (10 effortful and 10 non-effortful) of saline (5-mL per bolus) and viscous saline (5-mL per bolus) per participant. Data were collected from the high-resolution protocol that corresponded to the Castell Catheter's sensor locations. Specifically, the sensors that were 1 cm below the upper esophageal sphincter and 5 cm distal to this first sensor were used to collect data from the upper esophagus. In the lower esophagus, the data were collected from two sensors starting 5 cm above the LES and then 5 cm proximal to that sensor. This method insured that the data were collected at similar positions for both catheters.

Manometric and impedance waveforms were analyzed offline by the first and second authors, respectively. Peak amplitudes of the five designated sensors were measured in mmHg. The waveforms also were analyzed relative to pressure duration measurements in seconds. Velocity of peristaltic transmission was calculated in centimeters per second. Lastly, complete *vs* incomplete bolus clearance data were acquired for each individual swallow using the impedance channels. Requirements for complete bolus transit were: (i) bolus entry in the proximal sensor indicated by a decrease in the impedance tracing to 50% of average of baseline and subsequent nadir, and (ii) bolus exit in each of the three distal sensors, as indicated by return of the impedance tracing to the same 50% point for 5 s or more.¹² If the impedance data did not meet these requirements, the designation of incomplete bolus clearance was applied. Liquid bolus transit was required to be within 12 s and viscous bolus transit was required to be within 13 s. Bolus time clearance was calculated from the entry of the bolus in the proximal sensor to the exit of the bolus past the most distal sensor. Calculations were performed with the Sandhill Bioview analysis software (Sandhill Scientific) and manually confirmed for each individual swallow.

Twenty-four manometric measures [2 swallow conditions (i.e., non-effortful *vs* effortful) $\times$ 4 sensor locations (i.e., striated, mixed, smooth 1, and smooth 2) $\times$ 3 variables (i.e., amplitude,

duration, and velocity)] were extracted from each swallow. Thus, 240 measurements were available per participant (24 measures $\times$ 10 trials), affording a study total of 4320 measurements. Of the 4320 possible data points, 243 (6% of study total) were missing in one of the 10 trials for a particular condition. In all cases of missing data, that particular aspect of the waveform was considered unanalyzable. The 10 trials for each condition were averaged/collapsed for the inferential analyses. In cases where one or more trials were missing for a particular condition, the average was still taken with the available number of trials present. In one condition, all 10 trials were not available to compute the average, so the value was replaced with the condition mean. For the bolus clearance data, four measures [2 swallow conditions (i.e., non-effortful vs effortful) $\times$ 2 bolus types (i.e., liquid vs viscous)] were extracted from each swallow. Given each participant provided 10 liquid swallows and 5 viscous swallows for each condition, there were 30 bolus clearance measurements available per participant affording a study total of 540 bolus clearance measurements.

Data analysis

Means and standard errors were calculated for esophageal amplitude, duration, and velocity by swallowing condition and sensor location. Three separate analyses of covariance (ANCOVA) with repeated measures were utilized to examine the effects of swallowing condition on esophageal amplitude, duration, and velocity, adjusted for gender and sensor location (for velocity, no sensor location was adjusted). Interactions between swallowing condition and sensor location were tested and dropped from the final models of esophageal amplitude and duration, if not significant. For the bolus flow outcomes (complete vs incomplete), logistic regression with repeated measures was used to model the relative risk of incidence of incomplete bolus flow, represented by odds ratio (OR) and its corresponding 95% confidence interval (CI). For both ANCOVA and logistic regression models, the correlation of the measures from the same subject was taken into account using an exchangeable covariance structure. All tests were set at a significance level of 0.05 and all analyses were performed using SAS 9.2 software (SAS Institute, Inc., Cary, NC, USA).

RESULTS

Amplitude

Mean esophageal swallowing amplitudes as a function of sensor location (i.e., striated, mixed, smooth 1, smooth 2) and swallowing condition (i.e., non-effortful vs effortful) collapsed across trials are presented in Table 1. No significant interaction between sensor location and swallowing condition was found from the ANCOVA model ($P > 0.99$). The main effect of condition revealed that the effortful swallow ($M = 75.69$ mmHg) had significantly higher mean esophageal peak pressures than the non-effortful swallow ($M = 67.47$ mmHg) ($P < 0.05$) across all sensor locations. Furthermore, the mean esophageal peak pressures for all sensor locations were significantly different from each other ($P < 0.0001$). The striated sensor location had the highest pressures ($M = 101.08$ mmHg), followed by the smooth 2 ($M = 37.35$ mmHg), then smooth 1 ($M = 62.76$ mmHg) sensor locations; the mixed sensor location had the lowest pressures ($M = 85.12$ mmHg) (Fig. 1). Although males (80.45 mmHg) had greater mean esophageal amplitudes than females (62.71 mmHg), no significant gender effect was detected ($P = 0.16$).

Duration

Mean esophageal duration as a function of sensor location and swallowing condition collapsed across trials are presented in Table 2. No significant interaction between sensor location and swallowing condition was found from the ANCOVA model ($P = 0.67$). The main effect of condition revealed that the effortful swallow ($M = 2.20$ s) tended to have longer mean esophageal durations than the non-effortful swallow ($M = 2.04$ s) ($P = 0.09$) across all sensor locations; however, this difference did not reach statistical significance. The mean esophageal durations were significantly different across sensor locations ($P < 0.001$). The smooth 2 ($M = 2.74$ s) had the longest duration, followed by the smooth 1 sensor ($M = 2.26$ s) location. Both of these sensor locations had longer durations than striated ($M = 1.75$ s) and mixed ($M = 1.72$ s) sensor locations, and the latter two were not different from each other (Fig. 2). Although males (2.21 s) had greater mean esophageal duration than females (2.03 s), no significant gender effect was detected ($P = 0.43$).

Velocity

ANCOVA with repeated-measures model was performed to investigate the esophageal velocity as a function of swallowing condition and gender. The mean velocity for the effortful swallow ($M = 5.40$ s) and females ($M = 5.55$ s) was longer than that for the non-effortful swallow ($M = 4.95$ s) and males ($M = 4.82$ s), respectively. However, the main effects of condition as well as gender, and all interactions, were non-significant ($P > 0.05$).

Impedance/bolus clearance

A logistic regression model with repeated measures was fitted to the bolus clearance outcomes (incomplete vs complete). There was no interaction between swallowing condition (effortful vs non-effortful) and bolus type (liquid vs viscous) (P -value = 0.362). There was no difference between males and females on the incidence of incomplete bolus flow (OR: 0.79; 95% CI: 0.41–1.51). However, the effortful swallow condition decreased the risk of incomplete bolus clearance when compared with non-effortful swallowing (OR: 0.51; 95% CI: 0.30–0.86). The incidence of incomplete bolus clearance for liquid swallows was lower than that of viscous swallows (OR: 0.51, 95% CI: 0.33–0.80).

DISCUSSION

The effects of non-effortful vs effortful swallowing on esophageal amplitude, duration, velocity, and impedance (bolus flow/clearance) were measured via solid-state esophageal manometry in 18 healthy adults in an effort to duplicate and improve on a previous water perfusion manometry study.² Results of our study showed that effortful swallowing elicited significantly greater amplitudes at all sensor locations. In addition, the effortful swallow elicited longer pressure durations at the striated portion of the esophagus, although not statistically significant. Although the effortful swallow did not significantly alter velocity measures compared with the non-effortful swallow, the effortful swallow did result in a lower risk for incomplete bolus clearance. Lastly, females did not generate statistically longer esophageal pressure, durations, or velocities compared with males.

The effortful swallow has been found to have an effect on the oropharyngeal phase of swallowing in healthy adults as it typically generates greater amplitude/displacement^{4,6-9,13-15} and longer physiologic durations;^{4,5,8,16} however, its impact on swallowing safety in patients with dysphagia is still under scrutiny.^{3,17-19} Given the strong support for the effects of the effortful swallow impacting the oropharyngeal phases of swallowing in healthy adults, it was hypothesized that the effortful swallow may affect the esophageal phase as well. It seems especially plausible that the effortful swallow may influence the striated portions of the esophagus; however, Lever *et al.*² found that the effortful swallow elicited significantly greater amplitudes only in the distal esophagus.

Lever *et al.* called for a duplication study as they noted some limitations of their study design. For example, they used a water perfusion manometric catheter that is limited in its temporal resolution. Therefore, the current study employed the use of a solid-state manometric catheter. Furthermore, they only studied 10 participants, whereas the current study recruited 18 participants. They also noted that perhaps the finding of increased amplitudes in the lower esophagus during the effortful swallow may have simply reflected the artifact of abdominal muscle use. Thus, the current study utilized sEMG biofeedback on the abdominal musculature of the participants during the effortful swallow condition to verify that no abdominal muscle activity was recruited, impacting the esophageal amplitude measurements. Finally, Lever *et al.* did not concurrently measure impedance (i.e., bolus flow/clearance); therefore, they were unable to correlate the increase in distal esophageal peristaltic pressures with bolus transit. The current study expanded upon the previous study by incorporating intraluminal impedance testing with solid-state esophageal manometry to determine whether in fact the effortful swallow may affect esophageal motility.

This study revealed no statistically significant differences in amplitude, duration, or velocity between males and females. This was surprising as Vega *et al.* reported that, in a sample of 129 healthy volunteers (63 males and 66 females), females had significantly longer distal esophageal contraction durations, higher distal contraction amplitudes, and lower distal contraction velocity than males.²⁰ It may be that in our cohort of 18 adults, the study was not adequately powered to sufficiently assess gender differences. Additionally, in this small group, female height and weight may have approximated that of the male group, thereby negating anatomical effects on esophageal amplitude, duration, and velocity.

Identifying a behavioral manipulation that may alter esophageal functioning is a novel and exciting supposition. Currently, individuals with dysphagia related to esophageal dysmotility are largely limited to pharmacologic treatment, which is not very effective and carries with it negative side effects. If esophageal motility could be manipulated via behavioral modifications similar to that of oropharyngeal function, then new treatment options could be explored for those individuals with esophageal dysmotility.

The results of this study differed from Lever *et al.* study in two primary ways. Firstly, we found that the effortful swallow affected the pressures generated in both the striated and smooth muscle portions advantage of the esophagus, as opposed to only the smooth muscle portions. Secondly, Lever *et al.* did not assess the esophageal bolus clearance. Given our use of impedance, we were able to demonstrate that the effortful swallow reduced the risk of

incomplete bolus clearance compared with the non-effortful condition. This is perhaps the most important and clinically relevant finding. Although the participants in this study were healthy volunteers with no reports of dysphagia or suspected esophageal dysmotility, the findings of this study suggest that the effortful swallow, which is an easy-to-employ compensatory technique, may elicit improved bolus clearance for patients with esophageal dysmotility.

The next stages of this research will need to be twofold. Firstly, a future study will need to duplicate our methodology using patients with diagnosed esophageal dysmotility. This step is necessary to determine whether the effortful swallow results in improved bolus clearance in patients with esophageal dysmotility. Secondly, a treatment effects study should be conducted like in oropharyngeal strength training programs. For example, if a patient performs 20 repetitions of effortful swallows twice daily for 8 weeks, can they improve the strength and efficiency of esophageal peristalsis and bolus transit without the direct compensatory technique of the effortful swallow while eating? Thus, the current study, although promising as a potential treatment or compensatory technique for esophageal dysmotility, needs to be expanded on before generalization to clinical populations can be made.

A potential limitation of the current study is that the individuals acquiring the manometric and bolus flow measures were not blinded to the condition of the effortful vs non-effortful swallow. Lastly, future studies that utilize the high-resolution manometry system for all participants can take advantage of acquiring data from all sensors, not just five sensors as in this study, and include additional measures available to a high-resolution manometry system.

SUMMARY

This investigation revealed significant effects of swallowing condition (i.e., effortful vs non-effortful) on esophageal pressure and bolus clearance. Specifically, effortful swallows elicited higher esophageal pressures and more complete bolus clearance than the non-effortful swallows. This study provides valuable data that support a possible clinical potential to treat diseases that manifest in decreased esophageal pressures and/or decreased bolus clearance as the main symptoms of dysphagia. Future investigations are needed to elucidate these possibilities.

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Figure 1. Esophageal amplitude as a function of sensor location for non-effortful and effortful swallows.

Figure 2. Esophageal duration as a function of sensor location for non-effortful and effortful swallows.

Table 1

Mean esophageal pressure relative to manometric sensor location and swallowing condition (mmHg)

	Swallow condition	
	Non-effortful	Effortful
Striated	97.23 (9.50)	104.93 (10.22)
Mixed	33.63 (4.26)	41.08 (6.32)
Smooth 1	58.76 (6.45)	66.76 (6.29)
Smooth 2	80.26 (9.82)	89.98 (11.27)

Standard errors of the means are presented in parentheses.

Table 2

Mean esophageal duration relative to manometric sensor location and swallowing condition (seconds)

	Swallow condition	
	Non-effortful	Effortful
Striated	1.75 (0.16)	1.75 (0.12)
Mixed	1.67 (0.16)	1.77 (0.18)
Smooth 1	2.13 (0.12)	2.39 (0.14)
Smooth 2	2.60 (0.22)	2.87 (0.20)

Standard errors of the means are presented in parentheses.