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Effect of bolus volume on pharyngeal swallowing assessed by high-resolution manometry☆,☆☆,★

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HIGHLIGHTS

- High-resolution manometry can detect the effect of volume on pharyngeal swallowing.
- Increase in bolus volume increases UES residual pressure and UES relaxation duration.
- Maximum preopening and postclosure UES pressures are not affected by bolus volume.
- Bolus volume has no effect on the hypopharynx.

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ABSTRACT

Objective: Solid-state high-resolution manometry (HRM) is fast becoming the gold standard for studying pharyngeal and esophageal motility. However, very few studies have ever evaluated the effect of bolus volume on the physiology of swallowing using HRM. We aimed to determine the effect of bolus volume on pressure, duration and velocity of the hypopharynx as well as the upper esophageal sphincter during pharyngeal swallowing using HRM.
Methods: Thirty-four healthy subjects completed nine swallows (3 ml, 5 ml and 10 ml of water, thick liquid, and paste, respectively) in the natural sitting position. Pressure and duration measurements were acquired from the hypopharynx and upper esophageal sphincter (UES) using HRM. The UES residual pressure, UES relaxation duration, maximum preopening UES pressure, maximum postclosure UES pressure, maximum hypopharyngeal pressure, maximum hypopharyngeal pressure rise rate and hypopharyngeal pressure duration were analyzed across bolus volumes using repeated measures of one-way analysis of variance.
Results: A significant increase in UES residual pressure associated with increased bolus volume during water and paste swallowing was observed. Furthermore, UES relaxation duration was significantly increased with increasing in bolus volume for all three material swallows. No significant volume effects were found on the hypopharynx.
Conclusions: In summary, bolus volume has a significant effect on the residual pressure and relaxation duration, but no effect on maximum preopening pressure or maximum postclosure pressure of the UES. Maximum hypopharyngeal pressure, maximum hypopharyngeal pressure rise rate and pressure duration were also not affected by bolus volume. Consideration of these variables is paramount in understanding normal and pathological swallowing.

1. Introduction

Bolus volume is an important modulator of the biomechanical events that occur during oropharyngeal swallowing [1]. In the case of varied volume bolus swallows, volume accommodation guarantees the safety and efficacy of swallowing. While patients with neurologically impaired dysphagia may face the risk of penetration and aspiration with increase in bolus volume, decrease in bolus volume beyond a certain extent may not trigger the automatic swallowing reflex [2]. Therefore, alterations in bolus volume can bring about changes in swallowing physiology in ways that can compensate for or exacerbate deficits. Volume modification in

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dysphagia patients has already been employed in routine clinical therapy.

To understand the pathology of swallowing, we need to identify the characteristics of normal swallowing physiology. Previous studies used techniques like ultrasonography [3], videofluoroscopy [2,4–9], electromyography [10–12] and traditional manometry [9,13–18] to determine the effect of bolus volume on pharyngeal swallowing. However, the results of these studies were inconsistent, owing to discrepancies in designs and methods, relatively small number of subjects, and different definitions for the variables used. Moreover, ultrasonography, videofluoroscopy and electromyography techniques cannot provide adequate quantization of pharyngeal propulsive force, UES squeezing tone and timing of the coordination between the pharyngeal contraction and UES relaxation. Previous studies using traditional manometry have contributed to our knowledge regarding bolus volume on pharyngeal swallowing physiology [13–18]. However, traditional manometric catheters have been proved unsuitable due to only a small number of sensors and rostral movement (2–4 cm) of the UES during the course of swallowing [14]. Besides, unidirectional sensors are inappropriate for using in an asymmetric pharynx, since pharyngeal pressure is 2 to 3 times higher in the anterior and posterior directions than in the lateral directions [19,20]. Therefore, traditional manometry fails to offer a comprehensive analysis of pharyngeal and UES physiological characteristics.

Solid-state high-resolution manometry (HRM) provides technological advances over conventional manometry, which has overcome previous equipment shortcomings and allows accurate measurements of the rapid response of striated muscle, regardless of the asymmetric pressure distribution of the pharynx and UES. Using solid-state HRM, Ghosh et al. [21] performed a detailed analysis of deglutitive UES function in normal individuals during 1 ml, 5 ml, 10 ml, and 20 ml water swallowing and found that UES relaxation duration and peak pharyngeal contraction increased with bolus volume. Similarly, Hoffman et al. [22] determined the effect of bolus volume on pharyngeal swallowing in 12 healthy subjects using solid-state HRM, and reported an increase in peak velopharyngeal pressure, velopharyngeal pressure duration, UES opening duration and UES residual pressure as the bolus volume increases. However, neither of the aforementioned studies investigated volume effect on pharyngeal swallowing by using bolus of different viscosities, and did not focus on the hypopharynx.

Accurate identification of bolus volume effect is crucial to our understanding of normal and dysfunctional swallowing. This study examined how bolus volume can affect hypopharyngeal and upper esophageal sphincter pressure, duration and velocity measurements during the process of swallowing in 34 healthy subjects, using the novel solid-state HRM test.

2. Materials and methods

2.1. Participants

Thirty-four young healthy volunteers (age range = 20–45 years; mean age = 24.3 ± 5.93 years; gender equally represented) were enrolled in the study. All participants were in good health without symptoms or history of swallowing difficulty, reflux symptoms, medications known to interfere with swallowing, speech disorders, structural disorders, cognitive disorders or neurologic and/or muscular diseases. Informed consent was acquired from each participant before data collection. Ethics approval was obtained from the clinical research ethics committee of the third affiliated hospital of Sun Yat-sen University.

2.2. High resolution manometry

This study featured a solid-state manometric assembly with 4.2 mm outside diameter and having 36 circumferential sensors spaced at 1-cm intervals (Sierra Scientific Instruments, Los Angeles, CA). This device uses proprietary pressure transduction technology (TactArray) that allows each of the 36 pressure sensing elements to detect pressure over a length of 2.5 mm in each of 12 circumferentially dispersed sectors. The sector pressures are then averaged to obtain a mean pressure measurement, making each of the 36 sensors a circumferential pressure detector with the extended frequency response characteristic of solid-state manometric systems. Before recording, the transducers were calibrated at 0 and 300 mm Hg using externally applied pressure, according to manufacturer specifications. The response characteristics of each sensing element were such that they could record pressure transients in excess of 6000 mm Hg/s and were accurate to within 1 mm Hg of atmospheric pressure after thermal calibration correction. The data acquisition frequency was 35 Hz for each sensor. All pressure measurements were referenced to atmospheric pressure [23].

2.3. Data collection

After a brief interview, an examination was performed to ensure the absence of gastrointestinal symptoms. The participants then underwent transnasal placement of the manometric assembly in a natural sitting position with the head in neutral position. Real-time pressure imaging during catheter intubation enabled accurate placement. The catheter was fixed in place by taping it at the nostril. Following a quiet resting adaptation period (up to 10 min) each participant was instructed to swallow 3 ml, 5 ml, and 10 ml of water, thick liquid, and paste materials, respectively. All consistencies were prepared 5 min prior to use. Slip tip syringes were used to measure liquid and paste volumes to ensure that the bolus quantities were accurate.

Water at room temperature was combined with Simply & Thicker® (Nestle Nutrition) to prepare the thick liquid and pastes. Both thick liquid and pastes were prepared consistently following this protocol: 100 ml of water combined with 1 tablespoon + 1 teaspoon of thickener (thick liquid), 100 ml of water combined with 2 tablespoons + 2 teaspoon of thickener (paste). The mixtures were stirred and left to stand for 5 min prior to use.

Once the bolus was placed in the mouth, each participant was instructed to breath gently through the nose. Each physiologic channel was monitored to obtain baseline levels. The participant was then instructed to swallow, and all manometric data were recorded on the manometer during the respective examinations. A total of nine swallows (water, thick liquid, and paste material in 3 ml, 5 ml, and 10 ml amounts, respectively) were measured from each participant at each assessment time point.

2.4. Data analysis

Pressure and timing data were initially analyzed using ManoView analysis software (Sierra Scientific Instruments, Los Angeles, CA). According to the methods of McCulloch [24] and Takasaki [23], the pharyngeal region was defined as the area of swallow related pressure change, with a high pressure zone identified approximately midway between the nasopharynx and the UES, with its epicenter at the high pressure point and extending 2 cm proximal and distal to that point. In the present study, the hypopharyngeal region was defined as the area between velopharyngeal and the UES. The UES region was defined as the midpoint of stable high pressure just proximal (rostral) to the baseline low esophageal pressure zone, extending to a point of low esophageal pressure distally and low baseline pharyngeal pressure proximally [23,24]. During swallowing, this anatomic area is mobile along the catheter, moving rostrally as much as 2–4 cm [14].

Values were recorded for maximum pressure, maximum pressure rise rate and duration of pressure above baseline in the regions of the hypopharynx, UES residual pressure, UES relaxation duration, maximum preopening UES pressure and maximum postclosure UES pressure. Duration of pressure above baseline within a region was defined as the time duration between the onset of pressure escalation and its return to, or below, baseline using the single sensor where