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Dysphagia

The Effects of Intraoral Pressure Sensors on Normal Young and Old Swallowing Patterns

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Abstract. Lingual pressure generation plays a crucial role in oropharyngeal swallowing. To more discretely study the dynamic oropharyngeal system, a 3-bulb array of pressure sensors was designed with the Kay Elemetrics Corporation (Lincoln Park, NJ). The influence of the device upon normal swallowing mechanics and boluses representative of flow relative to age and bolus condition was the focus of this study. Twelve healthy adults in two age groups (31 ± 5 years, 2 males and 4 females, and 78 ± 7 years, 2 males and 4 females) participated. Each subject was instructed to swallow four boluses representative of conditions with and without three pressure sensors affixed to the hard palate. Postswallow residue at four locations, Penetration/Aspiration Scale scores, and three bolus flow timing measures were assessed videofluoroscopically with respect to age and bolus condition. The only statistically significant influences attributable to the presence of the pressure sensors were slight increases in residue in the oral cavity and upper esophageal sphincter with some bolus consistencies, 8% more frequent trace penetration of the laryngeal vestibule predominantly with effortful swallowing, and variances in oral clearance duration. We conclude that the presence of the pressure sensors does not significantly alter normal swallowing patterns of healthy individuals.

Key words: Deglutition — Lingual pressure — Instrumentation — Deglutition disorders.

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Lingual pressure generation plays a crucial role in oropharyngeal swallowing and is likely an important factor for effective bolus clearance. Abnormal lingual physiology often is associated with reduced bolus clearance in the upper aerodigestive tract. Such residue may contribute to the occurrence of airway penetration or aspiration leading to pneumonia, malnutrition, or dehydration [1,2]. Despite the importance of the oral phase of the swallow, research on oropharyngeal pressure dynamics and tongue movement characteristics during swallowing and their influence on bolus transit is in its infancy [3–6]. Until such information is available, accurate diagnosis of dysphagia may be a dilemma, and age-appropriate treatment strategies and rehabilitation goals remain unclear [2].

A focus of our ongoing efforts to improve dysphagia assessment and treatment has been the development, refinement, and application of an intraoral pressure-measuring device with multiple sensors to provide accurate, high-temporal-resolution information about lingual pressure generation. In conjunction with Kay Elemetrics (Kay Elemetrics Corp., Lincoln Park, NJ), the configuration of a prototype intraoral pressure instrument was modified to specifically measure lingual pressure generation at the tip, blade, and dorsum of the tongue for our clinical research. The purpose of this study was to investigate how the presence of the instrument affected normal swallowing dynamics relative to the cofactors of age and bolus condition. Fluoroscopically determined postswallow residue measures, Penetration/Aspiration Scale ratings [7], and oropharyngeal bolus clearance duration times were used as the dependent variables against which to compare swallows performed with and without the instrument in place.

Methods

Subjects

The research was conducted with approval of the University of Wisconsin–Madison Health Sciences Human Subjects Committee (Protocol Number 93-676-507) and the Research & Development Committee of the William S. Middleton Memorial Veterans Hospital. A total of 12 healthy men and women were recruited in two gender-matched age groups, young (31 ± 5 years, 2 male and 4 female) and old (78 ± 7 years, 2 male and 4 female). Each subject was examined by a physician and completed an extensive health history questionnaire. No subjects were included who had prior or existing medical conditions and/or used medication that could potentially influence oropharyngeal motor performance or sensation. An oropharyngeal motor examination revealed normal structures and function of the oral cavity. All subjects denied swallowing problems.

Experimental Procedure

Lateral fluoroscopic imaging of the oral cavity, pharynx, and cervical esophagus was recorded with the subjects seated comfortably in an upright position for each of the swallowing tasks. Each subject performed swallows of boluses comprising four representative conditions: six 3-ml thin-liquid swallows, six 3-ml semisolid swallows, six 10-ml thin-liquid swallows, and four 3-ml thin-liquid "effortful" swallows for a total of 22 swallows (11 with the pressure bulb array attached to the hard palate and 11 without the pressure bulb array). The order in which the four bolus conditions were performed and the order of the presence/absence of the pressure sensor were randomized. The thin-liquid boluses were a 3:1 mixture of water: Liquid Polibar Plus (EZ-EM Inc., Westbury, NY) with a viscosity of 15 CP, and the semisolid bolus was a mixture one-half cup of vanilla pudding and 2 teaspoons EZ-HD powder barium (EZ-EM Inc.). Subjects were cued to "swallow hard" for the effortful swallowing condition and to swallow "naturally" for all other swallow conditions.

Pressure Instrumentation and Placement

The Kay Elemetrics Swallowing Workstation 7100 was used to record and time-link concurrently recorded lingual pressure and videofluoroscopic data. Oral pressure was measured using three air-filled bulbs that were 13 mm in diameter and spaced 8 mm apart on a silica strip. The strip was attached longitudinally along the midline of the hard palate using Stomahesive (ConvaTec, Princeton, NJ), with the anterior bulb positioned at the alveolar ridge and the posterior bulb at the approximate junction of the hard and soft palates (Fig. 1). Bulb locations were preselected with the intention of measuring the spatial and temporal patterns of lingual pressure generation responsible for bolus transit during a swallow, but exact placement of the bulb array varied slightly to accommodate individual shape and length of the hard palate. The bulbs were connected to an external transducer (hung comfortably from the neck), which measured pressure within the bulbs as a function of time. The pressure sensors were sampled at a temporal resolution of 0.004 s.

Residue Measures

Postswallow residue was judged from the videofluoroscopic image at the time that the hyoid bone returned to rest marking the end of the swallow [1,4]. Measurements were taken in the oral cavity, vallecula, posterior pharyngeal wall, pyriform sinuses, and upper esophageal sphincter (UES). A three-point scale was used with 0 corresponding to no residue, 1 to coating of residue (a line of barium on a structure), and 2 to pooling of barium (anything more than a line of barium). Interjudge reliability, completed by two clinical research speech–language pathologists with more than four years of experience in measuring residue, was 84%. Intrajudge reliability was 90%.

Fig. 1. Array of three air-filled bulbs (13 mm in diameter and spaced 8 mm apart) affixed to the hard palate using Stomahesive (ConvaTec, Princeton, NJ).

Penetration/Aspiration Scale Ratings

Each swallow was assessed using the 8-point Penetration/Aspiration Scale 7.12. The scale ratings were determined by the depth of barium invasion in the airway and whether or not the barium was expelled. Rosenbek et al. published intrajudge reliability of 91% and interjudge reliability of 89% within one scale score [7].

Bolus Flow Timing

Three durational measures of bolus movement were obtained for each swallow. The measures were based on previously published methods using the ramus of the mandible and the UES as anatomical references [8–10]. Oral clearance duration (OCD) was measured from the beginning of posterior bolus movement in the oral cavity to the time when the tail of the bolus passed the ramus of the mandible [11]. Pharyngeal clearance duration (PCD) was calculated from arrival of the bolus head at the ramus of the mandible until the tail of the bolus passed through the UES [11]. Total swallowing duration (TSD) was measured from initiation of posterior bolus movement until the hyoid returned to rest. Ten percent of the swallows were randomly selected and bolus clearance duration times were reanalyzed by the same judges. The overall intrajudge reliability was ±0.037 s (1.1 frames), while the overall interjudge reliability was ±0.093 s (2.8 frames).

Data Analysis

Repeated measures analysis of covariance (ANCOVA) models were used to assess the impact of the pressure-sensing bulbs on residue, penetration/aspiration, and clearance duration while accounting for the correlations between observations on the same subject. Age (young/old) and bolus type (3-ml thin-liquid swallows, 3-ml semisolid swallows, 10-ml thin-liquid swallows, and 3-ml

Table 1. Effect of the presence of bulbs affixed to the hard palate (bulbs in vs. bulbs out) on the mean residue (measured using 3-point scale) at various locations

	Bulb effect	(95% CI)	*p*-value
Oral cavity	0.73	(0.60, 0.86)	<0.0001
Posterior pharyngeal wall	0.03	(−0.02, 0.09)	0.22
Valleculae	0.08	(−0.01, 0.18)	0.085
Pyriform sinuses	−0.04	(−0.12, 0.04)	0.37
UES	0.16	(0.07, 0.25)	0.001

CI = confidence interval; UES = upper esophageal sphincter.

"effortful" swallows) were included in these models as covariates. Interactions between all three factors (age, bolus type, and bulb) were also included in the model. Analyses were conducted using Proc Mixed in SAS (SAS Institute, Cary, NC). A nominal p value of 0.05 was regarded as being statistically significant.

Results

Residue Measures

Residue significantly increased with the presence of the bulbs in the oral cavity ($p < 0.0001$) and the UES ($p = 0.0005$) in both the young and old subjects. Bulb presence had no significant influence for young and old subjects on residue at the valleculae, posterior pharyngeal wall, or pyriform sinuses. Table 1 shows the change effect (bulbs in relative to bulbs out) of the presence of the bulb array on residue at various locations.

Penetration/Aspiration Scale Ratings

There were significantly higher scores on the Penetration/Aspiration Scale with the presence of bulbs ($p = 0.032$). Since these were normal, healthy subjects, most scores were 1(no penetration/aspiration). With the bulbs present in the oral cavity, there was an estimated 8% increase in the frequency of scores of 2 or higher. There was a significant interaction between the presence of bulbs and age/bolus type ($p = 0.008$). The presence of bulbs had no effect on penetration/aspiration when older and younger subjects swallowed the semisolid and when younger subjects executed the hard swallow. The increase in penetration/aspiration was most notable when older subjects executed the hard swallows ($p = 0.0006$) (Table 2).

Bolus Clearance Durations

There were no significant changes in total swallowing duration (TSD) and pharyngeal clearance duration (PCD) associated with the presence of bulbs in the oral cavity. The presence of the bulb array did affect oral clearance duration (OCD); this effect varied based on bolus type and age ($p = 0.027$). Young subjects cleared semisolid material from the oral cavity faster with the bulb array present, while older subjects cleared semisolid material faster without the bulb array present ($p = 0.0089$). A similar pattern is observed for the hard swallow but the difference between ages is not statistically significant ($p = 0.11$) (Fig. 2).

Discussion

The major finding of this study was that the presence of an intraoral device designed to measure pressures was well tolerated by normal individuals across the adult age span. While this instrument had been used previously to study swallowing dynamics [1,4], there have yet to be data published indicating any impact the device itself may have on oropharyngeal biomechanics and bolus flow. The findings provide preliminary validation for its use in studying relatively natural swallowing patterns regardless of age and provide a resource for data interpretation by researchers using this device. Replication of this study with a larger subject sample is warranted to confirm these findings.

Increased oral cavity residue with the bulb array attached to the hard palate was observed in both young and old healthy subjects alike, which most likely reflects the adherence of the barium material to the intraoral device itself. The reason for increased coating at the UES when the bulbs are present in the oral cavity is unclear and seemingly functionally insignificant. The authors speculate that minor change in duration of or range of UES opening could have resulted in capturing this minimal amount of barium. These findings are important for data interpretation in future uses of this instrument, i.e., the presence of increased residue must be interpreted as normal and referred to as a baseline when comparing findings from individuals with dysphagia.

The minimal increase in Penetration/Aspiration (P/A) Scale scores with thin liquid by older subjects from a score of 1, which indicates no penetration, to a score of 2, which indicates slight penetration, without residue in the laryngeal vestibule, during the hard swallow are of minor consequence because a score of 2 does not reflect a significant risk to swallowing safety. In fact, Robbins et al. [12] indicated that trace penetration is common in healthy elders. The increase in P/A scale score was most

Table 2. Penetration/Aspiration Scale score for old and young subjects by bolus type comparing when bulbs were affixed to the hard palate with when they were not

P/A Scale score	3-ml liquid				10-ml liquid				3 ml semisolid				3 ml liquid (hard swallow)			
	Young		Old		Young		Old		Young		Old		Young		Old	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1	15	18	16	17	17	18	17	16	18	18	18	18	12	12	8	12
2	3	0	2	1	1	0	1	1	0	0	0	0	0	0	3	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	$p = 0.092$		$p = 0.57$		$p = 0.092$		$p = 0.092$		$p = 1.00$		$p = 1.00$		$p = 1.00$		$p = 0.0006$	

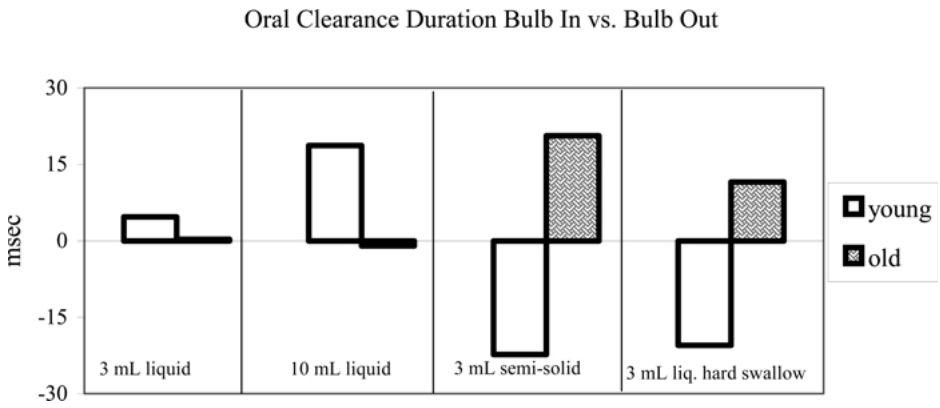

Fig. 2. Difference in mean oral clearance duration (ms) between the two conditions of bulbs by bolus type and age. p values for differences by age within bolus type ($p = 0.79$ for 3 ml liquid, $p = 0.22$ for 10 ml liquid, $p = 0.0089$ for 3 ml semisolid, and $p = 0.11$ for 3 ml liquid effortful swallow).

notable with the bulbs in older subjects while executing the effortful swallow. This may reflect how older individuals adjust to multiple perturbations in the swallowing system such as the combined effect of having a device in their mouth while attempting a strategy. However, a significant increase in the incidence of penetration was not observed in a larger group of 64 healthy adults using the same device to compare P/A scale scores in normal swallowing versus effortful swallowing [8].

The results of our study indicated that young subjects cleared the oral cavity faster than old subjects when the bulbs were present with semisolids and when swallowing hard, which is consistent with work of Robbins et al. [1], who found that young individuals swallow faster than old individuals. Clearing of the oral cavity more quickly by older subjects with larger liquid boluses may be attributed to previously reported findings that showed that older individuals hold a bolus posteriorly in the oral cavity and use the posterior tongue as a "floodgate" to release the bolus posteriorly [10]. This pattern is facilitated by gravity and may be a strategy to compensate for age-related slowing and reduced lingual strength as reported by Robbins et al. [2]. While interesting, the impact of the presence of the bulbs on these durational patterns is unclear because there were no significant results indicating the bulbs were solely responsible for changes in the clearance timing.

The measures obtained in this study and described above indicate the preliminary validity of the use of this instrument to study relatively natural swallows and to emphasize the ability of healthy individuals, regardless of age, to accommodate or adequately compensate for the intraoral perturbation that the presence of the instrument represents. The current findings serve as a resource for interpretation with other studies in the future. The lack of a significant age/bulb condition interaction is a powerful indicator that the altered sensory conditions imposed by the instrument's intraoral presence minimally influences the swallowing pattern generator in a normal-functioning mechanism. Therefore, deviations from the current findings that may be found in future studies using these methods may be interpreted as indicative of dysphagia-related pathology in young and old individuals. In conclusion, our findings support the use of this new instrument, with confidence, to better understand pressure aspects of swallowing and dysphagia.

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