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Dysphagia

Measures of Tongue Function Related to Normal Swallowing

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Abstract. The availability of objective measures of tongue function presents a possible supplement to the clinical dysphagia evaluation. The purpose of this study was to improve our understanding of normal tongue physiology during swallowing and maximum isometric tasks, establish a preliminary database of tongue function variables, and determine if differences existed among the variables as a function of age, gender, or varied bolus consistency. Ninety subjects, divided into age and gender groups, participated in tasks that determined maximum isometric tongue pressure, mean tongue pressure during swallowing, and percentage of maximum isometric pressure used during swallowing. Descriptive statistics, correlations, and analyses of variance were computed to analyze the data. Results indicated that males had significantly higher maximum isometric pressures than females, and the youngest group had significantly higher maximum pressures than the oldest group. Mean swallowing pressures and percentage of maximum isometric pressures used during swallowing differed as a function of bolus type but did not differ as a function of age or gender. In addition, maximum isometric pressures were correlated with mean swallowing pressures, and mean swallowing pressures and percentage of maximum isometric pressures used during swallowing were correlated between consistencies.

Key words: Deglutition — Swallowing — Tongue strength — Isometric pressure — Deglutition disorders.

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The tongue contributes a large and significant role in the oral and pharyngeal phases of swallowing. This role includes the formation, placement, and manipulation of a bolus during the oral preparatory phase, the posterior transfer of the bolus from the oral cavity to the pharyngeal cavity during the oral transit phase, the direction of the bolus into the pharyngeal cavity, and retraction against the pharyngeal walls to assist in moving the bolus down the pharynx and into the upper esophageal sphincter during the pharyngeal phase [1–5]. Subsequently, abnormal tongue function can lead to impaired mastication, poor bolus formation, abnormal bolus positioning, oral residue, disorganized oral transit, premature spillage of the bolus into the pharynx, and pharyngeal residue, all of which constitute oral and/or pharyngeal dysphagia [2]. The condition of dysphagia carries with it far-reaching implications that affect not only the health of the individual but also his/her quality of life [5]. Consequently, it is important to identify those conditions (i.e., measures of tongue function) that contribute to dysphagia so they may be targeted for remediation.

Examination of oral motor function has long been a component of the clinical assessment of the swallowing mechanism. Traditionally, methods used to evaluate tongue function have been subjective in nature [4,6,7]. Subjective measures of tongue strength have typically relied on a speech-language pathologist's judgment as to the force a patient applies against resistance, usually applied manually by the examiner via a tongue blade [4,8]. Despite the recurrent use of subjective evaluations of tongue function, these methods do not offer reliable measurements of tongue force, making it difficult to accurately diagnose the degree of tongue dysfunction or to reliably compare treatment effects across time or between patients.

Recent development of devices designed to quantify tongue function offer the clinician an objective means of assessment. Unfortunately, although objective measurements are now possible, they have not achieved extensive application despite their potential clinical value. It is possible that the lack of published research related to normal and disordered tongue measurements, especially during swallowing, contributes to the limited use of objective devices for evaluation purposes. There are a few studies that guide clinicians in terms of normal isometric tongue function [9,10]. However, the majority of research in this area has focused on measures of tongue function and their relation to speech [6,11–21]. Comparatively few studies have investigated tongue function and swallowing [3,4,22–24].

Studies have been conducted to determine the normal variation of nonswallowing isometric tongue function as a result of age and gender in healthy individuals. Crow and Ship [9] examined the tongue strength and endurance of 99 persons with no history of dysphagia using a handheld tongue force measurement device, the Iowa Oral Performance Instrument (IOPI) [25]. The participants, aged from 19 to 96 years, were divided into four age groups based on 20-year age intervals and participated in three trials of strength and endurance tasks. Tongue strength was significantly higher in males than in females and decreased significantly with increasing age in males but not in females. Also, there were statistically significant differences in tongue strength upon comparison of their oldest group (ages 80–96) with younger groups. In a similar study by Youmans et al. [10], tongue strength measures were obtained with the IOPI for 77 healthy subjects. The variables of interest were maximum tongue strength, age, and gender. A significant negative correlation was found between tongue strength and age in the absence of any other significant results. That is, as age increased, tongue strength decreased, but there was no difference between genders as was found in some previous investigations [9,11,26].

The primary focus of studies investigating the relation of the tongue to swallowing has been on comparing measures of tongue function between subjects with dysphagia and control subjects during nonswallowing tasks. Robinovitch et al. [4] studied tongue function in the context of the oral phase of swallowing with an instrument called the Tongue Force Measurement System (TOMS). Two subjects with dysphagia and six subjects without dysphagia were compared across three trials, producing tongue force readings in the superior, left lateral, and right lateral directions. The results of the study yielded no significant findings; however, this may have been a consequence of the small number of subjects. The authors reported trends indicative of force differences between the impaired and unimpaired sides of subjects with unilateral weakness and dysphagia. In a somewhat larger study, Stierwalt and Clark [24] compared the tongue strength of 35 individuals with oral phase dysphagia to 35 age- and gender-matched control subjects with the IOPI. The authors found that the group with oral phase dysphagia had significantly reduced tongue strength compared to individuals with normal swallowing. They concluded that the difference can be quantified with tools like the IOPI. Lazarus et al. [22] investigated the differences between the tongue functions of 13 patients with oral and oropharyngeal cancer pre- and posttreatment and age- and gender-matched controls. They also investigated the relation between tongue function and oropharyngeal swallowing ability. The results relevant to our study included significantly higher tongue strength scores elicited by the control group compared with the experimental group on both occasions. Significant positive correlations were found in the control group between tongue strength and duration of contact of the tongue base to three areas of the pharyngeal wall during the pharyngeal phase of swallowing. In the experimental group, tongue strength was negatively correlated with number of swallows per bolus for some of the boluses pre- and posttreatment, and, unexpectedly, tongue strength was positively correlated with oral transit time on some swallows pre- and posttreatment. The authors attributed the unexpected results to the influence of xerostomia (drying of the oral mucosa) as a result of the cancer treatments, which may have overridden tongue function. The authors concluded that their study supports the assumption that tongue strength contributes to oropharyngeal swallowing.

As mentioned, the previously reviewed studies examined static measures of tongue function, namely, maximal measures of strength. To obtain a more functional index of the strength necessary for swallowing, pressures generated ***during*** the swallow must be explored. To date, only two relatively small studies have examined tongue pressure during swallowing and compared it with the maximal tongue pressures. Robbins et al. [23] studied maximal isometric pressures and swallowing pressures in two age groups. The first group consisted of 14 males (mean age = 75 yr) and the second group consisted of 10 males (mean age = 25 yr). The IOPI was used to obtain tongue pressures in three different locations on the tongue (tip, blade, and dorsum) during the typical IOPI strength task and a swallowing task. The swallowing task consisted of a ''dry'' swallow with the IOPI in place. Maximum isometric tongue pressures, or strength measures, were significantly greater for the group of younger subjects than for the older subjects at the tongue blade site; however, peak swallowing pressures were similar between the age groups.

Finally, Nicosia et al. [3] completed the only study that examined tongue pressure during bolus swallowing and compared it with maximal isometric lingual pressures. Two groups, one elderly (mean age = 81 yr) and one young (mean age = 51 yr) and each consisting of ten subjects (5 women, 5 men), participated in the study. Three air-filled bulbs were attached to each subject's hard palate and to a Kay Elemetrics Swallowing Workstation (Model 7100, Kay Elemetrics, Lincoln, NJ). The lingual pressure on the bulbs was used to determine maximal isometric tongue pressure, and lingual pressure during the swallowing of 3-ml semisolid, 3-ml thin liquid, and 10-ml thin liquid boluses. The authors found a significant decrease in maximal isometric pressure in their older group compared with their younger group in the absence of a significant difference in tongue pressure during swallowing. In addition, significantly more time was taken to reach peak pressure during swallowing in the older group than in the younger group with both thin liquid boluses but not with the semisolid bolus. The authors did not find significant gender differences for maximal lingual pressure, swallowing pressures, or time taken to reach peak pressure.

As shown, some groundwork research has been done to examine tongue function and swallowing. Given that the tongue's role in deglutition is extensive and that disordered lingual strength and coordination can be disruptive to safe, organized, and efficient swallowing, objective evaluation of lingual functioning during swallowing and nonswallowing tasks seems to be a reasonable addition to existing clinical swallowing evaluations. Continuation of previous research examining differences in tongue strength across age and gender should be conducted with large sample sizes and compared with prior investigations to determine if agreement exists and findings have been replicated. In addition, little research has been conducted that examines objective tongue force measurements during the deglutitory act, and further investigations to establish the normal ranges of tongue function during swallowing are warranted to add more meaning to tongue function measurements obtained during clinical evaluations. Once normal tongue ranges have been established, it might then be possible to distinguish normal from abnormal tongue function, in addition to identifying potential dysphagia related to tongue impairment, with a simple and cost-effective augmentation to existing evaluations. Hence, it would be useful to extend the findings of Robbins et al. [23] and Nicosia et al. [3] by measuring tongue strength during the swallowing of various bolus consistencies with a relatively large sample of subjects.

The purpose of our investigation, therefore, was to describe and examine tongue function variables in swallowing and isometric tasks across different ages, genders, and bolus types with a relatively large sample of subjects. Tongue function variables included maximum isometric tongue pressure, peak swallowing pressure, and percentage of maximum anterior tongue strength used during swallowing. Based on the sum of the findings of previous investigations, we hypothesized that (1) maximum isometric tongue pressures would be higher in younger subjects than in older subjects and higher in males than in females, (2) mean peak swallowing pressures would not be significantly different based on age or gender, and (3) percent of maximum tongue strength used during swallowing would be greater for older subjects than for younger subjects and for females than for males [3,9–11,23,26]. In addition, we hypothesized that because of their greater resistance to flow, (4) mean peak swallowing pressures would be significantly greater for thick compared with thin consistencies.

Methods

Participants

Ninety participants (age range = 20–79 yr) were divided into three age groups based on 20-yr intervals. Group 1 consisted of subjects aged 20–39 yr, Group 2 consisted of subjects aged 40–59 yr, and Group 3 consisted of subjects aged 60–79 yr. Each group contained 30 subjects (15 males and 15 females). To be included in the study the participants had to fit into one of the age groups, report being in good general health, and speak English. A questionnaire regarding each participant's medical background was completed. Exclusion criteria included reported history of swallowing, respiratory, or speech impairments; neurologic trauma, disease, or insult; head or neck surgery (with the exception of dental work, including wisdom teeth extraction); or cancer. In addition, all participants possessed oral anatomy and physiology judged to be within normal limits based on an oral mechanism examination.

Instrumentation

The IOPI was used to measure the variables related to tongue function. Maximum tongue strength and peak pressure during swallowing scores were obtained by measuring the amount of pressure exerted by the tongue on an air-filled bulb that was attached to a pressure transducer. A technical description of the IOPI is provided in the reference manual: "The instrument is basically a pressure transducer connected to a battery-operated amplifier, signal conditioning circuit, and digital voltmeter" [25, p. 23]. A peak holding circuit displays peak pressure on a digital readout in kilopascals (kPa). To ensure accuracy of measurement, calibration was checked once a week as recommended in the IOPI manual.

Procedures

Subjects were seated in an upright position and instructed on proper tongue bulb placement. Specifically, they were instructed to place the tongue bulb between the midline of their tongue and their hard palate just behind the upper alveolar ridge [25]. Once participants demonstrated appropriate tongue bulb placement, tongue function tasks were initiated.

First, data from three peak isometric tongue pressure trials were recorded for each subject. Subjects were instructed to place the tongue bulb in the predetermined location and press against the tongue bulb with as much effort as possible with encouragement provided by the examiner. Subjects were given a 1-min rest period between trials. Specific instructions were as follows:

Put the tongue bulb in your mouth in the same place that you did during practice. When I say "go," use your tongue to press the tongue bulb against the roof of your mouth as hard as you can, and hold it for three seconds. Press the tongue bulb only with your tongue; do not use your teeth.

The peak isometric tongue pressures from each of the three trials were taken directly from the IOPI's digital readout and recorded. This procedure, as outlined in the IOPI manual, has been tested and demonstrated strong intra- and interexaminer reliability [1,18].

Following data collection for maximum isometric tongue pressure, peak tongue pressures generated during swallowing liquid boluses of two different consistencies were recorded. There were three trials each for thin liquid and thickened liquid swallows. Thin liquid boluses consisted of 30 ml of tap water, and honey-thick liquid boluses consisted of 30 ml of apple juice mixed with Thick-It brand thickener. Peak pressures while swallowing thin and honey-thick liquids were obtained by directing the subject to take the bolus, hold it in the mouth, place the tongue bulb in the mouth at the predetermined location, and swallow the bolus. During the measurement, the examiner observed each participant's placement of the tongue bulb to ensure consistent placement and lack of movement during swallowing. Participants also confirmed consistency of placement following each trial. Specific instructions were as follows:

I am going to give you a small cup of liquid. When I say "go," put the liquid in your mouth, hold it, put the tongue bulb in your mouth in the same place that you did during practice, and swallow as normally as you can. Try not to push harder with your tongue than you would when you are swallowing normally.

The peak pressures from each of the three trials were taken directly from the IOPI's digital readout and recorded.

Dependent Measures

Three tongue function variables were measured or calculated. The maximum isometric tongue pressure (MIP) was defined as the highest of the three peak isometric tongue pressure scores. The MIP (measured in kPa) was a reflection of the subject's maximum tongue blade strength in a superior direction.

The mean peak tongue pressure used during swallowing (MSP) was defined as the average of the peak tongue pressures during swallowing across three trials for both consistencies. The MSP was a reflection of the average peak functioning of the subject's anterior tongue during the swallowing of boluses. An MSP (measured in kPa) was calculated for each subject for thin liquids by averaging the three trials for that consistency, and for honey-thick liquids by averaging those three trials.

Finally, the percentage of maximum tongue pressure used during swallowing (PMPS) was defined as the quotient of the MSP divided by the MIP, multiplied by 100. The PMPS was a reflection of the portion of the total anterior tongue strength that was used during swallowing. A PMPS was calculated for thin liquids and for honey-thick.

Data Analysis

Descriptive statistics were calculated for the three variables. An analysis of variance (ANOVA) was computed to determine if the MIP variable differed significantly based on age or gender. Repeated measures ANOVAs were calculated for the MSP and PMPS variables to determine if these dependent variables differed as a result of age, gender, or bolus type. Age and gender comprised the between-subjects factors, and bolus type was the within-subjects factor. Because of the multiple ANOVA procedures, a Bonferroni correction was performed for all omnibus tests, which set the alpha at 0.016. An alpha of 0.05 was used for all other statistical procedures. The Tukey HSD procedure was used for pairwise comparisons. Pearson product-moment correlations were calculated to determine to what extent dependent variables were related, and to determine if there were significant correlations between the bolus types for the MSP and PMPS variables. SPSS v11.0 (SPSS Inc., Chicago, IL) was used to complete all data analyses.

Reliability

A single investigator performed all initial testing and data measurements. To determine interjudge reliability, an additional examiner was trained to measure the dependent variables. Following reanalysis of 15% of the data, interjudge reliability was calculated. Paired t-tests were performed to examine whether the original analysis results differed significantly from the reanalyzed results for each dependent variable. The tests revealed no statistically significant differences for any of the comparisons thus establishing adequate reliability. Correlations between the raters and results for the paired t-tests for interjudge reliability are reported in Table 1. The finding of high reliability further supports earlier findings of high inter- and intrajudge reliability [1,18].

Results

Descriptive Statistics

Overall, the mean for the MIP variable was approximately 60 kPa with a standard deviation of 13.62 kPa. Individual MIP results ranged from 32 to 94 kPa. The mean for the MSP when the data were collapsed across bolus types was 30.48 kPa with a standard deviation of 13.41 kPa. Individual MSP results ranged from 5.67 to 67.33 kPa. The mean for

Table 1. Correlations and results of paired *t*-tests for interjudge reliability

Paired variables	Bolus type	Correlation	*p*-value	*t*	*p*-value
MIP	n/a	0.94	< 0.001	−0.30	0.77
MSP	Thin	0.87	< 0.001	−0.49	0.63
	Honey	0.92	< 0.001	1.43	0.17
	Collapsed	0.93	< 0.001	0.51	0.62
PMPS	Thin	0.82	< 0.001	1.43	0.17
	Honey	0.90	< 0.001	−0.35	0.74
	Collapsed	0.90	< 0.001	0.52	0.61

the PMPS variable collapsed across bolus types was 51.33% with a standard deviation of 19.99%. Individual PMPS results ranged from 7.38% to 100%. Descriptive statistics for the MIP, MSP, and PMPS variables by age and gender groups and bolus types are shown in Table 2.

Analyses of Variance

The results of the ANOVA for the MIP variable indicated that males demonstrated a significantly larger mean than females ($F_{1,84} = 9.55$; $p < 0.01$). The means are depicted graphically in Figure 1. In addition, the omnibus test for the age groups was significant ($F_{2,84} = 4.61$; $p = 0.01$), and pairwise comparisons indicated that Group 1 differed significantly from Group 3 ($p = 0.01$) in the absence of other significant differences (Fig. 2). The interaction between age and gender was not significant ($F_{2,84} = 2.50$; $p = 0.09$).

The results of the repeated measures ANOVA computed for the MSP variable indicated that there was a significant within-subjects difference between the bolus types for the MSP variable ($F_{1,84} = 6.55$; $p = 0.01$). That difference is displayed graphically in Figure 3. There were no other significant differences for the MSP variables in this sample based on age or gender or interactions between age, gender, and/or bolus type.

The results of the repeated-measures ANOVA computed for the PMPS variable indicated that there was a significant within-subjects difference between the bolus types (Fig. 4) for the PMPS variable ($F_{1,84} = 6.20$; $p = 0.015$). There were no other significant differences observed for the PMPS variables in this sample based on age or gender or interactions between age, gender, and/or bolus type.

Correlations

Significant positive correlations existed between MIP and MSP for honey ($r = 0.42$; $p < 0.0001$) and thin liquids ($r = 0.33$; $p < 0.01$). Significant positive correlations also existed between the MSP and the PMPS variables for all possible combinations of bolus types ($p < 0.0001$ for all combinations). In addition, the MSP variable was significantly positively correlated between bolus types ($r = 0.87$; $p < 0.0001$), as was the PMPS variable ($r = 0.86$; $p < 0.0001$). The correlation observed between the MIP and the PMPS variables for either bolus type was not significant in this sample of subjects.

Discussion

The purpose of our investigation was to examine and describe tongue function through objective means, including maximum isometric pressure, mean peak tongue pressure during swallowing, and percentage of maximum tongue pressure used during swallowing, and to determine if differences or interactions existed in a sample of subjects based on age, gender, and bolus type. Based upon our review of the extant literature, we hypothesized that males and younger subjects would exhibit higher maximum isometric pressure scores. In addition, we hypothesized that mean peak tongue pressures during swallowing would not differ based on age or gender, but percentage of maximum tongue strength used during swallowing would be greater for older subjects than younger subjects, and for females than for males.

The results for the maximum isometric tongue pressure variable (MIP) or the subject's maximum anterior tongue strength compared favorably with those from previous studies that reported mean MIP in normal or control subjects [10,22,24]. The mean MIP in the current study was 59.97 kPa, with a standard deviation of 13.62 kPa. These data compared favorably with the results from other studies that used the same instrumentation and involved normal or control subjects, including Lazarus et al. [22] (mean = 60.15 kPa; SD = 3.68 kPa), Stierwalt and Clark [24] (mean = 54.69 kPa; SD 13.4 kPa),

Table 2. Means and standard deviations for dependent variables

Age	Gender	MIP (kPa)	MSP (kPa) Honey	Thin	PMPS (%) Honey	Thin
20–39	Male	72.0 (13.4)	30.6 (12.4)	27.3 (14.9)	43.2 (17.5)	39.2 (22.2)
	Female	55.7 (12.5)	28.1 (14.8)	24.6 (12.6)	50.0 (20.2)	44.3 (18.5)
	Total	63.9 (15.2)	29.4 (13.5)	26.0 (13.6)	46.6 (18.9)	41.7 (20.3)
40–59	Male	63.9 (11.8)	37.2 (15.4)	36.0 (13.0)	57.5 (19.7)	56.3 (16.7)
	Female	59.1 (14.0)	30.9 (14.2)	29.9 (15.8)	54.1 (21.5)	51.9 (24.9)
	Total	61.5 (13.0)	34.0 (14.9)	33.0 (14.5)	55.8 (20.4)	54.1 (20.9)
60–79	Male	56.1 (11.6)	29.4 (14.9)	29.0 (12.6)	51.1 (20.7)	51.1 (17.3)
	Female	52.9 (10.7)	32.4 (12.3)	30.2 (13.3)	60.9 (21.3)	56.5 (23.0)
	Total	54.5 (11.1)	30.9 (13.5)	29.6 (12.7)	56.0 (21.2)	53.8 (20.2)
Data collapsed across age	Male	64.0 (13.7)	32.4 (14.4)	30.8 (13.7)	50.6 (19.8)	48.8 (19.9)
	Female	55.9 (12.5)	30.5 (13.6)	28.3 (13.9)	55.0 (21.0)	50.9 (22.4)
	Total	60.0 (13.6)	31.4 (13.9)	29.5 (13.8)	52.8 (20.4)	49.9 (21.1)

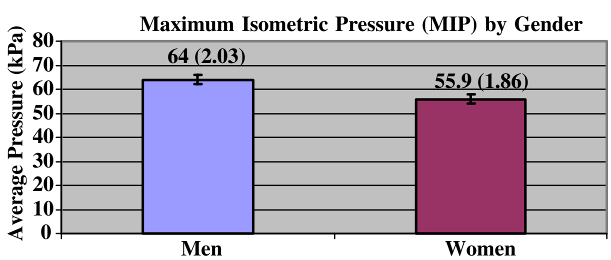

Fig. 1. Results revealed a statistically significant difference for maximum isometric tongue pressures across gender (men, $N = 45$; women, $N = 45$). Mean and standard error values are reported.

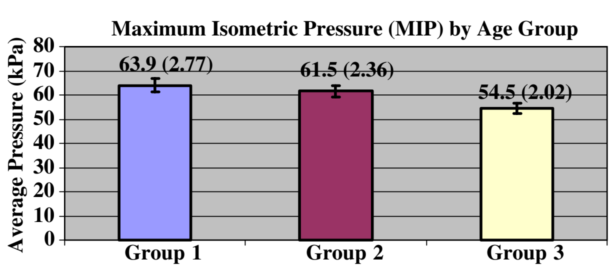

Fig. 2. Analysis of group performance on the maximum isometric pressure (MIP) variable indicated that the pressures obtained by the oldest group were significantly lower than the youngest group. No other group differences were revealed. Mean and standard error values are reported.

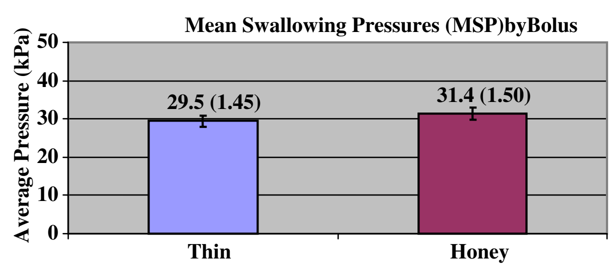

Fig. 3. Mean swallowing pressures (MSP) obtained for honey-thick liquid were significantly greater than for thin liquid. Age and gender differences were not noted for MSP. Mean and standard error values are reported.

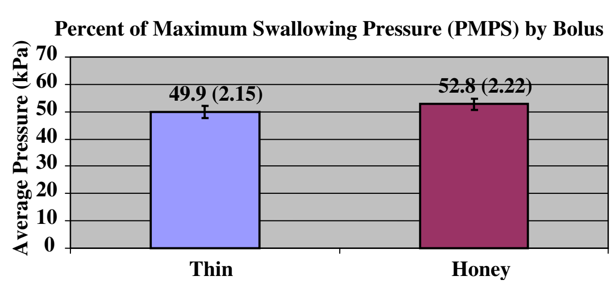

Fig. 4. The percentage of maximum pressure used during swallowing (PMPS) was significantly greater for honey-thickened liquid. No statistically significant age or gender differences were observed. Mean and standard error values are reported.

and Youmans et al. [10] (mean = 59.3 kPa; SD = 14 kPa).

As hypothesized, the results of our study supported claims that younger individuals generally have greater maximum tongue strength than older persons [3,9,10]. In addition, ANOVA results supported claims that men tend to have greater maximum tongue strength than women [9,11,26]. The results appear to mirror muscle strength in other parts of the body, i.e., in general, males have higher strength capacities than females, and muscle strength in both genders begins to deteriorate as part of the natural aging process [9,23]. Tongue strength decline with age could possibly be a result of an age-related reduction in muscle mass [23]. The results of our study demonstrated a gradual decline in tongue strength across age groups overall, with a significant difference between the youngest and oldest groups.

The MSP variable referred to the mean of the peak pressures elicited by the anterior tongue during swallowing across three trials. Nicosia et al. [3] and Robbins et al. [23] provided the only other studies that included variables comparable to our MSP variable. Nicosia and coworkers presented their means in graphic form, without exact numbers; therefore, exact results could not be compared. In their study, Robbins and colleagues included an investigation into the tongue pressures during dry swallowing of 10 younger (mean age = 25 yr) vs. 14 older (mean age = 75 yr) males using the IOPI with a modified tongue bulb that was reported to simulate a 3-ml semisolid bolus. An approximate mean of 21 kPa was found at the tongue tip position. The subjects in our study yielded a mean MSP of 29.57 kPa collapsed across bolus types, and mean MSPs of 31.44 kPa (honey) and 29.52 kPa (thin) for individual bolus consistencies. Because of the differences between the two investigations, including the differences in subject attributes, instrumentation, and materials swallowed, it was difficult to compare them. Although the results are not largely dissimilar, the means in our study were consistently higher than those found by Robbins et al. [23]. If, as the authors suggested, the apparatus did in fact simulate a 3-ml semisolid bolus and all other things were equal, then the differences in the means might be attributed to bolus volume and/or consistency differences between the two studies. The difference warrants further investigation on tongue pressures generated according to bolus volume and consistency.

The MSP variable was highly variable between subjects as evidenced by the relatively large range of pressures generated and large standard deviation. This indicated that the participants in this investigation elicited very different peak anterior tongue pressures from each other independent of bolus type. Some participants used a relatively small amount of anterior tongue pressure when swallowing (e.g., one subject had a MSP of 5.67 kPa); others used a relatively large amount of tongue pressure (e.g., one subject had a MSP of 67.33 kPa). Interestingly, inclusion criteria required normal swallowing ability; thus, our findings exemplified a large amount of variability in anterior tongue physiology related to normal swallowing in this sample of 90 subjects.

As hypothesized, the MSP variable did not differ significantly as a function of age or gender based on the results of the ANOVA. The similarity in MSP scores across age also supported previous results [3,23], as did the similarity in MSP scores across genders [3]. Thus, although maximum tongue strength was demonstrated to decline with age in this sample of subjects, the pressures generated for swallowing remained somewhat constant across age, and although males demonstrated a higher maximum tongue strength capacity, strength scores were similar between the genders during swallowing.

Analysis of swallowing pressures also indicated that the mean anterior tongue strength elicited by subjects during swallowing was significantly greater for honey-thick liquids than for thin liquids. It is important to note, however, that the consistency (thin, honey) variable was a within-subjects variable; thus, a large difference was not needed to obtain statistical significance. Figure 5 illustrates the mean difference between MSP scores for thin and honey consistencies within subjects. This finding suggested that an individual will consistently use slightly more pressure while swallowing a bolus of greater viscosity. The finding was intuitive because honey-thick liquids are more viscous or resistant to flow than thin liquids; therefore, the recruitment of additional tongue strength would be expected to propel the more viscous bolus posteriorly than something less resistant to flow. While the difference between the tongue strength used by subjects to propel the boluses was statistically significant, the force used to propel both bolus types was functionally similar. In addition, the mean anterior tongue pressure used during swallowing honey-thick liquids was highly correlated with MSPs for thin liquids, indicating that although honey-thick liquids were generally swallowed with more anterior tongue force than thin liquids, they were highly related. That is, an individual who used a relatively low amount of anterior tongue force during the consumption of honey-thick liquids would tend to use a relatively low amount during thin liquids, and an individual who used a relatively high amount of anterior tongue force while consuming honey thick liquids would also use a relatively high amount while consuming thin liquids. The significant correlations obtained further illustrate the within-subjects nature of the finding of increased pressure for a higher-viscosity bolus. The same concept of a within-subjects difference should be applied to the significant consistency finding for the percentage of maximum anterior tongue pressure elicited during swallowing (PMPS).

The results for the PMPS can be compared with those from only one previous study that measured the same variable [23]. In the study described above, Robbins et al. [23] calculated the PMPS in their groups. Their younger group yielded a mean PMPS of 40.8% and their older group elicited a mean

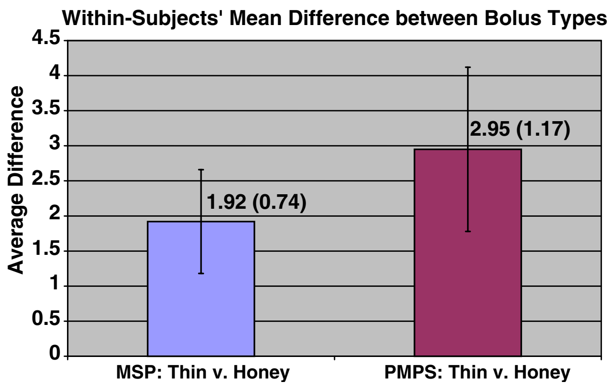

Fig. 5. The within-subjects' mean differences between bolus types (thin and honey) are reported for the MSP and PMPS variables. Mean and standard error values are reported.

of 45.9% at tongue tip position. The results of our study were consistently higher than those of Robbins et al. Again, the studies differed in many ways and may be difficult to compare, especially in light of our findings of within-subject MSP differences with consistency type. The consistency type described in the Robbins study was reported as a semisolid; thus, given the differences in our study between a thin liquid and a honey-thickened liquid, further differences would be expected with a semisolid. In addition, volume differed between the two studies. It is likely that volume, in addition to consistency, was a factor that contributed to changes in the tongue pressures needed to effectively swallow a bolus. The fact that volume was constant in each study points to the need for research that manipulates bolus volume to more carefully examine the potential relation between volume and tongue swallowing pressures. To date, only one small study ($n = 8$) included volume differences in the study of tongue pressure, and its preliminary findings demonstrated no volume effect on tongue pulsive force and bolus-clearing pressure [27]. Interestingly, the authors of that study did note an effect due to changes in viscosity that supported our findings (i.e., increased tongue force with increased viscosity) [27]. Finally, the difference between the pressures in the two studies might simply be the direct result of the higher MSP scores obtained in our study. Because PMPS was calculated by dividing MSP by MIP, higher MSP scores (numerator) would result in a higher PMPS if MIP scores (denominator) were held constant.

Our hypothesis that the percentage of maximum tongue strength used during swallowing (PMPS) would differ significantly as a function of age was not supported by the results, nor was our hypothesis that the PMPS variable would differ significantly between men and women. These hypotheses were based on the notion that if PMPS is calculated by dividing MSP by MIP, then a decreased MIP (denominator) with an unchanging MSP (numerator) would result in a higher PMPS. Thus, if MSP is constant across age and gender but MIP is decreased in older subjects and women, then their PMPSs would be higher than younger subjects and men. The reality of the matter was that although MSP did not change greatly, it did change. Maximum anterior tongue strength (MIP) was found to increase significantly with increasing mean peak anterior tongue pressure during swallowing (MSP), indicating the MSP is somewhat proportional to MIP. Thus, one who has an increased tongue strength capacity may tend to use more strength during swallowing. Therefore, although MIP was significantly different as a function of age and gender and MSP was not, both of the variables changed together thus reducing the change in the PMPS variable.

This lack of significant differences between the men and women and age groups for the PMPS variable does not support the issue previously identified by Robbins et al. [23] and Nicosia et al. [3], which was the notion of a reduced pressure reserve. The idea was that a lower maximum capacity for tongue strength in view of unchanging pressures required for swallowing results in a lower reserve. However, the aforementioned argument regarding the dependency of the PMPS on the MIP and MSP variables and the reduction of the differences in the PMPS due to nonsignificant changes in the MSP variable provide reasonable explanations for this lack of support. Ultimately, the findings of our study do not clearly support or refute the notion of a changing pressure reserve with age or gender. This issue should be investigated further to determine if, in fact, a person's pressure reserve for swallowing is age or gender dependent. If so, it could have significant clinical implications for these populations.

The ANOVA for the percentage of maximum anterior tongue pressure used during swallowing variable (PMPS) resulted in a significant difference between the bolus types on this measure. Subjects tended to use a higher PMPS swallowing honey-thick liquids than they did swallowing thin liquids. The explanation for this result follows the same line of reasoning as that for the MSP variable. Subjects used a higher percent of their maximum anterior tongue strength during the consumption of honey-thick liquids than they did swallowing thin liquids because honey-thick liquids were more viscous and, therefore, required more muscular effort. Again, the difference, while statistically significant, was not largely functionally different. Figure 5 also includes the mean difference between PMPS scores for thin and honey consistencies within subjects. Also similar to the MSP variable, the PMPS variable was highly correlated between bolus types, indicating that while subjects tended to use a larger PMPS for thicker materials, results for both boluses were relatively consistent.

The findings of our investigation yield significant implications. This is the first large study to quantify tongue strength during swallowing and compare it across consistencies. This preliminary database can be used as a point of comparison by researchers until a large, normative database is established. Several studies have reported on anterior tongue strength scores [9,10,22,24]; however, relatively little research literature has dealt with tongue pressures during swallowing [3,23].

Of clinical importance, the MSP variable was highly correlated between consistencies. This finding implies that the MSP variable was somewhat consistent within individuals across bolus consistencies. Therefore, if a clinician is assessing mean peak anterior tongue strength clinically, he/she would expect MSP scores that were not largely dissimilar for honey-thick liquids and thin liquids. A drastically different score between those consistencies might indicate a potential problem.

A potential limitation of our investigation was that 30-ml boluses were used in the measurement of the MSP variable. Some participants reported difficulty in manipulating that bolus volume. Although it was interesting to determine the anterior tongue force with which subjects propelled a large bolus posteriorly, it appeared that this bolus size may have been larger than was typically consumed by some subjects and may have resulted in a MSP that did not reflect their usual performance. Even if the subjects elicited multiple swallows on one bolus administration, only the peak force of the tongue tip during swallowing was recorded across trials. In future studies, it would be interesting to include smaller bolus volumes. Since these data were gathered, there has been additional research completed that investigated typical bolus volume consumption across groups. In an investigation that examined the effects of age, gender, and cup versus straw sipping on bolus volume, it was determined that physical characteristics, such as height, influenced typical bolus volumes for individuals [28]. One result of that study led to general guidelines of 25 ml for males and 20 ml for females for cup drinking. These findings again point to the need for further systematic investigation of volume along with swallowing pressures.

In conclusion, our study increased our knowledge of normal tongue physiology in general and during swallowing. In addition, it provided relevant, objective tongue function measures that might be useful in determining impairment during bedside dysphagia evaluations. Future investigation should include measurements of tongue function during swallowing in normal subjects and individuals with dysphagia during the consumption of the additional bolus types and volumes to both replicate and extend the findings of our study. As we increase the size of the database that indicates normal function, the data obtained can be used for comparison to data obtained from persons with dysphagia. Information regarding the differences in tongue function between normal and dysphagic swallows could be extremely useful in the detection and diagnosis of dysphagia related to tongue weakness, as well as our understanding of the tongue's role in swallowing.

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