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A Comparison of Lingual Pressure Generation Measures Using Two Devices in Community-Dwelling, Typically Aging Adults: An Important Clinical Implication

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ABSTRACT

Design: A multisite, prospective, and randomized within-subject design study.
Setting: Five university settings in varied geographical areas in the United States.
Purpose: The purpose of this study was to compare lingual pressure generation using the Tongueometer (TO) and the Iowa Oral Performance Instrument (IOPI) in typically aging, community-dwelling adults during three measurement tasks: maximum isometric pressure (MIP), regular effort saliva swallow (RESS) pressure, and effortful saliva swallow pressure (ESP).
Participants: Eighty-seven typically aging, community-dwelling adults (aged 55 years and over) with no self-reported history of swallowing or neurological disorders were recruited to complete this study.
Results: Strong positive associations were found between the lingual pressure generation measures from the TO and IOPI in all tasks in typically aging adults, with Pearson correlations ranging from r = .780 to .874, p < .001. Agreement between the devices (Lin's concordance correlation coefficient) ranged from moderate for the MIP (ρ_c = .78) and ESP (ρ_c = .61) tasks to weak agreement for the RESS task (ρ_c = .47). MIP, RESS pressure, and ESP were lower when measured by the TO compared with the IOPI, p < .001.
Conclusions: The TO measures lingual pressure generation similarly to the IOPI but pressures register lower when using the TO than the IOPI in typically aging persons. This supports the need for developing normative values specific to the TO device or development of a valid and reliable conversion formula from TO to IOPI normative values. At this time, the clinical use of reference values from the TO should not be generalized to IOPI normative values.

An effective and efficient swallow is dependent on adequate lingual function for preparation, propulsion, and containment of the bolus. Abnormal lingual strength has been associated with oropharyngeal dysphagia (swallowing difficulty; Clark et al., 2003; Stierwalt & Youmans, 2007), including bolus invasion into the airway (aspiration; Butler et al., 2011). Oropharyngeal dysphagia in adults results from varied neurological injuries or disease processes and contributes to serious medical and/or psychosocial consequences such as pneumonia (Almirall et al., 2013), malnutrition (Carrión et al., 2015), anxiety and social isolation (Ekberg et al., 2002), and increased caregiver burden (Rangira et al., 2022). Furthermore, reduced lingual strength has been associated with presbyphagia,

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when changes to the swallowing mechanism occur secondary to the typical aging process in otherwise healthy adults (Robbins et al., 1995, 2005).

Maximum isometric pressure (MIP), an index of lingual strength, is documented to decrease during typical aging (Adams et al., 2013; Arakawa et al., 2021; Clark & Solomon, 2012; Fei et al., 2013; Robbins et al., 2016; Stierwalt & Youmans, 2007; Vanderwegen et al., 2013), potentially related to changes in skeletal muscle mass, strength, and function (Cruz-Jentoft et al., 2010; de Sire et al., 2022). The effect of aging on lingual pressure generation during saliva and bolus swallowing remains debated, although reduced saliva swallowing pressure has been documented in typically aging persons (Robbins et al., 2016). Youmans and colleagues (Youmans & Stierwalt, 2006; Youmans et al., 2009) reported that lingual pressure generation during bolus swallowing also worsens with aging. Reductions in MIP generation have been associated with symptoms of dysphagia in older persons (Yoshida et al., 2006), while reduced saliva swallowing pressures increased the odds for signs of dysphagia and longer mealtime durations in older persons residing in long-term care (Namasivayam-MacDonald et al., 2017). Improvements in MIP and regular effort saliva swallow (RESS) pressure have been documented in typically aging persons following lingual resistance strength training (McKenna et al., 2017; Robbins et al., 2005; Van den Steen et al., 2018).

Patients with dysphagia from various etiologies widely demonstrate reduced MIP (Adams et al., 2013; Franciotti et al., 2022; Pitts et al., 2022) and may be at risk for reduced lingual pressure during swallowing. Lingual resistance strength training uses isometric lingual exercises to target lingual–palatal pressure generation and is a promising clinical approach during swallowing rehabilitation. Persons with dysphagia demonstrate increases in lingual strength following lingual resistance strength training exercise programs (McKenna et al., 2017; Robbins et al., 2007; Rogus-Pulia et al., 2016; Smaoui et al., 2020). The effect of gains in lingual strength on functional swallowing outcomes remains unclear, but some patient studies do suggest transference of improved tongue strength to swallowing pressure generation (McKenna et al., 2017; Oh, 2022; Robbins et al., 2007; Smaoui et al., 2020).

Given the association between abnormal lingual pressure generation and dysphagia (Franciotti et al., 2022; Konaka et al., 2010; Pitts et al., 2019; Robison et al., 2023; Sevitz et al., 2023), measurement of lingual pressure generation with lingual resistance strength training is becoming more common in standard clinical practice for dysphagia. The documented reduction of MIP in typically aging adults also supports the need for more investigation into the role of using lingual pressure generation in identifying persons at risk for dysphagia. Thus, understanding lingual manometry device differences in clinical practice is critical.

Lingual manometry devices, quantitatively measuring lingual pressure generation with dynamic visual displays, have emerged as a valid and reliable method for obtaining lingual pressure generation measurements (Adams et al., 2013, 2014, 2015). Lingual manometry devices determine lingual pressure generation by using tongue-to-hard palate contact to depress an air-filled bulb placed intra-orally. Pressure measurements are typically displayed digitally in kilopascals (kPa). Devices generally can measure anterior and posterior MIP, lateral isometric pressure, lingual pressure endurance (lingual press duration completed at $\geq$ 50% of max), and lingual pressure during swallowing of saliva and other bolus types and sizes (Mckenna et al., 2017; Smaoui et al., 2020).

The Iowa Oral Performance Instrument (IOPI; IOPI Medical) is the most commonly used device in lingual pressure generation research (Smaoui et al., 2020). It has been used to derive normative values for MIP in older healthy adults (> 60 years of age; Clark & Solomon, 2012; Robbins et al., 1995; Solomon & Munson, 2004; Stierwalt & Youmans, 2007; Youmans & Stierwalt, 2006; Youmans et al., 2009) and are reported on the IOPI website. Another lingual manometry device that is gaining clinical and research use is the Tongueometer (TO) Tongue Strength Biofeedback Device (CranioMandibular Rehab). The TO is a handheld device that interfaces with an application loaded on a tablet or smartphone. Similar to the IOPI, the TO measures lingual pressure generation for strength and endurance assessment and can record data for tracking progress. Both the IOPI and the TO provide visual feedback, allowing the patient to receive real-time feedback on meeting their exercise targets. However, the TO is considerably more cost-effective than the IOPI device. The addition of a low-cost lingual pressure measurement device option such as the TO will likely increase clinical access for lingual pressure measurement and improve feasibility to procure devices for use in lingual resistance strength training home programs.

Unlike the IOPI, limited normative data are available for lingual pressure generation measurements with the TO device. This is problematic because it is unclear if the two devices provide similar lingual pressure value readings for the same tasks. Clinicians may reasonably assume generalizability between pressure generation value readings on the IOPI and TO, given that both are lingual manometry devices with similar methods for data collection. However, preliminary data suggest a trend for lower pressure readings using the TO compared to the IOPI, but this evidence is based on small samples (Gibbons et al., 2023). Curtis et al. (2023) also reported lower pressure readings in the TO than the IOPI when a simultaneous, predetermined weight was applied to each device (with its respective bulb attached). Additional evidence from larger, randomized studies is needed to inform clinical practice when using and referencing lingual pressure generation measurements.

The purpose of this study was to determine relationships and differences between lingual pressure generation measurements collected with the IOPI and the TO in typically aging adults for three tasks: MIP, RESS pressure, and effortful saliva swallow pressure (ESP). Research questions and associated hypotheses were as follows:

- What is the relationship between lingual pressure generation measures (MIP, RESS, and ESP) collected with the IOPI and the TO in typically aging adults? We anticipated to find a positive association between the IOPI and TO, given the similar design and methodology used in data collected for both devices.
- What is the agreement between pressure measurements generated by the IOPI and the TO in typically aging adults for three separate tasks (MIP, RESS, and ESP)? We anticipated to find statistically significant lower TO measures across tasks compared to the IOPI device given documented preliminary findings comparing the two devices (Curtis et al., 2023; Gibbons et al., 2023) and our own pilot work for this study.
- Is there a difference between female and male lingual pressure generation measures (MIP, RESS, and ESP) collected with the IOPI and the TO in typically aging adults? We anticipated to find no statistically significant difference between typically aging females and males across devices, given that a number of previous studies (Arakawa et al., 2021; Clark & Solomon, 2012; Nicosia et al., 2000; Yeates et al., 2010) have documented no sex differences in lingual pressure measurement tasks.

Ultimately, this study contributes to the normative data set that is needed for the TO device.

Method

This research was conducted at five institutions across the United States. The study was approved by the institutional review board at Samford University with a reliance agreement with the remaining four recruiting sites: Case Western Reserve University, Emerson College, James Madison University, and Texas Christian University. Participants signed an informed consent form prior to initiating the study procedures.

Participants

Typically aging, community-dwelling participants were recruited to complete this study from five geographical communities based on recruiting institution locations across the United States. Initially, a telephone screening was conducted to obtain demographic information and health history and to complete the Eating Assessment Tool (EAT-10), which is a valid and reliable 10-question patient-reported swallow symptom screening tool (Belafsky et al., 2008). A swallow screen score of < 3, indicative of typical swallowing, on the EAT-10 was requisite for inclusion. Additionally, participants aged 55 years old and above with no history of neurological disease or seizures, absence of a pain disorder involving the jaw or mandible, and no history of oral surgery (other than routine dental surgery) were eligible for study inclusion. Participants meeting the telephone screening inclusion criteria were scheduled for in-person inclusion screening procedures. Potential participants completed a cognitive screen (Mini Mental State Examination; score ≥ 24; Rovner & Folstein, 1987) and a brief oral mechanism screen (standardized across sites) at the in-person screening session. Eligible persons were invited to participate in the study and completed the informed consent process to enroll in the study.

Data Collection

Participants completed two in-person sessions for this study. Session 1 included the informed consent, in-person screening, and lingual pressure generation measurements. The aim of the lingual pressure generation measurements in the first session was to gain familiarity with the following: (a) the devices, (b) bulb placement, and (c) the measurement tasks. Data collection for lingual pressure statistical analyses was completed in Session 2, which was completed from 24 hr up to 1 week after Session 1.

Lingual pressure generation measurements were completed using both the IOPI and the TO devices. Measurements (kPa) collected included the following: (a) MIP, (b) RESS pressure, and (c) ESP. In Session 1, lingual bulbs for the IOPI and TO, respectively, were placed on the anterior tongue per manufacturers' specifications for each device. While the device bulb was positioned on the anterior tongue and secured intra-orally with a labial seal, a small piece of tape was wrapped around the flexible tubing of the respective bulb to ensure that the superior edge of the tape contacted the upper and lower lip. This facilitated reliable bulb placement between trials and across the two sessions. The TO bulb was inflated with the manufacturer-provided syringe prior to completing lingual pressure generation trials. Participants were provided verbal training using a standardized script on how to complete each measurement task; participants completed practice trials until they had no further questions and were comfortable with the task. For the MIP task, participants were instructed to "push the bulb to the roof of the mouth as hard as you can for two seconds." For RESS, they were instructed to "swallow your saliva like you normally would." For ESP, they were instructed to "swallow as hard as you can" while encouraging them to "think about putting as much effort into your swallow as possible."

Participants completed five trials of one task (e.g., MIP) with a device before switching to the alternate device to complete five trials for the same task (Oh, 2022), for a total of 10 trials per task. The order for completing the measurement tasks and the device order within each task set were randomized for each participant. A 30-s rest break was completed between each trial while a 2- to 3-min rest break was completed between task sets. Prior to initiating the RESS pressure and the ESP tasks, participants were provided 10 cc of water by cup to moisten the mouth to comfortably complete the multiple swallow trials. Participants were instructed to avoid talking for the duration of the measurements, and they were not provided auditory or visual feedback during or after trials. Measurements using the IOPI were obtained using the "peak" pressure setting and using the "repetitive strength" setting in the TO application, both of which provide the maximum pressure applied during a single repetition.

Data Analysis

Statistical analyses were completed with Statistical Package for the Social Sciences (Version 27.0; IBM), and statistical significance was set at an α level of .05. For each participant, a mean for each task (i.e., MIP, RESS pressure, and ESP) was computed using all completed trials of each task (Clark et al., 2003), separately for each device from the second session measurements. Eight participants demonstrated a lingual pressure mean of zero during the RESS task with the TO. A paired t test revealed that lingual pressures in RESS with the TO when mean of 0 kPa pressures were included (M = 7.22 kPa, SD = 7.85) was not different than when they were excluded (M = 7.95 kPa, SD = 7.89), $t(164) = -0.60$, p = .55. Thus, all RESS data were included in the statistical analyses. Pearson's correlations (ρ) examined the relationship (e.g., linearity) between devices for each of the MIP, RESS pressure, and ESP tasks. Agreement between the IOPI and TO devices for the three unique tasks were determined using Lin's concordance correlation coefficient (ρ_c), which tests the agreement of a set of measures against the clinical gold standard using the formula $\rho_c = \rho \times C_b$, where C_b is defined as the bias correction factor for the fit of a 45° line (e.g., accuracy; Akoglu, 2018). Correlation coefficient (ρ_c) interpretation followed the recommendation of Altman and Altman (1999) to use Pearson's guidelines in explaining the strength of the agreement. Mixed analyses of variance (ANOVAs) determined the differences between the values obtained with the TO compared to the IOPI and the interaction of sex on these values. Examination of standard deviations for the three tasks across devices was also completed with paired t tests. Effect size statistics (Cohen's d) are included when pertinent. Alpha level was set to .05 with Bonferroni corrections as needed.

Results

Participants' Demographic Descriptive Data

Eighty-seven participants completed the study, including 61 females (M = 63.97 ± 6.76 years of age) and 26 males (M = 63.69 ± 6.27 years of age). Participant ages ranged from 55 to 82 years. Mini Mental State Examination scores ranged from 26 to 30 (M = 29.36 ± 0.96). EAT-10 scores ranged from 0 to 2 (M = 0.36 ± 0.63).

Relationship Between Lingual Pressure Generation Measures

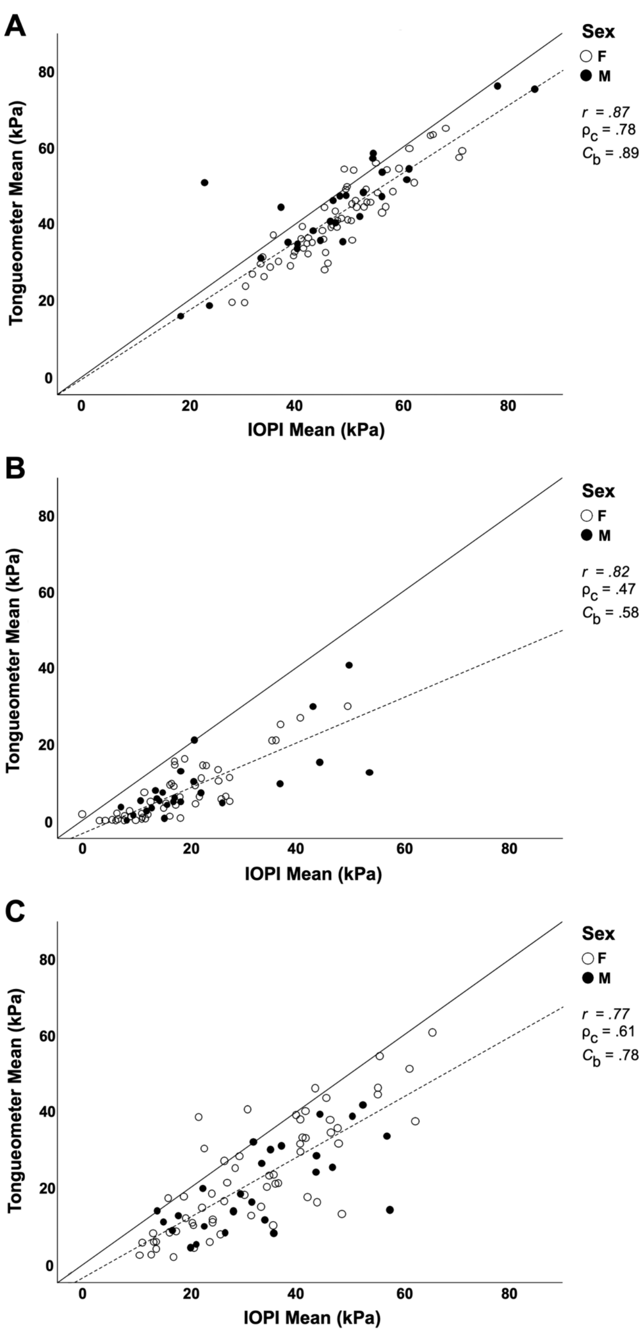
A Pearson's correlation determined the relationship between the IOPI and the TO lingual pressure generation measurements for the MIP, RESS, and ESP tasks, respectively. A strong positive relationship was found between the IOPI and TO for all tasks: $r(85) = .874$, $p < .001$ for MIP; $r(85) = .821$, $p < .001$ for RESS pressure; and $r(85) = .780$, $p < .001$ for ESP (see Figure 1).

Differences in Lingual Pressure Generation Measures

Means and standard deviations for each task are provided in Table 1. Lin's correlations revealed that MIP and ESP had moderate levels of agreement between the TO and IOPI (ρ_c = .78, 95% CI [0.70, 0.85], and ρ_c = .61, 95% CI [0.49, 0.70], respectively). RESS had weak agreement between the two devices (ρ_c = .47, 95% CI [0.37, 0.56]; see Figure 1).

Lingual pressure measurements were lower when measured with the TO than with the IOPI in all tasks. There was a mean decrease for the MIP task of −5.62

Figure 1. Association and agreement between IOPI and Tongueometer lingual pressure generation measures across (A) MIP, (B) RESS pressure, and (C) ESP tasks and delineated by sex. Dotted line represents the linear relationship between the two devices. Solid line represents a 45° line that would represent complete agreement between the devices. r = Pearson's correlation coefficient; ρ_c = Lin's concordance correlation coefficient; C_b = bias correction factor; F = female; M = male; IOPI = Iowa Oral Performance Instrument; MIP = maximum isometric pressure; RESS = regular effort saliva swallow; ESP = effortful saliva swallow pressure; kPa = kilopascals.



kPa (95% CI [−6.88, −4.36]) for the TO compared to the IOPI. The data were normally distributed, as assessed by Shapiro–Wilk's test of normality ($p > .05$), and there was homogeneity of variances (Levene's, $p > .05$). There was a statistically significant effect of device, $F(1, 85) = 54.0$, $p < .001$, partial $\eta^2 = .39$, as well as an interaction between device and sex, $F(1, 85) = 7.1$, $p = .009$, partial $\eta^2 = .08$. Post hoc testing indicated no differences in MIP between the sexes within each device but that there was a difference between the devices within each sex group meaning that device differences for MIP were present regardless of sex (see Table 2).

There was a statistically significant mean decrease for the RESS task of −10.76 kPa (95% CI [−12.11, −9.42]) for the TO compared to the IOPI. RESS data were not normally distributed for either device, as assessed by Shapiro–Wilk's test of normality ($p < .001$), but the groups were similarly skewed. There was homogeneity of variances (Levene's, $p > .05$). Parametric statistics were still used based on the large number of participants and ANOVAs are considered to be fairly robust to deviations from normality (Blanca et al., 2017; Schmider et al., 2010). There was a statistically significant effect of device, $F(1, 85) = 234.6$, $p < .001$, partial $\eta^2 = .73$. There was no interaction between device and sex, $F(1, 85) = 2.5$, $p = .12$, partial $\eta^2 = .03$. Examination of the effect of sex indicated no differences in RESS between the sexes within each device, but that there was a difference between the devices within each sex group meaning that devices differences for RESS were present regardless of sex (see Table 2).

There was also a statistically significant mean decrease for the ESP task of −10.45 kPa (95% CI [−12.40, −8.50]) for the TO compared to the IOPI. ESP data were normally distributed as assessed by Shapiro–Wilk's test of normality ($p < .05$), with the exception of TO ESP data from female participants ($p = .013$). There was homogeneity of variances (Levene's, $p > .05$). Parametric statistics were used. There was a statistically significant effect of device, $F(1, 85) = 112.6$, $p < .001$, partial $\eta^2 = .57$. There was no interaction between device and sex, $F(1, 85) = 3.2$, $p = .074$, partial $\eta^2 = .04$. Examination of the effect of sex indicated no differences in ESP between the sexes for either device, but that there was a difference between the devices within each sex group meaning that devices differences for ESP were present regardless of sex (see Table 2).

The standard deviations for lingual pressure generation measures in the MIP and RESS tasks were not statistically different between the devices ($p = .751$ and $p = .503$, respectively). Standard deviations of lingual pressure generation measures in the ESP task were higher when using the TO than the IOPI device, with a statistically

Table 1. Means of lingual pressure generation in kilopascals (kPa) with Iowa Oral Performance Instrument (IOPI) compared to Tongueometer (TO) in typically aging adults (n = 87).

Condition	IOPI		TO		$F(1, 85)$	p	Partial η^2
	M	*SD*	*M*	*SD*			
MIP	47.86	11.58	42.23	11.91	54.0	< .001[a]	.39
RESS	17.98	10.89	7.22	7.86	234.6	< .001[a]	.73
ESP	32.77	13.71	22.32	13.87	112.6	< .001[a]	.57

Note. Mean and standard deviations for the pairwise t tests are provided for the three measurement tasks. MIP = maximum isometric pressure; RESS = regular effort saliva swallow; ESP = effortful saliva swallow pressure.

[a]Statistically significant difference between devices.

significant mean difference of 1.44 *SD*, 95% CI [0.63, 2.25], $t(86) = 3.52$, $p = .001$, $d = 3.81$ (see Table 3).

Discussion

This research study aimed to determine the relationship, agreement, and potential differences between the IOPI and the TO in typically aging persons across lingual pressure generation tasks and between sexes. Measurements included MIP, RESS pressure, and ESP. Although there were strong positive relationships across MIP, RESS, and ESP between the IOPI and TO devices, the TO device had weak to moderate levels of agreement with the IOPI as it consistently had lower pressure values across all tasks. Furthermore, the TO had greater deviation from the mean for the ESP task compared to the IOPI. For each device, there was no difference in the pressure values between the sexes for any task in typically aging persons.

Our study examining typically aging adults contributes to emerging evidence that supports the TO as a valid method for determining different forms of lingual pressure generation measurements (Curtis et al., 2023; Gibbons et al., 2023) with significant potential benefits for clinical practice. Gibbons et al. (2023), examining lingual pressures in a pilot study of healthy persons (aged 20–92 years), determined that the TO is a valid clinical tool based on concordance correlation values (ρ_c ranging .62–.81) across tasks, including anterior and posterior MIP generation and RESS. When applying predetermined, matched weights to the devices in a laboratory, Curtis et al. (2023) also found substantial to excellent agreement (ρ_c = .986) between the TO and IOPI device pressure readings.

Relationship Between Lingual Pressure Generation Measures

The strong positive relationship demonstrated between the IOPI and TO devices across MIP, RESS, and ESP tasks was anticipated. Both lingual manometry devices use similar air-filled bulbs and connector tubing to collect digital pressure readings in kPa. There are slight differences, for example, the IOPI bulb is smooth and the TO bulb has small, raised surfaces on it, so these minor differences may contribute to the absence of a perfect positive association. For tongue elevation, Solomon and Clark (2020) found no difference in MIP measures between a smooth and textured bulb. However, the strong positive correlation in this study does indicate that IOPI and TO

Table 2. Means of lingual pressure generation (in kilopascals) based on sex with Iowa Oral Performance Instrument (IOPI) compared to Tongueometer (TO) in typically aging adults.

Condition	Device	Female (n = 61)		p^a	Male (n = 26)		p^a	p^b
		M	*SD*		*M*	*SD*		
MIP	IOPI	47.93	10.03	< .001	47.69	14.84	.006	.93
	TO	41.24	10.92		44.56	13.94		.24
RESS	IOPI	16.62	9.56	< .001	21.18	13.18	< .001	.07
	TO	6.55	7.16		8.79	9.26		.23
ESP	IOPI	32.45	14.10	< .001	33.52	12.97	< .001	.74
	TO	23.15	14.83		20.39	11.32		.40

Note. All p values are Bonferroni corrected. MIP = maximum isometric pressure; RESS = regular effort saliva swallow; ESP = effortful saliva swallow pressure.

[a]Paired comparison within each sex group. [b]Comparison between sex groups.

Table 3. Means of standard deviations (in kilopascals) for lingual pressure generation measurements with Iowa Oral Performance Instrument (IOPI) compared to Tongueometer (TO) in typically aging adults (N = 87).

Condition	IOPI		TO		t	p	Cohen's d
	M	SD	M	SD			
MIP *SD*	4.13	2.85	4.22	2.19	.318	.751	.034
RESS *SD*	4.16	3.13	3.86	3.40	−.672	.503	.072
ESP *SD*	5.15	3.15	6.59	3.76	3.52	.001[a]	.378

Note. Mean and range for the pairwise t tests are provided for the standard deviations of the three measurement tasks. MIP = maximum isometric pressure; RESS = regular effort saliva swallow; ESP = effortful saliva swallow pressure.

[a]Statistically significant difference in standard deviation between devices.

devices both measure changes in lingual pressure generation similarly. That is, both devices detect lingual movement for isometric contraction and swallowing in a similar manner. Although Gibbons et al. (2023) examined the concurrent validity of the TO compared to the IOPI in healthy adults, Pearson's correlations between the two devices were not reported, so no comparisons can be made.

Differences in Lingual Pressure Generation Measures

Lingual pressure generation measures were lower when measured using the TO device compared to measures completed using the IOPI device in the study's large sample of typically aging adults across all tasks. In fact, eight participants (9.2%) averaged a value of "0" across all five RESS trials using the TO, indicating that the device did not register the lingual pressure, while the IOPI pressure ranged from 3.2 to 10.0 kPa for these participants (see Figure 1B). Participants demonstrating a lingual pressure mean of zero during RESS with the TO were enrolled at four of the five sites, indicating that the reduced TO values do not appear to be related to a specific device or researcher. While agreement values ranged from weak (RESS pressure) to moderate (MIP and ESP) between the two devices, there were significant differences between the pressure means obtained with the TO and those obtained with the IOPI. Given that participants were not provided auditory or visual feedback during any task with either device, biofeedback cannot account for any of the differences found in these measures. Differences in design of the bulb, type and length of connector tubing, and device design may have contributed to differences in lingual pressure measures, although this was not specifically examined in this study. The IOPI bulb is slightly elongated, flatter, and smooth compared to the TO's bulb which is more rounded and bumpier surface. The IOPI utilizes a flexible connecting tube (approximately 67.5 cm in length) that couples the tongue bulb tubing to the IOPI device pressure port (IOPI Medical, LLC, 2019). The TO bulb tubing attaches directly to the handheld device once threaded through a circular lip guard, which aids in stabilizing the bulb from slippage (E2 Scientific Corp, 2020). Importantly, and as discussed above, the strong positive correlation between the two devices suggests that the IOPI and TO devices measure changes in lingual pressure generation similarly.

To date, a single pilot study has reported lingual pressure generation outcomes with the IOPI and TO devices for comparison in healthy persons with our study findings. Gibbons et al. (2023) reported that 76 healthy adults had a mean anterior MIP of 51.5 ± 12.6 kPa, while a subset composed of typically aging adults (≥ 60 years of age; N = 24) had a mean anterior MIP of 45.2 ± 12.8 kPa. The latter aligns with the means of the typically aging adults (42.2 ± 11.91 kPa) reported in this study. They also reported moderate to strong agreement between the IOPI and TO devices for anterior tongue MIP (ρ_c = .74), posterior tongue MIP (ρ_c = .81), and regular swallowing (ρ_c = .62; Gibbons et al., 2023). Both study and the current data report moderate agreement levels for anterior tongue MIP (ρ_c = .74 vs. ρ_c = .78, respectively); however, we are reporting weaker device agreement during regular swallowing tasks (ρ_c = .62 vs. ρ_c = .47, respectively).

For the IOPI device, the anterior MIP results for typically aging adults in the current study (M = 47.86 ± 11.5 kPa) are also similar to prior studies. In a systematic review and meta-analysis, Arakawa et al. (2021) reported an unweighted mean of 41.3 ± 11.3 kPa for anterior MIP using the IOPI in typically aging persons (≥ 60 years old), based on 17 studies (N = 986). Gibbons et al. (2023) reported anterior MIP measures with the IOPI for persons ≥ 60 years of age to be 55.6 ± 8.4 kPa, which is higher than our reported MIP with the IOPI (47.9 ± 11.6). This may be accounted for based on our method of averaging the five completed trials for the task in lieu of taking the highest value of three trials.

While a number of studies have examined lingual pressure generation during swallows using boluses of varying volumes and viscosities (Nicosia et al., 2000; Robbins et al., 2005; Youmans et al., 2006), only a small number of studies have investigated RESS. Of the previous studies examining RESS, most were conducted with units of measurement (Fei et al., 2013; Robbins et al., 2016) different than kPa used in this study, making comparisons challenging. Gibbons et al. (2023) reported higher RESS in typically aging adults than in our study, with 25.3 ± 10.9 kPa for the TO and 33.3 ± 10.5 kPa for the IOPI device. Our findings of 7.22 ± 7.86 kPa and 17.98 ± 10.89 kPa, respectively, may be partially explained once again by the variability in averaging our five trials for the task in each participant in lieu of taking the highest value, as previously described. Although there were eight instances of 0 kPa lingual pressure mean in RESS measures taken with the TO, a comparison of RESS lingual pressures with and without these cases indicated they did not significantly change the mean, $p = .55$. Comparatively, only one participant produced a 0 kPa pressure reading mean for RESS using the IOPI device, which likely had minimal to no impact on our RESS mean for the IOPI. Curtis et al. (2023) reported pressure readings of 0 kPa occurred in the TO when air pressure was applied simultaneously to both devices (without the bulbs attached) for pressures < 10 kPa measured on the IOPI. This device difference should be investigated further.

To our knowledge, this is the first study to examine lingual pressure generation during ESP using the TO device. Tongue-to-palate pressure is greater in effortful swallows than in noneffortful swallows (Bahia & Lowell, 2020; Fukuoka et al., 2013; Hind et al., 2001; Huckabee & Steele, 2006). The current study aligns with these findings. The ESP mean pressure was higher than the RESS with a mean difference of 15.1 kPa for the TO and a mean difference of 14.9 kPa for the IOPI. Although the impact of effortful swallow exercise inclusion in dysphagia management has had mixed findings (Bahia & Lowell, 2020), effortful swallows may be a beneficial exercise when aimed at improving oral phase function. In fact, promising clinical evidence in patients following stroke (Park et al., 2019) shows greater positive oral phase swallowing outcomes when the effortful swallow exercise is included. Our study provides reference values for ESP in typically aging for both the TO and IOPI devices.

Prior work indicates that anterior MIP and RESS measures have relatively low variability in aging, although RESS does show greater variability than MIP (Peladeau-Pigeon & Steele, 2017). In the present study, the standard deviations were similar between the devices for the MIP and RESS tasks; however, the variability in the ESP task was increased in the TO compared to the IOPI device. Data on variability in ESP measures in general are lacking, and further investigation is warranted. Our data provide a starting point for ESP variability investigation within and between the lingual manometry devices.

Differences Considerations Based on Sex

Our findings of no significant difference between typically aging males and females for MIP (Arakawa et al., 2021; Clark & Solomon, 2012; Nicosia et al., 2000), RESS pressure, and ESP (Yeates et al., 2010) are similar to previous work examining sex differences in lingual pressure generation. Simply stated, device differences in lingual pressures tasks were present for both sexes.

Role of the TO in Clinical Practice

The TO is an additional lingual manometry device option for clinicians assessing lingual strength and endurance and implementing lingual resistance strength training exercise programs. Its ability to interface with an application on a tablet or smartphone to provide biofeedback and track exercise data has potential benefits for improving access to care for patients seeking lower cost device options. Many patients have access to a tablet or smartphone capable of running applications; thus, only the handheld device and tongue bulb are requisite of the patient or clinical site to purchase. Importantly, this work highlights the need for additional studies across the age continuum to determine reference values specific to the TO device. Given this study focused on typically aging, community-dwelling persons without swallowing difficulty, future studies are also needed to examine lingual pressure measures using devices in patients with dysphagia and various etiologies.

The current study's confirmation of previous work that the TO yields lower values for maximum isometric and swallowing tasks in typically aging adults compared to the IOPI device and clinicians should be mindful of this difference and avoid applying reference values for the IOPI to clinical or research measures obtained with the TO. Applying IOPI reference values to lingual pressures measurements obtained with the TO may lead to over identification of lingual weakness. These findings support the need for clinicians to document which lingual pressure measuring device was utilized and ensure that future lingual pressure measures within a patient are measured with a similar device to enable a clinician's ability to determine the patient's progress. Additionally, given that a small number of typically aging participants in this study demonstrated means of 0 kPa, it is important to consider that the TO, in some instances, may not be sensitive enough for lower lingual pressure generating tasks, such as saliva swallows.

Limitations

This study focused on the examination of lingual pressure generation differences in typically aging, community-dwelling adults using two lingual manometry devices. Generalizations cannot be made to younger healthy adults or patients with dysphagia. While this study did not find sex differences for any of the study measurement tasks, we cannot rule out that the lower number of males participating in the study compared to females may have impacted the sex-based findings. A method for measuring from the IOPI and TO simultaneously could have strengthened the results of this study. Finally, this study examined anterior maximal isometric pressure but did not examine posterior maximal isometric pressures, although other studies have included this measure in their data collection. Future investigations should include persons with dysphagia in various clinical populations.

Conclusions

This study supports recent findings that the IOPI and TO lingual manometry devices similarly measure MIP, RESS pressure, and ESP tasks. However, all measures were significantly lower using the TO compared to the IOPI and measures of agreement ranged from weak to moderate. In clinical practice, the normative values associated with the IOPI device should not be generalized to the TO device values. Development of normative references for the TO and/or a valid and reliable formula to convert TO values to IOPI normative values is warranted.

Data Availability Statement

The data sets utilized during this study are available from the corresponding author upon reasonable request.

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