Dysphagia
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ORIGINAL ARTICLE

Comparison of Three Types of Tongue Pressure Measurement Devices

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Abstract A new tongue pressure device consisting of a simple and safe disposable probe and manometer has been developed. This report describes a study that examined the validity of the new device, comparing it to a widely used tongue pressure manometer, the Iowa Oral Performance Instrument (IOPI), and to the stable adhered three air-filled bulbs manometry system. The first test compared maximum tongue pressure measured with the new device and the IOPI (13 male, 9 female, 25.0 years). The second test compared maximum tongue pressure and swallowing tongue pressure measured with the new device and the three-bulb device (13 male, 9 female, 31.0 years). Significant correlations of maximum tongue pressure were found between the new device and the IOPI in the first test ($p < 0.05$). In the second test, significant correlations of maximum tongue pressure were found between the new device at the anterior and middle sensors ($p < 0.05$) but not at the posterior sensor of the three-bulb device. Significant correlations of swallowing tongue pressure between the new device and the three-bulb device were found ($p < 0.05$). These findings demonstrate that the measurements by the new simple tongue pressure device are closely equivalent to those of the IOPI and three-bulb devices, demonstrating that the new device is capable of accurately measuring the pressure generated by the whole tongue.

Keywords Tongue · Tongue pressure · Deglutition · Deglutition disorders

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Decompensation in swallowing function is common among the elderly [1]. Such changes are recognized as a degenerative consequence of aging and/or as a secondary effect of progressive diseases or acute events [2]. A major finding among studies on swallowing among different age groups is that older people swallow more slowly than their younger counterparts [3, 4]. Interestingly, an increase in the duration of oral transit of the bolus preceded the more automatic pharyngeal phase of swallowing. The tongue plays a key role in bolus transport from the oral cavity to the pharynx, and tongue movement may stimulate faucial and oropharyngeal receptors that trigger consequential swallowing events [5]. Therefore, measurement of tongue pressure may be important in the evaluation of swallowing function and the determination of subsequent treatment.

Several methods have been used to measure tongue strength as pressure within the oral cavity, including strain-gauge manometry [6, 7], force-sensitive resistors [8, 9], and bulb pressure sensors [10, 11]. Of these methods, only bulb pressure sensors have been used to evaluate changes in tongue pressure that occur as a function of healthy aging [12, 13]. These studies suggest that tongue pressure generated during swallowing is less than maximum isometric pressure for all ages, demonstrating that swallowing is a submaximal tongue strength task. This "functional reserve" is defined as the difference between maximum tongue strength and the tongue strength needed for the generation of swallowing. It is the loss of this "functional

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reserve" that may precipitate dysphagia as the individual ages [12].

Hayashi et al. [13] designed an inexpensive, safe, sterilizable disposable probe assembled from a latex rubber balloon and a tuberculin test syringe cylinder. This method is quite convenient and involves minimal patient/subject burden and is hygienically appropriate. However, during tongue pressure measurements, the subject must hold a plastic pipe lightly between the upper and lower central incisors to stabilize the pressurized parts in the oral cavity (Fig. 1). The force of the front part of the tongue, especially tongue tip, made by extrinsic and intrinsic muscles of the tongue against hard palate could be measured by this probe. As a result, tongue pressure is measured with the mouth slightly open, which may affect the accuracy of the measurement. Data on maximum tongue pressure in 853 subjects (408 male, 445 female, 20-79 years old) as measured with this new device has been reported [14].

To evaluate the application of this device in clinical practice, this study compared measurements obtained with the new device with measurements obtained using the Iowa Oral Performance Instrument (IOPI) and the tongue pressure measurement device of the internationally recognized KayPENTAX Digital Swallowing Workstation™. The main purpose of this study was to prove that measurements using our new device are the same quality as those from the IOPI and Kay devices. A tool to express the level of oral function easily and objectively is needed in our country, but the IOPI and Kay devices are currently not permitted to be used in our country because of legal issues.

Methods

Using the new device, tongue pressure was measured by a disposable probe and a simple pressure recording manometer [13] (Fig. 1). A recording device with a manual pressurization system as described by Yoshida et al. [15] was modified into an autopressurization system. By pushing the pressurization button, the probe was inflated with air at an initial pressure of 19.6 kPa, setting the balloon's diameter at approximately 18 mm with a volume of 3.7 ml. This pressure was taken as zero calibration. During all measurements, the subject held the cylinder so that the balloon could be placed between the tongue and the anterior section of the palate. Subjects were asked to place the central incisors against the stainless steel pipe and to close the lips.

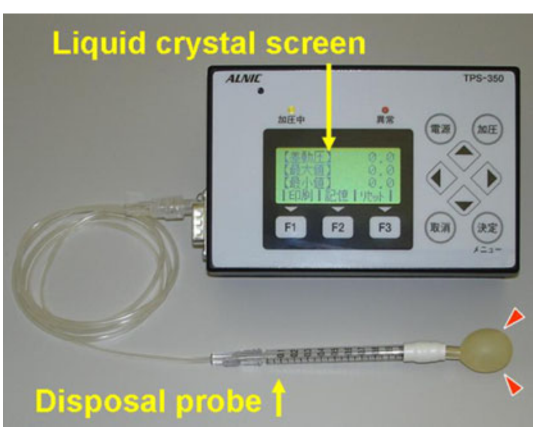

Fig. 1 Tongue pressure measurement device. This device consists of a disposable oral probe and a recording device (Prototype device PS-03, ALNIC)

The two segments of the study were labeled "New device—IOPI comparison" and "New device—Kay comparison."

New Device—IOPI Comparison

The sample was composed of 22 young healthy volunteers (13 male and 9 female; age range = 21–29 years, mean age = 25.0). Measurements of maximum tongue pressure were performed using the new device and the IOPI bulb. The measurement method was based on the method described by Hayashi et al. [13]. Maximum pressure values were obtained by instructing subjects to press the tongue to the palate as firmly as possible for 7 s.

The IOPI device (Northwest Co., LLC, Carnation, WA) utilizes an air-filled bulb held between the tongue and the hard palate. The pressure bulb was placed between the tongue and the anterior part of the palate, a location almost the same as used with the balloon of the new device. It was little bit difficult to measure the pressure at the middle and posterior parts of tongue against the hard palate with the new device because of the presence of the plastic pipe.

To compare the IOPI and the new device, we wanted to use the same procedure for both measurements. That meant that the pressure at anterior part of tongue needed to be measured to determine the quality of our new device. In our pilot study, we tried to put IOPI's balloon on the median and posterior parts of the tongue face, but we could not adjust the balloon's position because it was very easy for the balloon to move on the tongue's surface before measurement.

In comparing the Kay device and the new device, the images obtained were completely different. We measured maximum tongue pressure and swallowing pressure. Because three bulbs of the Kay device are on the hard palate, it is easy to measure pressure on the anterior, median, and posterior parts of the tongue and the Kay bulb's figure is completely different from our probe.

We put sentences about the "benefits and negatives" of the devices in the first paragraph of the Discussion. "Tongue pressure" measured by our new device is not "whole tongue pressure" we believe. However, we might be able to hypothesize that the Kay device's three pressures are almost the same as whole pressure, but the pressures measured by the IOPI and the new device are not whole pressure through our results.

New Device—Kay Comparison

Twenty-two healthy volunteers (13 male and 9 female; age range = 21–39 years, mean age = 31.0) comprised the sample. Measurements were performed using the new device and the Kay manometer. The measurement method was based on that of Hayashi et al. [13]. Maximum pressure values were obtained by instructing subjects to press the tongue to the palate as firmly as possible for 7 s.

The Kay manometer is part of the KayPENTAX Digital Swallowing Workstation™ (Model 7100) and Kay Swallowing Signals Lab (Model 7120, KayPENTAX, Lincoln Park, NJ). Tongue pressure against the hard palate was measured with a linear strip of three air-filled bulbs (13 mm diameter, 5 mm height, and 8 mm spacing) connected to a transducer (KayPENTAX). The bulbs were placed on a silica strip and attached to the bony palate with Stomahesive (ConvaTec, Princeton, NJ) on the midline between the anterior edge of the alveolar ridge and the approximate junction of the hard and soft palates (Fig. 2). Prior to placement on the palate, the pressure bulbs were calibrated using the internal calibration capabilities of the KayPENTAX system. Pressure signals were processed at a 500 Hz sampling frequency, with a bandwidth of 200 Hz.

In addition, swallowing tongue pressure was measured as subjects swallowed 5 ml of water. To measure swallowing tongue pressure with the new device, each subject was asked to (1) hold 5 ml of water in the floor of the mouth, (2) put the balloon into the mouth and set the position of balloon, and (3) maintain the probe position with the lips and incisors closed while swallowing the water. To measure swallowing tongue pressure with the Kay device, the manometer was set in the mouth and the subject was asked to swallow 5 ml of water from a paper cup using the command swallow style. The values from the Kay device were converted from mmHg to kPa for this study.

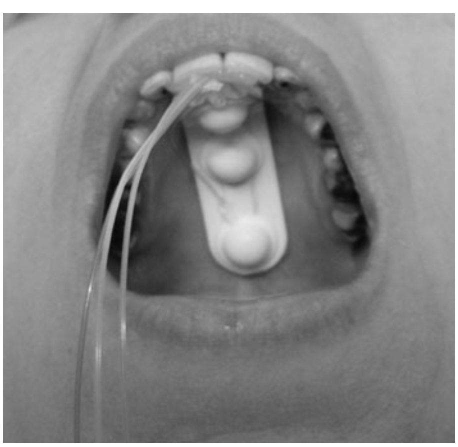

Fig. 2 Three air-filled bulbs were mounted on a silica strip and attached with Stomahesive (ConvaTec, Princeton, NJ) on the midline of the palate between the alveolar ridge and the approximate junction of the hard and soft palate

Statistical Analysis

After calculating the mean value of three measurements for both maximum tongue pressure (mean ± 1 SD) and swallowing tongue pressure (mean ± 1 SD), the values were compared using Spearman rank correlations.

Results

New Device—IOPI Comparison

The mean value for maximum tongue pressure using the new device was 49.2 ± 9.5 kPa and that with the IOPI was 63.9 ± 13.1 kPa. Significant correlations were found between measurements made by the new device and the IOPI (Spearman's $r_s = 0.686$, $p < 0.05$) (Fig. 3). The value measured by the new device equaled the value measured by IOPI × 0.5 + 17.1.

New Device—Kay Comparison

The mean value for maximum tongue pressure as measured by the new device was 32.7 ± 5.3 kPa and the mean values measured by the KAY device were 41.8 ± 13.6 kPa (anterior sensor), 31.8 ± 14.5 kPa (middle sensor), and 29.8 ± 14.9 kPa (posterior sensor). The overall average

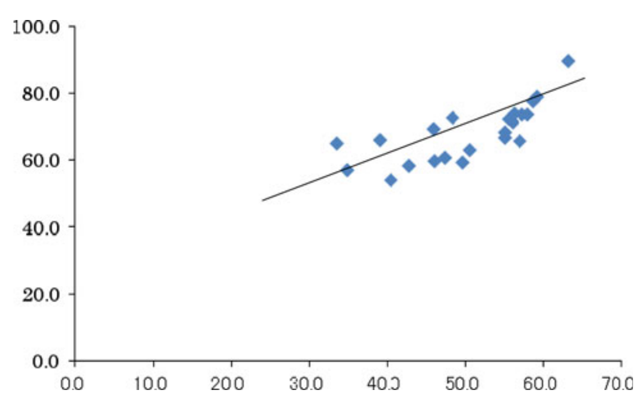

Fig. 3 Comparison of maximum tongue pressure values (kPa) obtained using the new device (*X* axis) and IOPI (*Y* axis)

was 34.8 ± 10.7 kPa. Significant correlations were found between the new device's measurement and the Kay device's anterior and middle sensor measurements (anterior: $r_s = 0.61$, $p < 0.05$; middle: $r_s = 0.46$, $p < 0.05$), but not for the posterior bulb's measurement (Fig. 4). The value measured by the new device equaled the value measured by Kay at the anterior sensor × 0.22 + 23.7. The value measured by the new device equaled the value measured by Kay at middle sensor × 0.18 + 26.9.

The mean value for swallowing tongue pressure as measured by the new device was 13.1 ± 8.8 kPa and the mean values measured by the KAY device were 6.5 ± 8.5 kPa (anterior sensor), 6.9 ± 7.7 kPa (middle sensor), and 12.0 ± 8.1 kPa (posterior sensor). The overall average was 8.5 ± 7.1 kPa. Significant correlations were found between the new device and the Kay device at all measurement sites (anterior: $r_s = 0.43$, $p < 0.05$; middle: $r_s = 0.81$, $p < 0.05$; posterior: $r_s = 0.58$, $p < 0.05$) (Fig. 5). The value measured by the new device equaled the value measured by Kay at the anterior sensor × 0.62 + 9.05. The value measured by the new device equaled the value measured by Kay at middle sensor × 0.87 + 7.1. The value measured by our device equaled the value measured by Kay × 0.65 + 5.3.

Discussion

Although tongue movement, strength, and coordination are normally a part of the clinical evaluation of swallowing [16, 17], these evaluations are often quite subjective. Objective assessments are necessary if treatment goals include changing tongue performance during swallowing. To meet this need, flash diaphragm pressure inverters [18] have been used to implant small pressure sensors into the oral cavity. This requires special devices customized for each subject, however, and utilizing these devices is limited to dentists or some auxiliary personnel. Thus, the use of a flash diaphragm pressure inverter is not very useful for routine diagnosis or treatment. Because our new device was designed for basic clinical application, its advantages include ease of operation with no extensive training necessary so that most auxiliary staff members can manage the procedure. IOPI is handy and almost everyone can use it; however, we cannot adjust its position because the air-filled bulb slides too easily on the tongue surface and the connected tube is not scaled. On the other hand, the Kay device has bulbs that can be adjusted in the mouth and measure tongue pressure almost naturally; however, the KayPENTAX workstation is not easy to handle and an operator is needed to put the sensor sheets in the patient's mouth. The new device is handy and everyone can use it; however, the posterior part of tongue is difficult to measure because of the presence of the plastic pipe. This study found that this device can work almost as well as the IOPI and Kay devices.

Tongue strength assessment involves placing the teeth on the pressure-sensing instrument, causing an interincisor separation of approximately 2 mm. Solomon et al. [19] found that although tongue strength decreases as lip separation increases, there is no significant difference in tongue strength as long as the jaw position remains the same

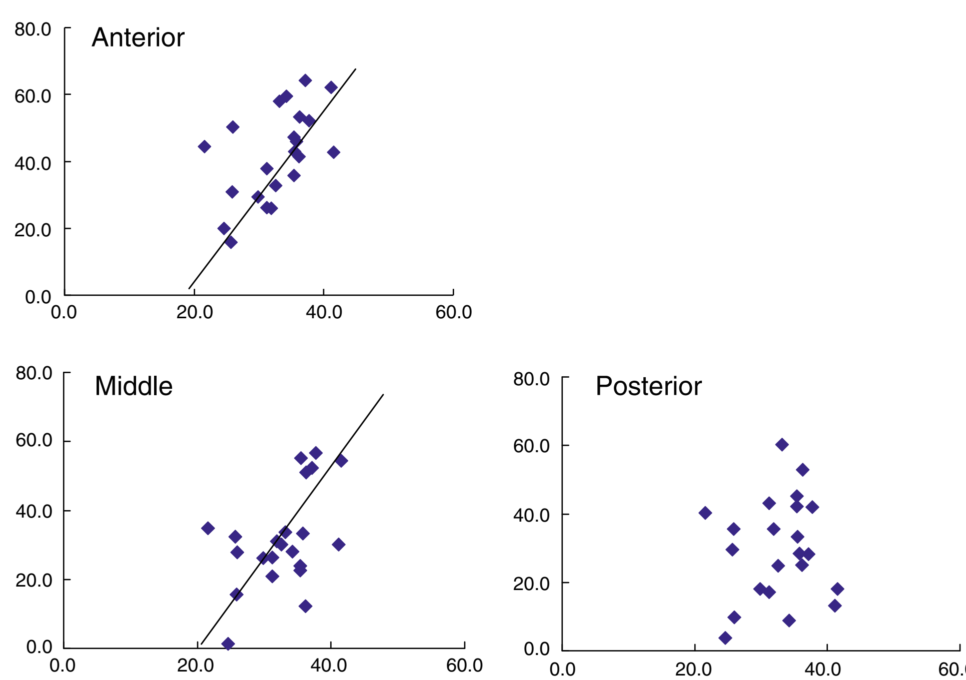

Fig. 4 Comparison of maximum tongue pressure values (kPa) obtained by the new device (*X* axis) and the KAY device (*Y* axis)

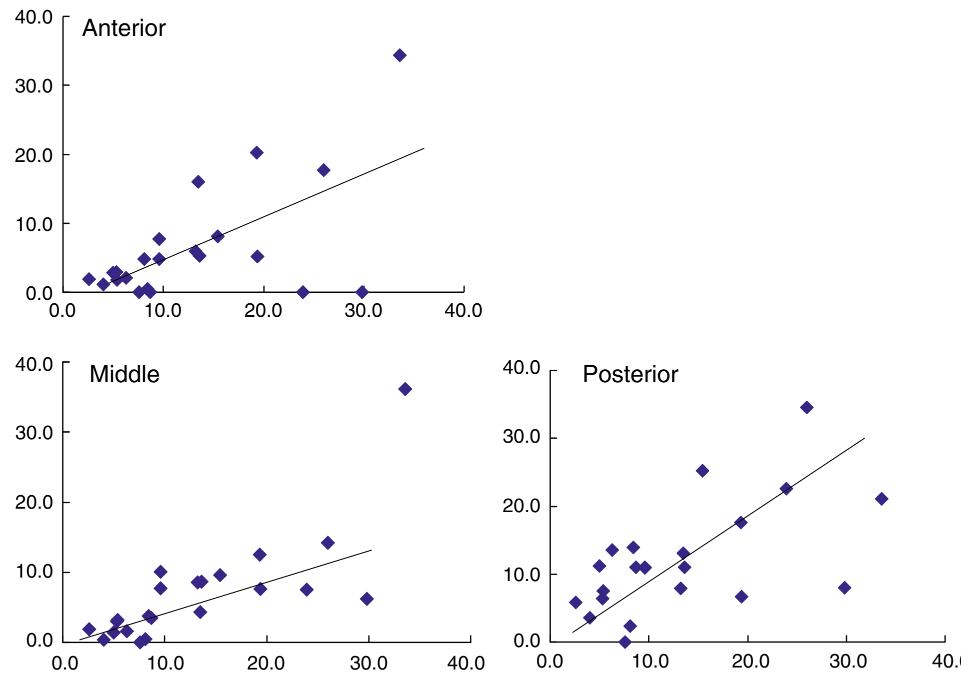

Fig. 5 Comparison of swallowing tongue pressure values (kPa) obtained by the new device (*X* axis) and the KAY device (*Y* axis)

(< 5 mm). Our study found that the maximum tongue strength measured by the IOPI (there was interincisor separation but the space between the incisors with the IOPI was narrower than with the new device) and by the KAY device was slightly higher than that measured by the new manometer.

Tongue pressures measured by the new device correlated well with the values obtained by the Kay device. Only pressure at the anterior part of the hard palate can be measured by the new device. However, the positive correlations between our device and the Kay device suggest that the new device effectively measures pressures at anterior and median locations in the oral cavity. Swallowing pressure as measured by the new manometer significantly correlates with swallowing pressures registered by the Kay device at the anterior, median, and posterior locations. Therefore, the new manometer can be used to generate useful, meaningful, and valid tongue pressure values. With these results we may hypothesize that the data obtained by the new device is very similar to the data obtained by the Kay device at anterior and median positions.

Tongue movement can be separated into two types [20]: (1) actions of the anterior part of the tongue and tongue body which function to hold the bolus, and (2) tongue movement that facilitates smooth transit of the bolus. At the same time, the tongue base exerts a driving force to push the bolus into the pharynx and plays an important role in strengthening laryngeal closure by pressing the epiglottis [20–22]. An earlier study [20] analyzed tongue movement during swallowing and discussed the anchoring of the tongue tip against the palate and the periphery of the tongue surface to establish a seal against either the lateral alveolar ridge or the pharyngeal walls, as well as the relationship between the anchoring of the tongue tip and the tongue-base movement. Few other reports have examined this relationship [23]. Most reports document that tongue-tip anchoring plays an important role in swallowing. Exercises to strengthen the anterior part of the tongue might be useful, in particular, for dysphagia in the oral stage and/or the oral preparation stage.

It may also be clinically relevant to measure the tongue strength as part of the evaluation for dysphagia [24, 25]. It is recognized that measurements of anterior tongue strength during swallowing is used more with the aging population and that tongue strength at the anterior and medial sites seems to be most responsive to tongue-strengthening exercises [26]. However, this practice is still uncommon in routine clinical care. This study seems to validate the new device in comparison with others that have undergone extensive research worldwide.

The new balloon-type tongue pressure manometer [9, 13, 15] described in this report has been developed to facilitate tongue strength measurement as part of the routine evaluation of dysphagia. In addition, standard values for tongue strength have been obtained using this device in multiple cohorts differentiated by age [25]. Youmans et al. [27] have also clarified maximum tongue pressure using another balloon-type manometer associated with the IOPI. The data in this study suggest that tongue pressure measurements obtained by the new device are comparable to pressures obtained by the IOPI and Kay devices. The findings in this report suggest that the new device may be useful for the rehabilitation of dysphagic patients.

Conclusion

This study has demonstrated that a new, simple tongue pressure manometer developed by the authors is capable of precisely measuring pressure created by the whole tongue. The new device has proven sufficiently reliable and accurate for tongue pressure screening and observation of changes over time.

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