

Effect of Supraglottic and Super-supraglottic swallows on Tongue Pressure Production against Hard Palate

Shigehiro Fujiwara · Takahiro Ono · Yoshitomo Minagi ·
Masako Fujii-Kurachi · Kazuhiro Hori · Yoshinobu Maeda ·
Sara Boroumand · Ina Nitschke · Vith Ursula · Jörg Bohlender

Received: 21 December 2013 / Accepted: 23 June 2014 / Published online: 24 July 2014
© Springer Science+Business Media New York 2014

Abstract The objectives of this study were to evaluate the state of tongue pressure production during supraglottic swallow (SS) and super-supraglottic swallow (SSS) performed by healthy adults, and to investigate the effects of these swallowing maneuvers on the oral stage of swallowing. The participants were 19 healthy individuals. Tongue pressure against the hard palate during swallowing was measured using a tongue pressure sensor sheet system with five pressure-sensitive points. The tasks comprised swallowing 5 mL of water by normal wet swallow, SS, and SSS, and the parameters for analysis were the duration, the maximal magnitude, and the integrated value of tongue pressure during swallowing. The duration of tongue pressure was significantly longer at the anterior-median part of the hard palate during both SS and SSS than with normal

wet swallow. The maximal magnitude increased significantly only at the posterior part of the hard palate during SS, but at all points during SSS. The integrated value increased significantly only at the posterior-median part of the hard palate during SS, but at all points except the mid-median part of the hard palate during SSS. The maximal magnitude and integrated value were also significantly higher at the anterior-median and posterior circumferential parts during SSS than during SS. These results show that these two swallowing maneuvers, which are known primarily as techniques to protect the airway, also function to strengthen the tongue pressure produced by the contact between the tongue and the hard palate during swallowing and this effect is more pronounced during SSS.

Keywords Supraglottic swallow · Super-supraglottic swallow · Swallowing · Tongue · Pressure · Dysphagia · Deglutition · Deglutition disorders

S. Fujiwara · T. Ono (✉) · Y. Minagi · Y. Maeda
Department of Prosthodontics, Gerodontology and Oral
Rehabilitation, Osaka University Graduate School of Dentistry,
1-8 Yamada-oka, Suita, Osaka 565-0871, Japan
e-mail: ono@dent.osaka-u.ac.jp

M. Fujii-Kurachi
Department of Rehabilitation, Niigata University of
Rehabilitation, Murakami, Japan

K. Hori
Division of Dysphagia Rehabilitation, Niigata University
Graduate School of Medical and Dental Sciences, Niigata, Japan

S. Boroumand · I. Nitschke
Clinic of Masticatory Disorders, Removable Prosthodontics,
Geriatric and Special Care Dentistry, Center of Dental Medicine,
University of Zurich, Zurich, Switzerland

V. Ursula · J. Bohlender
Department of Phoniatics and Logopedics, Clinic for
Otorhinolaryngology, Head and Neck Surgery, University
Hospital Zurich, Zurich, Switzerland

Introduction

Supraglottic swallow (SS) and super-supraglottic swallow (SSS) are swallowing maneuvers that prevent the aspiration of food or liquid by closing the airway before swallowing [1]. These methods involve holding one's breath to close the airway prior to swallowing, followed by coughing voluntarily immediately after swallowing to clear any residual food or liquid from the airway entrance. The difference between these two swallowing techniques lies in the degree of effort involved during breath-holding prior to swallowing: in SS, the breath is held without effort, whereas in SSS, a greater effort is exerted during breath-holding. The mechanism of action of these two maneuvers has previously been studied using videoendoscopy (VE) [2,

3], videofluorography (VF), and manometric measurement [4–6], and a previous study [7] has reported that SS and SSS affect not only airway closure but also hyoid bone and laryngeal movement. However, most reports have focused on the status of airway closure and kinetic changes during the pharyngeal stage of swallowing; there have been few studies that observed tongue movement in detail during the oral stage of swallowing [8].

The mechanism of bolus transfer is reported to depend on the oropharyngeal propulsion pump and the hypopharyngeal suction pump, which act together in a synergistic and elaborate manner [9]. According to Shaker et al. [10], intraoral pressure is generated from the anterior to the posterior during swallowing, and the tongue pressure generated by contact between the tongue and the palate provides the largest force that propels the bolus from the mouth to the pharynx. An evaluation of tongue pressure against the hard palate with SS and SSS during the oral stage of swallowing may therefore provide valuable information for elucidating the mechanism of action of the swallowing movements involved in these maneuvers.

On the grounds that the measurement of tongue pressure may be a useful method of evaluating tongue movement, tongue pressure measuring devices have been developed and used in a number of studies on tongue pressure [11–18]. The sensor sheet system for measuring tongue pressure, developed by Horii et al. [19], uses an extremely thin sensor sheet (thickness ~ 0.1 mm) that can be applied directly to the palatal mucosa, enabling the measurement of tongue pressure that better reflects physiological conditions. Tamine et al. [20] used this sensor sheet system to measure tongue pressure and reported the normal pattern of tongue pressure production during swallowing in healthy young and elderly volunteers. It has also been used to analyze tongue movements in patients with dysphagia, with Hirota et al. [21] and Konaka et al. [22] reporting on the relationship between dysphagia and tongue pressure production in stroke patients. This sensor sheet has also been used to elucidate the characteristics of tongue pressure production during various types of swallowing, such as chin-down posture [23], effortful swallow and the Mendelsohn maneuver [24], and tongue-hold swallowing [25].

The sensor sheet system for measuring tongue pressure thus may be useful for evaluating tongue movements during SS and SSS. In this study, this sensor sheet system was used to evaluate the characteristics of the state of tongue pressure production during SS and SSS performed by healthy adults, and the effects of these swallowing maneuvers on the oral stage of swallowing were investigated.

Materials and Methods

Participants

The participants were 19 healthy young staff members of the University of Zurich Dental School (13 females, 6 males; mean age = 25.9 ± 6.6 years, age range = 17–40 years) with no subjective or objective temporomandibular joint problems, eating difficulties, or dysphagia. The content of the study was explained in writing, and informed consent was obtained from all participants. This experimental protocol was approved by the Ethics Committees of Osaka University and the University of Zurich.

Tongue Pressure Measurement

Tongue pressure was measured with the Swallow Scan System (Nitta Corporation, Osaka, Japan) (Fig. 1). The tongue pressure sensor sheet in this system forms a T shape that follows the curve of the palatal surface. It is extremely thin (~ 0.1 mm thick) and thus poses no impediment to the measurement of physiological swallowing [26]. Depending on the size of the palate of the subject, a small, medium, or large sensor sheet was selected and attached to the palate with a sheet-type denture adhesive (Touch Correct II, Shionogi, Osaka, Japan). None of the subjects reported any gagging sensation during the experiment. The tongue pressure sensor sheet incorporates pressure-sensitive points at five locations regarded as necessary for measuring tongue pressure during swallowing: the anterior-median part of the hard palate (Ch. 1), the mid-median part of the hard palate (Ch. 2), the posterior-median part of the hard palate (Ch. 3), the right posterior-circumferential part of the hard palate (Ch. R), and the left posterior-circumferential part of the hard palate (Ch. L). The production of tongue pressure at each channel was recorded in temporal sequence. The position where pressure was applied was determined using the incisive papilla and hamular notch as anatomical landmarks. Ch. 1 was positioned 5 mm posterior to the incisive papilla. Ch. 2 was positioned one-third of the way from the incisive papilla along the midline perpendicular to the line joining the bilateral hamular notches. Ch. 3 was positioned two-thirds of the way from the incisive papilla along the same line. Ch. R and Ch. L were positioned two-thirds of the way from the incisive papilla along the lines joining the incisive papilla and the left and right hamular notches. The wires from the sensor sheet were passed out of the mouth through the oral vestibule, so as not to interfere with occlusion, and connected to a personal computer.

Before starting tongue pressure measurements, a vacuum pump was used to apply a specific negative pressure

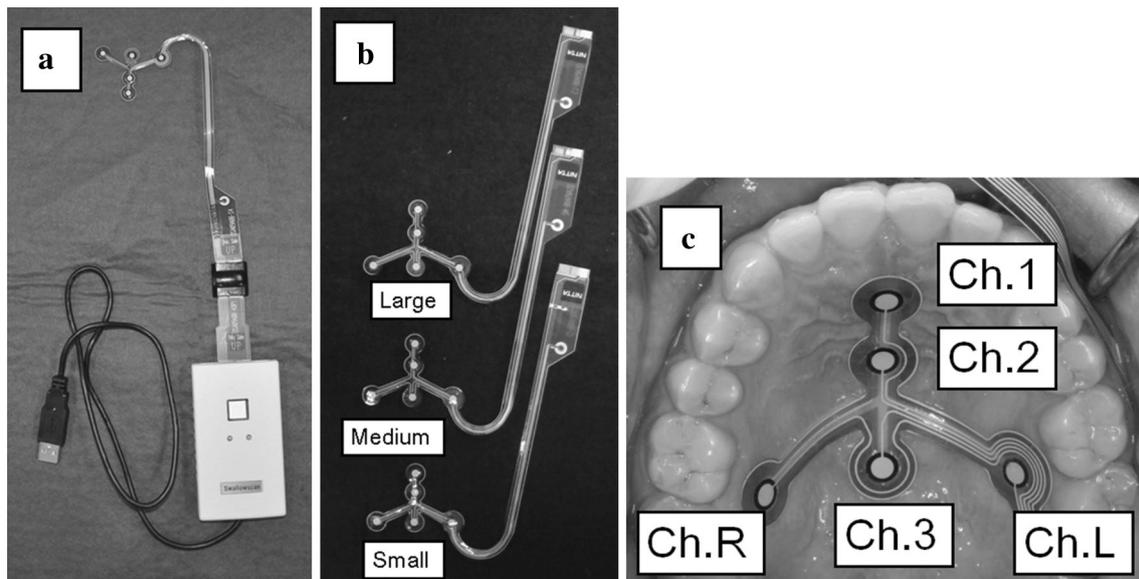


Fig. 1 a Swallow scan system for measuring tongue pressure with a sensor sheet. b The sensor sheet (three sizes). c The original sensor sheet for measuring tongue pressure at five measuring points (Chs. 1–3, R and L) attached to the palatal mucosa with a sheet-type denture adhesive

via the air duct provided at the exit of the tongue pressure sensor sheet for calibration of the pressure-sensitive points. During measurements, participants were seated in an upright position with their heads immobilized by a headrest. The Frankfort plane was parallel with the floor, and the participants' feet were touching the floor. The sampling frequency was 100 Hz.

Procedures

The measurement tasks comprised normal wet swallow, SS, and SSS; for all three swallow types, the participants were asked to swallow 5 mL of water at room temperature. For SS, a syringe was used to inject 5 mL of water onto the floor of the oral cavity, after which participants were instructed to “Breathe through your nose, then hold your breath lightly before and during swallowing. Cough immediately after you finish swallowing.” For SSS, a syringe was used to inject 5 mL of water onto the floor of the oral cavity, after which participants were instructed to “Breathe through your nose, then hold your breath as strongly as you can before and during swallowing. Cough immediately after you finish swallowing.” Participants were told to put the palms of their hands together in front of their chest and press them hard against each other while they held their breath [1]. They practiced the different swallowing techniques thoroughly before the measurements were taken. A total of nine measurements were made, three times each for normal wet swallow, SS, and SSS, which were performed in random order.

Statistical Analysis

The tongue pressure waves obtained (Fig. 2) were used to analyze the duration, the maximal magnitude, and the integrated value of tongue pressure during swallowing at each pressure-sensitive location (Fig. 3). The duration of tongue pressure was defined as the time from onset to offset of tongue pressure, the maximal magnitude of tongue pressure during swallowing was defined as the maximal value of tongue pressure that appeared during the time from onset to offset, and the integrated value of tongue pressure was defined as the integrated value that appeared during the time from onset to offset. The mean value of each parameter for every pressure-sensitive point was calculated for each subject. The intraclass correlation coefficient of these three values for each subject was greater than 0.8, which meant that intraindividual differences were small enough to use the mean value as the representative value for each subject. Friedman's test was used to compare these analysis parameters between different measurement tasks, and if a significant difference was evident, multiple comparison was then performed using Wilcoxon's signed rank-sum test, with the level of significance corrected according to Bonferroni's inequality. PASW Statistics 18 (SPSS, Chicago, IL) was used for statistical processing, and the level of significance was 5 % in all cases.

Results

Table 1 gives the duration, maximal magnitude, and integrated value of tongue pressure during swallowing recorded

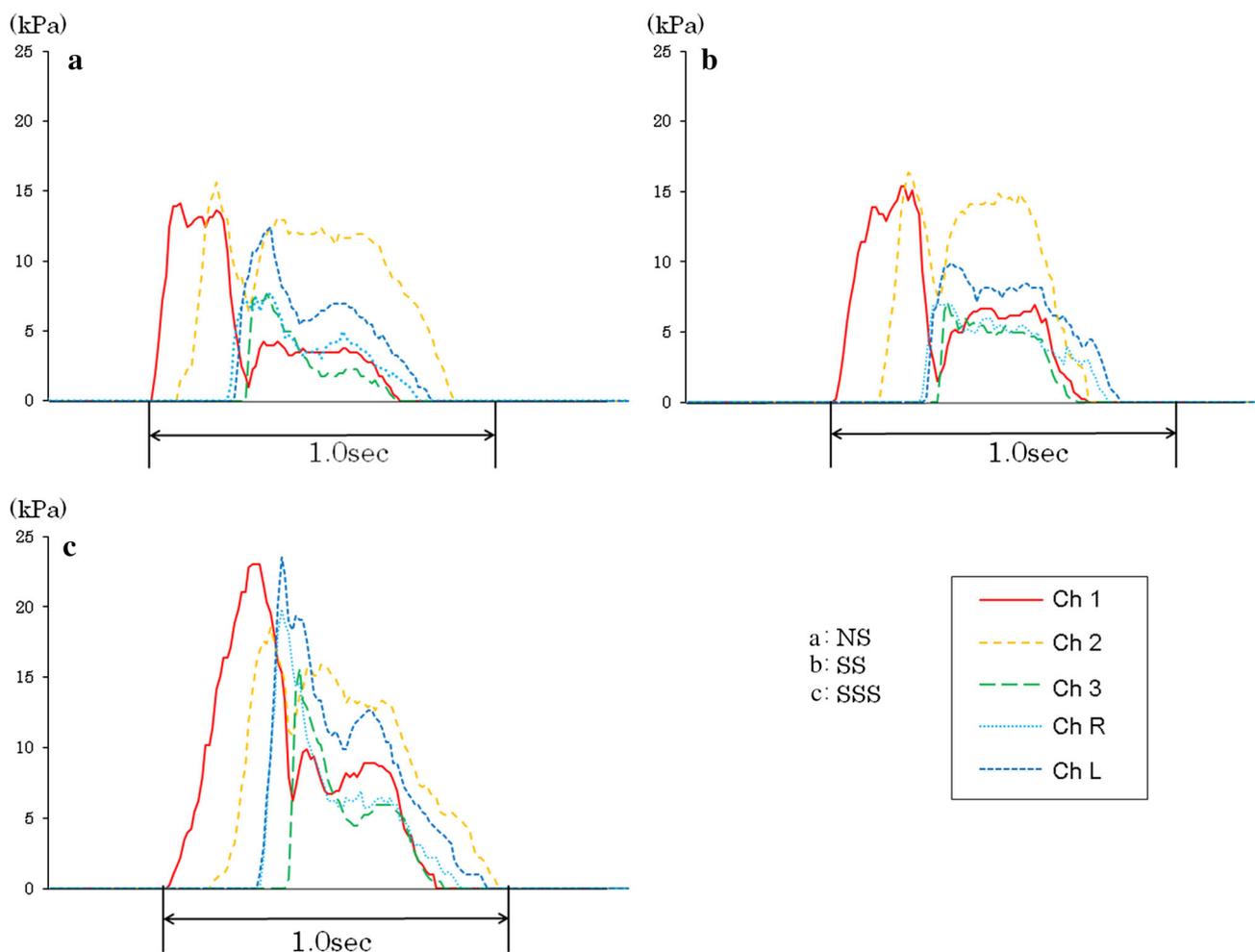


Fig. 2 Comparison of the patterns of pressure generation obtained during three swallow tasks. **a** Normal wet swallow. **b** Supraglottic swallow. **c** Super-supraglottic swallow

at each channel during each measurement task as the mean \pm standard error, and (Figs. 4, 5, 6) show a comparison among the different measurement tasks of the duration, maximal magnitude, and integrated value of tongue pressure during swallowing recorded at each channel.

Duration of Tongue Pressure during Swallowing

The duration of tongue pressure during swallowing was significantly longer at the anterior-median part of the hard palate (Ch. 1) during both SS and SSS than during normal wet swallow.

Maximal Magnitude of Tongue Pressure during Swallowing

The maximal magnitude of tongue pressure during swallowing increased significantly during SS compared with

normal wet swallow at the posterior part of the hard palate (Chs. 3 and R). It increased significantly at all channels during SSS. The maximal magnitude of tongue pressure during swallowing also increased significantly at channels 1, R, and L during SSS compared with SS.

Integrated Value of Tongue Pressure during Swallowing

The integrated value of tongue pressure during swallowing showed a tendency to increase during SS compared with normal wet swallow at all channels, but this increase was significant only at the posterior-median part of the hard palate (Ch. 3). It increased significantly at the anterior-median and posterior parts of the hard palate (Chs. 1, 3, R, and L) during SSS. The integrated value of tongue pressure during swallowing also increased significantly at channels 1, R, and L during SSS compared with SS.

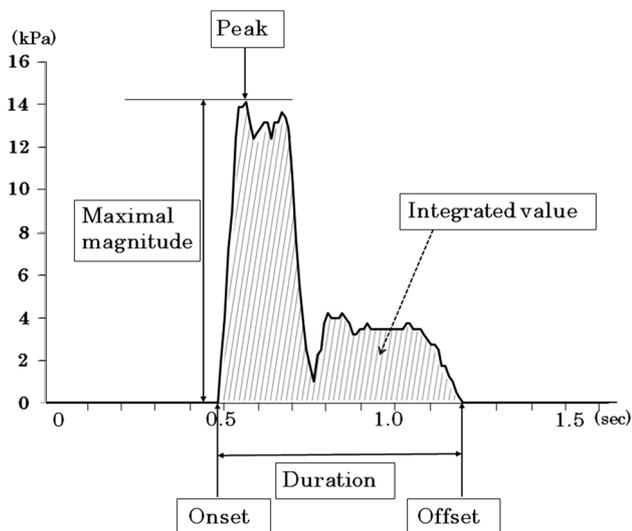


Fig. 3 Representative waves of tongue pressure during normal wet swallow and items for evaluating the state of tongue pressure production

Table 1 Mean values and standard errors for each tongue pressure measurement at Chs. 1–3, R, and L during three swallow tasks

Task	Channel	Duration (s)	Maximal magnitude (kPa)	Integrated value (kPa × s)
NS	Ch. 1	0.39 ± 0.07	9.4 ± 2.6	3.0 ± 1.2
	Ch. 2	0.53 ± 0.06	9.5 ± 2.2	3.9 ± 1.3
	Ch. 3	0.27 ± 0.05	7.5 ± 1.9	1.8 ± 0.6
	Ch. R	0.55 ± 0.05	13.6 ± 2.6	4.0 ± 1.5
	Ch. L	0.58 ± 0.04	11.2 ± 1.7	3.1 ± 0.7
SS	Ch. 1	0.47 ± 0.07	10.8 ± 2.5	4.1 ± 1.6
	Ch. 2	0.55 ± 0.07	11.4 ± 2.6	5.1 ± 1.8
	Ch. 3	0.30 ± 0.05	10.2 ± 2.5	2.9 ± 1.1
	Ch. R	0.62 ± 0.07	16.6 ± 2.9	4.9 ± 1.5
	Ch. L	0.63 ± 0.07	13.5 ± 2.0	3.8 ± 0.8
SSS	Ch. 1	0.51 ± 0.06	14.3 ± 2.8	4.9 ± 1.3
	Ch. 2	0.52 ± 0.05	13.0 ± 2.4	4.7 ± 1.2
	Ch. 3	0.30 ± 0.04	11.6 ± 2.3	2.6 ± 0.7
	Ch. R	0.61 ± 0.05	20.4 ± 3.5	6.3 ± 1.8
	Ch. L	0.65 ± 0.05	17.0 ± 2.5	5.1 ± 1.0

NS normal wet swallow, SS supraglottic swallow, SSS super-supraglottic swallow

Discussion

This is the first study to evaluate the characteristics of the state of tongue pressure production during SS and SSS. Previous studies of the physiological effects of these maneuvers have involved only the use of VE to observe the status of supraglottic closure and the use of VF or manometry to assess pharyngeal contraction [2–6], and

very few studies have investigated tongue movements during swallowing [8, 27]. In this study, the duration of tongue pressure during SS was significantly prolonged at the anterior-median part of the hard palate when compared with that during the normal wet swallow (Ch. 1). The maximal magnitude of tongue pressure during swallowing showed a tendency to increase at all channels during SS, with this increase being particularly significant at the posterior part of the hard palate (Chs. 3 and R). Kahrilas et al. [28] reported that contact between the anterior part of the tongue and the palate constitutes the anchor for tongue movements, and it is important for bolus maintenance and propulsion. The prolonged contact between the anterior tongue and hard palate observed in the present study likely indicates the reinforced anchoring function of the tongue, which in turn can lead to increased tongue pressure generated at the posterior part of the palate.

The duration of tongue pressure was also significantly longer at the anterior-median part of the hard palate (Ch. 1) during SSS than during normal wet swallow, in the same way as during SS. An increase in the maximal magnitude of tongue pressure during swallowing, which was not statistically significant during SS, was significant at all channels during SSS, and the integrated value of tongue pressure was also significant at all pressure-sensitive locations except Ch. 2. When SS and SSS were compared, the maximal magnitude and integrated value of tongue pressure during swallowing were also significantly higher at Chs. 1, R, and L during SSS than during SS. This shows that the greater effort exerted in breath-holding by pressing the palms together further increased the degree of biomechanical changes that occurred during SS [29]. It has been believed that the main physiological effects of SS and SSS are airway protection and improved pharyngeal function, but the present results suggest that these maneuvers may also improve tongue–palate contact during swallowing.

In previous studies of SS and SSS, Mendelsohn et al. [2] and Donzelli et al. [3] reported that bearing down harder when performing SS results in more reliable closure of the glottis. According to Bulow et al. [4], there was no difference in swallowing movements or swallowing pressure between normal wet swallow and SS performed by healthy individuals. This research team also carried out a comparison within a patient population and found that even among patients, there was no difference between normal wet swallow and SS in the maximal swallowing pressure, duration of swallowing pressure [5], or the frequency of laryngeal penetration or aspiration [6]. Ohmae et al. [7] found that early closure of the larynx and prolongation of the duration of hyoid and laryngeal excursion were evident in both SS and SSS performed by healthy individuals, and that these findings were more pronounced during SSS. Many such studies comparing SS and normal wet swallow during

Fig. 4 Comparison of the duration of tongue pressure during three swallow tasks measured at five different points. *NS* normal wet swallow, *SS* supraglottic swallow, *SSS* super-supraglottic swallow

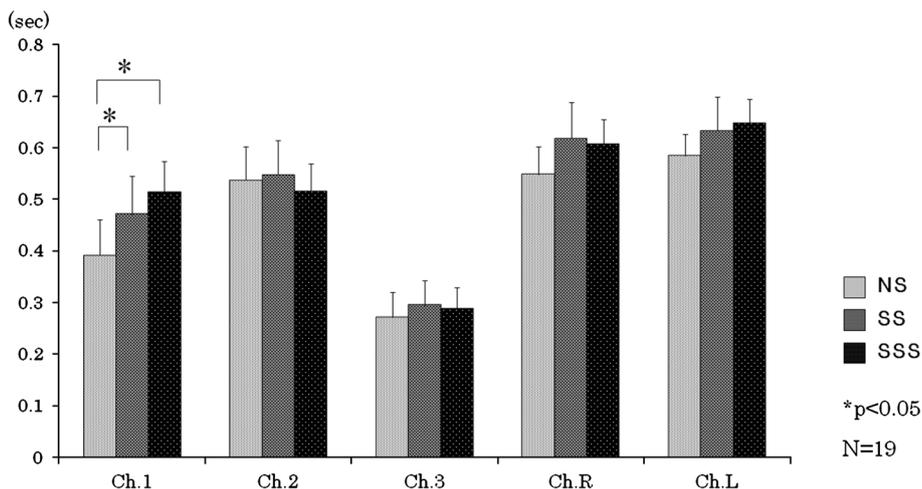


Fig. 5 Comparison of the maximal magnitude of tongue pressure during three swallow tasks measured at five different points. *NS* normal wet swallow, *SS* supraglottic swallow, *SSS* super-supraglottic swallow

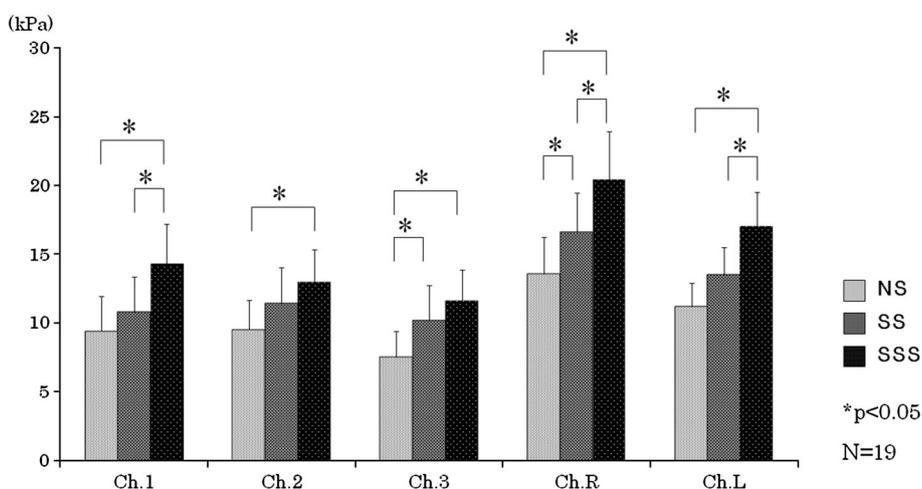
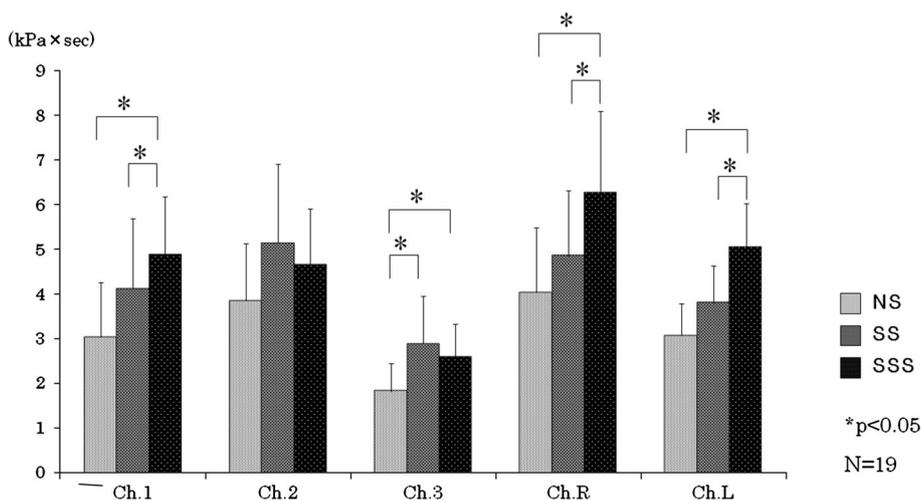


Fig. 6 Comparison of the integrated value of tongue pressure during three swallow tasks measured at five different points. *NS* normal wet swallow, *SS* supraglottic swallow, *SSS* super-supraglottic swallow



pharyngeal swallowing have found no difference between the two, and SSS is regarded as more effective in producing greater biomechanical changes than SS. These findings are

consistent with the results of the present study. The maximal magnitude of tongue pressure during swallowing did increase during SS, but this increase was statistically

significant only at limited sensor locations, whereas during SSS, the maximal magnitude of tongue pressure during swallowing increased significantly across the entire palate. This suggests that the use of SSS is more effective for reliably increasing tongue pressure production.

The integrated value of tongue pressure increased significantly during SSS compared with that during normal wet swallow. This indicates that the tongue performs a greater amount of work during SSS, meaning that this swallowing technique may also function as a tongue strengthening exercise. Yet, due to the relative complexity and physical burden of this maneuver, such a possibility will be a subject for future research.

In the present study, the maximal magnitude of tongue pressure during swallowing was smaller than that reported in previous studies that used other tongue pressure measurement systems [13, 30]. This may be due to the different measuring systems in each experiment and the tongue behavior of each subject. The present sensor sheet system has a rated capacity of 70 kPa and a measuring accuracy of 0.27 kPa [31]. Therefore, it can be used to measure a wide range of tongue pressure, and the value of the maximal magnitude of tongue pressure during swallowing obtained in the present study can occasionally be found in healthy subjects.

Because the sensor sheet system for measuring tongue pressure used in the present study cannot directly measure the pharyngeal pressure generated between the base of the tongue and the pharyngeal wall, a limitation of this study was that there were no findings related to the mode of pressure propagation during swallowing maneuvers or the relationship between the oral and pharyngeal pressure events. If it were possible to use the sensor sheet system for measuring tongue pressure simultaneously with manometry or VF measurements to evaluate these swallowing maneuvers, this would make it easier to elucidate the mode of pressure propagation from the mouth to the pharynx. The participants in the present study were also healthy young adults, and measurements of elderly people and patients with dysphagia are required to investigate the effects of SS and SSS on tongue movement.

Acknowledgments This study was supported by the Global COE Program “In Silico Medicine” at Osaka University.

Conflicts of interest None of the authors has financial or other relationships that would influence assessment of the data or that would constitute a conflict of interest.

References

- Logemann JA. Manual for the Videofluoroscopic Study of Swallowing. 2nd ed. Austin: Pro-Ed; 1993. p. 54–7.
- Mendelsohn MS, Martin RE. Airway protection during breath-holding. *Ann Otol Rhinol Laryngol.* 1993;102:941–4.
- Donzelli J, Brady S. The effects of breath-holding on vocal fold adduction: implications of safe swallowing. *Arch Otolaryngol Head Neck Surg.* 2004;130:208.
- Bülöw M, Olsson R, Ekberg O. Videomanometric analysis of supraglottic swallow, effortful swallow, and chin tuck in healthy volunteers. *Dysphagia.* 1999;14:67–72.
- Bülöw M, Olsson R, Ekberg O. Supraglottic swallow, effortful swallow, and chin tuck did not alter hypopharyngeal intrabolus pressure in patients with pharyngeal dysfunction. *Dysphagia.* 2002;17:197–201.
- Bülöw M, Olsson R, Ekberg O. Videomanometric analysis of supraglottic swallow, effortful swallow, and chin tuck in patients with pharyngeal dysfunction. *Dysphagia.* 2001;16:190–5.
- Ohmae Y, Logemann JA, Kaiser P, Hanson DG, Kahrilas PJ. Effects of two breath-holding maneuvers on oropharyngeal swallow. *Ann Otol Rhinol Laryngol.* 1996;105:123–31.
- Lazarus C, Logemann JA, Song CW, Rademaker AW, Kahrilas PJ. Effects of voluntary maneuvers on tongue base function for swallowing. *Folia Phoniatr Logop.* 2002;54:171–6.
- Cerenko D, McConnel MS, Jackson RT. Quantitative assessment of pharyngeal bolus driving forces. *Otolaryngol Head Neck Surg.* 1988;100:57–63.
- Shaker R, Cook IJ, Dodds WJ, Hogan WJ. Pressure-flow dynamics of the oral phase of swallowing. *Dysphagia.* 1988;3:79–84.
- Robbins J, Levine R, Wood J, Roecker EB, Luschei E. Age effects on lingual pressure generation as a risk factor for dysphagia. *J Gerontol A.* 1995;50:M257–62.
- Crow HC, Ship JA. Tongue strength and endurance in different aged individuals. *J Gerontol A.* 1996;51:M247–50.
- Youmans SR, Stierwalt JA. Measures of tongue function related to normal swallowing. *Dysphagia.* 2006;21:102–11.
- Nicosia MA, Hind JA, Roecker EB, Carnes M, Doyle J, Dengel GA, Robbins J. Age effects on the temporal evolution of isometric and swallowing pressure. *J Gerontol A.* 2000;55:M634–40.
- Hayashi R, Tsuga K, Hosokawa R, Yoshida M, Sato Y, Akagawa Y. A novel handy probe for tongue pressure measurement. *Int J Prosthodont.* 2002;15:385–8.
- Nagao K, Kitaoka N, Kawano F, Komoda J, Ichikawa T. Influence of changes in occlusal vertical dimension on tongue pressure to palate during swallowing. *Prosthodont Res Pract.* 2002;1:16–23.
- Utanochara Y, Hayashi R, Yoshikawa M, Yoshida M, Tsuga K, Akagawa Y. Standard values of maximal tongue pressure taken using newly developed disposable tongue pressure measurement device. *Dysphagia.* 2008;23:286–90.
- Hewitt A, Hind J, Kays S, Nicosia M, Doyle J, Tompkins W, Gangnon R, Robbins J. Standardized instrument for lingual pressure measurement. *Dysphagia.* 2008;23:16–25.
- Hori K, Ono T, Tamine K, Kondo J, Hamanaka S, Maeda Y, Dong J, Hatuda M. Newly developed sensor sheet for measuring tongue pressure during swallowing. *J Prosthodont Res.* 2009;5:28–32.
- Tamine K, Ono T, Hori K, Kondoh J, Hamanaka S, Maeda Y. Age-related changes in tongue pressure during swallowing. *J Dent Res.* 2010;89:1097–101.
- Hirota N, Konaka K, Ono T, Tamine K, Kondo J, Hori K, Yoshimuta Y, Maeda Y, Sakoda S, Naritomi H. Reduced tongue pressure against the hard palate on the paralyzed side during swallowing predicts dysphagia in patients with acute stroke. *Stroke.* 2010;41:2982–4.
- Konaka K, Kondo J, Hirota N, Tamine K, Hori K, Ono T, Maeda Y, Sakoda S, Naritomi H. Relationship between tongue pressure and dysphagia in stroke patients. *Eur Neurol.* 2010;64:101–7.
- Hori K, Tamine K, Barbezat C, Maeda Y, Yamori M, Müller F, Ono T. Influence of chin-down posture on tongue pressure during dry swallow and bolus swallows in healthy subjects. *Dysphagia.* 2011;26:238–45.

24. Fukuoka T, Ono T, Hori T, Tamine K, Nozaki S, Shimada K, Yamamoto N, Fukuda Y, Domen K. Effect of effortful swallow and Mendelsohn maneuver on tongue pressure production against hard palate. *Dysphagia*. 2013;28:539–47.
25. Fujiu-Kurachi M, Fujiwara S, Tamine K, Kondo J, Minagi Y, Maeda Y, Hori K, Ono T. Tongue pressure generation during tongue-hold swallows in young healthy adults measured with different tongue positions. *Dysphagia*. 2014;29:17–24.
26. Hori K, Taniguchi H, Hayashi H, Magara J, Minagi Y, Li Q, Ono T, Inoue M. Role of tongue pressure production in oro-pharyngeal swallow biomechanics. *Physiol Rep*. 2013;1:e00167.
27. Lazarus C, Logemann JA, Gibbons P. Effects of maneuvers on swallowing function in a dysphagic oral cancer patient. *Head Neck*. 1993;15:419–24.
28. Kahrilas P, Lin S, Logemann JA, Ergun G, Facchini F. Deglutitive tongue action: volume accommodation and bolus propulsion. *Gastroenterology*. 1993;104:152–62.
29. Froeschels E, Kastein S, Weiss DA. A method of therapy for paralytic conditions of the mechanisms of phonation, respiration and glutination. *J Speech Hear Disord*. 1955;20:365–70.
30. Youmans SR, Youmans GL, Stierwalt JA. Differences in tongue strength across age and gender: is there a diminished strength reserve? *Dysphagia*. 2009;24:57–65.
31. Ono T, Hori K, Masuda Y, Hayashi T. Recent advances in sensing oropharyngeal swallowing function in Japan. *Sensors*. 2010;10:176–202.

Shigehiro Fujiwara DDS, PhD

Takahiro Ono DDS, PhD

Yoshitomo Minagi DDS

Masako Fujiu-Kurachi PhD

Kazuhiro Hori DDS, PhD

Yoshinobu Maeda DDS, PhD

Sara Boroumand DDS

Ina Nitschke DDS, PD

Vith Ursula SLP

Jörg Bohlender MD