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ORIGINAL ARTICLE

Effect of the Effortful Swallow and the Mendelsohn Maneuver on Tongue Pressure Production against the Hard Palate

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Abstract Although effortful swallow and the Mendelsohn maneuver are commonly used in dysphagia rehabilitation, little is known about their effects on tongue-palate pressure production. The purpose of this study was to investigate the effects of effortful swallow and the Mendelsohn maneuver on tongue pressure production. Fourteen healthy volunteers (10 men, 4 women; age range = 21–41 years) participated. Tongue pressures during dry swallow, water swallow, effortful swallow, and the Mendelsohn maneuver were measured using a sensor sheet system with five measurement points on the hard palate. Sequential order, duration, maximal magnitude, and the integrated value of tongue pressure at each measurement point were compared among the four tasks. Onset of tongue pressure at the posterior-circumferential parts occurred first in the Mendelsohn maneuver; that at the anterior-median part was earlier than at other parts in the effortful swallow. At all measurement points, tongue pressure duration was significantly longer in the Mendelsohn maneuver than in other tasks. Effortful swallow was most effective in increasing tongue pressure. The integrated value of tongue pressure at the posterior-circumferential parts in the Mendelsohn maneuver and at the median parts in the effortful swallow showed a tendency to increase. These results suggest that tongue pressure increases along a wide part of the hard palate in effortful swallow because the anchor of tongue movement is emphasized at the anterior part of the hard palate. The Mendelsohn maneuver provides prolonged and accentuated tongue-palate contact at the posterior-circumferential parts, which might be important for hyoid-laryngeal elevation during swallowing.

Keywords Effortful swallow · Mendelsohn maneuver · Swallowing · Tongue · Pressure · Dysphagia

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Introduction

The effortful swallow and the Mendelsohn maneuver are commonly used as compensatory techniques to improve swallowing function in the rehabilitation of patients with pharyngeal dysphagia. The effortful swallow is designed to increase posterior motion of the tongue base and anterior motion of the posterior pharyngeal wall, thereby increasing bolus pressure and subsequently decreasing pharyngeal residue [1, 2]. The Mendelsohn maneuver is designed to augment opening of the upper esophageal sphincter (UES) by prolonging laryngeal elevation during swallowing. Use of this maneuver has resulted in increased duration of vertical-anterior excursion of the larynx and subsequent prolonged UES opening [1, 3–6]. A number of studies have investigated the effect of these techniques using videofluoroscopy and manometry [2–4, 6–13]. Although the effects of these maneuvers on pharyngeal stage swallowing have been evaluated, little is known about the effect on tongue-palate pressure production of oral stage swallowing.

Bolus transit during swallowing relies on the synergistic action of two pumps, the oropharyngeal propulsion pump and the hypopharyngeal suction pump [14]; the major propulsive force of the oropharyngeal propulsion pump is the pressure of contact between the tongue and the hard palate during the oral phase of swallowing [15]. It has been reported that the anchor of tongue movement formed by contact between the anterior part of the tongue and the palate plays an important role in bolus maintenance and transport [16].

Therefore, evaluation of tongue-palate pressure in the effortful swallow and Mendelsohn maneuver may provide useful information about the effect that these maneuvers have on the oral and pharyngeal stages of swallowing. However, the state of tongue-palate pressure production has yet to be clarified because of the lack of an adequate measuring device. The aim of the present study was to investigate the effects of the effortful swallow and the Mendelsohn maneuver on tongue pressure using a sensor sheet system.

Materials and Methods

Subjects

The subjects were 14 healthy volunteers (10 men and 4 women; age range = 21–41 years; mean age = 30.4 ± 6.5 years) without disturbances in mastication and swallowing, temporomandibular disorder, or abnormalities in occlusion. All subjects had more than 28 natural teeth. Informed consent was obtained from each subject after being given an explanation of the aim and methodology of the study. This study received approval from the ethics committee of Hyogo College of Medicine and Osaka University Graduate School of Dentistry.

Tongue Pressure Measurement

The tactile sensor system (Swallow Scan, Nitta Co., Osaka, Japan) was used for the measurement of tongue pressure [17–20]. Pressure measured by the sensor is transmitted in real time to a personal computer that displays the data. The T-shaped sensor sheet used for measuring tongue pressure is very thin (0.1 mm in thickness) and has five measurement points (Chs. 1–5) to record tongue pressure production. The rated capacity of the sensor sheet was set to 70 kPa, with a measuring accuracy of 0.27 kPa, and the sampling frequency was 100 Hz. Three measurement points (Chs. 1–3) were placed along the median line (Ch. 1 was set at the anterior-median part, Ch. 2 was set at the mid-median part, and Ch. 3 was set at the posterior-median part), and two sensors (Chs. 4 and 5) were situated in the posterior-circumferential parts (Ch. 4 on the right side and Ch. 5 on the left side) of the hard palate (Fig. 1). For each subject, a sensor sheet of suitable size to fit his/her hard palate was chosen from the three available sizes (small, medium, and large) [18]. The sensor sheet was attached directly to the palate using a sheet-type denture adhesive (Touch Correct II, Shionogi, Osaka, Japan). The cable exited the oral cavity via the oral vestibule to avoid interference with occlusion and was then connected to the computer. The system was calibrated by applying negative pressure using a vacuum pump through an air duct in the cable of the sensor sheet.

Procedures

Tongue pressure during swallowing was recorded with the subject sitting in an upright position. The experimental tasks consisted of four swallow maneuvers (dry swallow, water swallow, effortful swallow, and the Mendelsohn maneuver), and three tasks, except for dry swallow, used 5 mL of water at room temperature. For the effortful swallow, after 5 mL of water was injected onto the floor of the mouth, subjects were instructed to swallow hard, emphasizing tongue-to-palate contact with verbal instructions that were consistent with those of Huckabee and Steele [21] ("As you swallow, push your tongue really hard against the roof of your mouth"). For the Mendelsohn maneuver, subjects were instructed as follows: "Swallow normally and in the middle of your swallow when you feel your Adam's apple lift, hold it up for 2–3 s with your throat muscles before finishing the swallow" [22, 23]. Subjects were instructed several times before the measurement with the two maneuvers and it was confirmed that the subjects performed the maneuvers correctly. Each swallow was performed three times by each subject in random order. To minimize muscle fatigue, each subject rested for more than 1 min between tasks. From the wave of tongue pressure recorded for the four tasks, the order (time of onset, peak, and offset), duration, maximal magnitude, and integrated value of tongue pressure were analyzed [17–20] (Fig. 2).

Statistical Analysis

The order (time of onset, peak, and offset), duration, maximal magnitude, and integrated value of tongue

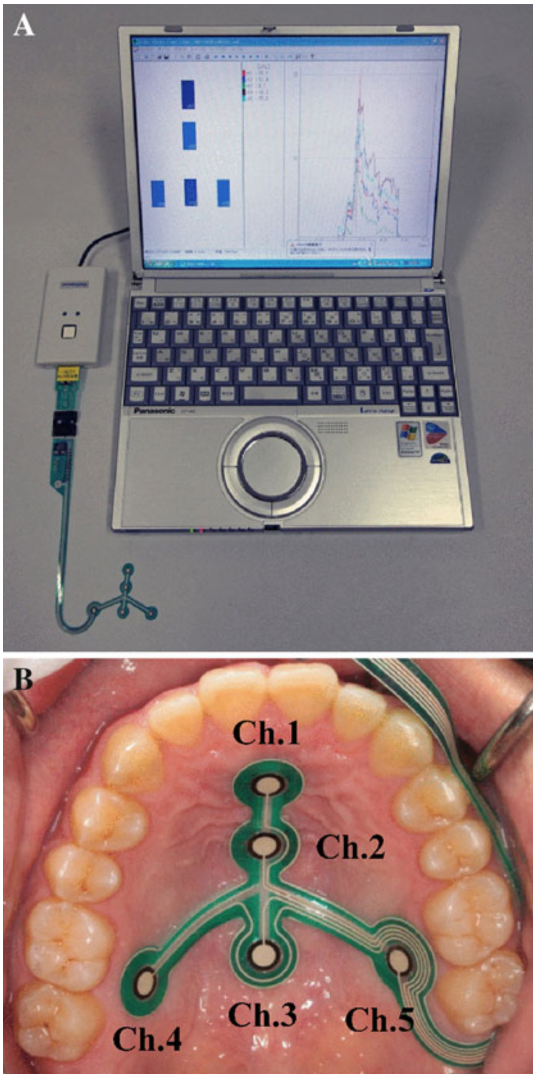

Fig. 1 **a** Swallow Scan system for measuring tongue pressure. **b** The sensor sheet with five measurement points attached to the hard palate directly with denture adhesive. *Ch. 1* anterior median part, *Ch. 2* mid-median part, *Ch. 3* posterior median part, *Ch. 4* right lateral part, *Ch. 5* left lateral part

pressure were compared using repeated-measures analysis of variance, followed by Tukey's post hoc test, among the four tasks and among the measurement points. All statistical analyses were performed using SPSS ver. 12.0 for Windows software (SPSS Japan, Tokyo, Japan), and statistical significance was established at the $P < 0.05$ level.

Results

Figure 3 provides representative waveforms of tongue pressure for the four tasks performed by a single subject. The sequential order of tongue pressure production at Chs. 1–5 in four tasks is illustrated in Fig. 4, with onset of

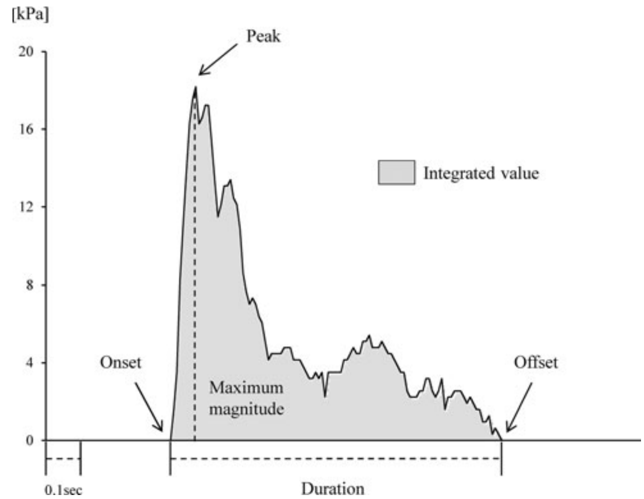

Fig. 2 Representative waves and items for evaluating the state of tongue pressure production at Ch. 1 recorded during 5-mL water swallow

tongue pressure at Ch. 1 in each task set to 0 s. Comparisons of maximal magnitude, duration, and integrated value of tongue pressure at Chs. 1–5 among the four tasks and among the measurement points are provided in Fig. 5 and Table 1, respectively.

Order of Tongue Pressure Production

Onset was earlier at the posterior-circumferential parts (Chs. 4 and 5) than at the median part (Chs. 1–3) in dry swallow and 5-mL water swallow, with no significant differences at the median part. This tendency was similar in the Mendelsohn maneuver. On the other hand, for the effortful swallow, onset was earlier at the anterior-median part (Ch. 1) than at the mid-median part (Ch. 2) and posterior-median part (Ch. 3), though no significant difference was found between Ch. 1 and the posterior-circumferential parts (Chs. 4 and 5). For the peak time, no significant difference was found between any measurement points in all tasks. For the offset time, the posterior-median part (Ch. 3) was the earliest and the posterior-circumferential parts (Chs. 4 and 5) were the latest in all tasks.

Duration of Tongue Pressure

At all measurement points (Chs. 1–5), the duration of tongue pressure was significantly longer in the Mendelsohn maneuver than in other tasks. The duration of tongue pressure at Ch. 1 was longer in the effortful swallow than in water swallow. In all tasks, the duration of tongue pressure tended to be longer at the posterior-circumferential parts (Chs. 4 and 5) than at the median part (Chs. 1–3).

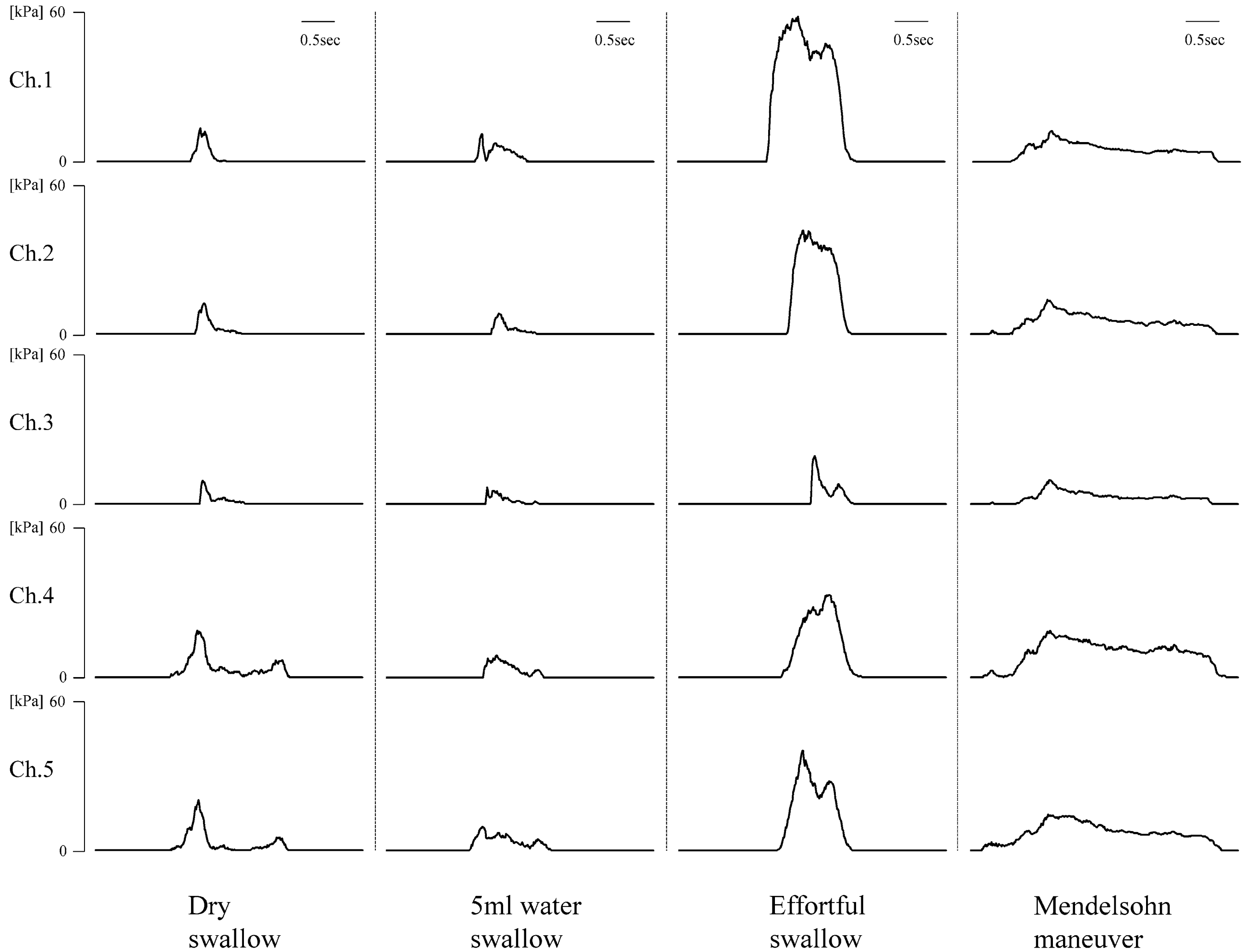

Fig. 3 Tongue pressure pattern from one subject showing dry swallow, 5-mL water swallow, effortful swallow, and the Mendelsohn maneuver

Maximal Magnitude of Tongue Pressure

At all measurement points (Chs. 1–5), the magnitude of tongue pressure was significantly larger in the effortful swallow than in the other tasks. The magnitude of tongue pressure at Ch. 1 was significantly larger in the Mendelsohn maneuver than in the dry swallow and water swallow, and at Ch. 4 it was larger than the value in the water swallow. In the dry swallow, the magnitude of tongue pressure was significantly larger at the posterior-circumferential parts (Chs. 4 and 5) than at the median part (Chs. 1–3). In the water swallow, the magnitude of tongue pressure tended to be higher at Ch. 1 and the posterior-circumferential parts (Chs. 4 and 5) than at Chs. 2 and 3, but no significant difference was found. In the effortful swallow, the magnitude of tongue pressure was significantly larger at Ch. 1 than at the other measurement points. In the Mendelsohn maneuver, the magnitude of tongue pressure was significantly larger at Ch. 4 than at Chs. 2 and 3.

Integrated Value of Tongue Pressure

The integrated value of tongue pressure at the median part (Chs. 1–3) was significantly larger in the effortful swallow and the Mendelsohn maneuver than in the dry swallow and the water swallow, though at Ch. 3 there was no significant difference between the dry swallow and the Mendelsohn maneuver. The integrated value of tongue pressure at the posterior-circumferential parts (Chs. 4 and 5) was significantly larger in the Mendelsohn maneuver than in the dry swallow and water swallow, and it was larger in the effortful swallow than in the water swallow, but no significant difference was found between the effortful swallow and the Mendelsohn maneuver.

In the dry swallow, the integrated value of tongue pressure was larger at the posterior-circumferential parts (Chs. 4 and 5) than at the median part (Chs. 1–3). A similar tendency was observed in the water swallow, but a significant difference was found only between Ch. 3 and Ch. 5.

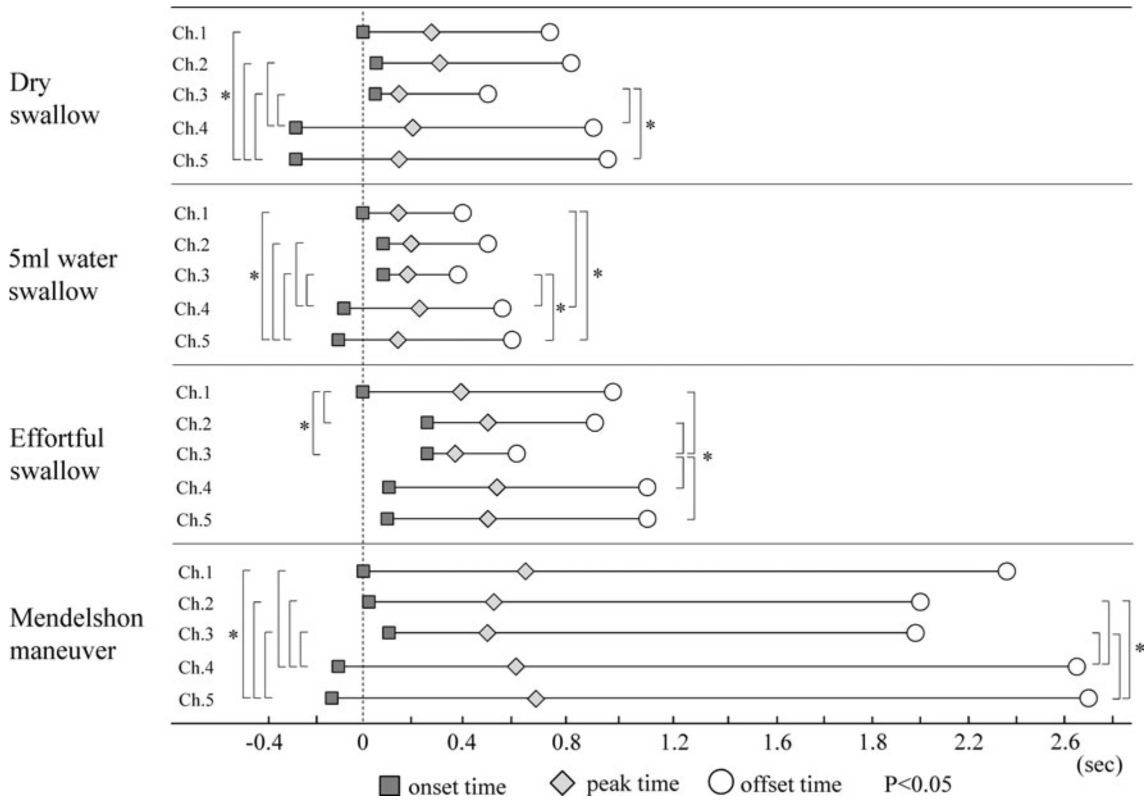

Fig. 4 Order of tongue pressure production during four tasks at each measurement point (Chs. 1–5). Onset time of tongue pressure at Ch. 1 is set to 0 s

In the effortful swallow, the integrated value of tongue pressure was significantly larger at Ch. 1 than at other measurement points, and it was smaller at Ch. 3 than at other measurement points except for Ch. 2. In the Mendelsohn maneuver, the integrated value of tongue pressure was significantly larger at Ch. 4 than at Ch. 3.

Discussion

This is the first study to investigate the state of tongue pressure production in the effortful swallow and the Mendelsohn maneuver under nearly natural conditions. Tongue movement during swallowing can be observed using videofluorography and ultrasonography, but it is difficult to quantify and evaluate precisely. Tongue pressure against the hard palate at maximal isometric voluntary contraction has been measured using probe-type pressure-measuring devices and pressure sensors [24–27]. These techniques are not suitable for measuring tongue pressure during physiologically natural swallowing because occlusal contact is inhibited with the thick probe inserted in the oral cavity.

Since the tactile sensor sheet used in the present study is very thin, it is considered effective for reducing discomfort in the oral cavity. Additionally, the pathway of the cable of the sensor sheet was designed to not inhibit physiological swallowing with occlusal contact. In the existing research, the evaluation of tongue movement according to tongue pressure production was not feasible because the number of measurement positions was fewer than three [9, 21, 28, 29]. Our sensor sheet can measure the posterior-circumferential parts of the hard palate and the median part by having five measurement points. Based on the foregoing, this sensor sheet system made it possible to evaluate contact of the tongue against the hard palate in the effortful swallow and Mendelsohn maneuver in greater detail.

The results of the present study showed that tongue pressure production was generated initially at Chs. 4 and 5 in both the dry swallow and the water swallow, but the effortful swallow started at Ch. 1. Moreover, the magnitude of tongue pressure was significantly larger at all measurement points (Chs. 1–5) in the effortful swallow than in other tasks. Hind et al. [9] investigated the effect of effortful swallowing in healthy participants using videofluoroscopy and oral pressure bulbs attached to the center of the hard palate (anterior, middle, and posterior). They documented significantly increased pressure at all three bulb locations in the effortful swallow, with the pressure increase greater in middle-aged than older subjects.

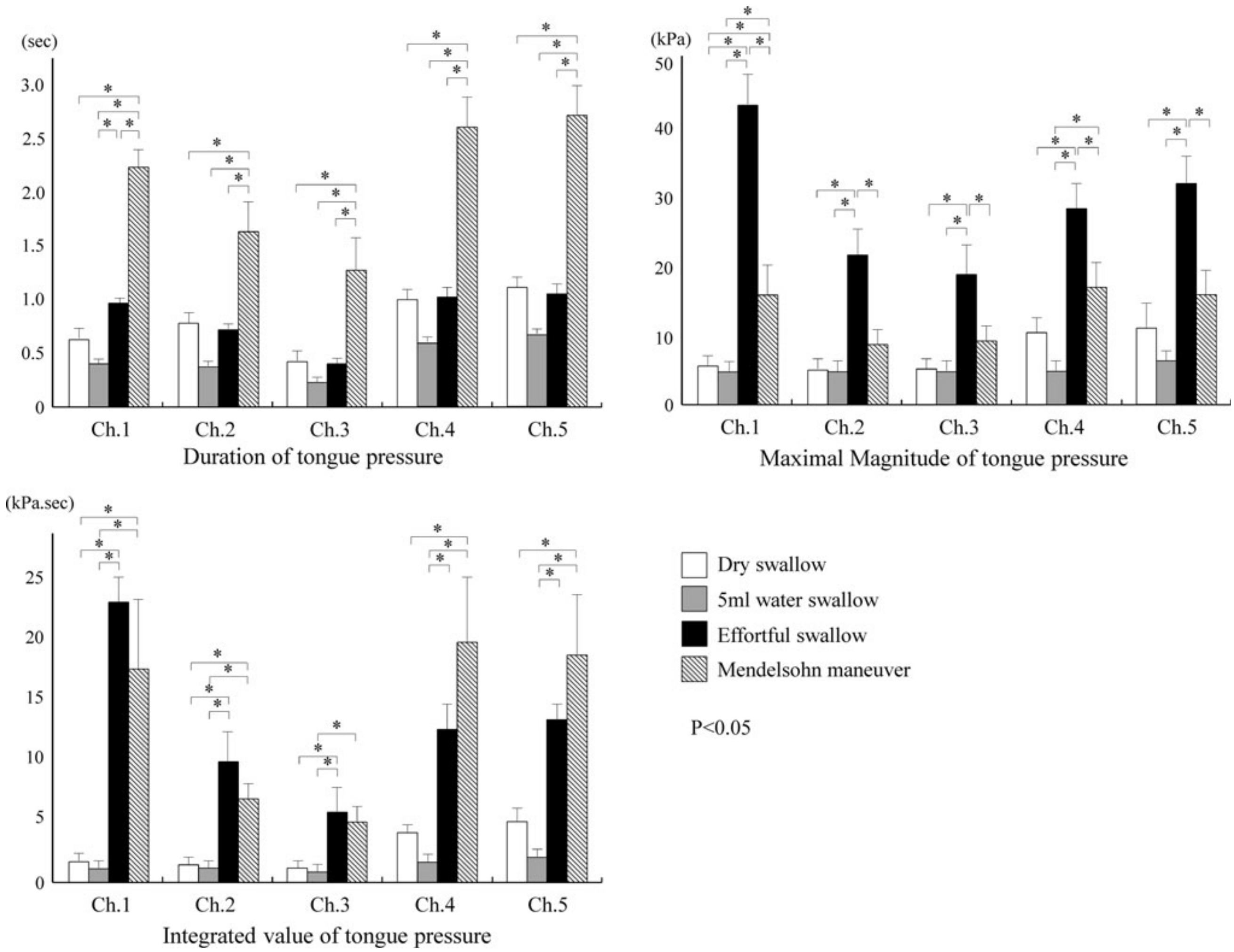

Fig. 5 Comparisons of maximal magnitude, duration, and integrated value of tongue pressure at each measurement point (Chs. 1–5) for four tasks ($P < 0.05$). *Error bars* represent ±1 standard error of the mean (SEM)

Although the present data support their results, the percentage of increasing pressure between the regular swallow and the effortful swallow was larger in the present study. The difference in oral pressure may be larger with decreasing age, since the present subjects were younger.

The novel aspect of the present study of the effortful swallow is that measurements were taken at the posterior-circumferential parts by having five point sensors and then compared. In the effortful swallow, both the magnitude and the integrated value of tongue pressure were significantly larger at Ch. 1 than at other measurement points. Therefore, it appears that tongue pressure increases in a widespread area on the hard palate in the effortful swallow because tongue movement is anchored and accentuated at the anterior part of the hard palate during swallowing.

There are various instructions for the effortful swallow, such as “Swallow very hard while squeezing the tongue in an upward-backward motion toward the soft palate” [7, 8], “Swallow hard” [9], or “As you swallow, push really hard with your tongue” [21, 28, 29]. Huckabee [21] reported that tongue-to-palate emphasis during execution of the effortful swallow increased submental activation, orolingual pressure, and upper pharyngeal pressure to a greater degree than a strategy of inhibiting tongue-to-palate emphasis. Based on this research, the present study used the instruction of Huckabee and Steele. In patients with oral cancer, insertion of a palatal augmentation prosthesis resulted in improved swallow efficiency, increased duration of tongue contact with the pharyngeal wall, and improved speed of movement of the bolus [30]. With the effortful swallow, increasing oral pressure between the tongue and palate may contribute to increasing the pharyngeal pressure and the driving force, which propel a bolus from the oral cavity into the pharynx.

In the present study, the Mendelsohn maneuver showed an increased magnitude of tongue pressure compared with the dry swallow and the water swallow, and a longer duration at all measurement points (Chs. 1–5) than in other

Table 1 Mean and 95 % confidence intervals for each tongue pressure measurement at Chs. 1–5 for four tasks

task	Ch.	Tongue pressure measurement: Duration	Maximal magnitude	Integral value
Dry swallow	1	0.63(0.41-0.84)	5.21(2.69-7.74)	1.74(0.68-2.80)
	2	0.75(0.48-1.02)	3.87(1.80-5.94)	1.25(0.40-2.10)
	3	0.40(0.18-0.61)	4.83(1.20-8.47)	1.16(0.13-2.18)
	4	1.10(0.83-1.36)	10.13(6.31-13.96)	3.83(2.38-5.27)
	5	1.14(0.83-1.45)	11.66(5.82-17.50)	4.27(2.82-6.62)
5ml water swallow	1	0.34(0.22-0.46)	4.81(2.18-7.44)	1.05(0.45-1.64)
	2	0.33(0.14-0.52)	3.33(0.52-6.15)	0.90(0.03-1.77)
	3	0.21(0.08-0.35)	3.69(0.40-6.98)	0.65(-0.02-1.33)
	4	0.59(0.40-0.78)	4.78(2.96-6.59)	1.37(0.59-2.16)
	5	0.68(0.50-0.86)	6.39(3.87-8.91)	1.92(1.03-2.82)
Effortful swallow	1	0.96(0.84-1.08)	43.35(35.25-51.45)	22.44(17.45-27.43)
	2	0.70(0.53-0.87)	21.51(13.04-29.97)	9.05(4.15-13.94)
	3	0.39(0.24-0.53)	19.39(10.37-28.41)	5.07(0.69-9.44)
	4	1.01(0.74-1.29)	29.19(19.88-38.49)	12.08(7.47-16.69)
	5	1.07(0.80-1.33)	31.50(24.32-38.69)	13.52(9.80-17.25)
Mendelsohn maneuver	1	2.15(1.51-2.80)	15.87(6.48-25.27)	17.35(3.54-31.16)
	2	1.62(0.98-2.27)	8.17(3.95-12.40)	6.37(3.00-9.73)
	3	1.25(0.51-1.99)	8.45(3.12-13.79)	4.87(1.54-8.20)
	4	2.61(2.06-3.15)	17.00(7.92-26.08)	19.64(7.49-31.80)
	5	2.69(2.12-3.26)	15.44(9.19-21.69)	18.08(7.44-28.73)

* $P < 0.05$

tasks. Comparing the measurement points in the Mendelsohn maneuver, we found that the duration of tongue pressure was longer at Chs. 4 and 5 than at the median part (Chs. 1–3), and the integrated value also showed a similar tendency. These results suggest that prolonging tongue-palate contact strongly at the posterior-circumferential parts was important for hyoid-laryngeal elevation during swallowing. Moreover, these findings are considered related to the results of Hoffman et al. [31] who used high-resolution manometry to show that the Mendelsohn maneuver yielded longer velopharyngeal pressure duration and increased velopharyngeal area and integrals.

The present study had limitations. The sensor sheet system used cannot measure tongue base-pharyngeal wall pressure directly. Therefore, a limitation of this study is that the relationship between contact of the tongue and palate and pharyngeal pressure in the swallow maneuver could not be examined. Further studies are needed to clarify the propagation of pressure from the oral cavity to the pharynx by measuring the tongue pressure and pharyngeal pressure simultaneously in the effortful swallow and the Mendelsohn maneuver. It also remains unclear whether the pattern of tongue pressure with the swallow maneuver in aged individuals and dysphagia patients shows similar results, because the present subjects were healthy young individuals.

The effortful swallow and the Mendelsohn maneuver are used in patients with a pharyngeal stage swallowing disorder, and clinicians mainly instruct them verbally about the methods of the voluntary maneuvers. There are various biofeedback techniques related to voluntary swallow maneuvers, such as using surface submental EMG and a neck force transducer [5, 21, 32, 33]. A sensor sheet system of tongue pressure can display contact pressure of the tongue-palate by a waveform or a bar graph for every part of the measurement in real time; it may therefore be used as a biofeedback tool for tongue movement in the effortful swallow and the Mendelsohn maneuver. Further studies should be done in dysphagic patients to confirm the effectiveness of tongue pressure measurement during these swallowing maneuvers as a biofeedback tool.

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Conflict of interest The authors have no conflicts of interest to disclose.

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