Effect of body position on tongue movement during swallowing

Kaori Tsujimoto¹, Kazuya Takahashi, Tomomi Shibuya and Yutaka Komasa
Department of Geriatric Dentistry, and ‘Graduate School of Dentistry (Geriatric Dentistry), Osaka Dental University, 8-1 Kuzuhahazone-cho, Hirakata-shi, Osaka 573-1121, Japan

In patients with feeding/swallowing disorders, adjustment of posture is a very effective means of preventing aspiration. A posteriorly flexed rather than vertical trunk position is widely known to be a safe body position in which aspiration is less likely to occur. Therefore, in patients at high risk of aspiration, the trunk and neck angles are adjusted clinically in various situations. Regarding the relationship between posture adjustment and swallowing dynamics, although there have been a number of evaluations in the pharyngeal and esophageal phases, few detailed evaluations have been made in the oral phase despite its importance. Physiologic evidence is considered to be insufficient in this area. In this study, the effects of posture adjustment on tongue dynamics in the oral phase were evaluated by measuring the tongue pressure on the palate using touch sensors.

The subjects were 7 healthy dentulous individuals who had no feeding/swallowing disorder with a mean age of 26 years. The test food was water at 37°C. Swallowing volume was determined by having each subject swallow water 10 times consecutively and calculating the mean volume of a single gulp, which was found to be 7.9±1.4 mL. The test maneuver was a single gulp on instruction of the examiner. Swallowing was performed in a total of 6 body positions, i.e., at trunk angles of 90°, 60° and 30° relative to the floor, and with neck angles of neutral and anteriorly flexed/protruded positions at each trunk angle. Sensors were attached using the denture stabilizer Touch Correct II (Shionogi, Osaka, Japan) as follows: Sensor 1 was placed at the point of intersection between the line connecting the basal tubercles of the bilateral upper canine teeth and median line, Sensor 2 at the intersection between the line connecting the distal palatal cusps of the bilateral second upper molars and the median line, and the center of Sensor 3 immediately below the palatal neck of the left upper second molar on the line connecting the distal palatal cusps of the bilateral upper second molars.

In the neutral neck position, all sensors indicated significant shortening of the duration of tongue pressure with increases in the angle of trunk flexion. In Sensors 1 and 3, the maximum tongue pressure decreased with increases in the angle of trunk flexion. In the anteriorly flexed/protruded neck position, no shortening of the duration of tongue pressure or decrease in the maximum tongue pressure associated with trunk flexion was noted. Changing the neck angle from the neutral to anteriorly flexed/protruded position seemed to compensate for the decrease in the maximum tongue pressure and the tongue pressure duration. (J Osaka Dent Univ 2012 ; 46 : 147–156)

Key words: Body position; Trunk angle; Neck angle; Tongue pressure
INTRODUCTION

The elderly population continues to increase as Japan grows into a super-aging society. Cerebrovascular disorders, which are the third most frequent cause of death in Japanese, and neurological disorders often lead to feeding/swallowing disorders and malnutrition, and readily deteriorate the patient's condition into a care-dependent state, posing a major problem for the entire population. In the field of dentistry, there has been increased interest in the rehabilitation of feeding/swallowing, which has been attempted from various viewpoints including the adjustment of food properties and oral function training. However, recovery of swallowing function to the pre-morbid level is difficult to achieve in some patients even with appropriate feeding/swallowing rehabilitation, and measures to compensate for this decreased function are needed.

Posture adjustment is a very effective means to prevent aspiration in patients with feeding/swallowing disorder. A posteriorly flexed trunk position has been advocated, and is widely recognized today to be safer than the vertical position in avoiding aspiration. Therefore, the trunk and neck angles are adjusted in various situations such as feeding patients at high risk of aspiration by placing them in a posteriorly flexed trunk position, and performing oral care of hemiplegic patients by placing them in the recumbent position with the paralyzed side uppermost.

Concerning the relationship between posture adjustment and swallowing dynamics, although there have been a number of studies in the pharyngeal and esophageal phases, studies in the oral phase are rare. In particular, there have been few studies on the effects of the trunk and neck angles on swallowing dynamics, and physiologic evidence is scarce. In this study, therefore, the effects of adjustment of the trunk and neck angles on the swallowing dynamics in the oral phase were evaluated taking into consideration the tongue dynamics by measuring the tongue pressure against the palate using touch sensors.

MATERIALS AND METHODS

Subjects

The subjects were 7 healthy dentulous individuals (4 males and 3 females) with a mean age of 26 years who had no subjective or objective abnormality in the feeding/swallowing function. This study was approved by the Osaka Dental University Ethics Committee (Approval No.100714).

Measurement sites

The tongue pressure was measured at three sites (Fig. 1). Sensor 1 (S1) was placed at the point of intersection between the line connecting the basal tubercles of the bilateral upper canine teeth and the median line, Sensor 2 (S2) at the intersection between the line connecting the distal surfaces of the bilateral second upper molars and the median line, and the center of Sensor 3 (S3) immediately below the neck of the left upper second molar on the line connecting the distal proximal surfaces of the bilateral upper second molars.

Measurement apparatus

Measurement was performed using capacitive touch sensors (Oga, Inc., Toyama, Japan). The pressure-sensing part of the sensor was 6 mm in diameter, the sensor head including the water-proof cap covering the pressure-sensing part was 10.0 mm in diameter and 1.2 mm thick, and the coaxial cable was 0.3 mm in diameter. The sensors were attached directly at the above positions on the palate using the denture stabilizer Touch Correct II (Shionogi, Osaka, Japan). To prevent the patient's occlusion from breaking of the cable, a protector
was prepared using autopolymerizing resin (Unifast III, GC, Tokyo, Japan). The protector covered the crown except for the occlusal surface from the upper left lateral incisor to the second premolar, and the coaxial cable was fixed in the incisal embrasure between the canine and first premolar and led through the oral vestibule and brought out near the left angle of the mouth. The shape and occlusion of the protector were adjusted not to interfere with occlusion, mastication, or swallowing (Fig. 2).

Experimental procedure
Prior to the experiment, the subjects were asked to repeatedly swallow water 10 times, and the mean volume of one gulp of each subject was determined. The mean volume for all of the subject was 7.9 ± 1.4 mL (Table 1). Swallowing was then performed in a total of 6 body positions: at trunk angles of 90°, 60° and 30°, with neutral and anteriorly flexed/protruded neck positions at each trunk angle. The neutral neck position was defined as the position that the subject took in looking straight ahead when seated, and the anteriorly flexed/protruded neck position as the position that the subject took while normally eating a meal in the seated position (Fig. 3). The neck position was fixed using a headrest during the experiment. The measurements were performed a few minutes after placement of the sensors in the mouth and after confirming stabilization of the waveform on the monitor to prevent distortion of the sensors due to temperature changes. The test food was water adjusted to 37°C, and the test maneuver was a single swallow on instruction.

Analytical methods
Figure 4 shows a block diagram of the experiment. The waveforms obtained by each sensor were stored in a personal computer using a signal processing board. Analyses of the parameters shown in Figure 5 were done employing the following proce-

Table 1 Gulp volume

<table>
<thead>
<tr>
<th>Subject</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>8.2</td>
<td>7.6</td>
<td>7.8</td>
<td>5.0</td>
<td>9.3</td>
<td>9.3</td>
<td>7.8</td>
</tr>
</tbody>
</table>

(mL)
The items measured were: (1) the duration of tongue pressure from its appearance to disappearance ($t_{s1}$, $t_{s2}$, $t_{s3}$), and (2) the maximum tongue pressure ($p_{s1}$, $p_{s2}$, $p_{s3}$) for each sensor. Comparisons among the groups were made using the Kruskal-Wallis test, and multiple comparisons were made using the Steel-Dwass method. Two-tailed tests were performed at a significance level of 5%.

RESULTS

Duration of tongue pressure

Figure 6 shows the duration of tongue pressure measured with each sensor. It was significantly shorter in S2 than in S1 at trunk angles of 90° and 60° in the neutral neck position. Although similar tendencies were observed in the other postures, the differences were not significant. Figure 7 compares the duration of tongue pressure among the trunk angles. When the neck was in the neutral position, the duration of tongue pressure was significantly shortened as the trunk was flexed further in all sensors. In the anteriorly flexed/protruded neck position, no significant change was noted in the duration of tongue pressure with changes in the trunk position.

Fig. 5 The time for pressure appearance (A) and maximum pressure for each sensor (B) were measured.

Fig. 6 Duration of tongue pressure measured with each of the three sensors (Mean ± SE, *p < 0.05, **p < 0.01).
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Fig. 7 Duration of tongue pressure among the trunk angles.

Fig. 8 Maximum tongue pressure registered by each sensor.

Maximum tongue pressure
Figure 8 shows the maximum tongue pressure registered by each sensor. In all combinations of the trunk angle and neck position, the maximum tongue pressure was significantly larger in S1 than in S2 or S3. No significant difference was noted between S2 and S3. Figure 9 compares the maximum tongue pressure according to the trunk angle. When the neck was in the neutral position, the maximum tongue pressure in S1 was significantly lower at a trunk flexion angle of 30° than at 90° or 60°. A similar tendency was also noted in S2 and S3, although the differences were not significant. When the neck was in the anteriorly flexed/protruded position, no significant change in the maximum tongue pressure was noted with changes in the trunk angle, and no particular tendency was observed, unlike in the neutral position.
DISCUSSION

Regarding the methods

Sensors

The sensors used in this study were capacitance sensors, which have advantages over common resistive sensors such as low noise, adaptability to curved surfaces and detectability of only changes compared with the initial state even if the sensor is disfigured on application. In addition, it is stable to temperature changes. As the diameter of the coaxial cable is small (0.3 mm), it does not interfere with lip closure during swallowing, can be led out of the mouth through the oral vestibule rather than being detoured around the distal aspect of the most distal molar, and has no marked effect on oral sensations. In addition, although the sensors were embedded in a frame for placement in many previous reports, they could be attached directly to the palate without using a frame in this study, making the experimental design simpler and not interfering with the range of motion of the tongue or the feel of the oral cavity. We allowed the subjects to get accustomed to the sensors after their placement by swallowing saliva. The experiment was only started after confirming with the subjects that they could swallow without difficulty.

Sensor positions

The sensor positions were determined based on reports in the literature. During swallowing, the tip of the tongue presses against the anterior of the palate and areas near the lingual surfaces of the necks of incisors, and is important as an anchor on the mandible in elevating the hyoid bone and larynx. Therefore, S1 was placed at the intersection between the line connecting the basal tubercles of the bilateral upper canines and the median line. S2 was placed at the intersection of the line connecting the distal surfaces of the bilateral upper second molars and the median line, because it should be placed outside the soft palate, and because movements of the posterior part of the tongue are important in transporting food into the pharynx. S3 was placed on the line connecting the distal proximal surfaces of the bilateral upper second molars asymmetrically with its center immediately below the neck on the left upper second molar, because the lateral regions of the tongue use the areas near the palatal necks of the molar regions as anchors for making a depression in the center of the tongue for bolus formation, and because no lateral difference is noted in the tongue pressure in healthy adults.
**Gulp volume**

Sensory tests on swallowing, have shown that it becomes more difficult both when the volume swallowed either decreases or increases from the optimal volume.\(^5\) In studies on the effects of the swallowed volume on the velopharyngeal closure function during swallowing, it was found that although activity of the levator veli palatine muscle did not correlate with the swallowed volume when the individual optimal volume was disregarded,\(^6\) it did correlate with the swallowing volume in innate individual ranges when that volume was changed from the optimum.\(^7\) These reports suggest that each subject has a different oral cavity capacity and an inherent optimal swallowing volume. If the same volume is swallowed by all subjects while ignoring individual differences in the optimal swallowing volume, tongue movements in habitual swallowing maneuvers may not be evaluated accurately. In this study, therefore, the optimal swallowing volume, or the volume that each subject could swallow in a relaxed state without making special efforts, was determined and used as the volume for the foods tested.

**Test food**

Since swallowing of liquid has been reported to be markedly affected by the body position,\(^8\) water was used as the test food to observe differences more clearly. Also, while capacitance sensors are considered to be relatively unaffected by temperature changes, to eliminate any effect of temperature changes the temperature of the water was adjusted to 37°C, close to body temperature, using a thermostatic bath based on the report by Murayama et al.\(^8\)

**Posture**

As for placing patients with severe swallowing disorder in the posteriorly inclined trunk position, Ohta\(^9\) observed that deglutition and respiratory muscles are closely related and that they are also involved in the maintenance of posture. For example, when a patient with a poor respiratory condition is brought into a 90° seated position, it fatigues the antigravity muscles, mobilizes the swallowing and respiratory muscles for maintaining posture, and makes swallowing and respiratory movements inadequate. This means that, from the viewpoint of systemic muscle tension, inclining the trunk is advantageous in that it relieves the muscles involved in swallowing from the burden of maintaining posture.

Currently, the 30° recumbent position, which is called the semi-Fowler's position, is considered suitable for the initiation of swallowing training.\(^3\) In this position, the trachea is located above the esophagus, and gravity can be utilized for food transport. The 60° recumbent position is called Fowler's position and is frequently used clinically as a position that causes less fatigue to the patient and facilitates treatment by therapists. The 90° seated position is usually considered best for meals. Evaluation was made in these three positions.

Concerning the neck angle, although many experiments have been carried out in the neutral and anteriorly flexed positions,\(^5\) 21-23 few are done in the anteriorly flexed/protruded position. By anteriorly flexing the neck, jaw movements during swallowing are restricted, and the anterior neck muscles are tensed. The pharyngeal cavity is also narrowed to interfere with the posterior and superior shift of the hyoid bone,\(^3\) making swallowing difficult. On the other hand, in the anteriorly flexed/protruded position, which is closest to the usual neck position during meals,\(^3\) no tension is caused in the anterior neck muscles. Although the pharyngeal cavity and piriform recess are widened, the airway orifice remains narrow. Therefore, this position was used in this study.

**Regarding the results**

**Maximum tongue pressure**

The pressures indicated by various sensors were significantly higher in S1 than in S2 or S3, similar to the report on tongue pressure by Ono et al.\(^5\) that used sheet type sensors. Although there have been reports that the pressure did not differ significantly with sensor placement,\(^4,9,16\) frames were used for placing the sensors in those reports.
The tip of the tongue is important as an anchor during swallowing.\textsuperscript{23} Since it touches the palate at the position of S1, a larger tongue pressure was expected to be registered by S1 placed at the anchor position of tongue movements. Indeed, in this study, in which the sensors were attached directly to the palate without using frames, and in studies using sheet type sensors, the pressure at S1 was significantly higher than that at S2 or S3. This suggests that, in this study, the tip of the tongue functioned as an anchor as usual. However, in studies using frames for sensor placement, the thickness and size of the frames are considered to have caused discomfort in the oral cavity and prevented the tongue from functioning in its usual manner, resulting in the absence of significant differences among the sensor sites. Therefore, measures to minimize discomfort are considered important for sensor placement.

The results obtained in this study showed that changes in the maximum tongue pressure resulted from changes in the neck and trunk angles. When the neck was in the neutral position, the tongue pressure registered by all sensors tended to decrease as the trunk was inclined from 90° to 60°, and to 30°. Tamura et al.\textsuperscript{18} also reported that the maximum tongue pressure at a position the same as S1 decreased significantly as the trunk angle was changed from 90° to 0°. However, when the neck position was changed from the neutral to the anteriorly flexed/protruded position, no decrease in the tongue pressure was observed in S1, S2 or S3 with inclination of the trunk. Inclination of the trunk with the neck maintained in the neutral position is thought to cause tension in the anterior neck muscles, i.e., the suprahyoid and infrahyoid muscles.\textsuperscript{3} Since the suprahyoid muscles are involved in elevating the hyoid bone during swallowing, restriction of their activities leads to restriction of tongue movements. This is thought to explain the progressive decrease in the tongue pressure with inclination of the trunk. However, in the anteriorly flexed/protruded neck position, the anterior neck muscles, which are tense in the neutral position, are relaxed,\textsuperscript{9} causing less restriction of tongue movements. In this study, also, the decrease in tongue pressure disappeared by changing the neck position to the anteriorly flexed/protruded position, supporting the above speculation.

**Duration of tongue pressure**

The duration of tongue pressure registered by S2 tended to be shorter than that registered by S1 or S3, similar to the reports by Murayama et al.\textsuperscript{8} and Ono et al.\textsuperscript{9} In transporting a bolus into the pharynx, the tongue pressure is generated first in the anterior regions of the tongue, then in the lateral regions, and finally in the posterior regions.\textsuperscript{8} This is considered to have resulted in the shorter duration of pressure at S2.

Also, when the neck was in the neutral position, the duration of tongue pressure decreased as the trunk was inclined. This was in agreement with the report that the duration of tongue pressure in swallowing liquid was shorter when the trunk was inclined compared with the upright seated position.\textsuperscript{25} In the anteriorly flexed/protruded position, however, the duration of tongue pressure was not affected by inclination of the trunk, similar to the situation with maximum tongue pressure. This was also in agreement with the report by Murayama et al. that the decrease in the tongue action time observed with posterior inclination of the trunk disappeared in the anteriorly flexed neck position.

In the neutral neck position, the anterior neck muscles involved in swallowing are made tense by inclination of the trunk, elevation of the tongue is restricted, and the duration of tongue pressure is shortened. As a sufficient duration of tongue pressure is reported to be necessary for the transport of a bolus,\textsuperscript{18} a posteriorly inclined trunk position may be regarded as disadvantageous for swallowing. However, as mentioned in the section on posture,\textsuperscript{19} the deglutition muscles can function sufficiently in a posteriorly inclined posture in consideration of the state of systemic muscles. Although posterior inclination of the trunk causes local disadvantages in swallowing such as shortening of the tongue pressure in the oral cavity, placing the neck in the anteriorly flexed/protruded position compensates for this
Effect. Thus, we confirmed that the anteriorly flexed/protruded neck position is safer than the neutral position for feeding patients in a posteriorly inclined body position.

CONCLUSION

The effects of the trunk and neck angles on the oral phase of swallowing were evaluated in 7 healthy dentulous individuals based on tongue dynamics by measuring the tongue pressure against the palate using touch sensors. In the neutral neck position, although decreases in the maximum tongue pressure and shortening of the duration of tongue pressure were observed by inclining the trunk, they disappeared in the anteriorly flexed/protruded neck position. These results suggest that the decrease in the maximum tongue pressure and shortening of the tongue pressure duration can be prevented by changing the neck position from the neutral position to an anteriorly flexed/protruded position.

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REFERENCES