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Original Article

Effect of tongue-hold swallow on pharyngeal cavity: kinematic analysis using 320-row area detector CT

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ABSTRACT
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Purpose: This study analyzed the effect of the tongue-hold swallow (THS) on the pharyngeal cavity during swallowing three-dimensionally using 320-row area detector computed tomography (320-ADCT). We hypothesized a greater decrease in pharyngeal volume with the THS than with the saliva swallow (SS); that is, the pharyngeal cavity would be more constricted with the THS.

Methods: The THS and SS were examined using 320-ADCT in six speech language pathologists (22−29 years old). Pharyngeal volume, hyolaryngeal displacement, and cross-sectional area of the upper esophageal sphincter (UES) were measured frame-by-frame and compared between the two swallows.

Results: Although some participants showed smaller pharyngeal volume with the THS than hypothesized, others showed larger pharyngeal volume. With the THS, the hyoid bone was positioned significantly higher at swallow onset, the hyoid and larynx were significantly higher at maximum superior displacement, and the cross-sectional area of the UES was significantly larger.

Discussion: No constant effect of the THS on pharyngeal volume was found. The THS may influence hyolaryngeal elevation and UES opening. Further study is necessary to consider the methodology of the THS, such as tongue protrusion length.

Key words: tongue-hold swallow, 320-row area detector CT, dysphagia

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Introduction

The tongue-hold swallow (THS) is one of the indirect swallowing exercises reported by Fujiu & Logemann [1] and involves swallowing saliva while holding the anterior part of the tongue between the upper and lower teeth. They proposed that the increase in pharyngeal wall bulging compensates for the reduced tongue base retraction during the swallow, which in turn may strengthen pharyngeal constriction [1, 2]. Because there are few indirect exercises to strengthen pharyngeal constriction, the THS has been widely used in swallowing rehabilitation. However, no consistent findings have been reported to date for the physiologic effect of THS exercise and there is currently insufficient evidence to establish the THS as a technique for strengthening pharyngeal constriction.

The conflicting findings of several studies that have analyzed pharyngeal pressure with the THS do not support the hypothesis that the THS increases pharyngeal constriction. Lazarus et al. performed manometry and videofluoroscopy (VF) in three patients with head and neck cancer and reported that the THS increased the magnitude and duration of pharyngeal pressure. They concluded that the THS was effective for pharyngeal constriction [3]. Umeki et al. used high-resolution manometry (HRM) and found that the THS tended to increase both nasopharyngeal and oropharyngeal pressure but not significantly [4]. On the other hand, Doeltgen et al. found with HRM that the THS decreased

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both oropharyngeal and hypopharyngeal pressure [5, 6]. Also using HRM, Hammer et al. found no difference in pharyngeal pressure between the regular saliva swallow (SS) and the THS [7].

Since Fujiu & Logemann first reported kinematic analysis using VF, few studies have reported the effect of the THS on structural movements during swallowing. This may be due to limitations of the method for analyzing the THS. Because the muscles targeted by the THS are the pharyngeal constriction muscles surrounding the pharyngeal cavity, not only the posterior pharyngeal wall, but also the lateral pharyngeal wall is affected by pharyngeal constriction. However, VF allows for only two-dimensional evaluation of the pharyngeal cavity and not three-dimensional (3D) kinematic analysis of the effect on the pharyngeal cavity.

The recently-developed 320-row area detector computed tomography (320-ADCT) enables 3D kinematic analysis during swallowing and quantitative measurement of structural movements [8−10]. It allows 3D analysis of the pharyngeal cavity and calculation of the pharyngeal constriction ratio by measuring the volume of the pharyngeal cavity. Therefore, it should be possible to clarify the kinematic effect of the THS by conducting a 3D quantitative analysis of the pharyngeal cavity by 320-ADCT.

In this study, we used 320-ADCT to determine the kinematic effect of the THS on the pharyngeal cavity by measuring the change in pharyngeal volume, distance of hyolaryngeal elevation, cross-sectional area of the upper esophageal sphincter (UES), and its opening duration. We hypothesized that the volume of the pharyngeal cavity would decrease more with the THS than with the regular SS; that is, pharyngeal volume would be smaller with the THS than with the regular SS.

Methods

1. Participants

Six speech language pathologists who were able to perform the THS as instructed (all female; 22−29 years old) were recruited for this study. They had no history of dysphagia, were following a regular diet, and were independent in daily living. All provided informed consent to participate in the study following comprehensive explanation of the study's purpose and procedure. This study was approved by the institutional review board at our university (HM16-135).

2. Procedure

2.1 CT imaging

A 320-ADCT scanner (Aquilion ONE vision; Canon Medical Systems, Otawara, Japan) was used for imaging. The gantry was tilted 30° and the customized offset-sliding CT chair (eMedical Tokyo, Chuo-ku, Japan; Tomei Brace, Seto, Japan) was positioned on the opposite side of the CT table. The participants were first seated on the chair, the reclining angle of the chair was adjusted to 45°, and then the scanning structures were positioned to the right of the scanner by sliding the chair posteriorly. The participants started one SS and then one THS upon the examiner's verbal cues, and one scan was performed for each swallow. The THS instruction was "Protrude your tongue between your front teeth. Hold it in place by gently biting down on the anterior part of the tongue and swallow while maintaining this posture," which follows that described in the "Summary of Swallowing Exercises" published in 2014 by the Japanese Society of Dysphagia Rehabilitation.

The scanning parameters were scanning range 160 mm from the skull base to the upper esophagus, scanning duration 2.2−3.3 s for each swallow using 8−12 rotations of the gantry (0.275 s/1 rotation of the gantry), tube voltage 120 kV and current 40 mA.

The radiation dose was DLP 219.3 mGy and the effective dose was 1.08 mSv per swallow, which was equivalent to 1−5 min of videofluoroscopy [11]. To minimize the radiation dose, the scanning duration was adjusted for each participant according to swallowing duration, which was measured beforehand.

2.2 Image reconstruction

To generate the images, a half reconstruction technique was used and 22−33 image phases were created at 0.10-s intervals over 2.2−3.3 s (10 frames/s). Multiplanar reconstruction images and 3D-CT images were created using the 320-ADCT software. The air column surface was depicted with a window level of <300 HU, and the hyoid bone and cranial bones were depicted with a window level of >450 HU [12].

2.3 Measurement of pharyngeal volume

The air space of the pharyngeal cavity was viewed on 3D-CT images and its volume was measured using the scanner software.

The borders of the pharyngeal cavity were defined as follows: 1) superior–axial through the anterior nasal spine and posterior nasal spine (PNS) parallel to the infraorbital line, then diagonally from the PNS to the anterior arch of the atlas; 2) anterior–coronal from the PNS perpendicular to the superior plane; and 3) inferior–axial through the superior surface of the true vocal cords, inferior edge of the pyriform sinus, and above the pharyngoesophageal segment (Figure 1). As a reference time for swallow onset, time 0 was defined as the onset of rapid anterosuperior movement of the hyoid bone and the volume of the pharyngeal cavity was measured at every frame. The change in pharyngeal volume throughout the swallow and two integral volumes were compared between the SS and the THS: 1) from −0.3 to 0 s (swallow onset) and 2) from 0 s (swallow onset) to the time of minimum pharyngeal volume.

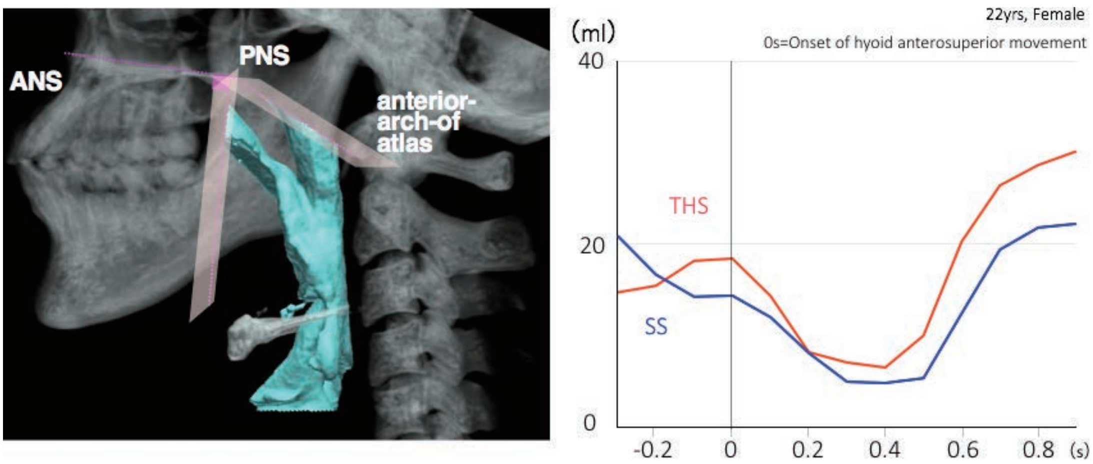

Figure 1. Method of measuring pharyngeal volume.
3D-CT images were used for measurement.
Left and right orbitomeatal base lines were adjusted in parallel, and upper, anterior, and lower borders were defined.
Upper border: Superior-axial through the anterior nasal spine and posterior nasal spine (PNS) parallel to the infraorbital line, then diagonally from the PNS to the anterior arch of the atlas.
Anterior border: Anterior-coronal from the PNS perpendicular to the superior plane.
Lower border: Inferior-axial through the superior surface of the true vocal cords, inferior edge of the pyriform sinus, and above the pharyngoesophageal segment.
Right graph shows the change of pharyngeal volume measured at every frame using the calculation software of the workstation. X axis is time and Y axis is volume.
SS, Saliva swallow; THS, Tongue-hold swallow.

2.4 Measurement of hyoid and laryngeal displacement

An x-y coordinate system was used for measurement. The origin (0, 0) is the anterior-superior corner of the fourth cervical vertebra (C4), the y-axis lies in the plane made by the anterior-inferior corner of the second cervical vertebra and anterior-superior corner of C4, and the x-axis lies in the plane perpendicular to the y-axis and crosses the origin. The hyoid bone and larynx were tracked frame-by-frame during swallowing. The anterior-superior corner of the symphysis was set as the anatomical landmark for the hyoid bone, while the center of the laryngeal prominence was set as the landmark for the larynx. Maximum anterior displacement for both the hyoid and larynx was calculated as the difference from the starting position to the most anterior position. Maximum superior displacement was calculated as the difference from the starting position to the most superior position.

2.5 Measurement of duration of UES opening and cross-sectional area of UES

The UES was identified on axial sections at the level of the lower aspect of the thyroid cartilage, parallel to the true vocal cords. The cross-sectional area of the UES was measured frame-by-frame during UES opening using the calculation software of the workstation. Among the calculated areas, the maximum cross-sectional area was identified.

3. Statistical analysis

Wilcoxon's signed-rank test was used for comparing hyolaryngeal displacement, duration of UES opening, and cross-sectional area between the SS and THS. Statistical significance was set at $p<0.05$. SPSS ver. 22.0 was used for analysis.

Results

1. Volume of pharyngeal cavity

Pharyngeal volume in both the THS and SS decreased rapidly immediately after swallow onset, but there were differences between participants (Figure 2). Participants 1 and 2 showed smaller pharyngeal volume with the THS than with the SS from before the onset of hyoid anterosuperior movement and throughout swallowing. Participants 3, 4, and 5 showed greater laryngopharyngeal volume with the THS than with the SS before swallow onset and throughout swallowing. Participant 6 showed larger pharyngeal volume before swallowing but an earlier decrease in pharyngeal volume with the THS than with the SS.

There were also differences between participants in the integrated volume from −0.3 s to swallow onset and from swallow onset to minimum pharyngeal volume (Figures 3, 4). Some showed decreased pharyngeal volume with the THS, whereas others showed an increase. When comparing the shape of the pharyngeal cavity at the onset of anterosuperior movement of the

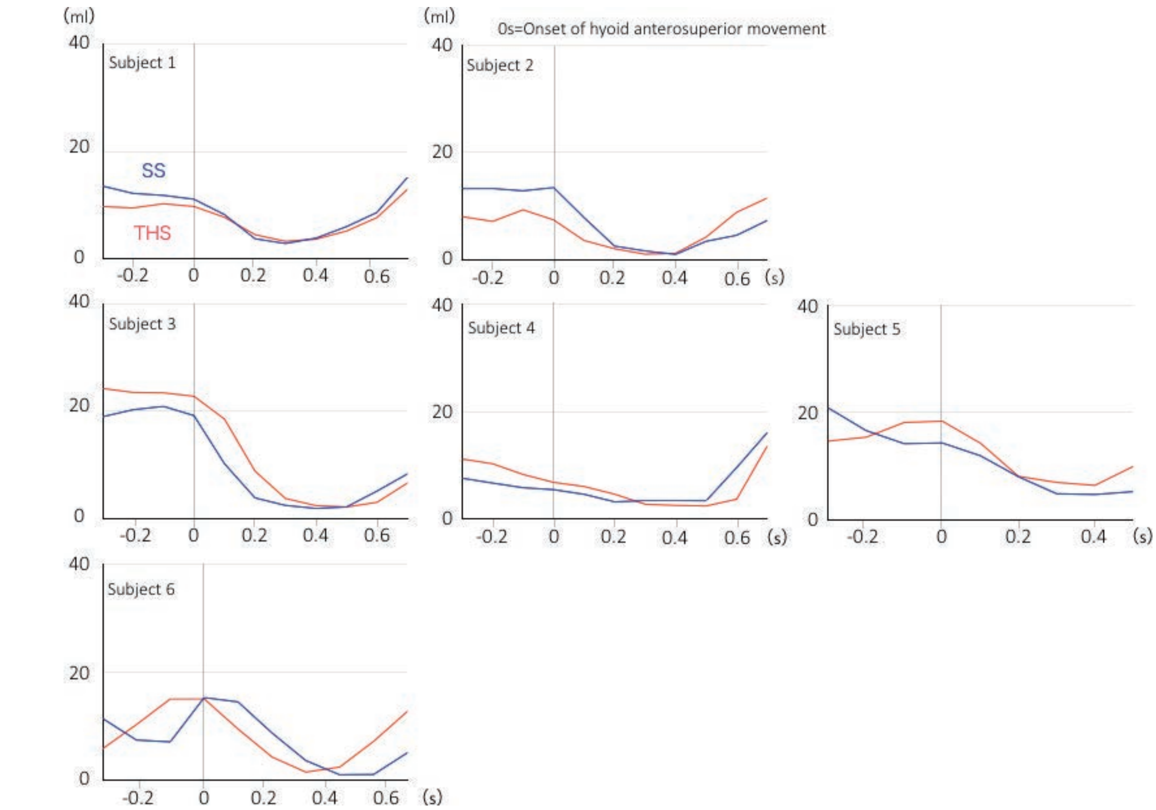

Figure 2. Pharyngeal volume change for six subjects.
Upper: Subjects who showed smaller pharyngeal volume with THS than with SS from before swallow onset and throughout swallowing.
Middle: Subjects who showed greater pharyngeal volume with THS and with SS before swallow onset and throughout swallowing.
Lower: Subject who showed another pattern.
SS, Saliva swallow; THS, Tongue-hold swallow.

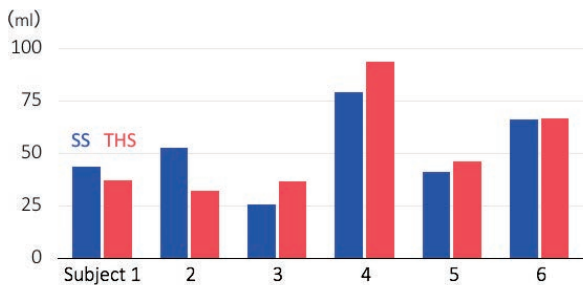

Figure 3. Integral volumes from −0.3 to 0 s (swallow onset).
SS, Saliva swallow; THS, Tongue-hold swallow.

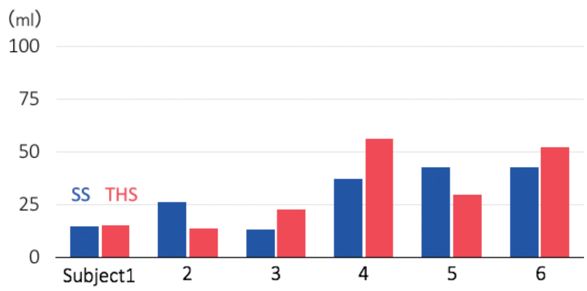

Figure 4. Integral volumes from 0 (swallow onset) to the time of minimum pharyngeal volume.
SS, Saliva swallow; THS, Tongue-hold swallow.

hyoid (Figure 5), the anteroposterior diameter was shorter in some participants and longer in others. Similarly, some participants showed a shorter lateral diameter, whereas others showed a longer lateral diameter. Similar to volume, anteroposterior and lateral distances varied between participants. These results do not support our hypothesis that pharyngeal volume is smaller with the THS than with the SS.

2. Hyolaryngeal displacement (Table 1)

At swallow onset, there was no significant difference in the forward position of the hyoid between the two swallows, but the hyoid was positioned significantly higher with the THS than with the SS (p=0.001); the hyoid was located 29.3±2.5 mm forward and 17.7±5.7 mm upward from the anterosuperior corner of C4 with the THS vs 30.4±1.5 mm forward and 14.1±6.1 mm upward with the SS. There was also no significant

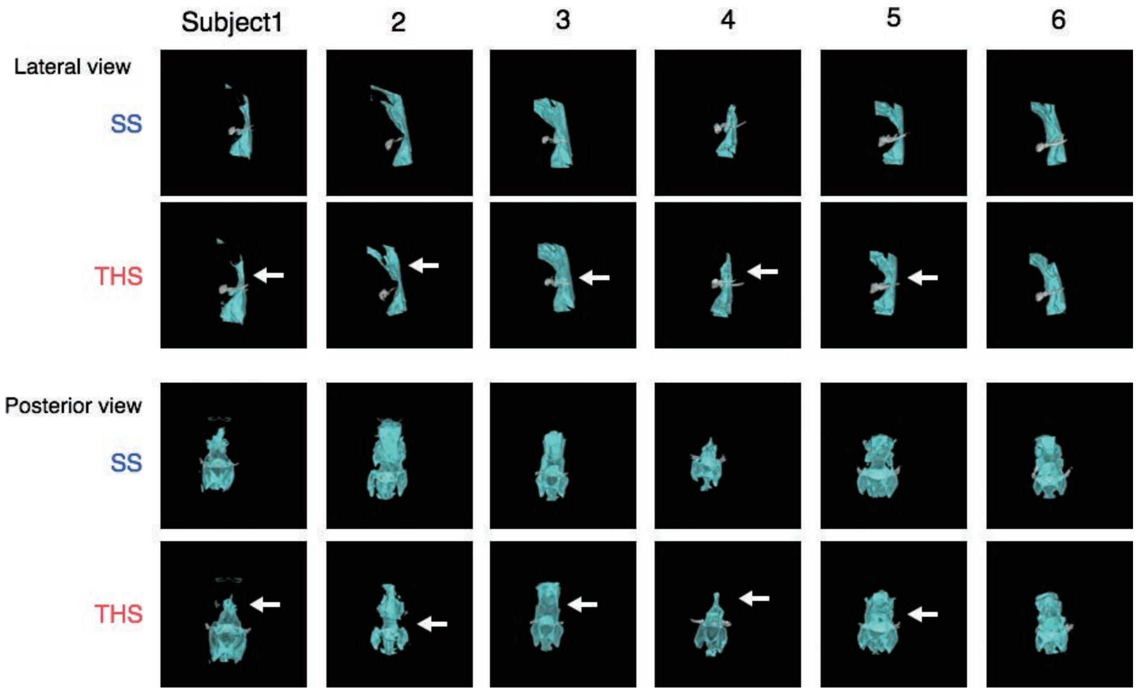

Figure 5. 3D-CT images of pharyngeal cavity for six subjects.
Arrows show the pharyngeal parts of which SS and THS look different.
In subject 1, the pharyngeal cavity seemed larger in the lateral view (lateral antero-posterior distance), however, it seemed smaller in the posterior view (smaller lateral distance).
SS, Saliva swallow; THS, Tongue-hold swallow.

Table 1. Hyoid and larynx movement.

			SS	THS	*p*-Value
Hyoid	Forward	Swallow onset	30.4±1.5	29.3±2.5	0.25
		Maximum anterior position	41.6±0.7	41.8±1.1	0.60
		Maximum anterior displacement	11.3±1.7	12.3±2.6	0.23
	Upward	Swallow onset	14.1±6.1	17.7±5.7	<0.01*
		Maximum superior position	17.1±6.5	20.4±7.6	<0.01*
		Maximum superior displacement	3.7±2.6	3.6±3.5	0.60
Larynx	Forward	Swallow onset	26.6±2.3	25.4±3.1	0.25
		Maximum anterior position	29.1±2.2	29.5±2.7	0.46
		Maximum anterior displacement	2.5±0.8	4.1±1.8	0.22
	Upward	Swallow onset	19.7±4.0	20.5±5.6	0.11
		Maximum superior position	32.1±5.1	35.1±5.0	0.04*
		Maximum superior displacement	12.4±2.6	14.6±3.6	0.02*

difference in maximum anterior position between the two swallows, but the maximum superior position was significantly higher with the THS (p=0.001; maximum anterior location 41.8±1.1 mm with the THS vs 41.6±0.7 mm with the SS; maximum superior location 20.4±7.6 mm with the THS vs 17.1±6.5 mm with the SS). Neither anterior nor superior displacement differed between the swallows (anterior displacement: 12.3±2.6 mm with the THS vs 11.3±1.7 mm with the SS; superior displacement: 3.6±3.5 mm with the THS vs 3.7±2.6 mm with the SS).

The larynx at swallow onset was located forward and upward from the anterosuperior corner of C4 at 25.4±3.1 mm and 20.5±5.6 mm, respectively, with the THS and at 26.6±2.3 mm and 19.7±4.0 mm, respectively, with the SS. There was no significant difference in maximum anterior location of the larynx between the two swallows, but it was located significantly higher at the maximum position with the THS than with the SS (p=0.04; maximum anterior location: 29.5±2.7 mm with the THS vs 29.1±2.2 mm with the SS; maximum superior location: 35.1±5.0 mm with the THS vs 32.1±5.1 mm with the SS). Superior displacement of the larynx was significantly larger with the THS than with the SS (p=0.02; 14.6±3.6 mm vs 12.4±2.6 mm, respectively). However, there

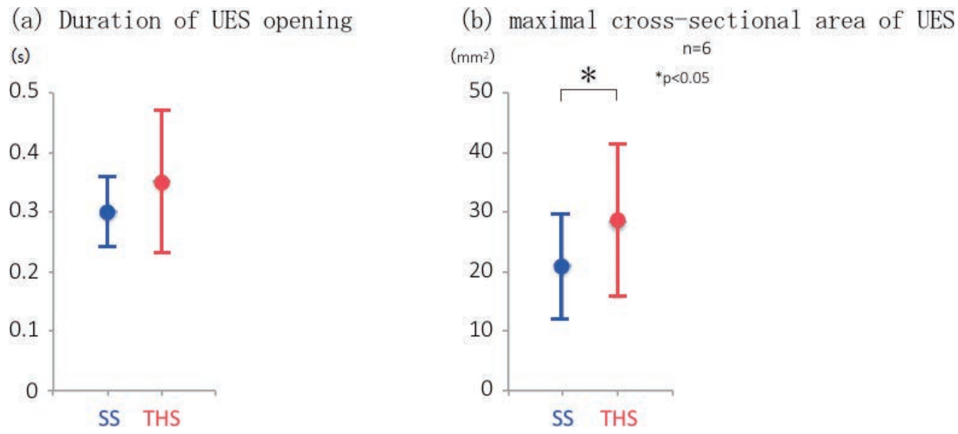

Figure 6. Duration of UES opening and maximum cross-sectional area of UES.
(a) Duration of UES opening; (b) maximum cross-sectional area of UES.
SS, Saliva swallow; THS, Tongue-hold swallow.
*p-Value by Wilcoxon's test ($p<0.05$).

was no significant difference in anterior displacement of the larynx between the two swallows (4.1±1.8 mm vs 2.5±0.8 mm, respectively).

3. UES opening duration and cross-sectional area of UES (Figure 6)

Although UES opening tended to be longer with the THS than with the SS, the difference was not significant (p=0.15; 0.36±0.10 s vs 0.30±0.06 s, respectively). The maximum cross-sectional area of the UES was significantly larger with the THS than with the SS (p=0.03; 28.4±12.8 mm^2 vs 20.8±8.9 mm^2, respectively).

Discussion

In this study, we analyzed the kinematic effect of the THS on the pharyngeal cavity by measuring pharyngeal volume, hyolaryngeal movement, and UES opening duration and cross-sectional area using 320-ADCT.

1. Pharyngeal volume change

The pharyngeal cavity is surrounded by the base of the tongue and the pharyngeal wall. Tongue base retraction and pharyngeal constriction during swallowing exert a force that transports the bolus into the esophagus. The THS may reduce tongue base retraction by anchoring the protruded tongue and to compensate for this, the anterior posterior pharyngeal wall bulges.

We hypothesized that pharyngeal volume would decrease as the pharyngeal posterior wall approaches the base of the tongue during the THS, and it is this decreased volume that contributes to pharyngeal constriction. We confirmed our hypothesis in a few participants whose pharyngeal volume decreased with the THS compared with the SS, but pharyngeal volume unexpectedly increased in some participants. Therefore, we are unable to conclude that the pharyngeal cavity is more constricted with the THS than with the SS. However, the differences we observed in pharyngeal volume and pattern of volume change between the THS and SS indicate that the effect on the pharyngeal cavity with the THS may be different from that with the SS.

Fujiu reported that although anterior bulging of the posterior pharyngeal wall tended to increase with the THS, between-subject variability was evident [13]. The results of studies investigating pharyngeal pressure using HRM have also been inconsistent, with some researchers reporting an increase in pharyngeal pressure, others reporting no pressure change, and yet others reporting a decrease in pressure [3−7]. Such discrepancies may be due to between-subject variability in effects on the pharynx, as seen in our study.

One possible explanation for the individual differences we observed in pharyngeal volume concerns the THS instruction given: "Protrude your tongue between your front teeth. Hold it in place by gently biting down on the anterior part of the tongue and swallow while maintaining this posture." This may not have been sufficient to limit tongue base retraction because the instruction was not specific enough. As a result, some of our participants did not show changes in the posterior pharyngeal wall and decreased pharyngeal volume. In support of this notion, Fujiwara et al. found, using a tongue pressure sensor, that tongue protrusion length influenced increases or decreases in tongue pressure with the THS. Thus, adjustment of tongue protrusion length is an important component of the THS [14]. The THS limits tongue motion due to protrusion and promotes compensational movement of the posterior pharyngeal wall. For greater protrusions, the tongue is positioned more anteriorly, which triggers anterior movement of the posterior pharyngeal wall and results in larger momentum. This therefore suggests that adjusting tongue protrusion length is critical to accurately understanding the effect of the THS on pharyngeal volume.

2. Hyolaryngeal movement and cross-sectional area of UES

The hyoid bone was located significantly higher at swallow onset and its maximum elevation position was significantly higher with the THS than with the SS. Laryngeal superior displacement was also significantly larger with the THS. These results can be interpreted to have occurred because of hyoid superior excursion accompanying tongue protrusion. Moreover, by holding the tongue between the incisors, the hyoid bone may be anchored more strongly, which might facilitate greater laryngeal elevation and thus result in increased superior displacement of the larynx. This increased superior displacement could also explain the significant increase in the cross-sectional area of the UES with the THS.

Oh et al. compared hyolaryngeal elevation after 4 weeks of training between a THS practice group and a normal swallow practice group. They found no difference in hyolaryngeal elevation between the two groups and concluded that the THS does not affect hyolaryngeal elevation during swallowing [15]. In our study, however, comparison of the kinematics between the THS and SS suggested that the THS may facilitate the superior movement of the hyolarynx because the hyoid and larynx were positioned more superiorly with the THS than with the SS. We also found that when the cross-sectional area of the UES was larger, hyolaryngeal elevation was increased with the THS. To the best of our knowledge, no studies have yet reported the effect of the THS on UES opening. Our findings that not only pharyngeal constriction, but also hyolaryngeal elevation and UES opening change with the THS may be important in clinical practice. Further study is needed to analyze the effect of the THS on hyolaryngeal elevation and UES opening by adjusting tongue protrusion length.

There were some limitations in this study. First, our protocol was limited to one SS scan and one THS scan for each participant in order to minimize the potential risk associated with radiation exposure. All participants were speech language pathologists who were knowledgeable about the THS and were familiar with its methodology, and thus variability was expected to be small between trials. In future, however, it will be necessary to minimize variability between trials by ensuring that participants practice the THS sufficiently before scanning. The second limitation was the 45° reclining posture during scanning, which was the only position technically feasible with 320-ADCT. Generally, the reclining posture, which changes the angle of the trunk, is used to facilitate bolus transport to the pharynx. The effect of posture is an important consideration during swallowing. Because food is not used with the THS, the influence of the reclining posture on the results was probably low. However, we cannot eliminate the possibility that gravity may have altered the positional relation of swallowing structures.

In future, tongue protrusion length should be adjusted and the effect of the THS on pharyngeal volume change, hyolaryngeal movement, and UES opening should be addressed to clarify whether the THS is effective for strengthening pharyngeal constriction and to determine the optimal THS methodology. Moreover, the effect of the THS in patients with dysphagia needs to be analyzed in order to comprehensively understand its feasibility in this population.

Conclusion

We analyzed the effect of the THS on swallowing kinematics. Pharyngeal volume differed with the THS compared with the regular SS. This suggests that the THS influenced the pharyngeal cavity in some way, but we could not identify a clear trend. To clarify the effect of the THS on the pharyngeal cavity, more specific THS instruction is recommended. Our study also revealed the potential effect of the THS on hyolaryngeal elevation and UES opening.

Acknowledgments

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