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Evaluation of swallowing movement using ultrasonography

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Abstract

The aim of this study is to develop an index to assess swallowing function by ultrasonography in order to evaluate the relationship between movements of the hyoid bone and the larynx while swallowing water. Forty-two younger participants (mean age, 20.3 ± 3.4 years) and 42 older participants (mean age, 75.1 ± 10.6 years) with normal swallowing function were included in the study. Movements of the hyoid bone and the larynx while swallowing 5 mL of water were observed using ultrasonography.

Two-dimensional distances from the starting points of the hyoid bone and the larynx to their points of maximum movement were measured as displacements. The hyoid bone–laryngeal motion ratio was defined as the hyoid bone displacement divided by the laryngeal displacement. Parameters were compared among four groups: younger male, younger female, older male, and older female. The hyoid bone displacement differed significantly between the younger and older groups, and the laryngeal displacement differed significantly between age groups and sexes. The hyoid bone–laryngeal motion ratio was not significantly correlated with age, height, or body weight, and did not show a significant difference between the four groups. Thus, the hyoid bone–laryngeal motion ratio is an index that evaluates swallowing movement and is independent of physique and physiological

changes associated with aging.

Keywords: ultrasonography, hyoid bone, laryngeal movement, swallowing movement, hyoid bone–laryngeal motion ratio

1 Introduction

The clinical investigation of swallowing disorders typically involves a swallowing screening test followed by a close examination of swallowing function by video fluoroscopy (VF), which is considered the gold standard [1,2]. As well as showing aspiration, VF can also show the movement of the oral cavity, the pharynx, and the esophagus and is used to elucidate the regulatory mechanisms of the various organs involved in swallowing [3]. Swallowing training programs can be designed based on the food form, swallowing method, and posture for ingestion appropriate to the pathology and severity of the patient's swallowing disorder. However, there are many risks associated with VF such as radiation exposure and the danger of aspirating the contrast medium; thus, its use is not straightforward, even at medical facilities [4]. Dysphagic patients may be encountered in settings other than medical practice, such as nursing care facilities and private residences [5]. Therefore, there is a need for diagnostic techniques of swallowing disorders suitable in these settings. In this study, we focused on the evaluation of swallowing function by ultrasonography (US) which can be performed in a patient's home and used at the bedside without radiation exposure or the danger of aspiration of the contrast medium.

Previous studies on the evaluation of swallowing function by

US [6-10] showed that movement of the hyoid bone and the larynx could be quantitatively evaluated by visualizing the dynamics of the various organs related to swallowing. Because normal swallowing movement is confirmed by the appropriate movement of the hyoid bone and the larynx [3,11], assessing the coordinated movement of these organs is important for evaluating swallowing movement. Only hyoid bone movement and not the larynx movement or the coordination of both, was evaluated in previous studies. The present study reviews previous methods for evaluating swallowing movement by US and proposes a new index to evaluate swallowing-related muscle coordination.

2 Materials and Methods

2.1 Participants

The participants included 42 healthy younger and 42 healthy older individuals with no medical history of any disease of the head and neck region that influenced ingestion. The participants were divided by sex and age into four groups: younger male, younger female, older male, and older female. A speech therapist with 5 years of experience with image US examined their swallowing movements.

The study was approved by the Research Ethics Committee of Kansai University of Welfare Sciences (Approval number: 17-64).

Written informed consent was provided by the participants.

2.2 Visualization of movement of the hyoid bone and larynx

The participant assumed a posture with the neck in a neutral position such that a line from the acromion to the opening of the ear canal was at 100°–110° to the horizontal plane (Figure 1). To minimize movement during the measurements, the head and the neck were stabilized in this position using an immobilization device (Figure 1).

A 5- to 12-MHz linear probe (Digital Color Doppler Ultrasound System JS2; SonoScape Medical Corp, Centennial, CO, USA) was attached to the left or right plate of the thyroid cartilage, taking care to avoid disturbing the laryngeal elevation while swallowing. Image US was directed toward the anterior angle of the thyroid cartilage to visualize the movement of the larynx while swallowing. The caudal and cranial sides were displayed on the right and left sides of the US monitor, respectively. The superior end of the thyroid cartilage was displayed on approximately one-third of the right side of the monitor, with the image adjusted to visualize the hyoid bone and larynx. The hyoid bone was identified as a high echoic area with posterior acoustic shadow by the echo scan. The measurement point was the tip of the caudal hyoid bone, and the monitor displayed the cranial portion on the left and the caudal portion on the right. The thyroid cartilage was identified as a low echoic area by US. The measurement point was the tip of the cranial thyroid cartilage (Figure 2).

The participants swallowed 5 mL of cold water and the movements of the hyoid bone and the larynx were visualized by US, acquiring images at a frame rate of 54 fps. This was performed three to five times. Three of these image sets, in which the movements of the hyoid bone and larynx could be sufficiently tracked, were selected for the analysis.

2.3 Image analysis and parameter measurement

The acquired images were converted into audio video interleave format and transferred from the US device's hard drive to a personal computer, where they were analyzed using two-dimensional data analysis software (Dipp Motion Ver 1.1.31; DITECT Co, Tokyo, Japan). Markers were set at the anterior inferior margin of the hyoid bone and the uppermost end of the larynx, and measurement points were automatically tracked in each frame using the tracking function of the analysis software. Vertical and anteroposterior directions were considered to be the x- and y-axes, respectively, and the distances moved in these directions were measured. When the hyoid bone movement was accompanied by an instantaneous shadow, this was corrected manually.

The swallowing movement was measured from the initiation of the laryngeal elevation to the completion of the downward laryngeal movement. The hyoid bone displacement and the laryngeal displacement were defined by the two-dimensional maximum distances of the hyoid bone and the larynx movements from their starting points (Figure 3). The elevation and descending phases were defined as the period from the starting point to the position of maximum movement and the period from this position back to the resting position, respectively. The hyoid bone and the laryngeal displacements were measured in both elevation and descending phases. In addition, an index of swallowing, the hyoid bone–laryngeal (HL) motion ratio, was calculated as the hyoid bone displacement (elevation phase) divided by the laryngeal displacement (elevation phase).

The height and body weight of each participant were also recorded as basic information. Table 1 summarizes the participants' physical characteristics for the four groups based on sex and age.

2.4 Statistical analysis

Pearson's correlation analysis was used to evaluate correlations among the participants' physical characteristics and hyoid bone displacement, laryngeal displacement, and HL motion ratio. One-way analysis of variance was used to evaluate differences in the hyoid bone displacement, the laryngeal displacement, and the HL motion ratio among the four groups. Tukey's method was used for post hoc multiple comparisons. The statistical analysis was performed using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp., Armonk, NY, USA), and the significance level was set at $p < 0.05$.

3 Results

Table 2 summarizes the Pearson correlation coefficients for the correlations between the swallowing parameters (the hyoid bone displacement, the laryngeal displacement, and the HL motion ratio) and the participants' heights and body weights. Both the hyoid bone and the laryngeal displacements showed significant positive correlations with height, indicating that displacement increased with height. The hyoid bone displacement during the descending phase and the laryngeal displacement during the elevation phase showed significant positive correlations with body weight. The HL motion ratio showed no significant correlations with height or weight.

Figure 4 summarizes the comparisons of the swallowing parameters between the four groups based on sex and age. There were significant differences between two or more groups for the hyoid and the laryngeal displacements during both the elevation and descending stages. In contrast, the HL motion ratio showed no significant differences among the four groups.

Together, these findings suggest that the HL motion ratio index was independent of height, weight, sex, and age.

4 Discussion

The evaluation of swallowing function by VF can be used to assess the various organs involved in swallowing and the presence or absence of aspiration. However, VF has a number of associated risks, such as radiation exposure and the danger of aspiration of contrast medium. There are also various restrictions and conditions regarding equipment and personnel. These risks and restrictions can make it difficult to perform VF in individuals in nursing care facilities and private residences. Image US is simpler to use and less invasive than VF, and the hyoid bone and the laryngeal motion analysis by US images provides data that are consistent with those obtained by VF [9,12,13]. For these reasons, we used US in this study to measure the movement of the hyoid bone and the larynx.

4.1 Evaluation of swallowing movement by US

When VF and US were compared in the present study, the presence or absence of aspiration was observed by VF, but not in evaluations of swallowing function by US. However, US allows visualization of muscle movement and cartilage components. VF is used to assess swallowing in clinical settings, however it has a number of limitations, such as practicality and the exposure of patients to radiation. Image US is widely used in clinical practice because of its low cost, safety, and speed, and because there is no radiation exposure. In addition, because it is non-invasive, US can be performed repeatedly as required. Image US can be used to evaluate the movement of soft tissue, such as muscles and tendons, in real-time. Thus, useful information can be obtained in clinical practice by evaluating dynamic US images during muscle contraction. Many techniques using US to examine swallowing function have recently been reported [7,9,10]. For example, it is possible to measure muscle dynamics related to the hyoid bone using an evaluation method that combines the M and B modes [8] and Doppler function [6]. In previous studies, swallowing function was evaluated mainly by focusing on the hyoid bone. In the present study, we confirmed the coordinated movement of the hyoid bone and the larynx during swallowing and also constructed a movement index indicating the swallowing function of a healthy subject. We certainly consider that this indicates innovation in the evaluation of swallowing function by US. Although VF is the gold standard for confirming suspected dysphagia [1, 2], an evaluation of swallowing by US as well as VF could facilitate the appropriate management of swallowing function.

4.2 Hyoid bone movement

VF has been used to measure the hyoid bone movements while swallowing [3,11], during which, the hyoid bone moves upward in the early phase, then forward, and finally downward to return to the resting position [14]. Recently, Okada et al. [15] analyzed the length of the suprahyoid muscles using 320-row area detector computed tomography and observed that forward movement of the hyoid bone and the thyrohyoid muscle contraction occurred simultaneously. In the present study, the measurement starting point was set at the initiation of the laryngeal elevation, and the hyoid bone displacement during the elevation phase was considered to correspond to the forward movement of the hyoid bone. In Okada et al.'s study [15], the mean distance of forward movement of the hyoid bone measured in 26 healthy men was 12.8 ± 5.0 mm; in comparison, the hyoid bone displacement during the elevation phase in the 18 younger male participants in the present study was 12.3 ± 2.4 mm. In a study using VF [16], the mean distance of forward movement of the hyoid bone while swallowing 5 mL of cold water, measured in 20 older adults, was 11.7 ± 5.5 mm. In the present study, the mean hyoid bone displacement during the elevation phase in the two older groups was 9.9 ± 4.7 mm. Thus, our results were consistent with those of previous studies.

4.3 Laryngeal movement

Previous studies by VF have reported the laryngeal elevation while swallowing to be approximately 20–30 mm [17,18]. In comparison, the mean laryngeal displacement during the elevation phase in the present study was 23 mm in the younger groups and 19 mm in the older groups. Logemann et al. [1] noted that the laryngeal elevation decreased in older adults compared to younger people, consistent with the finding of the present study using US. In our study, there was a significant difference in laryngeal displacement during the elevation phase between the younger male group and the two older groups. There was also a significant difference between the younger and older female groups, but no significant difference between the younger female group and the older male group. Laryngeal displacement correlated positively with height, and the mean height of the younger female group was lower than that of the younger male group. Therefore, the laryngeal displacement may have been influenced by both height and sex. When measuring the laryngeal elevation by VF, it is possible to calculate the position of the larynx relative to the cervical spine [1,19]. The larynx descends relative to the cervical spine in older people [1], and it is thought that the laryngeal elevation increases to compensate for this, to maintain swallowing function. The significant difference in the laryngeal displacement between the younger female and older male groups may therefore be the result of the older male participants being taller than the younger female participants along with an increase in laryngeal elevation to compensate for the lower position of the larynx.

4.4 HL motion ratio

The stylohyoid, the digastric, and the mylohyoid muscles mainly function during the upward movement of the hyoid bone, whereas the geniohyoid muscle mainly acts during the forward movement of the hyoid bone [15]. During normal swallowing, the infrahyoid muscles act antagonistically to the upward movement of the hyoid bone. The forward movement of the hyoid bone and the laryngeal elevation occur simultaneously while the hyoid bone position is stably fixed by antagonism between the supra- and the infrahyoid muscles. The distance of the hyoid bone displacement measured in the present study corresponded to the distance of the forward movement of the hyoid bone. Therefore, the HL motion ratio is a potential index of the degree of coordination between the geniohyoid muscle moving the hyoid bone forward and the thyrohyoid muscle elevating the larynx. No significant difference in HL motion ratio while swallowing was observed among the four participant groups, suggesting that, for people with normal swallowing function, the relationship between the laryngeal elevation and the distance the hyoid bone moves forward is not influenced by age or sex. Age-associated physiological changes vary markedly among individuals. In addition, several factors influence the swallowing function of older people [1,16,20]. When evaluated individually, there were significant differences in the hyoid bone and laryngeal displacements between the younger and older groups and between male and female participants, suggesting an influence on these parameters of physiological changes associated with age and height. Conversely, such influences may be excluded from evaluations based on the HL motion ratio. The value of HL motion ratio for normal swallowing is approximately 0.5.

4.5 Limitations of this study and future prospects

This study had some limitations. Only two age groups were investigated and the number of participants was insufficient to clarify how the characteristics of swallowing movements changed with age. Furthermore, only healthy participants were included in the study. We intend to investigate whether the HL motion ratio could serve as a reference index in experiments with participants that include those with swallowing disorders.

5 Conclusion

The hyoid bone and the laryngeal displacements while swallowing were measured in groups of healthy younger and older people. The results suggested that the HL motion ratio, an innovative index calculated as the hyoid bone displacement during the elevation phase divided by the laryngeal displacement during the elevation phase, is 0.5 for normal swallowing. This index is independent of physiological changes associated with height and age.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were performed in accordance with the Research Ethics Committee of Kansai University of Welfare Sciences (Approval number: 17-64) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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Informed consent: Written informed consent was obtained from all participants for publication of this case report and accompanying images.

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Table 1 Characteristics of participant groups

	Younger group (n = 42)		Older group (n = 42)	
	Male (n = 18)	Female (n = 24)	Male (n = 18)	Female (n = 24)
Age (years)	20.5 ± 4.6	20.1 ± 2.5	76.5 ± 7.6	74.0 ± 12.4
Height (cm)	171.3 ± 6.3	157.8 ± 5.0	159.6 ± 10.0	149.8 ± 5.8
Weight (kg)	64.0 ± 11.8	50.2 ± 5.7	55.8 ± 7.6	54.2 ± 11.5

Data are presented as the mean ± SD

Table 2 Correlations between swallowing parameters and participants' height and weight

		Height		Weight	
		r	*p*	*r*	*p*
Hyoid bone displacement	Elevation phase	0.407	0.000**	0.159	0.143
	Descending phase	0.426	0.000	0.367	0.001**
Laryngeal displacement	Elevation phase	0.575	0.000	0.283	0.008**
	Descending phase	0.493	0.000	0.148	0.175
	HL motion ratio	-0.130	0.232	-0.154	0.157

* $p < 0.05$; ** $p < 0.01$. *r*, correlation coefficient *p*, probability HL, hyoid bone–laryngeal

Figure legends

Fig. 1 Method for immobilizing the head and neck for the measurements. The head was positioned with the line between the acromion and opening of the ear canal at an angle of 100–110° to the horizontal plane.

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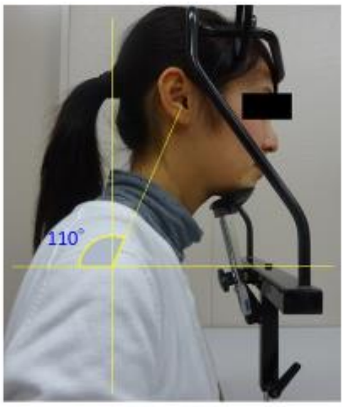

Fig. 2 (A) Probe position showing the hyoid bone and the larynx at the frontal plane. (B) The measurement points for the hyoid bone and the thyroid cartilage are indicated by asterisks.

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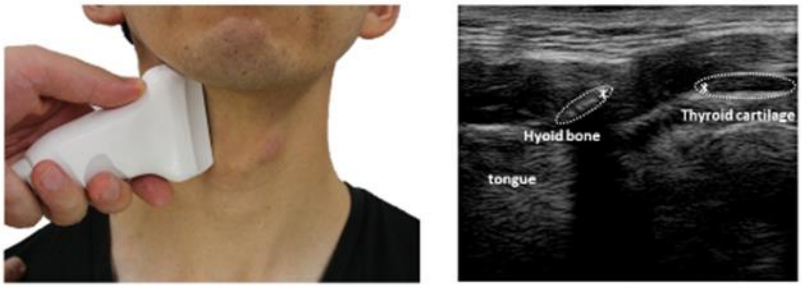

(A) (B)

Fig. 3 Visualization of the hyoid bone and the larynx by ultrasonography.

(A) Distance from the resting position at which elevation of the thyroid cartilage upper end begins, to the maximally elevated position at which elevation ends. (B) Distance from the resting position at which elevation of the hyoid bone begins, to the maximally elevated position at which elevation ends.

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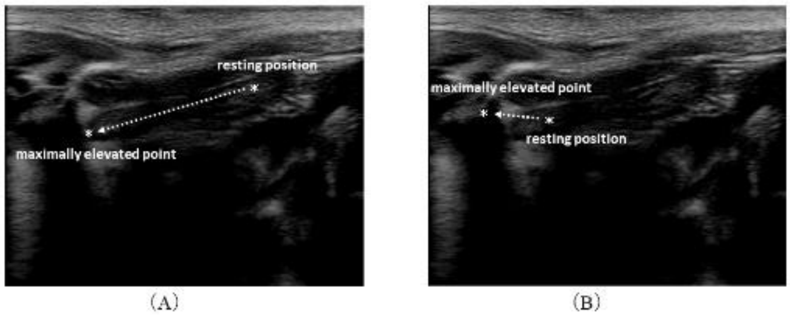
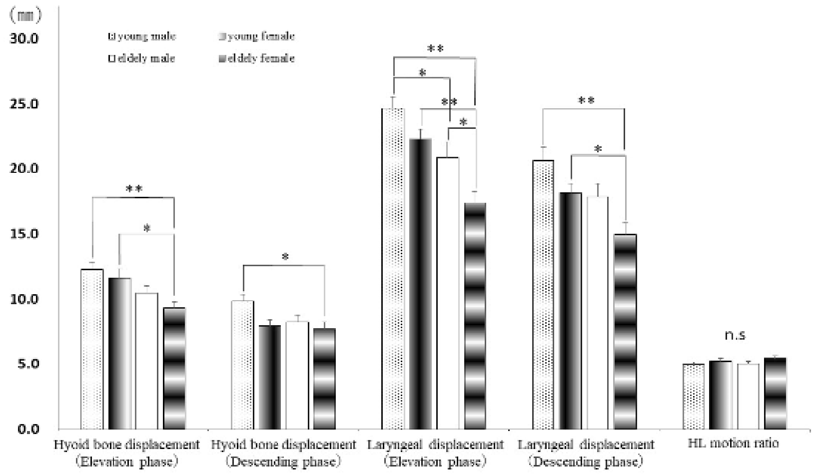


Fig. 4 Comparisons between the four groups of the laryngeal and hyoid bone displacements during the elevation and descending phases and of the hyoid bone–laryngeal (HL) motion ratio. The error lines represent the standard errors. * $p < 0.05$; ** $p < 0.01$; n.s, not significant



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