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原 著 論 文

Age-related Changes in Geniohyoid Muscle Morphology Predict Reduced Swallowing Function

Takuro BABA, Takaharu GOTO, Keiko FUJIMOTO, Tsuyoshi HONDA, Kazutomo YAGI, Kan NAGAO, Tetsuo ICHIKAWA

キーワード：Geniohyoid muscle, Swallowing, Presbyphagia, Ultrasonography

Abstract：**Background:** Early detection and treatment to sarcopenia and presbyphagia are needed to address the problems experienced by an aging population.

Objective: We aimed to clarify morphological changes in the geniohyoid (GH) muscle and associated aging-related factors, and to examine if changes in the GH muscle predict reduced swallowing function.

Materials and Methods: 103 participants (57 women and 46 men, mean age 59.4 ± 19.5 years) were recruited. GH muscle cross-sectional area (CSA) and contraction velocity were measured using ultrasonography. Body height and weight, neck circumference, body mass index, remaining teeth number, occluding teeth number, tongue pressure, and jaw-opening strength were measured. Swallowing function was evaluated using the swallowing screening assessment questionnaire and by measuring swallowing sound duration.

Results: GH muscle CSA significantly affected age, gender, body height and weight, neck circumference, remaining teeth number, occluding teeth number, tongue pressure, jaw-opening strength, duration of swallowing sounds, and GH muscle velocity. Covariance structure analysis showed that GH muscle CSA directly influenced swallowing sound duration.

Conclusion: Morphological changes in the GH muscle are predictive of decline in swallowing function.

I. Introduction

Japan is currently faced with the world's highest proportion of older adults, and a critical issue at present is the growing number of elders requiring nursing care. Japanese society is urgently reconstructing its medical, nursing care, and welfare systems because of increased medical and long-term care costs[1]. One solution is preventing physical disabilities in old age before the needs of nursing care, a concept known as “compression of morbidity” , to slow the development of chronic disease and to extend healthy life expectancy[2, 3]. Functional decline in old age occurs not only from acute diseases but also from sarcopenia and frailty, such common and important conditions that are increasingly prevalent with advancing age[4, 5].

According to the European Working Group on Sarcopenia in Older People (EWGSOP), sarcopenia is the progressive and generalized loss of skeletal muscle mass and strength, with a risk of adverse outcomes such as physical disability,

Department of Oral and Maxillofacial Prosthodontics, Institute of Biomedical Sciences, Tokushima University Graduate School

poor quality of life, and death[6, 7]; it is diagnosed by measuring skeletal muscle mass, hand grip strength, and walking speed [8]. Maintaining muscle mass and strength is necessary for managing the health of older adults. The definition of sarcopenia is expanded to include swallowing muscles as well as skeletal muscles, because ingestion and swallowing functions are important for elderly quality of life. The decline in swallowing function in healthy older adults—such as slow tongue movements and uncoupling of oral and pharyngeal events—is referred to as "presbyphagia" [9]. Presbyphagia is an early stage of dysphagia, or difficulty in swallowing, which will be caused by sarcopenia in swallowing muscles[10].

The muscles related to swallowing are composed of a variety of muscles, including internal tongue, suprahyoid, buccal, and lip muscles, among others. The suprahyoid muscles are critical for opening the jaw during mastication[11] and elevating the hyoid bone, widening the esophagus[12, 13], thereby assisting in swallowing. Swallowing disorder may be caused by morphological and functional changes in the suprahyoid muscles caused by sarcopenia. A number of studies have reported on the relationship between the contraction of masseter muscle[14, 15], tongue morphology, and movements[16-20] and the motion of the hyoid bone[21-23] and ingestion functions. However, few studies have focused on the role of suprahyoid muscles. The geniohyoid (GH) muscle, which arises from the inferior mental spine of the mandible and inserts into the anterior surface of the body of the hyoid bone, plays the most important role, together with the digastric muscle, in pulling the hyoid bone forward, and opening the upper esophagus during swallowing. We have focused on a suprahyoid muscle, the geniohyoid (GH) muscle, hypothesizing that a decrease in GH muscle mass may lead to a decline in its strength and functions, resulting in reduced swallowing function.

The aim of this study was to investigate the effect of age-related changes in the GH muscle and other related factors, and to examine if GH muscle function predicts reduced swallowing function.

II. Materials and Methods

1. Participants

The participants were randomly recruited from patients in the Tokushima University Hospital dental division and faculty members from the Tokushima University Faculty of Dentistry over the period of April 2014 to August 2016. Inclusion criteria included participants without gnathological and swallowing disorders, having the ability to walk independently and follow our directions. A total of 103 participants (57 women and 46 men; mean age 59.4 ± 19.5 years, range 25-87 years) were selected and provided written informed consent to participate. This study was approved by the Ethics Committee of the Tokushima University Hospital (No. 2225).

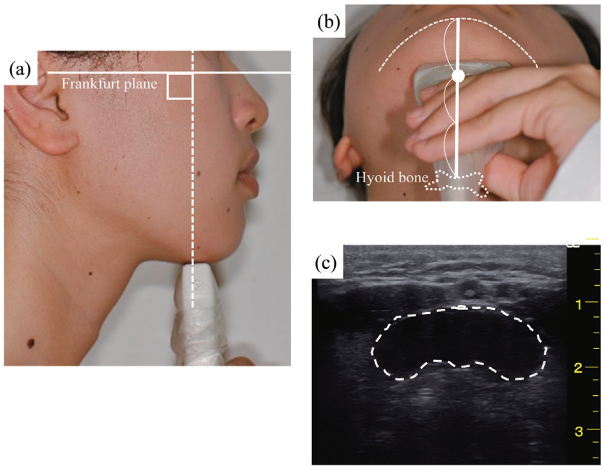

Fig. 1 Measurement of the geniohyoid (GH) muscle cross sectional area (CSA) using ultrasonography.
(a) Probe angle. (b) Probe position. (c) GH muscle (dashed outline) on the B-mode (brightness mode) image.

2. Morphological and functional evaluation of the GH muscle

The cross-sectional area (CSA) and contraction velocity of the GH muscle were measured using ultrasonic diagnostic equipment (LOGIQBookXP, GE, Tokyo, Japan) as shown in Figure 1. Participants were seated on the dental chair in an upright position so that their Frankfurt planes were positioned horizontally. The head and back were fixed to the backrest of the dental chair to suppress any motion. The ultrasonic probe (GE 8L-RS Liner Array Ultrasound Probe, frequency: 6 MHz, dynamic range: 90 dB, gain: 58 dB) was positioned at the base of resting jaw position at the first of the three divisions between the bottom of the mentalis and the hyoid bone; and perpendicular to Frankfurt plane. The clear cross-sectional outline of the GH muscle was imaged in quintuplicate using B-mode imaging, and CSA images were analyzed using an imaging software (Image J, NIH, Maryland, USA).

The contraction velocity of the GH muscle was calculated using the M-mode of ultrasonic measurement after participants had drank 10 mL of mineral water (CRYSTAL GEYSER®, Otsuka Foods, Tokushima, Japan), as shown in Figure 2. Scans were conducted at the widest part of the GH muscle, and contraction velocity was calculated by dividing the distance change (mm) by the duration (seconds) from resting to peak contraction. Measurements were performed in quintuplicate with an appropriate rest interval between measurements, and are shown as mean values.

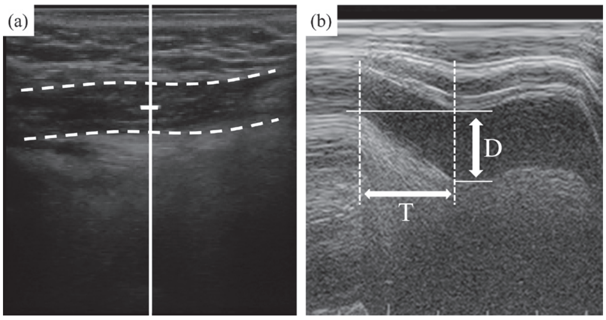

Fig. 2 Real-time B/M (brightness/motion) imaging of the geniohyoid (GH) muscle.
(a) B-mode image of the sagittal plane of GH muscle. The dashed outline indicates the GH muscle and solid line indicates the specific scan line. (b) M-mode display; D) maximum contraction distance during swallowing, T) maximum contraction duration. GH muscle contraction velocity was calculated by dividing D by T.

3. Physical and oral measurements

Physical measurements included body height and weight, neck circumference, and body mass index (BMI), while oral measurements included remaining teeth number, occluding teeth number, tongue pressure, and jaw-opening strength. Height, weight, and BMI were self-reported by participants during participant interviews. Neck circumference was measured at the cricothyroid membrane level[24], and remaining teeth and occluding teeth numbers were recorded during the oral examination.

Tongue pressure, or the maximum pushing force of the tongue on the palate, was measured using a commercial tongue pressure meter (JM-TPM, JMS Co. Ltd., Hiroshima, Japan). The disposable balloon probe was inserted into the mouth, participants were asked to bite the probe base with the upper and lower anterior teeth and to push the balloon with the tongue for 7 seconds with as much force as possible.

Maximum jaw-opening force was measured using a jaw-opening sthenometer (KT-2014, Livet Inc., Tokyo, Japan). The device consists of a headgear and a chin cap with a dynamometer. The relative force on the chin cap as a result of opening the jaw with as much force as possible was measured as jaw-opening strength. Head and body positions were the same as for the ultrasonic measurement.

4. Swallowing function

Swallowing function was evaluated using the swallowing screening assessment questionnaire (EAT-10, Japanese version)[25, 26] and by measuring swallowing sound duration according to Honda *et al.*[27]. Briefly, the tip of an ultra-small condenser microphone (AT9903, Audio-Technica, Tokyo, Japan; frequency characteristic: 30-18000 Hz) was enlarged to 10 mm in diameter using an auto-curing resin (UNIFASTII Clear, GC, Tokyo, Japan) for ease of attachment to the skin. The microphone was attached over the lateral laryngeal prominence using double-sided tape (1517, 3M Japan, Tokyo, Japan), and participants were asked to dry swallow. The output signal was recorded to a digital recorder (ICD-SX813, SONY, Tokyo, Japan) and analyzed using waveform analysis software (DADiSP, CAE Solutions Corporation, Tokyo, Japan). Swallowing sound onset occurred when the signal level exceeded the resting noise level, and offset was defined as the return to resting noise level. Swallowing measures were repeated in quintuplicate with an appropriate resting interval.

5. Statistical analyses

Single and multiple regression analyzes were conducted to clarify cause-effect relationships, followed by path analysis of the abstracted factors by covariance structure analysis. The covariance structure analysis was performed to investigate mutual interrelationships between abstracted factors, with significant associations analyzed by analysis of variance, unpaired t-tests, or χ^2 tests. We calculated the standardized parameter estimates using path model analysis and used a significance level of $p < 0.05$ for regression coefficients. We also calculated the goodness of fit index (GFI), the adjusted goodness of fit index (AGFI), the comparative fit index (CFI), and root mean square error of approximation (RMSEA) to examine the model's goodness of fit.

III. Results

GH muscle CSA significantly affected age, gender, body height and weight, neck circumference, remaining teeth number, occluding teeth number, tongue pressure, jaw-opening strength, duration of swallowing sounds, and GH muscle velocity (Table 1). Multiple regression analysis was performed to determine the influence of the variables on swallowing function; duration of swallowing sound and swallowing score were the dependent variables; the other factors (age, gender, body height and weight, neck circumference, remaining teeth number, occluding teeth number, tongue pressure, jaw-opening strength, GH muscle CSA, and GH muscle velocity) were the independent variables. The analysis showed that swallowing scores and duration of swallowing sound were significantly associated with remaining teeth number and GH muscle CSA, respectively ($p < 0.05$ for each; Table 2); the relationship between the dependent variables and all other independent variables was not significant.

Covariance structure analysis was performed to investigate

Table 1 Single regression analyses showing the effect of the geniohyoid (GH) muscle cross sectional area (CSA) on participants' measures.

	GH muscle CSA (Independent variable)	
Dependent variables	*Standardized coefficients*	*p value*
Age	-0.426	0.000*
Gender	-0.691	0.000*
Height	0.626	0.000*
Weight	0.535	0.000*
Body mass index	0.190	0.476
Neck circumference	0.269	0.006*
Remaining teeth number	0.371	0.012*
Occluding teeth number	0.375	0.010*
Tongue pressure	0.522	0.000*
Jaw-opening strength	0.648	0.000*
Swallowing score (EAT-10)	-0.186	0.060
Duration of swallowing sound	-0.435	0.000*
Contraction velocity of GH muscle	-0.600	0.015*

* Significance ($p < 0.05$)

Table 2 Stepwise regression analyses showing the effect of participants' measures on their swallowing score (EAT-10) or swallowing sound duration.

Dependent variables	*Independent variables*	*Standardized coefficients*	*t value*	*p value*
Swallowing score (EAT-10)	Remaining teeth number	-0.334	- 3.561	0.000*
			R^2=0.112	
Duration of swallowing sound	GH muscle CSA	-0.435	- 4.860	0.000*
			R^2=0.190	

R^2 is the multiple coefficient of determination.
GH muscle CSA is Geniohyoid muscle Cross sectional area. * Significance ($p < 0.05$).

the mutual interrelationship between jaw-opening strength, tongue pressure, and GH muscle CSA and velocity. Jaw-opening strength, tongue pressure, and GH muscle velocity were selected for single regression analysis. GH muscle CSA had significant influence on swallowing sound duration in multiple regression analysis. The adaptability of the model was not good (Figure 3): χ^2 = 6.390, df = 3, p = 0.094, GFI = 0.975, AGFI = 0.875, CFI = 0.971, RMSEA = 0.105. No significant associations were observed for the effect of GH muscle CSA on GH muscle velocity, or the effects of GH muscle velocity, tongue pressure, and jaw-opening strength on the duration of swallowing sound (Figure 4). The adaptability of the model was comparatively good: χ^2 = 1.413, df = 2, p = 0.493, GFI = 0.993, AGFI = 0.966, CFI = 1.000, RMSEA = 0.000.

IV. Discussion

Selective atrophy of fast-twitch muscle fibers is observed in sarcopenia[28-30]; the suprahyoid muscles, consisting of mostly fast-twitch muscle fibers[31], are suspected to be highly influenced by aging. There are four muscles in the suprahyoid muscle group (digastric, stylohyoid, geniohyoid, and mylohyoid). Suprahyoid muscles are involved in a variety of swallowing process; the jaw-opening muscle is

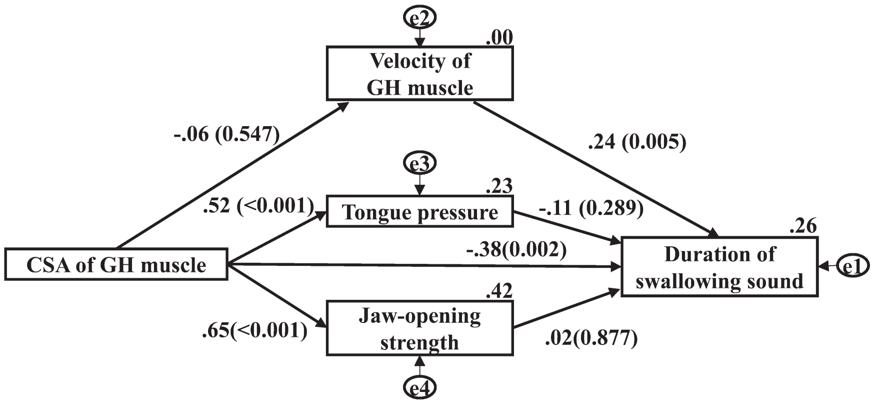

Fig. 3 Path model before modification.
The numbers above the arrow and box indicate estimation value and multiple coefficients of determination, respectively. P values are in parentheses. Error variables are denoted as e1 through e4.

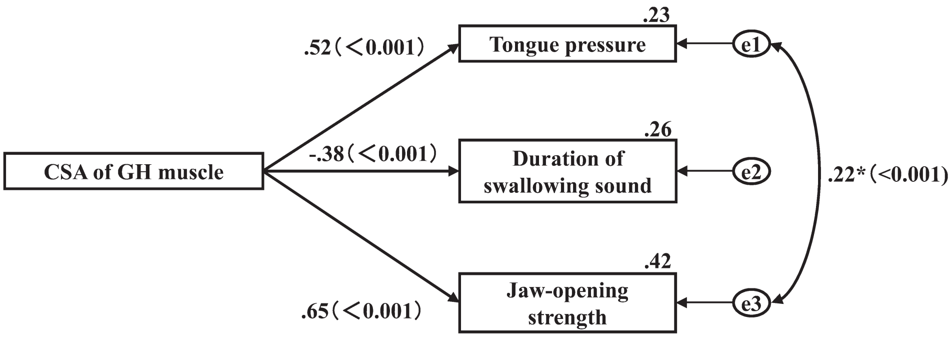

Fig. 4 Path model after modification.
The number above the arrow or box indicate estimation value or multiple coefficients of determination, respectively. P values are in parentheses. Error variables are denoted as e1 through e3.

involved in the oral preparation stage[11], and in controlling the hyoid bone position facilitating tongue movement in the oral transit stage[32], and finally in the elevation of hyoid bone in the pharyngeal stage[12, 13]. It is likely that sarcopenia in the suprahyoid muscles causes swallowing function decline. Pearson *et al.*[33] and Okada *et al.*[34] have shown that the GH muscle has the highest potential among the suprahyoid muscles to move the hyoid bone in the anterior direction and to widen the esophagus. We therefore examined the GH muscle as a possible predictor of swallowing dysfunction using ultrasonography.

Ultrasonography is noninvasive, cost-effective, enables repeat measurements for the quantitative evaluation of the GH muscle, and is available in the clinic. It is also easy to obtain a clear cross-sectional outline of the GH muscle, since it is a spindle-shaped superficial muscle below the submandible. Using computed tomography, Feng *et al.*[35] have shown that age is associated with increased fatty infiltration in the middle and posterior portions of the GH muscle. In measuring GH muscle CSA using ultrasonography, they positioned the ultrasonic probe at the anterior portion, where it had no significant increase in age-related fatty infiltration[36]. We also used the same positioning of the ultrasonic probe as well as perpendicular to Frankfurt plane for an additional standardization. GH muscle CSA significantly affected the duration of swallowing sounds. Swallowing sound is a measure for evaluating dysphagia, and longer duration has been reported in patients with aspiration or laryngeal penetration[37]. A significant positive correlation was found between GH muscle CSA and jaw-opening strength, tongue pressure, and GH muscle contraction velocity. Maximum force produced by extremity muscles has been widely accepted to be directly correlated to its muscle CSA[38]. A significant relationship was observed between GH muscle CSA and strength in the gnathological muscles. However, since this analysis had several confounders, multiple linear regression analysis was conducted using swallowing sound duration as a dependent variable. As a result, only the GH muscle CSA was found to a significantly influence the swallowing sound duration. GH muscle CSA appears to affect the duration of swallowing sounds directly, or indirectly through its effects on of tongue pressure, jaw-opening strength, and contraction velocity.

We examined a hypothesis model (Figure 3) in which the relationship between CSA and swallowing sound duration is explained, using a covariance structure analysis based on GFI, AGFI, CFI, and RMSEA. The first three measures range from 0 to 1, and indicate an acceptable fit with values >0.9, while a RMSEA value indicates an appropriate fit when <0.05, and poor fit when >0.10. Finally, we obtained a good fitting statistical model based on our hypothesis (Figure 4) by removing non-significant paths. This model indicated that the GH muscle CSA significantly affects tongue pressure, jaw-opening strength, and the duration of swallowing sound, but both tongue pressure and jaw-opening strength had lesser effects on swallowing sound duration. Therefore, GH muscle CSA directly influences swallowing sound duration. To our knowledge, only the study of Feng *et al*.[35] has indicated a direct relationship between GH muscle morphology and swallowing function. The study used computed tomography to show that GH muscle CSA in patients with aspiration was significantly smaller compared with that of patients without aspiration. The authors did not, however, see a decline in swallowing function before dysphagia, but rather at the critical problem of the presence or absence of aspiration; the study did not examine the possibility of predicting swallowing decline. It is widely reported that oral preparation, i.e. chewing and the first stage of swallowing, is influenced by age. Utanohara[39] reported that tongue pressure decreases with age, and Iida[40] also reported that jaw opening strength in men is greater than that in women. However, age and gender were not incorporated into our path model, and it remains unclear whether these factors affect the duration of swallowing sounds[41, 42] or not[43, 44] as there are conflicting reports. In the present study, there was a significant correlation between age and gender, and the duration of swallowing sounds, but the correlation coefficients of 0.289 and 0.321 were low and were strongly affected by other factors. Accordingly, age and gender were excluded in the final path model. It confirmed that there was no collinearity in the multiple regression analysis, and the path model, as shown in Figure 4, was considered to be appropriate.

We demonstrated that the duration of swallowing sound is influenced more by GH muscle CSA than by tongue pressure, and that jaw-opening strength and GH muscle CSA is able to predict the imperceptible decline in swallowing function, as shown by swallowing sound duration.

However, the stepwise regression analysis has some statistical shortcomings: such as biases in parameter estimation[45]. Hence, it is a fact that the model shown in this study is a model to suit well the measuring data, but it may not be statistically verified as a best fit model. Further studies are needed to examine the relationship between geniohyoid muscle and swallowing functions with an impact model through analyzing the model hypothesizing latent variables related to swallowing functions.

V. Conclusion

In conclusion, our study revealed that morphological changes in the GH muscle can predict reduced swallowing function, and that the noninvasive ultrasonography of GH muscle might be useful for screening decline of swallowing function and in evaluating the effectiveness of muscle strength exercises in preventing swallowing decline.

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