The association between jaw-opening strength, geniohyoid muscle thickness and echo intensity measured by ultrasound

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Abstract

Aim: Jaw-opening strength is an indicator of swallowing function including hyoid bone elevation. Geniohyoid muscles play an important role during hyoid bone elevation. This study aimed to investigate whether geniohyoid muscle thickness and echo intensity measured by ultrasonography were related to jaw-opening strength. Material and methods: Sixty-eight participants (39 men) with an average age of 77±7.7 years were recruited from a functional training health care facility. We measured muscle thickness and echo intensity of the geniohyoid muscle on transverse ultrasound images. Results: Age, calf circumference, grip strength, muscle thickness and echo intensity were significantly associated with jaw-opening strength in univariate analyses. After adjusting for grip strength in multiple regression analysis, geniohyoid muscle thickness and echo intensity were significantly associated with jaw-opening strength (β=0.29 for muscle thickness, β=−0.26 for echo intensity). Conclusions: There was a positive correlation between geniohyoid muscle thickness and jaw-opening strength; echo intensity negatively correlated with jaw-opening strength. Ultrasound evaluation of geniohyoid muscle status provides important information about maintaining jaw-opening strength.

Keywords: deglutition disorders; suprahyoid muscle; muscle thickness; muscle echo intensity; muscle strength

Introduction

Jaw-opening strength is a good indicator of the function of the geniohyoid muscles [1]. Cerebrovascular and neurological disease and aging are the main causes for pharyngeal residue and unintentional aspiration of food and liquid due to geniohyoid muscle malfunction [2-6]. Thus, insufficient jaw-opening force increases the risk of aspiration pneumonia. Due to the high mortality and recurrence rate of aspiration pneumonia [7,8], preventing the disease is a focus for many clinicians. Since jaw-opening strength declines with aging itself, an effective strategy to maintain muscle strength is needed. Moreover, non-invasive methods to evaluate jaw-opening strength to provide effective strategies for the elderly are required.

Jaw-opening strength has been measured with jaw-opening sthenometers consisting of belts, chin cap and head cap that fix the subject’s jaw, with a dynamometer below the chin cap [1,9]. This apparatus enables clinicians to determine a patient’s jaw-opening strength easily in a clinical setting. However, this measurement system does not provide information about geniohyoid muscle quality or size. Investigating the relationship between geniohyoid muscle status and muscle strength will help in understanding the mechanism by which jaw-opening strength could be increased and to determine effective...
strategies for maintaining or improving the jaw-opening strength. Ultrasonography (US) is useful for evaluating muscle status providing information about muscle size and quality [10–13]. Muscle thickness on US images is considered an indicator of muscle volume. Echo intensity can indicate muscle quality, because infiltration with adipose and connective tissue, which decrease muscle strength, appear as increased intensity on US images [14,15]. However, previous studies have only reported measurements of upper or lower limb muscles. Although some studies have revealed the feasibility of visualizing the suprathyoid muscles with US [16–18], the relationship between US parameters and muscle strength in geniohyoid muscle is unknown.

The aim of this study was to investigate whether geniohyoid muscle thickness and echo intensity measured by ultrasonography were related to jaw-opening strength. Our hypothesis was that geniohyoid muscle thickness would be positively associated with jaw-opening strength and that geniohyoid echo intensity would be negatively associated with jaw-opening strength.

**Material and methods**

**Participants**

We collected baseline data about individuals who had not performed jaw-opening exercises. The study was carried out from December 2013 to February 2014 in a functional training health care facility. All participants were community-dwelling people who used the facility at least once weekly for improvement or maintenance of physical function. We excluded individuals with a history of temporomandibular joint disorder, because measurement of jaw-opening force increased the risk of symptom recurrence. We also excluded those with defects or paralysis of specific muscles related to swallowing function.

**Ultrasound examination**

Bedside US (M-Turbo; Sonosite, Bothwell, WA, USA) was performed with a 6–15 MHz (HFL50x) linear array transducer. Participants sat upright in a chair with a backrest with their jaw closed during the examination. They were instructed to swallow their saliva, then a stable US image was obtained by a trained researcher. A generous amount of US conductive gel was placed over the transducer, which was then placed perpendicular to the submental muscle group with minimal pressure, to ensure that transducer pressure did not distort muscle structure. The distances from the parotid gland to the mandible were measured bilaterally to determine the scan area. Points were marked one-third of the distance from the mandible to the parotid. The line including these 2 points was determined as the scan area. The gain and the depth of the images were kept constant to allow quantitative image analysis. Figure 1 shows an example of the geniohyoid muscle and anterior bellies of the digastric muscles in an US image and in diagram form. The same investigator performed examinations twice in each participant to assess test–retest reliability of the measurements. The US image with the larger muscle area of the two was used to investigate the relationship between muscle strength and US parameters. Each muscle was defined as the area surrounded by the fascia with a hyperechoic line. Muscle thickness, cross-sectional area and echo intensity were analyzed with ImageJ software, version 1.37 (National Institutes of Health, USA). The researcher selected a region of interest excluding fascia, then the software drew an ellipse to approximate the muscle area. The short axis was defined as the thickness of the muscle. The mean echo intensity of the selected area was expressed in values from 0 to 255 (0: black; 255: white).

**Measurement of jaw-opening strength**

A well-trained dentist conducted the jaw-opening strength tests. A belt was placed as tightly as possible around the top of the subject’s head and under the jaw, with the sthenometer attached under the jaw [1,11]. The subject was seated comfortably on a chair with a back, with the head in a relaxed and neutral position and was instructed to attempt to open the jaw with as much strength as possible. Measurements were repeated 3 times and mean data were used for analysis.

**Measurement of covariates**

According to previous reports, sex and age may be associated with jaw-opening strength [1,11]. Moreover, some reports have suggested an association between oropharyngeal muscle strength and physical characteristics or grip strength [19,20]. Therefore, we collected these factors as covariates between US parameters and jaw-opening strength. Body mass index and muscle volume of the upper and lower limbs were included as physical characteristics in this study. For the muscle volume of the upper limbs, we calculated mid-upper arm muscle area from mid-upper arm circumference and triceps skinfold thickness [21]. Calf circumference was used as an indicator of muscle volume of the lower limbs. Measurements were repeated twice and mean values were used for the analysis.

**Statistical analysis**

To determine the intra-rater reliability of US examinations, a 2-way mixed-effects model of the intra-class correlation coefficient (ICC) was used. Pearson’s correlation coefficient was used to measure the relationships between US measurements, physical characteristics and jaw-opening strength. Multiple regression analysis was performed to determine the relative predictors of jaw-
opening strength. In addition to muscle parameters, independent variables that showed significant correlations with jaw-opening strength according to Pearson’s correlation coefficient were used as confounding factors. If a strong correlation was identified between independent variables, one of the variables was entered into the model to avoid multicollinearity. The variance inflation factor was used as an indicator of multicollinearity. All variables in the multivariate analysis were included together. The P-value was set at 0.05 for statistical significance. All analyses were conducted using STATA, version 14 (STATA Corp., College Station, TX, USA).

Results

This study included 68 participants (39 men), with an average age of 77±7.7 years. Table I shows the participants’ physical characteristics, US measurements and muscle strength. The ICC values for measurements of geniohyoid muscle thickness and echo intensity were 0.67 and 0.85, respectively. Men had greater muscle thickness and lower echo intensity than women. Jaw-opening strength was higher in men than women (Table I). Figure 2 shows typical US images of geniohyoid muscles from individuals with high and low jaw-opening strength.

Table II shows the correlation coefficients between jaw-opening strength and muscle thickness, echo intensity, physical characteristics, and grip strength. Muscle thickness showed a significant positive correlation with jaw-opening strength. Echo intensity showed a significant negative correlation with jaw-opening strength. Moreover, age, calf circumference, and grip strength were significantly associated with jaw-opening strength.

Table III shows the results of multiple regression analysis. Because grip strength was significantly associated with sex, age, and calf circumference, we included only grip strength as a confounding factor in the models. In multiple regression analysis, geniohyoid muscle thickness and echo intensity were significantly associated with jaw-opening strength ($\beta=0.29$, adjusted $R^2=0.36$ for muscle thickness; $\beta=-0.26$, adjusted $R^2=0.34$ for echo intensity). These results were independent from grip strength.

Fig 1. Ultrasound (US) image example and related anatomy. (a) US image from transverse scan. Bottom of the image is skin surface with US transducer contact. (b) Diagram of suprahoid muscles. 1, Geniohyoid muscle; 2, Anterior bellies of digastric muscles; 3, Skin and subcutaneous tissue; 4, Mylohyoid muscle; 5, Genioglossus muscle.

Fig 2. Typical Ultrasound (US) images of geniohyoid muscles from individuals with high and low jaw-opening strength. The yellow dashed lines represent geniohyoid muscles. (a) Seventy-two year old male whose average jaw-opening strength was 8.0 kg. The muscle thickness and echo intensity of geniohyoid muscle were 7.5 mm and 12, respectively. (b) Eighty-seven year old female whose average jaw-opening strength was 3.0 kg. The muscle thickness and echo intensity of geniohyoid muscle were 5.1 mm and 34, respectively.
The association between jaw-opening strength, geniohyoid muscle thickness and echo intensity measured by US

**Discussion**

This is the first study to show that geniohyoid muscle volume and quality measured by US are related to jaw-opening strength. The unique finding was that geniohyoid thickness was positively correlated and echo intensity was negatively correlated with jaw-opening strength. Our results suggest that these parameters can be used to estimate jaw-opening strength.

US measurement of geniohyoid muscle showed good intra-investigator reliability. US images are affected by the position of the transducer. We determined scan area based on the size of the participant’s mandible. Moreover, the size and echo intensity of the geniohyoid muscle are affected by the movement of other oropharyngeal muscles. We took US images just after participants swallowed saliva, when muscles maintain moderate contraction. These strategies were effective to obtain a stable image of the geniohyoid muscle.

The positive correlation between jaw-opening strength and muscle thickness suggests that patients with reduced muscle volume had relatively low jaw-opening strength. The negative correlation between jaw-opening strength and echo intensity suggests that deterioration of geniohyoid muscle strength related to infiltration of adipose tissue occurred in subjects with relatively low jaw-opening strength. These findings will help us to modify exercise protocols to improve muscle volume and reduce adipose tissue in the geniohyoid muscle. Although the results of US parameters showed the same trends as those reported in previous studies of upper and lower limbs,

**Table I. Characteristics of the participants**

|                  | Total (n=68) | Male (n=39) | Female (n=29) | p-value |
|------------------|-------------|-------------|---------------|---------|
| Age (years)      | 76.6±7.7    | 75.6±8.9    | 77.9±0.6      | 0.205   |
| BMI (kg/m²)      | 24.9±3.8    | 24.6±3.0    | 25.3±4.6      | 0.447   |
| AMA (cm²)        | 46.4±11     | 47.6±11     | 44.8±10       | 0.287   |
| CC (cm)          | 35.1±3.3    | 35.6±2.9    | 34.5±3.7      | 0.193   |

**US measurements**

|                  |            |             |              |         |
|------------------|------------|-------------|--------------|---------|
| Thickness (mm)   | 7.5±1.4    | 7.9±1.4     | 7.0±1.2      | 0.012   |
| Echo intensity (a.u.) | 15.7±9.4 | 13.3±8.5    | 19.0±9.7     | 0.012   |

**Muscle strength**

|                  |            |             |              |         |
|------------------|------------|-------------|--------------|---------|
| Grip strength (kg)| 21.9±7.8  | 25.5±7.6    | 17.0±4.9     | < 0.001 |
| Jaw-opening strength (kg) | 5.8±1.9  | 6.7±1.8     | 4.6±1.4      | < 0.001 |

The results are expressed as mean±standard deviation. a.u., arbitrary units; AMA, mid-upper arm muscle area; BMI, body mass index; CC, calf circumference; US, ultrasound.

**Table II. Correlation coefficients between ultrasound measurements, physical characteristics and muscle strength of the participants (n = 68).**

| Thickness | EI | Age | BMI | AMA | CC | GS | JOS |
|-----------|----|-----|-----|-----|----|----|-----|
| Thickness | -  | -0.52*| -0.06| 0.02| 0.09| 0.20| 0.18| 0.38† |
| EI        |    | -0.06| -0.04| -0.13| -0.13| -0.29*| -0.40*|       |
| Age       | 0.22| -    | -0.15| -0.09| -0.13| -0.38*| -0.24*|       |
| BMI       | -  | 0.29| -0.04| 0.09| 0.12| 0.59*| 0.72*| 0.05  |
| AMA       | -  | -    | -    | 0.59*| 0.12| 0.31*| 0.17 |       |
| CC        | -  | -    | -    | -    | 0.36*| 0.24*|       |       |
| GS        | -  | -    | -    | -    |      |     | 0.54*|       |
| JOS       | -  | -    | -    | -    |      |     |      |       |

AMA, mid-upper arm muscle area; BMI, body mass index; CC, calf circumference; EI, echo intensity; GS, grip strength; JOS, jaw-opening strength; US, ultrasound; Statistical significance: * p<0.05, † p<0.01

**Table III. Factors associated with jaw-opening strength in multiple regression analysis**

|                | Model 1 | Model 2 |
|----------------|---------|---------|
|                | β       | p value | β       | p value |
| Grip strength  | 0.49    | < 0.001 | 0.47    | < 0.001 |
| Thickness      | 0.29    | 0.004   | -       | -       |
| Echo intensity | -       | -       | -0.26   | 0.015   |
| R²             | 0.38    | 0.36    |         |         |
| Adjusted R²    | 0.36    | 0.34    |         |         |
| VIF            | 1.03    | 1.09    |         |         |

VIF, variance inflation factor
the correlation coefficients between the parameters and muscle strength were smaller in this study than in others [10,11]. This difference may result from the complex relationship between suprahyoid muscles and swallowing ability. The relationship between jaw-opening strength and US measurements of the other suprahyoid muscles should be investigated in future studies.

The main limitation of this study is that this is a cross-sectional study. We did not investigate the relationship between parameters measured by US and jaw-opening strength after a jaw-opening exercise. Multiple regression analysis showed that both muscle thickness and echo intensity were useful factors to estimate jaw-opening strength. However, we cannot ignore the importance of grip strength in these results. We need to consider that our data were obtained from participants who had never practiced jaw-opening exercises. Both geniohyoid muscle status and grip strength were related to jaw-opening strength at baseline. Not only regional muscle status but also whole-body muscle status is associated with jaw-opening strength before exercise. Therefore, we recommend measuring both grip strength and US parameters at baseline. Because jaw-opening exercise was developed to improve or maintain suprahyoid muscle strength, only the status of the suprahyoid muscles will be changed after exercise. Further longitudinal studies are required to investigate the relationship between jaw-opening strength and US parameters or grip strength. Another limitation of this study was that we did not measure inter-rater agreement of the US examination. An operator performed all US examinations in this study to keep the sufficient quality of US images. We need to evaluate inter-rater agreement in future studies after we develop a training method of US examination for geniohyoid muscle.

Because US measurement is noninvasive and has good portability, this method enables clinicians to monitor the effect of jaw-opening exercise out of the hospital. US measurement only requires participants to have contact with the transducer and echo gel; therefore, this method is useful for participants who feel uncomfortable wearing a sthenometer to measure jaw-opening strength. Previous studies revealed that US examination can detect laryngeal elevation, which is associated with the suprahyoid muscles [22,23]. Jaw-opening force does not indicate only laryngeal elevation. In addition to laryngeal elevation, jaw-opening force is associated with the opening of the upper esophageal sphincter and pharyngeal passage time. Both of these are important factors for swallowing ability. Our US method of estimating jaw-opening strength can be used as a comprehensive assessment tool for swallowing ability when combined with established methods. Timely monitoring of swallowing exercises will provide clinicians’ information regarding the effectiveness of the exercise. Clinicians will be able to modify exercises based on US images. This method will promote effective swallowing exercises to prevent aspiration pneumonia.

In conclusion, geniohyoid muscle thickness and echo intensity measured by US was correlated with jaw-opening strength. The noninvasive US measurement of geniohyoid muscle status will be useful to estimate jaw-opening strength and to monitor the effectiveness of swallowing exercises.

Conflict of interest: none

References

1. Hara K, Tohara H, Wada S, Iida T, Ueda K, Ansai T. Jaw-opening force test to screen for dysphagia: preliminary results. Arch Phys Med Rehabil 2014;95:867-874.
2. Yoshida T, Uchiyama Y. Clinical characteristics of swallowing disorders caused by cerebrovascular disease: A study using newly-developed indices for the basic elements of swallowing movement and neck range of motion. J Jpn Phys Ther Assoc 2007;10:11-15.
3. Mu L, Sobotka S, Chen J, et al. Altered pharyngeal muscles in Parkinson disease. J Neuropathol Exp Neurol 2012;71:520-530.
4. Kang BS, Oh BM, Kim IS, Chung SG, Kim SJ, Han TR. Influence of aging on movement of the hyoid bone and epi-glottis during normal swallowing: a motion analysis. Gerontology 2010;56:474-482.
5. Feng X, Todd T, Lintzenich CR, et al. Aging-related geniohyoid muscle atrophy is related to aspiration status in healthy older adults. J Gerontol A Biol Sci Med Sci 2013;68:853-860.
6. Bingjie L, Tong Z, Xinting S, Jianmin X, Guijun J. Quantitative videofluoroscopic analysis of penetration-aspiration in post-stroke patients. Neuroi India 2010;58:42-47.
7. Hayashi M, Iwasaki T, Yamazaki Y, et al. Clinical features and outcomes of aspiration pneumonia compared with non-aspiration pneumonia: a retrospective cohort Study. J Infect Chemother 2014;20:436-442.
8. Komiya K, Ishii H, Umeki K, et al. Impact of aspiration pneumonia in patients with community-acquired pneumonia and healthcare-associated pneumonia: a multicenter retrospective cohort study. Respirology 2013;18:514-521.
9. Iida T, Tohara H, Wada S, Nakane A, Sanpei R, Ueda K. Aging decreases the strength of suprahyoid muscles involved in swallowing movements. Tohoku J Exp Med 2013;231:223-228.
10. Fukumoto Y, Ikezoe T, Yamada Y, et al. Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. Eur J Appl Physiol 2012;112:1519-1525.
11. Cadore EL, Izquierdo M, Conceicao M, et al. Echo intensity is associated with skeletal muscle power and car-
diovascular performance in elderly men. Exp Gerontol 2012;47:473-478.
12. Abe T, Thiebaud RS, Loenneke JP, Ogawa M, Mitsukawa N. Association between forearm muscle thickness and age-related loss of skeletal muscle mass, handgrip and knee extension strength and walking performance in old men and women: a pilot study. Ultrasound Med Biol 2014;40:2069-2075.
13. Strasser EM, Draskovits T, Praschak M, Quittan M, Graf A. Association between ultrasound measurements of muscle thickness, pennation angle, echogenicity and skeletal muscle strength in the elderly. Age (Dordr) 2013;35:2377-2388.
14. Pillen S, Tak RO, Zwarts MJ, et al. Skeletal muscle ultrasound: correlation between fibrous tissue and echo Intensity. Ultrasound Med Biol 2009;35:443-446.
15. Janssen BH, Pillen S, Voet NB, Heerschap A, van Engelen BG, van Alfen N. Quantitative muscle ultrasound versus quantitative magnetic resonance imaging in facioscapulohumeral dystrophy. Muscle Nerve 2014;50:968-975.
16. Macrae PR, Jones RD, Myall DJ, Melzer TR, Huckabee ML. Cross-sectional area of the anterior belly of the digastric muscle: comparison of MRI and ultrasound measures. Dysphagia 2013;28:375-380.
17. Van Den Engel-Hoek L, Van Alfen N, De Swart BJ, De Groot IJ, Pillen S. Quantitative ultrasound of the tongue and submental muscles in children and young adults. Muscle Nerve 2012;46:31-37.
18. Prasad A, Yu E, Wong DT, Karkhanis R, Gullane P, Chan VW. Comparison of sonography and computed tomography as imaging tools for assessment of airway structures. J Ultrasound Med 2011;30:965-972.
19. Tamura F, Kikutani T, Tohara T, Yoshida M, Yaegaki K. Tongue thickness relates to nutritional status in the elderly. Dysphagia 2012;27:556-561.
20. Maeda K, Akagi J. Sarcopenia is an independent risk factor of dysphagia in hospitalized older people. Geriatr Gerontol Int 2016;16:515-521.
21. Heymsfield SB, McManus C, Smith J, Stevens V, Nixon DW. Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. Am J Clin Nutr 1982;36:680-690.
22. Huang YL, Hsieh SF, Chang YC, Chen HC, Wang TG. Ultrasonographic evaluation of hyoid-larynx approximation in dysphagic stroke patients. Ultrasound Med Biol 2009;35:1103-1108.
23. Yabunaka K, Sanada H, Sanada S, et al. Sonographic assessment of hyoid bone movement during swallowing: a study of normal adults with advancing age. Radiol Phys Technol 2011;4:73-77.