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RESEARCH PAPER

Associations of swallowing-related muscle quantity and quality with sarcopenic parameters

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Key summary points

Aim To elucidate the relationship between swallowing-related muscle characteristics and sarcopenic parameters in community-dwelling older adults.

Findings The cross-sectional area of the geniohyoid muscle was significantly associated with the grip strength, and tongue characteristics were significantly associated with the skeletal muscle mass index. Sarcopenic parameters were associated with swallowing-related muscle characteristics.

Message This research may increase our understanding of the pathophysiology of sarcopenic dysphagia and muscle physiology.

Abstract

Purpose To examine the associations between swallowing-related muscle characteristics and sarcopenic parameters.

Methods We included 147 community-dwelling older adults (age: 71.6 ± 4.7 years, body mass index: 23.0 ± 2.7 kg/m^2 (mean ± standard deviation), men: 50; women: 97) and categorized them into robust ($n = 125$), low-function ($n = 17$), and sarcopenia ($n = 5$) groups based on the diagnostic criteria of the Asia Working Group for Sarcopenia 2019. We evaluated the geniohyoid muscle (GHM) and tongue characteristics (muscle quantity and quality). The cross-sectional area (CSA) indicated the muscle quantity, and echo intensity (EI) values indicated the muscle quality. A multiple regression analysis was performed to clarify the relationship of swallowing-related muscle characteristics and strength with sarcopenic parameters.

Results The grip strength (CSA of GHM: $\beta = 1.64$, $p = 0.03$) and skeletal muscle mass index (CSA of tongue: $\beta = 74.81$, $p = 0.003$, EI of tongue: $\beta = 1.92$, $p = 0.009$) were better indicators of swallowing-related muscle characteristics.

Conclusion These findings may facilitate the early detection of aging-related deterioration in swallowing-related musculature through the diagnostic process of sarcopenia and increase our understanding of muscle physiology.

Keywords Community-based long-term care · Geniohyoid muscle · Sarcopenia · Tongue · Ultrasound

Introduction

The muscle mass and strength of both skeletal muscles and swallowing-related muscles decrease with aging. People in their 80 s lose approximately 40% of their muscle strength and 25% of their muscle mass than those in their 20 s [1]. Further, swallowing-related muscle strength decreases by approximately 25% in people in their 70 s, compared with those in their 20 s [2].

Sarcopenia attributed to the age-related loss of muscle mass and strength is defined as primary sarcopenia [3]. The probability of the co-existence of sarcopenia and dysphagia is high and is associated with more serious health problems

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[4], and it is increasingly being recognized as a factor related to dysphagia [5, 6]. A prospective cohort study of 95 hospitalized patients reported that decreased skeletal muscle mass was an independent predictor of dysphagia [7].

Swallowing-related muscle characteristics (i.e., quantity and quality), including those of the tongue and geniohyoid muscle (GHM), are important while considering the relationship between sarcopenia and dysphagia [8]. Both the quantity and quality of swallowing-related muscles deteriorate with aging [9, 10]. According to an observational study using computed tomography scanning, age-related atrophy of the GHM was associated with aspiration risk [11]. A study comparing swallowing-related muscles in patients with sarcopenia with and without dysphagia demonstrated reduced quantity and quality of tongue musculature in patients with sarcopenia and dysphagia [12]. Swallowing-related muscles and skeletal muscles may undergo deterioration via a common process [13].

Currently, researchers have not elucidated the relationships between swallowing-related muscle characteristics and sarcopenic parameters, such as the grip strength and walking speed. Conversely, we previously reported on the relationship between masseter muscles and sarcopenia parameters [14]. Clarifying the relationship between swallowing-related muscle characteristics and sarcopenic parameters may increase our understanding of the pathophysiology of sarcopenic dysphagia and muscle physiology (i.e., aging-related muscle atrophy and muscle fattening) and facilitate the development of early detection methods for swallowing deterioration in the diagnostic process of sarcopenia. The oral function deteriorates significantly in community-dwelling older women with low function (low muscle strength or/and low muscle function with normal muscle mass) and sarcopenia [15]. Therefore, we aimed to clarify the relationship between swallowing-related muscle characteristics and sarcopenic parameters in community-dwelling older adults. We hypothesized that swallowing-related muscle characteristics and strength are significantly associated with sarcopenic parameters, as indicated by a previous study [15].

Methods

Participants

This study was approved by the Ethics Committee of the Tokyo Medical and Dental University (ref: D2014-047) and met the guidelines of the Declaration of Helsinki. Initially, we screened participants from the health surveys conducted during March 2018 and October 2018 at Tochigi and Chiba in Japan [10, 16]. These surveys were advertised on the Internet and in local public relations magazines. The inclusion criteria were as follows: age > 65 years; the ability to perform daily living activities independently; the ability to follow instructions; and the availability of complete medical data. The exclusion criteria were as follows: known history of diseases affecting the muscles (e.g., cerebrovascular disorder with paralysis) and the use of pacemakers. Data were obtained from previous studies [10, 16] that did not analyze the sarcopenic parameters. After providing sufficient written and verbal explanations, informed consent was obtained from all participants.

Measurement of systemic factors

The body mass index (BMI) was calculated by dividing the body weight by the height squared. The muscle mass was measured using a direct segmental multifrequency bioelectrical impedance analysis (BIA; In Body S10, InBody Japan, Tokyo, Japan) at five sites as follows: the trunk and the left and right limbs. The appendicular skeletal muscle mass index (SMI) was calculated by dividing the sum of appendicular muscle mass by the square of the participant's height [17]. We measured the grip strength of the dominant hand using a handheld dynamometer (TTM Inc., Chiba, Japan) and used the higher of the two recordings as the measurement value. Walking speed was calculated as the time required to walk 4 m, while 2-m acceleration and 2-m deceleration paths were provided before and after the measurement path. Briefly, we used the 2019 Consensus Report of the Asia Working Group for Sarcopenia [17]. We measured the muscle strength (grip strength), physical function (walking speed), and systemic muscle mass (SMI by BIA). The cut-off value for grip strength was 28 kg for men and 18 kg for women; for walking speed, it was 1.0 m/s; and for SMI, it was 7.0 kg/m^2 for men and 5.7 kg/m^2 for women. The low functional group comprised those with normal muscle mass but reduced muscle strength or/and physical function. The sarcopenia group comprised those with reduced SMI and a decrease in either muscle strength or physical function. Finally, those with reduced SMI, muscle strength, and physical function were categorized under the severe sarcopenia group.

Measurement of swallowing-related muscle characteristics and strength

A tongue-pressure measuring device (JMS Co. Ltd., Hiroshima, Japan) was used to measure the tongue pressure as tongue strength [2], and the average value of three recordings was used as the measurement value. The participants seated themselves in a relaxed state and held the plastic probe between their anterior teeth during tongue strength measurement. Upon obtaining an internal pressure of 19.6 kPa in the balloon at the tip of the probe owing to automatic calibration by the device, the balloon was pressed against the palate maximally with the tongue for approximately 5 s. The interval between these measurements was approximately 30 s. Previous studies have demonstrated satisfactory intra-rater reliability of ultrasonography for the assessment of the tongue and GHM [10].We performed an ultrasonography of the GHM and tongue using an ultrasonic diagnostic apparatus (Sonosite M-turbo; Fujifilm, Tokyo, Japan). Ultrasonography was selected because it is an inexpensive and non-invasive method of accurately evaluating muscle characteristics [18] and can be applied to swallowing-related muscles to obtain a good perspective of deglutition [10]. The measurements were recorded by an experienced dentist (CA). We used a 2–5-MHz convex-type probe with a depth of 9.2 cm. During measurement, the participants sat facing forward. Constant frequency and depth were maintained during the measurements. The device was placed perpendicular to the Frankfurt plane at a point where an imaginary line connecting the right and left second premolars intersected [10]. Ultrasound images were analyzed using ImageJ (Version 1.49; National Institutes of Health, Bethesda, MD) software. We set the range of interest to include the maximum possible muscle mass while avoiding the fascia. The muscle cross-sectional area (CSA) and echo intensity (EI) values were evaluated to indicate the muscle quantity. The average value of two recordings was used as the measurement value.

Power calculation with a post-hoc test

We calculated the detection power of the multiple regression analysis with sarcopenic parameters as the explanatory variables using G power (Kiel University, Kiel, Germany). We obtained the following values: α, 0.05; explanatory variables, 5; and effect size, f^2, calculated as the result of the multiple regression analysis. The detection power of swallowing-related muscle characteristic and strength was as follows: 0.97 (CSA of GHM), 0.99 (CSA of tongue), 0.95 (EI of GHM), 0.99 (EI of tongue), and 0.96 (tongue strength), all of which were sufficiently high.

Statistical analyses

The participants were categorized into robust ($n = 125$), low function ($n = 17$), and sarcopenia ($n = 5$) groups. The normality of each variable distribution was confirmed using the Shapiro–Wilk test. For each item, we analyzed the differences using a one-way analysis of variance, Kruskal–Wallis test, or chi-squared test. Correlations among the GHM and tongue muscle characteristics, grip strength, SMI, and walking speed were calculated using the Pearson and Spearman correlation coefficients for parametric and non-parametric variables, respectively, stratified by sex. To investigate the relationship among the GHM and tongue characteristics, tongue strength, and sarcopenic parameters, we performed multiple regression analyses with swallowing-related muscle characteristics and tongue strength as the dependent variables. The explanatory variables were age, sex, and sarcopenic parameters. We selected the forced-input method as the input method. To avoid multicollinearity, we verified that the variance inflation factor was < 10.

Results

Of the 269 participants screened, 147 met the inclusion criteria. Of these participants, five had sarcopenia (3.4%) and none had severe sarcopenia. There were no significant differences in the swallowing-related muscle characteristics among the robust, low-function, and sarcopenia groups (Table 1).

The CSA of the GHM revealed a significantly positive correlation with the grip strength (CSA of the GHM: $r = 0.25$, $p = 0.015$ in women). CSAs of the GHM and tongue were positively correlated with the SMI (in men, CSA of the GHM: $r = 0.32$, $p = 0.023$, CSA of the tongue: $r = 0.32$. $p = 0.023$; and in women, CSA of the GHM: $r = 0.21$, $p = 0.044$, CSA of the tongue: $r = 0.24$, $p = 0.019$), despite no significant correlations with the EI of swallowing-related muscles (Table 2).

Multiple regression analyses revealed significantly positive associations between the CSA of the GHM and grip strength ($\beta = 1.64$, 95% confidence interval [CI] 0.17–3.11) and tongue characteristics and SMI (CSA of the tongue: $\beta = 74.81$, 95% CI 26.42–123.20; EI of the tongue: $\beta = 1.92$, 95% CI 0.49–3.36) (Table 3). The tongue strength was positively associated with the grip strength ($\beta = 0.44$, 95% CI 0.18–0.69; Table 3).

Discussion

In this study, the CSA of the GHM and tongue strength were significantly associated with the grip strength, whereas tongue characteristics were significantly associated with the SMI. Further, the tongue strength was associated with the grip strength.

Additionally, the relevant sarcopenic parameters depended on the swallowing-related muscles (i.e., GHM or tongue) and their characteristics (i.e., quantity or quality). These differences may be attributed to anatomical differences between the GHM and tongue or the respiratory input into muscles. In previous studies, the CSA of the GHM was significantly associated with the jaw-opening force [19], which in turn was significantly correlated with the grip strength in older men [20], consistent with our findings. The GHM plays a vital role in the movement of the hyoid bone during swallowing [21], and its atrophy is associated with

Table 1 Participant characteristics ($n=147$)

	Total ($n=147$)	Robust ($n=125$)	Low functional group ($n=17$)	Sarcopenia ($n=5$)	p value
Age, years	71.6 ± 4.7	71.3 ± 4.7	72.4 ± 4.9	76.2 ± 1.8	0.02[a]
Sex (men), %	34.0	32.8	35.3	60.0	0.45[b]
BMI, kg/m^2	23.0 ± 2.7	23.0 ± 2.6	23.9 ± 2.7	21.3 ± 3.6	0.11[a]
SMI, kg/m^2	6.6 ± 1.1	6.6 ± 1.0	6.8 ± 1.1	5.4 ± 0.2	0.006[a]
Grip strength, kg	26.1 ± 7.8	27.9 ± 7.7	21.1 ± 6.3	21.9 ± 6.1	0.001[a]
Walking speed, m/s	1.4 ± 0.3	1.5 ± 0.2	1.1 ± 0.4	1.3 ± 0.3	< 0.001[a]
Tongue strength, kPa	31.8 ± 8.3	32.7 ± 7.7	26.4 ± 10.0	28.0 ± 10.6	0.006[c]
CSA of GHM, mm^2	165.1 ± 47.8	165.2 ± 48.1	171.1 ± 48.4	143.0 ± 39.6	0.45[a]
CSA of tongue, mm^2	1671.9 ± 277.6	1670.8 ± 281.4	1677.0 ± 269.5	1682.5 ± 261.7	0.99[c]
EI of GHM	18.4 ± 8.5	18.3 ± 8.2	17.9 ± 10.0	23.0 ± 9.4	0.41[a]
EI of tongue	36.1 ± 8.1	36.0 ± 8.1	36.7 ± 8.7	36.4 ± 8.5	0.95[c]

Values are presented as the mean ± standard deviation

BMI body mass index, *SMI* skeletal muscle mass index, *GHM* geniohyoid muscle, *CSA* cross-sectional area, *EI* echo intensity

[a]Kruskal–Wallis test

[b]Chi-square test

[c]One-way analysis of variance

Table 2 Correlations between swallowing-related muscle characteristics and sarcopenic parameters

	Grip strength	SMI	Walking speed
Men			
CSA of GHM	0.26[a]	0.32[a]*	0.04[a]
CSA of tongue	0.19[b]	0.32[a]*	− 0.20[a]
EI of GHM	− 0.16[b]	0.12[a]	− 0.14[a]
EI of tongue	− 0.07[b]	0.19[a]	0.07[a]
Women			
CSA of GHM	0.25[a]*	0.21[a]*	0.10[a]
CSA of tongue	0.28[a]**	0.24[a]*	0.11[a]
EI of GHM	− 0.11[a]	− 0.05[a]	− 0.12[a]
EI of tongue	− 0.08[a]	− 0.10[a]	− 0.19[a]

CSA cross-sectional area, *EI* echo intensity, *GHM* geniohyoid muscle, and *SMI* skeletal muscle mass index

[a]Spearman rank correlation coefficient

[b]Pearson correlation coefficient

*$p < 0.05$

**$p < 0.01$

aspiration [11]. Type-2 muscle fibers account for approximately 60% of the GHM composition, similar to the composition of the biceps brachii, and previous studies have demonstrated an association between the grip strength and upper limb muscle mass [22, 23]. Moreover, these fibers are likely to undergo age-related atrophy [24]. Aging may affect the GHM and upper limb muscles, which are principally composed of type-2 muscle fibers. Further, the grip strength may be related to the CSA of the GHM.

In addition, the CSA of the tongue was associated with the SMI. Approximately 60% of the tongue is composed of type-1 muscle fibers [25], which are susceptible to atrophy owing to disuse rather than aging [26]. Physically active older adults have greater tongue strength and endurance than their inactive younger counterparts [27]. Physical activity is related to the SMI [28]. These previous studies confirmed the association between the CSA of the tongue and SMI. Contrarily, the SMI decreases with age, despite a tendency of the tongue to enlarge with age [9]. The tongue strength is related to various factors, such as the amount of physical activity [27] and having a social network [29], besides cross-sectional studies reporting on the relationship between tongue muscle mass and age [9, 30]. Therefore, it may be necessary to investigate age-related changes in the tongue and skeletal muscles through longitudinal studies. In this study, the tongue strength was associated with the grip strength, similar to that concluded by a systematic review [31].

In addition to these differences in muscle fiber composition, researchers are required to consider obtaining a cyclic respiratory input to evaluate the difference between GHM and tongue. The GHM, which does not receive respiratory input, atrophies with age [9]; while the thyrohyoid muscle, which receives respiratory input, does not display any distinct effects of aging [6]. The tongue is reportedly activated by breathing [32]; age-related changes in its CSA increase with age, unlike that in other skeletal muscles [9]. The differences in factors associated with swallowing-related muscle characteristics require further investigation from the respiratory perspective.

Table 3 Multiple regression analysis with swallowing-related muscle characteristics and tongue strength as the dependent variables and sarcopenic parameters as the explanatory variables

Dependent variable	Independent variable	B (95% CI)	Standard practical regression coefficient	*p* value	VIF	Adjusted R^2
CSA of GHM	Age	− 1.60 (− 3.24 to 0.10)	− 0.16	0.06	1.16	0.14
	Sex	3.55 (− 19.71 to 26.80)	0.04	0.76	2.33	
	SMI	7.68 (− 0.86 to 16.22)	0.17	0.08	1.54	
	Grip strength	1.64 (0.17 to 3.11)	0.27	0.03	2.52	
	Walking speed	− 8.32 (− 35.07 to 18.44)	− 0.05	0.54	1.07	
CSA of tongue	Age	− 3.01 (− 12.82 to 6.04)	− 0.01	0.53	1.16	0.18
	Sex	− 4.94 (− 136.77 to 126.89)	− 0.05	0.94	2.33	
	SMI	74.81 (26.42 to 123.20)	0.28	0.003	1.54	
	Grip strength	7.81 (− 0.52 to 16.14)	0.22	0.07	2.52	
	Walking speed	− 46.01 (− 197.67 to 105.66)	− 0.05	0.55	1.07	
EI of GHM	Age	0.13 (− 0.17 to 0.43)	0.07	0.40	1.16	0.12
	Sex	4.68 (0.51 to 8.84)	0.26	0.03	2.33	
	SMI	0.77 (− 0.76 to 2.30)	0.10	0.32	1.54	
	Grip strength	− 0.22 (− 0.48 to 0.05)	− 0.20	0.10	2.52	
	Walking speed	− 1.12 (− 0.76 to 2.30)	− 0.04	0.65	1.07	
EI of tongue	Age	0.17 (− 0.10 to 0.45)	0.10	0.22	1.16	0.16
	Sex	5.84 (1.94 to 9.74)	0.34	0.004	2.33	
	SMI	1.92 (− 5.95 to 3.04)	0.25	0.009	1.54	
	Grip strength	− 0.21 (− 0.48 to 0.03)	− 0.21	0.09	1.07	
	Walking speed	− 1.46 (− 5.95 to 3.04)	− 0.05	0.52	2.52	
Tongue strength	Age	− 0.28 (− 0.57 to 0.01)	− 0.16	0.06	1.16	0.13
	Sex	5.59 (1.54 to 9.63)	0.32	0.007	2.33	
	SMI	0.16 (− 1.33 to 1.64)	0.02	0.83	1.54	
	Grip strength	0.44 (0.18 to 0.69)	0.41	0.001	2.52	
	Walking speed	1.82 (− 2.84 to 6.47)	0.06	0.44	1.07	

β partial regression coefficient, *CI* confidence interval, *VIF* variance inflation factor, *R* coefficient of determination, *CSA* cross-sectional area, *EI* echo intensity, *GHM* geniohyoid muscle, and *SMI* skeletal muscle mass index

In this study, the EI of the tongue was positively associated with the SMI. The EI revealed non-contractile tissues in the muscles, i.e., the intramuscular adipose tissue [33], which is highly correlated with the evaluation of intramuscular fat percentage obtained by magnetic resonance imaging (MRI) [18]. The EI and muscle strength display a negative correlation in the skeletal muscles [34]. Because muscle fattening is attributed to muscle atrophy and the adipose differentiation of mesenchymal progenitor cells with muscle satellite cell depletion, the EI is negatively correlated with muscle mass in the skeletal muscles [35–37]. Muscles generally undergo atrophy with aging. While the GHM atrophies similar to any other muscle, the tongue tends to increase in size with aging, unlike other muscles [9]. The tongue strength was not correlated with the EI of the tongue in a previous study [10]. The muscle composition of the tongue is influenced by various factors such as breathing and physical activity [27, 32]. The mechanisms of muscle fattening may differ among swallowing-related muscles such as the tongue and skeletal muscle.

This study had several limitations. Because this was a cross-sectional study, it did not reveal a causal relationship between swallowing-related muscle characteristics and sarcopenia. In addition, we included only five participants with sarcopenia and no participants with severe sarcopenia. The proportion of participants with sarcopenia was 3.4%, which was lower than that reported in previous studies [38]. This difference in sarcopenic prevalence should be taken into account while generalizing our results. An ultrasound examination is dependent on operator skill and the setting, such as the gain and frequency. Therefore, researchers are required to consider these limitations before generalizing our results. However, previous studies have demonstrated a high correlation between muscle evaluation by ultrasonography and MRI [18], and the intraclass correlation coefficient is high [10]. The current study was conducted by a dentist (CA) with an extensive experience in ultrasonography.

Despite these limitations, this study provides useful insights for clinicians. Because the associated factors differ for each swallowing-related muscle as well as the muscle quantity and quality, it is necessary to use the grip strength and SMI correctly to anticipate the deteriorating swallowing-related muscle characteristics. Particularly, the grip strength would be an effective index of swallowing-related muscle characteristics and strength among sarcopenic parameters. In the community, it is important to detect and manage reversible swallowing deterioration at an early stage [39].

Conclusions

The CSA of the GHM was significantly associated with the grip strength, and tongue characteristics were significantly associated with the SMI. Sarcopenic parameters were associated with swallowing-related muscle characteristics. Insights from this study may contribute to the early detection of swallowing deterioration with aging in the diagnostic process of sarcopenia.

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Data availability All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This study was approved by the Ethics Committee of the Tokyo Medical and Dental University (ref: D2014-047) and met the guidelines of the Declaration of Helsinki.

Consent to participate After providing sufficient written and verbal explanations, written informed consent was obtained from all participants.

Consent to publish Not applicable.

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