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Relationship Between Swallowing Frequency and Swallowing-Related Muscle Mass in Older Adults

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ABSTRACT

Background: Older adults have decreased swallowing-related muscle mass, which may lead to decreased swallowing function. One of the causes of this decrease in muscle mass in older adults is a decrease in swallowing frequency.

Objective: The purpose of this study was to evaluate the relationship between swallowing frequency and swallowing-related muscle mass.

Methods: The study included 84 older adults residing in long-term care beds or elderly care facilities. The correlation between swallowing frequency measured by detecting swallowing sounds from laryngeal sounds and the coronal cross-sectional area of the geniohyoid muscle (GM) measured using an ultrasound diagnostic device was examined. Additionally, multiple regression analysis was used to examine the relationship between GM muscle mass and factors that may influence muscle mass, including sex, age, nutrition (body mass index), total body muscle mass (thigh muscle thickness [TMT]) and swallowing frequency.

Results: A significant positive correlation ($r = 0.437$, $p < 0.001$) was found between swallowing frequency and GM mass. A multivariate analysis including other factors revealed that sex ($\beta = 0.482$, $p < 0.001$), TMT ($\beta = 0.272$, $p < 0.005$) and swallowing frequency ($\beta = 0.193$, $p < 0.05$) were significantly correlated with GM mass.

Conclusion: The results of this study indicated that GM mass differed by sex and was correlated with whole-body muscle mass; furthermore, the findings suggest that it is also influenced by localised activity, specifically swallowing frequency.

1 | Introduction

Dysphagia reduces the quality of life by placing restrictions on eating, which is one of the joys in life, and causes problems related to sustaining healthy life, such as malnutrition, dehydration and aspiration pneumonia [1]. The incidence of dysphagia is particularly high in older adults [2], and the underlying cause is said to be a latent decline in swallowing function in this population [3]. Swallowing-related muscle (swallowing muscle) mass has been shown to be a factor in decreased swallowing function [4], and a number of clinical studies have reported that swallowing muscle mass is decreased in older adults [5–7]. In clinical settings, older adults often exhibit signs of muscle mass and strength loss, such as decreased pharyngeal contraction and pharyngeal residue [8, 9].

Muscle mass loss in older adults occurs owing to physiological changes associated with ageing; furthermore, this loss is accelerated by disuse [10, 11]. Loss of muscle mass due to disuse occurs as a result of a continued decrease in muscle activity. Many reports have used basic movements in daily life (daily movements) as an activity index. A study on lower limb muscles investigated the relationship between walking (a daily activity) and disuse and reported that a decrease in the number of steps taken per day by older adults resulted in a decrease in lower limb muscle mass [12].

Studies on swallowing muscles have investigated the number of swallowing movements, which is a daily movement [13–17]. A study on daytime swallowing frequency, excluding the night-time sleep period and eating and drinking periods, showed that the daily swallowing frequency in older adults requiring long-term care was approximately one-quarter lower than that in healthy adults [14]. This result suggests that the daily activity of swallowing muscles in older adults is reduced, which may lead to the disuse of swallowing muscles. Although there have been reports of a reduction in swallowing muscle mass [5–7] and a decrease in swallowing frequency in older adults [14], no reports on the relationship between swallowing frequency and swallowing muscle mass have been clarified. Since daily swallowing frequency reportedly varies from 2 to 19 times/h even among older adults requiring nursing care [14], we hypothesized that differences in individual swallowing frequency may be related to differences in swallowing muscle mass. Therefore, the purpose of this study was to evaluate the relationship between daily swallowing frequency and swallowing muscle mass in older adults.

2 | Methods

This study was conducted with the approval of the Ethical Committee of our university (approval No. R2-E29), and consent was obtained from all the participants. When participants had difficulty in expressing their wishes, consent was obtained from their family and the responsible person in the facility.

2.1 | Participants

Participants in this study were older adults hospitalised in long-term care beds or residing in elderly care facilities who were taking all their meals orally. Individuals were excluded from this study if their hospitalisation or residence period was less than 3 months, if their overall condition was unstable or if they had a muscle disease, such as myositis, that directly influences muscle mass. We obtained information on age, height, weight, comorbidities and the Barthel Index (BI), an index of activities of daily living (ADL), at the time of the study through medical records. Body mass index (BMI) was calculated using the height and weight and expressed as kg/m^2.

2.2 | Swallowing Frequency Measurement

We measured swallowing frequency by detecting the sound produced during swallowing (swallowing sound) from laryngeal sounds, following the method of Tanaka et al. [14–16] A laryngeal microphone (SH-12jK, Nanzu Wireless Electric Co. Ltd., Shizuoka, Japan) was attached to the neck, and laryngeal sounds were recorded using an IC recorder (IC D-PX240, Sony, Tokyo, Japan). We used the speech analysis software Audacity [18] to identify swallowing from the obtained speech data and speech waveforms (Figure 1). Swallowing identification and number of swallow measurement were conducted in consultation with two dentists who were engaged in the clinical treatment of dysphagia. The recording time was any hour between 2:00 and 4:00 p.m., at least 1 h after lunch, and the number of swallows per hour was used to reflect swallowing frequency. Participants were instructed to maintain their daily routine, except that eating, drinking and bathing were prohibited from 1 h before the start of recording until the end of recording. Otherwise, they were encouraged to continue their daily activities as usual. The two dentists supervised the participants during the recording to ensure that no eating or drinking occurred and that the laryngeal microphone had not become detached. To investigate whether the swallowing frequency in older adults during the day varies from day to day or remains stable, measurements were acquired twice on separate days in 10 of the participants. We calculated the intraclass correlation coefficient (ICC) from the two measurements to assess stability. The value calculated from the two measurements of the 10 participants was ICC (1, 1) = 0.91 (95% confidence interval [CI]: 0.71–0.98), and the two measurements in the same individual were almost identical. Given that the daytime swallowing frequency was stable and did not vary daily, measurements of each participant were conducted only once.

2.3 | Muscle Mass Measurement

The coronal cross-sectional area of the geniohyoid muscles (GM), which are responsible for laryngeal elevation during swallowing and have been reported to be related to swallowing function,

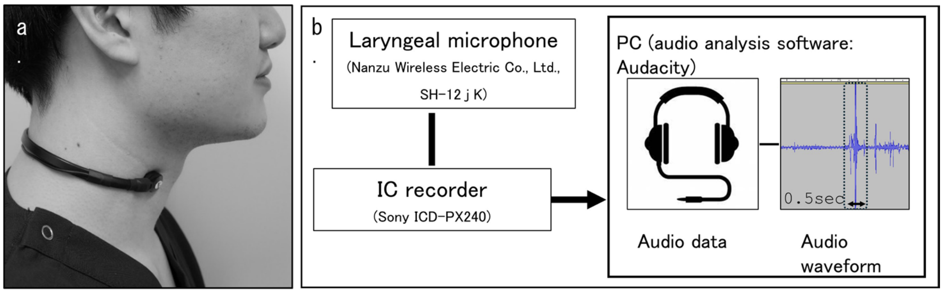

FIGURE 1 | Swallowing count measurement method. (a) Example of laryngeal microphone attachment. (b) Swallowing count measurement. Laryngeal sounds are recorded using a laryngeal microphone and an IC recorder. The audio data and audio waveforms obtained using audio analysis software are used to measure the swallowing count.

was used as an index of swallowing muscle mass [4, 19]. The coronal cross-sectional area of the GM was measured using an ultrasound diagnostic device (SONIMAGE MX1, KONICA MINOLTA, Tokyo, Japan) in accordance with the report by Baba et al. [4] A linear transducer was placed perpendicular to the epidermis at a point between the chin of the mandible and the hyoid bone, at the anterior third of the body. The coronal cross-sectional area of the GM in the obtained ultrasound images was measured using the image processing software ImageJ [20, 21] (US National Institutes of Health, Bethesda, United States; Figure 2).

We used thigh muscle thickness (TMT), which has been reported to be correlated with the total body skeletal muscle mass, as the index of total body muscle mass [22, 23]. We measured TMT using an ultrasound diagnostic device, following the report by Sanada et al. [23] The leg was fixed, and care was taken to avoid pressing the posterior part of the thigh against the seat surface and to avoid tension in the muscle. The measurement position was set at a point halfway between the lateral femoral condyle and the greater trochanter on the anterior part of the thigh, and a linear transducer was placed perpendicular to the long axis of the muscle. We used ImageJ to measure the TMT (distance from the boundary between subcutaneous fat and rectus femoris to the boundary between vastus intermedius and femur) of the obtained ultrasound images (Figure 3).

Although a method for measuring muscle mass using an ultrasound diagnostic device has been established, to examine the intra-examiner reliability of the ultrasound diagnostic device in this study, the coronal cross-sectional area of the GM and TMT was measured three times in 10 randomly selected participants. ICCs were calculated from the three measurements for each of the 10 participants. We examined the intra-examiner reliability by calculating the ICC from the three measurements. The value for the coronal cross-sectional area of the GM calculated from the three measurements conducted on the 10 participants was ICC (1, 1) = 0.93 (95% CI: 0.81–0.98), indicating that the three measurements taken on the same individual were almost consistent and that there was high intra-examiner reliability. The value for the three TMT measurements taken on the 10 participants was ICC (1, 1) = 0.97 (95% CI: 0.93–0.99), indicating that the three measurements taken on the same individual were almost consistent and that there was high intra-examiner reliability. Based on the above results, measurements were performed once in each participant.

2.4 | Statistical Analysis

The correlation between the GM and the factors reported to be related to swallowing frequency and GM, namely sex [24] (male: 1, female: 0), age [25], nutritional status [26] (BMI) and

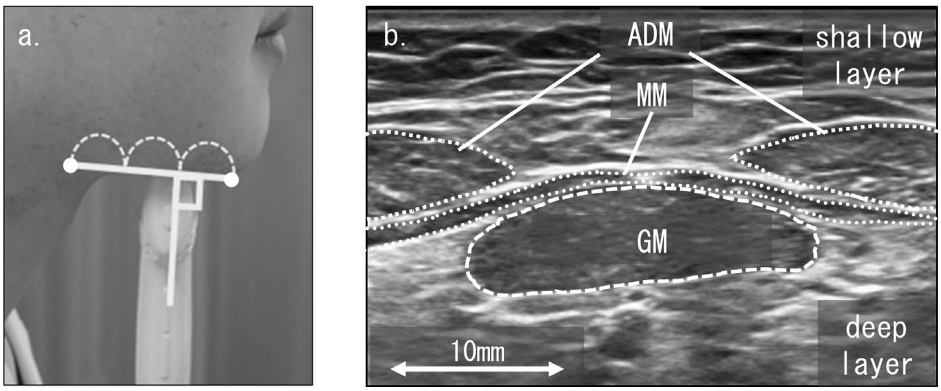

FIGURE 2 | GM measurement method. (a) GM measurement position. The measurement position is the anterior third point between the chin of the mandible and hyoid bone. (b) GM ultrasound image. GM, geniohyoid muscles.

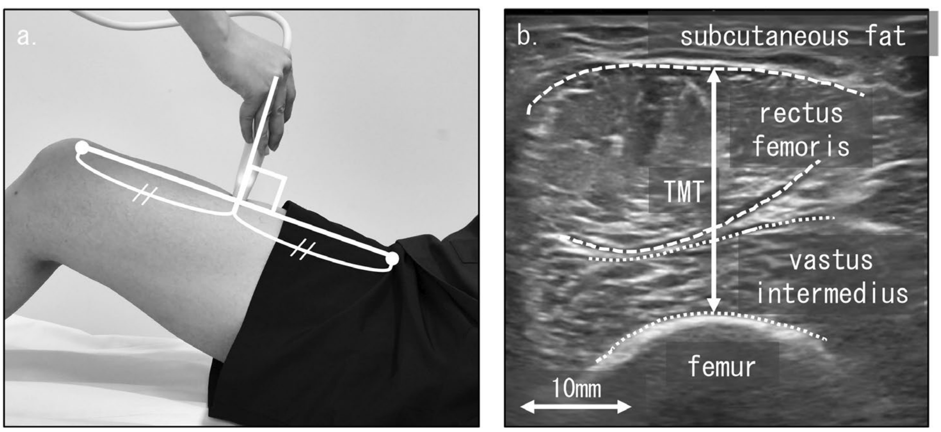

FIGURE 3 | TMT measurement method. (a) Thigh muscle thickness (TMT) measurement position: Measurement position is the midpoint between the greater trochanter and the lateral condyle of the femur. (b) Ultrasound image of the anterior thigh.

total body muscle mass [27] (TMT), was examined. Swallowing frequency and sex do not follow normal distributions; therefore, we used Spearman's rank correlation coefficient to analyse these variables. The other factors follow a normal distribution, so we used Pearson's product–moment correlation coefficient for them. Multiple regression analysis was also conducted using the coronal cross-sectional area of GM as the objective variable and swallowing frequency, sex, age, BMI and TMT as explanatory variables.

3 | Results

The participants consisted of 23 men and 61 women. The mean age was 87.2 (standard deviation [SD] 6.8) years and mean BMI 21.02 (SD 4.16) kg/m^2. The most common comorbidities were diseases of the circulatory system, such as hypertension (55 patients), and diseases of the nervous system such as Alzheimer's disease (34 patients). Many participants had multiple chronic diseases. BI results showed that 28 individuals required partial assistance or were independent (BI > 60), 23 moderate assistance (20 < BI ≤ 60) and 33 full assistance (BI ≤ 20), indicating no evident imbalance in ADL distribution. The oral and swallowing functions in the participants were at a level where they could ingest regular food (45 participants), chopped food (27 participants), bite-sized food (2 participants) and food such as jelly or paste (9 participants).

The median swallowing frequency in all 84 participants was 10 times per hour (interquartile range: 5–16.25). The distribution ranged from 1 to 89 times, with most patients having a value of ≥ 5 and < 10 times. The coronal cross-sectional area of the GM for all 84 participants also ranged from 44 to 126 mm^2, with a mean of 85 mm^2 (SD 18).

A significantly positive correlation was observed between the coronal cross-sectional area of the GM and swallowing frequency (Spearman's product–moment correlation coefficient, rs = 0.44). The correlation analysis of the coronal cross-sectional area of the GM with other factors showed significantly positive correlations with sex (rs = 0.60), BMI (Pearson's product–moment correlation coefficient r = 0.23) and TMT (r = 0.46) and a significantly negative correlation with age (r = −0.24; Figure 4, Table 1). The multiple regression analysis showed a corrected coefficient of determination (R^2 = 0.46), with significant correlations observed for swallowing frequency (standard partial regression coefficient = 0.19, t-value = 2.36), sex (standard partial regression coefficient = 0.48, t-value = 5.53) and TMT (standard

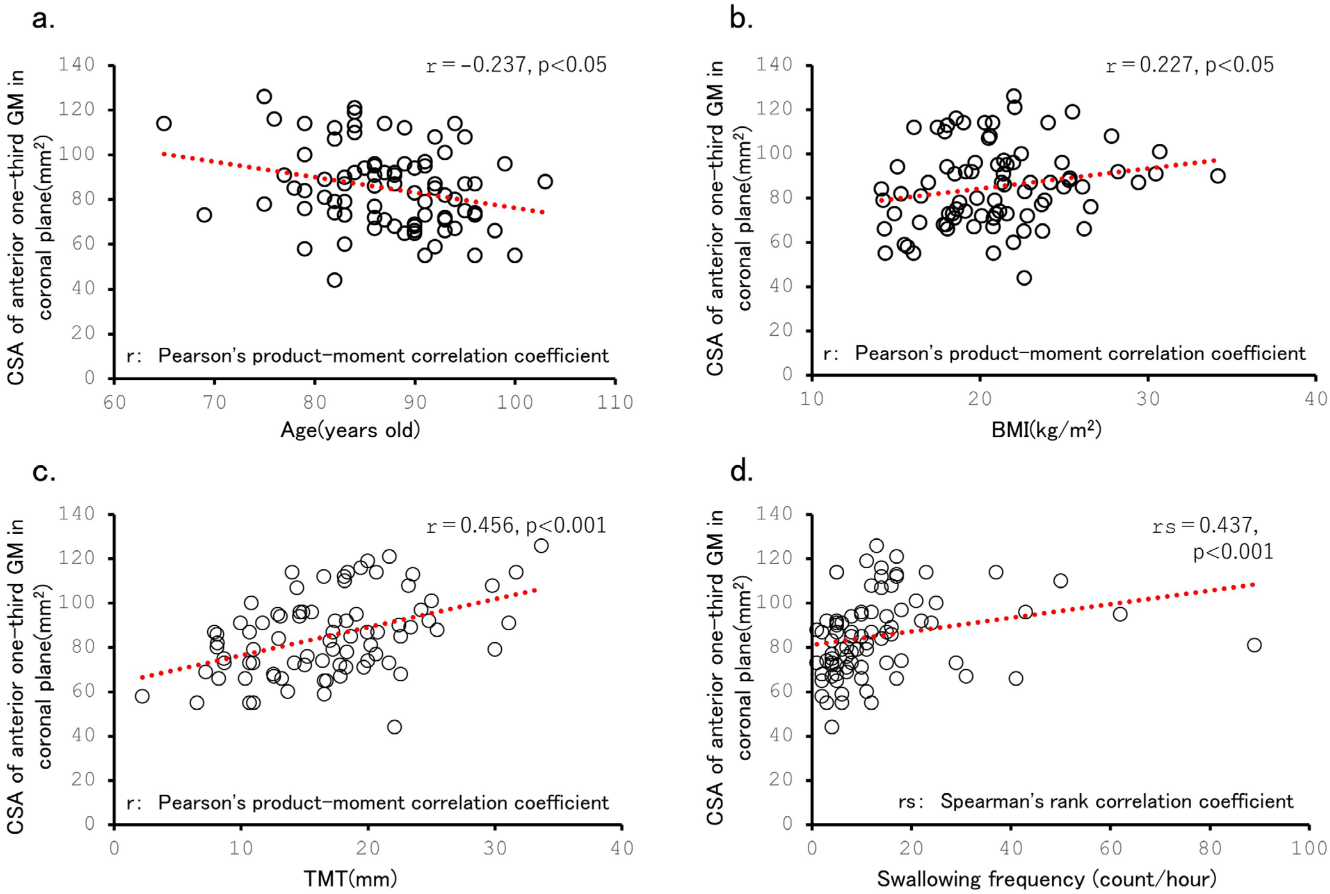

FIGURE 4 | Scatter plots showing correlations of different parameters with CSA of the GM. (a) Correlation between the age and CSA of anterior one-third GM in coronal plane. (b) Correlation between BMI and CSA of anterior one-third GM in coronal plane. (c) Correlation between TMT and CSA of anterior one-third GM in coronal plane. (d) Correlation between swallowing frequency and CSA of anterior one-third GM in coronal plane. BMI, body mass index; CSA, cross-sectional area; GM, geniohyoid muscles; *r*, Pearson's product–moment correlation coefficient; rs, Spearman's rank correlation coefficient; TMT, thigh muscle thickness.

partial regression coefficient = 0.27, *t*-value = 3.01). No significant correlations were observed between age and BMI (Table 2).

4 | Discussion

Although previous studies have reported age-related changes, associations with nutritional status and correlations with overall skeletal muscle mass in relation to swallowing muscle atrophy, no studies had investigated the relationship between swallowing muscle activity and muscle mass. In this study, we focused on the activity of swallowing muscles and examined the association between swallowing frequency—defined as the number of swallowing movements per hour—and the mass of the GM. As a result, a significant positive correlation was observed. Furthermore, multiple regression analysis including previously reported factors also showed significant correlation, supporting the existence of a relationship between swallowing frequency and GM muscle mass. The median swallowing frequency in the participants in this study was 10 times per hour, which was lower than the median value of 36 times per hour reported by Tanaka et al. [14] and the mean value of 61.2 times per hour reported by Crary et al. [17] The reasons for the low swallowing frequency in older adults are unclear, but several studies have reported stimuli that induce the swallowing reflex and age-related changes in sensitivity to stimuli [28–32], which are thought to be involved in swallowing frequency.

Stimuli that induce the swallowing reflex apart from eating and drinking include saliva, gastric contents by gastroesophageal reflux and secretions produced in the airways, such as the trachea and nasal cavity, with the amount of stimuli thought to influence swallowing frequency. The results of our study showed that swallowing frequency was low in older adults; however, among the stimuli mentioned above, the amount of secreted saliva was decreased in this population. Research on the association between swallowing frequency and saliva secretion was conducted by Kapila et al. [33], who reported that suppressing saliva secretion reduced swallowing frequency at rest and that promoting saliva secretion increased swallowing frequency. Many older adults have reduced saliva secretion owing to age-related changes and the effects of medication [28–30]; therefore, their swallowing frequency may be lower than that in healthy adults. Research on sensitivity to stimuli that induce the swallowing reflex includes reports suggesting that physiological changes associated with ageing cause a decrease in pharyngeal and laryngeal sensation, as well as a delay in the initiation of the swallowing reflex [31, 32]. The decreased sensitivity to stimuli among older adults that triggers the swallowing index was also thought to be involved in the decrease in swallowing frequency. The participants in this study were older adults, and it is likely that many of them had reduced salivary secretion and decreased sensitivity to stimuli required to elicit the swallowing reflex. Consequently, the median swallowing frequency across the cohort was relatively low. However, because age-related changes in salivary secretion and sensory sensitivity are not uniform, variability in swallowing frequency was observed among participants.

A single regression analysis revealed a significant positive correlation between swallowing frequency and the coronal cross-sectional area of the GM. This result suggested the possibility that swallowing frequency was related to the disuse of the GM.

TABLE 1 | Correlation analysis for GM.

	GM		
	Correlation coefficient	**Significance probability *p***	**Frequency *n***
Sex (M: 1, F: 0)	0.597	< 0.001	84
Age	−0.237	0.030	84
BMI	0.227	0.038	84
TMT	0.456	< 0.001	84
Swallowing frequency	0.437	< 0.001	84

Abbreviations: BMI, body mass index; GM, geniohyoid muscles; TMT, thigh muscle thickness.

TABLE 2 | Linear regression analysis for GM (multivariate model).

	Multivariate model: Significant variables forced in						
	Regression coefficient	**SE**	***β***	***t***	***p***	**Tolerance**	**VIF**
Sex_M (vs. F)	0.199	0.036	0.482	5.533	**< 0.001**	0.855	1.170
Age (per 1)	−0.002	0.002	−0.085	−1.018	0.312	0.925	1.081
BMI (per 1)	0.003	0.004	0.058	0.672	0.503	0.858	1.165
TMT (per 1)	0.008	0.003	0.272	3.015	**0.003**	0.798	1.252
Swallowing frequency (per 1)	0.003	0.001	0.193	2.362	**0.021**	0.972	1.028

Note: The bold text indicates significant differences.
Abbreviations: *β*, standardised regression coefficient; SE, standard error; VIF, variance inflation factor.

The single regression analysis also showed significant correlations with sex, age, total body muscle mass and BMI, which have previously been reported as factors associated with GM. The multiple regression analysis conducted using these factors as explanatory variables revealed that sex, TMT (index of total body muscle mass) and swallowing frequency showed a significant association, whereas age and BMI showed no significant association. Furthermore, the associations, in descending order of strength, were sex, TMT and swallowing frequency, as indicated by the correlation coefficients of the single regression analysis.

Age did not show a significant association in the multiple regression analysis. Yamaguchi et al. [25] reported that age was strongly associated with GM cross-sectional area in a study of healthy adults (mean age 28.4 years) and healthy older adults (mean age: 73.1 years). The participants of the present study were older adults, and their age range was narrower than that in the report by Yamaguchi et al. In participant groups with a wide age range, such as those in Yamaguchi et al.'s study, age was strongly associated with GM mass; however, it is inferred that other factors were more influential in the older adult group.

Regarding BMI, which was another factor that did not show a significant association in the multiple regression analysis, Wakabayashi et al. [26] reported a case in which GM mass was increased when nutritional status (BMI) improved through active nutritional administration. This report showed that skeletal muscle mass was also increased along with BMI and that BMI was related to both total body muscle and swallowing muscles. Therefore, BMI could be a confounding factor. In our study, multiple regression analysis was conducted, and TMT, an index of total body muscle mass, was included. It is thought that BMI did not show a significant correlation because it had a smaller association with swallowing muscle mass compared to TMT.

Regarding swallowing muscle mass and sex, our study showed that the coronal cross-sectional area of the GM was significantly larger in men than in women and that sex showed a particularly strong correlation among factors related to the coronal cross-sectional area of the GM. The influence of sex hormones explains the sex difference in muscle mass [34], and Feng et al. [24] reported that GM muscle mass was larger in men than in women. The factors and mechanisms of sex differences in muscle mass have only been partially elucidated, but research has reported that skeletal muscles throughout the body are larger in men than in women of all ages and in all parts of the body [34]. The results of the GM muscle mass in this study are also thought to reflect this difference attributed to sex.

In our study, TMT was measured as an index of total body muscle mass, and a significant correlation was found between TMT and the coronal cross-sectional area of the GM. The thigh is one of the largest muscles in the body, accounting for approximately 30% of total body muscle mass, so it is considered to represent the muscles of the entire body [35]. Yamaguchi et al. [27] reported that skeletal muscle mass and trunk skeletal muscle mass index (TMI) were correlated with the coronal cross-sectional area of the GM. The participants in Yamaguchi et al.'s study were community-dwelling older adults with a high level of independence in terms of ADL. The findings of our study, in which the participants' independence ranged from full assistance to independence, align with those of Yamaguchi et al. and support their results.

The single regression analysis showed a significantly positive correlation between swallowing frequency and the coronal cross-sectional area of the GM, and multiple regression analysis showed a significant correlation with the coronal cross-sectional area of the GM. The correlation was not as strong as that with sex and TMT, but this result indicated that swallowing frequency was an independent factor related to GM muscle mass. In other words, GM muscle mass, as part of the skeletal muscle, fluctuated in correlation with other muscles in the body and in correlation with swallowing frequency, which is the amount of activity of the local swallowing muscle. Regarding the relationship between activity level and muscle mass, many studies have shown that physical activity level affects muscle mass throughout the body. In the relationship between swallowing frequency and GM, it was suggested that low swallowing frequency may be a factor in the decreased GM muscle mass. In contrast, the opposite causal relationship, that is, a decrease in swallowing frequency due to low GM muscle mass, cannot be denied. However, although the act of swallowing can be performed voluntarily, most swallowing movements in daily life occur reflexively. Since muscle mass is unlikely to affect the reflex, it is more likely that swallowing frequency affects swallowing muscle mass.

As a future research topic, longitudinal studies are necessary to prove the above possibility. If a causal relationship can be demonstrated, we will then investigate factors that affect swallowing frequency. In the future, we aim to prevent and improve swallowing muscle atrophy by studying daily movements such as swallowing frequency.

In this study, while sex showed a strong correlation with swallowing muscle mass in older adults, external interventions targeting sex to increase GM are challenging. Furthermore, the changes in whole-body muscle mass and swallowing frequency, which reflect local activity in muscles such as the suprahyoid muscle group, were found to correlate with changes in swallowing muscle mass in older adults. These factors are modifiable and thus subject to intervention. Given the above, an effective method for preventing and improving GM mass loss is to maintain and increase total body muscle mass and maintain and improve swallowing frequency, such as encouraging daytime dry swallowing as a local approach.

This study has some limitations. However, this was a cross-sectional study; therefore, we could not show changes over time or causal relationships, such as the period over which swallowing muscle mass decreased due to disuse. Assessing the decrease in swallowing muscle mass owing to a decrease in swallowing frequency requires the implementation of longitudinal studies such as intervention and cohort studies.

5 | Conclusion

We investigated the relationship between swallowing frequency and swallowing muscle mass in the everyday lives of older adults. The results showed that GM mass exhibited differences depending on sex and was changed in correlation with total body muscle mass. Furthermore, GM mass showed changes correlated with swallowing frequency, a measure of the local activity of the swallowing muscles, suggesting that increasing swallowing frequency may be beneficial for maintaining greater swallowing muscle mass.

Author Contributions

Haruna Kawamichi: conceptualization, methodology, investigation, data analysis, writing – original draft, writing – review and editing, project administration. **Aya Obana:** conceptualization, methodology, resources, supervision, investigation, data analysis, writing – review and editing, validation, project administration. **Kanji Nohara:** conceptualization, methodology, resources, supervision, writing – review and editing, final approval of the manuscript. **Nobukazu Tanaka:** methodology, supervision, writing – review and editing, validation. **Takayoshi Sakai:** methodology, supervision, writing – review and editing, final approval of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Raw data were generated at The University of Osaka. Derived data supporting the findings of this study are available from the corresponding author Kanji Nohara on request.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/joor.70056.

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