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Aging Decreases the Strength of Suprahyoid Muscles Involved in Swallowing Movements

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Swallowing disorders are common in the elderly, and aging is a factor that affects swallowing function. The elevation of the hyoid bone is important for swallowing and is controlled by the suprahyoid muscles. The hyoid and laryngeal elevation allows the bolus to enter the esophagus. The suprahyoid muscles, therefore, play an important role in swallowing. The effects of aging on suprahyoid muscle strength are unclear. In this study, we analyzed the effects of aging on suprahyoid muscle strength by comparing the jaw opening functions of healthy adults and elderly adults. The subjects were 150 healthy volunteers consisting of 76 adults aged < 70 years (38 men and 38 women; mean age, 48.8 ± 13.8 years; range, 23-69) and 74 elderly adults aged > 70 years (37 men and 37 women; mean age, 78.1 ± 4.8 years; range, 70-92). The jaw opening force (JOF) was measured with a jaw opening sthenometer and compared between the healthy adult and elderly groups. The mean JOF of healthy adults was about 10 kg in men and about 6 kg in women, which was significantly greater than the mean JOF of the healthy elderly subjects (about 7 kg in men and about 4 kg in women). The JOF of the men was significantly greater than that of the women in the healthy adult and elderly groups. We thus propose that aging decreases the strength of suprahyoid muscles in healthy adults. The swallowing function may decrease even in healthy adults, aged over 70 years.

Keywords: healthy elderly; jaw opening force; muscle strength dynamometer; suprahyoid muscles; swallowing function
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Introduction

Dysphagia, a swallowing disorder, is common in the elderly, and many reports suggest that swallowing function is affected by aging (Robbins et al. 1992; Yokoyama et al. 2000; Kim and McCullough 2008). Dysphagia frequently leads to aspiration pneumonia, a major cause of death among the elderly. Symptoms of swallowing disorders include pharyngeal residue of ingested food, laryngeal penetration (food enters the laryngeal vestibule but does not pass below the true vocal cord), and aspiration (food passes through the true vocal cord and enters the trachea), each of which can be caused by poor opening of the entry into the esophagus, known as the pharyngo-esophageal sphincter (PES), because of poor hyoid/laryngeal elevation during swallowing. Hyoid elevation is important for swallowing and is controlled by the suprahyoid muscles, one of which, the geniohyoid muscle, reduces its mass with aging (Feng et al. 2013). Although the suprahyoid muscles can be strengthened with an isotonic/isometric head-raising exercise (Shaker et al. 1997), we developed a jaw opening muscle-strengthening exercise to train these muscles (Wada et al. 2012) that are involved in jaw opening (Ahlgren 1978; Pancherz et al. 1986). In our previous study, a videofluorographic evaluation of eight patients with swallowing disorders showed significant improvement in the upward movement of the hyoid bone, the PES opening, and the time for the pharynx passage after the jaw opening exercise intervention (Wada et al. 2012). These findings indicate that suprahyoid muscle strength is an important indicator of swallowing strength.

A recent evaluation of swallowing by diagnostic imaging methods such as videoendoscopy and videofluoroscopy has received increasing attention, as these methods provide clinically important details on swallowing strength. For example, pharyngeal swallowing strength can be measured indirectly by videofluorographic measurement of pharyngeal contraction (Kendall and Leonard 2001) with a tongue

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pressure-measuring device (Ono et al. 2004) or with pharyngeal pressure sensor (manometry) (Nativ-Zeltzer et al. 2012). These methods require specialized equipment and technical expertise. To address this technological requirement, we recently developed a jaw opening sthenometer that measures the strength of the suprahyoid muscles to evaluate the jaw opening force easily (Tohara et al. 2011). In that study, we reported data on the jaw opening force of healthy adults. Many patients with dysphagia are elderly individuals who have been affected by diseases such as stroke, Parkinson's disease and head and neck cancer. To evaluate the jaw opening force in this elderly population, the jaw opening force of a reference population of healthy elderly subjects must be determined. Thus, in this study, we obtained basic data on the jaw opening force of healthy elderly subjects to 1) evaluate the effects of aging on suprahyoid muscle strength and to 2) contribute to goal setting in exercise regimens aimed at strengthening the suprahyoid muscles in rehabilitation.

Methods

Subjects

The subjects were 150 healthy volunteers with no symptoms, history, or complaints suggestive of swallowing disorders. A total of 76 subjects aged < 70 years (38 men and 38 women; mean age, 48.8 ± 13.8 years; range, 23-69) comprised the healthy adult group, and 74 subjects aged > 70 years (37 men and 37 women; mean age, 78.1 ± 4.8 years; range, 70-92) comprised the healthy elderly group. The subjects were recruited by advertisement at our university hospital. All the subjects gave informed consent for participation in this study according to a protocol approved by the institutional ethical review board at Nihon University School of Dentistry.

Jaw opening sthenometer

The jaw opening sthenometer consists of durable fabric belts, Velcro, thermoplastic splint material (LMB Blend, Hogy Medical Co., Tokyo, Japan), and a small isometric dynamometer (μTas F-1, Anima Inc., Tokyo, Japan) (Fig. 1). One belt (1-1) encircles the head, two belts (1-2) fasten a belt (1-1) to the top of the head, and two belts (1-3) fasten a belt (1-1) to the mandible. The belt securing members (1-4) and the chin cap (1-5) were made from thermoplastic splint material. A dynamometer (1-6) for measuring the jaw opening force was fastened directly below the chin cap and hooked to a monitor (1-7). The chin cap and dynamometer were fastened to belt (1-1) via belt (1-3).

Fig. 2 depicts an individual wearing the jaw opening sthenometer. Given that the head circumference and the distance from the top of the head to the mandible differ among the subjects, the belt lengths were designed to be adjustable with Velcro. The belts were tightened and fastened as needed to ensure that no loosening occurred during the measurements, as well as to prevent the mouth from opening. The belts at the top of the head crossed over each other (2-1) (Fig. 2). The chin cap belts were placed so that they crossed over each other just before the chin cap (2-2) and encompassed the ears at the location of the belt securing components of the belt that encircled the head. Once past the chin cap, the belt was fastened to the belt-securing component on the other side.

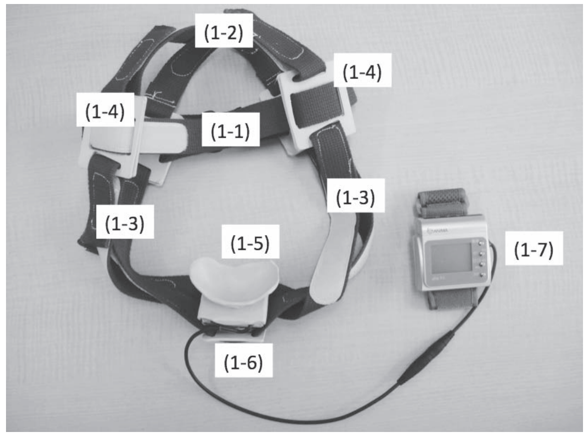

Fig. 1. The jaw opening sthenometer.
The head and mandible securing belts, chin cap, and dynamometer (μTas F-1) of the jaw opening sthenometer. The length of the head and mandible belts are adjustable with Velcro, and the dynamometer is attached to the bottom of the chin cap. (1-1) the head encircling belt, (1-2) the belt that secures the head and the top of the head (× 2), (1-3) the belt that secures the head and mandible (× 2), (1-4) the belt securing the member (× 4), (1-5) the chin cap, (1-6) the dynamometer (μTas F-1), and (1-7) monitor (μTas F-1).

Evaluation method

The jaw opening force was measured using the sthenometer described above. The examiner was a dentist with experience in dysphagia evaluation. A belt was placed around the top of the subject's head and under the jaw as tightly as possible to prevent the jaw from opening. A sthenometer was attached under the jaw. The subject was instructed to open the jaw to the greatest extent possible. The measurements were done in triplicate, and the highest value was used as the measured value.

Statistical analysis

The data were analyzed using SPSS Statistics 17.0 J (SPSS Japan, Inc., Tokyo, Japan). The intraclass correlation coefficients [ICC (1,1)] were calculated as a measure of the intra-rater reliability. The intra-rater reliability is the degree of consistency among multiple repetitions of a diagnostic test performed by a single rater. The student's t test was used to compare the jaw opening force between the two groups and between men and women. Cohen's d was used as the parameters of effect size.

Results

The calculated ICC (1, 1) was 0.907, indicating the high intra-rater reliability. The jaw opening force in the healthy adult group (mean age, 48.8 ± 13.8 years; range, 23-69) was about 7.8 ± 3.0 kg (men: mean strength, about 9.7 ± 2.8 kg; mean age, 48.5 ± 13.4 years; range, 26-69; women: mean strength, about 5.9 ± 1.6 kg; mean age, 49.2 ± 14.4 years; range, 23-69). The jaw opening force of the healthy elderly group (mean age, 78.1 ± 4.8 years; range, 70-92) was about 5.7 ± 2.3 kg (men: mean strength, about 7.0 ± 2.4 kg; mean age, 78.1 ± 5.2 years; range, 70-92; women: mean strength, about 4.4 ± 1.1 kg; mean age, 78.1

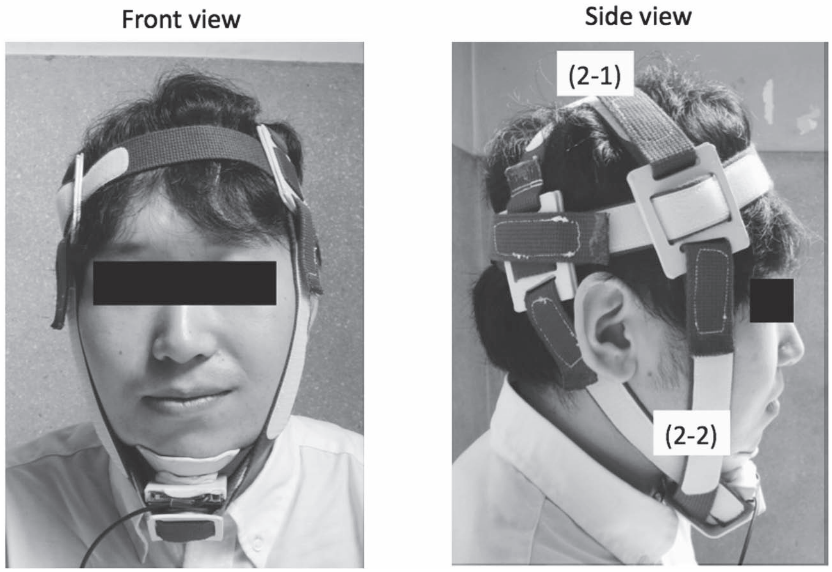

Fig. 2. Wearing the jaw opening sthenometer.
The belts bringing the head, mandible, and chin cap together are secured by tightening to prevent the mouth from opening during the jaw opening movements. The mandible belt is secured to the head belt behind the temple and ears. (2-1) The head belts cross over each other. (2-2) The mandible belts cross over each other just before the chin cap-securing member.

Table 1. The jaw opening force of healthy adults and elderly.

		Healthy adults (kg)		Healthy elderly (kg)		Adults vs. elderly	
		Mean ± S.D.	(95% C.I.)	Mean ± S.D.	(95% C.I.)	p	Cohen's d
Men		9.7 ± 2.8	(8.8-10.6)	7.0 ± 2.4	(6.2-7.8)	< 0.01	1.03
Women		5.9 ± 1.6	(5.4-6.4)	4.4 ± 1.1	(4.1-4.8)	< 0.01	1.09
Total		7.8 ± 3.0	(7.1-8.5)	5.7 ± 2.3	(5.2-6.2)	< 0.01	0.78
Men vs. women	p	< 0.01		< 0.01			
	Cohen's d	1.67		1.39			

Significant differences in the jaw opening force were observed between the healthy adults and healthy elderly adults, as well as between the men and women (student's *t*-test). Cohen's d was used as the parameters of effect size (−0.15 ≤ d < 0.15; negligible; 0.15 ≤ d < 0.4: small; 0.4 ≤ d < 0.75: medium; 0.75 ≤ d < 1.10: large; 1.10 ≤ d < 1.10: very large; 1.45 ≤ d: huge).

± 4.5 years; range, 70-86). The jaw opening force was significantly lower in the healthy elderly group than in the healthy adult group. Effect sizes for all groups were large (0.75 ≤ d < 1.10). Similar results were obtained when the two groups were compared by gender (Table 1). The in-group comparisons revealed a significant difference in the jaw opening force between the men and women. Effect sizes for both groups were very large (1.10 ≤ d < 1.45).

Discussion

Jaw opening force measurements

Only a limited number of studies have measured the jaw opening force. These studies measured the jaw opening force 1) to investigate the relationship between skeletal type and opening and closing forces (Yildirim and DeVincenzo 1971), 2) to investigate whether gnathodynamometers, the instruments for measuring the force exerted in closing the jaw, could be used to measure the jaw opening force (Wood and Williams 1981), 3) to investigate the relationship between jaw opening and closing forces and age and body type (Sharkey et al. 1984), 4) to obtain basic information regarding mandibular movement (Fujii et al. 1985), 5) to determine the reliability of measuring jaw opening force with an indirect cervical traction device (Koyama et al. 2005a), and 6) to evaluate mouth quantitatively opening force before and after surgery for tongue cancer using an indirect cervical traction device (Koyama et al. 2005b). However, except for our previous report (Tohara et al. 2011), the above-mentioned studies did not measure the jaw opening force to evaluate swallowing function.

The previously reported apparatuses for measuring the jaw opening force can be classified into the following two types: those that directly secure the chin to the head and those that secure the chin to the apparatus itself. The jaw opening force as assessed by non-head secured apparatuses has been reported as 14-17 kg (Yildirim and DeVincenzo 1971), 40-140 N (4-14 kg) (Wood and Williams 1981), or 118 N (about 12 kg) (Sharkey et al. 1984). With these apparatuses, the counteracting force on the head when opening the jaw is included in the measurement; i.e., when the subject stretches his/her back when opening the jaw and the head moves, this movement is added to the force calculation. It is unlikely that these measurements accurately reflect only the force required to raise the mandible (Wood and Williams 1981).

We found that the mean jaw opening force was about 8 kg for healthy adults and about 6 kg for healthy elderly adults. Whereas our values were somewhat lower than those discussed above, we note that our measurement method fixes the chin to the head with a belt. Thus, the influence of up and down head motion on the force measurements is likely to be minimal. We suspect that the higher values obtained in previous studies might reflect the inclusion of some component of the force exerted when the head tilts downward because of the contraction of the anterior neck or abdominal muscles when opening the jaw.

As in our study, Fujii et al. (1985) measured the jaw opening force by using the head for anchorage and reported a jaw opening force of about 2.5 kg in healthy adult. Our study design did not allow for us to determine whether the inconsistent results could be attributed to the use of a different apparatus. Our study had markedly lower values compared to other reports, and it had a limited sample size, which makes it difficult to conclude whether the obtained value could actually be considered a "standard value." We hypothesize that our measurement method and sthenometer are appropriate for our purposes, given the importance of using a method that is not susceptible to the influence of head movements.

Reliability of the jaw opening force measurements

The intra-rater reliability was high (ICC (1, 1): 0.907) for the measurements of the jaw opening force with the jaw opening sthenometer. This result demonstrates that the measurement by a single rater has highly stablitiy and consistency. Although the inter-rater reliability could not be assessed because only one person took the measurements, the inter-rater variability should be determined in future studies.

Significance of the jaw opening force measurements

Evaluating the motor function that relates to swallowing is essential for a clear understanding of swallowing function. In pharyngeal swallowing, the tongue contacts the hard palate and prevents regurgitation of food into the oral cavity, and the soft palate elevates to close the nasopharynx. The hyoid and laryngeal elevation causes the PES, which is closed in the resting state, to open and allow the bolus to enter the esophagus from the pharynx. These are involuntary reflexes. The methods of evaluating these functions have been previously described.

The tongue can be visually inspected and palpated, and articulation can be confirmed. It is possible to have the patient move the tongue for observation purposes. The soft palate elevation can be evaluated by visually inspecting the oral cavity, determining the presence of hypernasality, or nasal endoscopy. The hyoid and laryngeal elevation can be examined by visual inspection and palpation of the thyroid cartilage. Whereas pharyngeal contractions can be evaluated with the gag reflex or by the presence of curtain signs, no such method exists to externally observe the PES opening. Given that PES disorders can lead to swallowing disorders (Crichlow 1956; Belsey 1966; Silbiger et al. 1967; Ekberg and Nylander 1982; Curtis et al. 1984; Ekberg and Wahlgren 1985; Baredes et al. 1997), establishing methods for the external evaluation of the PES opening is of particular importance. Considering that the PES opening and forward movement of the hyoid bone are highly correlated (Jacob et al. 1989; Nakane et al. 2006), not only does evaluating the suprahyoid muscle strength by measuring the jaw opening force provide insight into hyoid elevation, it also possibly allows for the indirect evaluation of the PES opening. This finding probably does not apply to cases of PES scarring and cricopharyngeal bar, a specific type of cricopharyngeal achalasia (Dantas et al. 1990).

Among the suprahyoid muscles, the mylohyoid, the anterior belly of the digastric muscle, and the geniohyoid are involved not only in hyoid elevation but also in jaw opening. When jaw opening, supra- and infrahyoid muscles contract and depress the mandible without hyoid elevation. When swallowing, the mylohyoid and anterior belly of the digastric muscle pull the hyoid bone upwards and the geniohyoid pulls the hyoid bone forward. Thus, these muscles are collectively involved in moving the hyoid bone forward and upward.

The lateral pterygoid, a non-suprahyoid muscle, is involved in opening the jaw. When one side of the lateral pterygoid moves to pull the mandibular condyle forward, the anterior portion of the mandibular moves in the opposite direction. When both sides move, the entire mandible moves forward or opens to allow the condyle to move forward (Grant 1973). Whereas the posterior belly of the digastric muscle and the stylohyoid muscle are involved in hyoid elevation, they do not affect jaw opening. Whereas the jaw opening force is affected by the lateral pterygoid, which is not involved in swallowing, it is not affected by the posterior belly of the digastric muscle and the stylohyoid muscle, which are involved in swallowing. Whereas they are unlikely to greatly influence the jaw opening force measurements because of the size of these muscles, a detailed study on the relationship between the jaw opening force and the extent of dysphagia will be required to address this issue.

Effects from aging

Compared to healthy individuals aged < 70 years, we found that those aged > 70 years had a significantly lower jaw opening force. Previous studies have reported the lack of correlation between the jaw opening force and age in men and women aged 20 to 70 years old (Tohara et al. 2011). Robbins et al. (1992) measured the time it takes for hyoid elevation after a bolus passes through the oropharyngeal isthmus, the time it takes for a bolus to pass through, the time it takes for the PES to open, and the total duration of swallowing; the study showed that whereas the participants from 60 to 70 years old showed no differences in these parameters compared to the participants from 20 to 30 years old, the participants over 70 years old took significantly more time, suggesting that the PES opens significantly more slowly in these individuals. Kim and McCullough (2008) reported that the distance of the hyoid bone elevation during swallowing was significantly shorter in the elderly participants aged 70-87 years than in the adults aged 20-51 years. Our findings are consistent with these studies and with the study of pharyngeal pressure sensor by Yokoyama et al. (2000), which revealed that the minimum pressure of the PES is significantly higher in individuals aged 75-89 years than in those aged 21-31 years and 61-74 years. We reported on the jaw opening force of 64 healthy adults (mean age, 44.7 ± 12.6 years; range, 24-64) and found that the mean jaw opening muscle strength was about 8 kg (in men, about 10 kg; in women, about 6 kg). Men had significantly greater muscle strength than women, although no correlation with age was found (Tohara et al. 2011).

Sarcopenia, i.e., reduced muscle force because of decreased numbers of muscle fibers from aging and reduced muscle volume, might potentially explain the lower jaw opening force observed in the healthy elderly group. According to Baumgartner et al. (1998), the incidence of sarcopenia among individuals aged > 70 years is 13-24%; however, the incidence increases to 30% for individuals aged 75-80 years and 50% for individuals aged > 80 years. Larsson et al. (2001) previously reported that fast muscles (Major Histocompatibility Complex (MHC) class II; MHC-II) tended to atrophy more than slow muscles (MHC-I). Given that suprahyoid muscles are predominantly fast muscles (Korfage et al. 2001), this finding might explain the decrease in suprahyoid muscle strength from sarcopenia in elderly individuals and swallowing dysfunction resulting from aging.

Study Limitations

This study revealed that suprahyoid muscle strength deteriorated in the healthy elderly subjects aged > 70 years; however, the relationship between the jaw opening force and swallowing function remains unclear. Future studies should include patients with dysphagia and examine the relationships between the specific components of the swallowing function and the jaw opening force.

Conclusion

In this study, we used the jaw opening force as an indicator to examine the effects of aging on swallowing function. Our results suggest that aging affects and reduces the suprahyoid muscle strength in healthy elderly individuals aged > 70 years.

Conflict of Interest

The authors declare no conflict of interest.

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