Japanese Journal of Health, Fitness and Nutrition, 19(1), 18 － 26 (2014)

Original Article

Average bolus volume for water and intra- and interindividual variation

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Abstract

We examined the average bolus volume for water and intra- and interindividual variation in different age groups of healthy subjects to provide insight into prevention of aspiration in the elderly.

The subjects were 243 healthy individuals (114 men, 129 women). The average bolus volume for water was defined as the amount that the subject could drink with a single swallow. The coefficient of variation was calculated from the 7 measurements of average bolus volume for water. To examine interindividual variation, subject height and weight and oral cavity factors were measured.

Genders and age groups were compared using Student's t-test and a one-way analysis of variance. Correlation and regression analyses were performed for the average bolus volume for water and variation factors.

The overall average bolus volume for water was 17.6 ± 8.2 g. The volume was higher in men than women (20 ± 8.5 g vs 15.6 ± 7.5 g, $p < 0.01$), and lower in women in their 80s than those in their 70s ($p < 0.01$), suggesting that the appropriate volume varied according to gender and age group. Intraindividual variation in the average bolus volume for water was small and constant in subjects in their 20s-70s but greater in subjects in their 80s. The results suggest that interindividual variation in the average bolus volume for water was affected by the maximum oral cavity volume, mandibular length and age.

Key words： Average bolus volume for water, variation factors, maximum oral cavity volume, maximum tongue pressure

Ⅰ. Introduction

Pneumonia has recently become the third most common cause of death in Japan. Most of those who die from pneumonia are elderly, and roughly 70 percent of these elderly individuals die from pneumonia caused by aspiration [1]. Aspiration is also closely related to maintaining the quality of life of the elderly insofar as it pertains to their enjoyment of eating, making its prevention is important.

Previous research has shown that the risk of aspiration in elderly individuals increases if the bolus volume is increased [2]. Consequently, a recommended means of preventing aspiration is to ingest food in appropriate bite sizes, i.e., average bolus volumes. Liquids such as water and tea are newtonian fluids and therefore highly fluid and likely to cause aspiration in the elderly, whose swallowing function has begun to decline [3]. Therefore, an average liquid bolus volume is needed for elderly individuals.

Studies of the average bolus volume for water have been occasionally conducted in Japan and other countries, but the subjects have been mostly non-elderly men and women and few of the studies have included elderly individuals. Intraindividual variation in bite size for solid food that requires chewing has been found to be small and constant [4]. With regard to the factors that vary the average bolus volume for water, however, there have been few reports on interindividual variation in bolus volume for liquids, which do not require chewing. Moreover, although a relationship between water bolus volume and body height [5] and oral cavity volume [6] has been reported, it has not been firmly established.

To aid in preventing overt aspiration in the elderly, this study determined the average bolus volume for water in healthy men and women in their 20s-80s and examined in detail the average bolus volume and intra- and interindividual variation for each age group.

Ⅱ. Subjects and methods

1. Subjects

The subjects were 243 healthy individuals (114 men, 129 women; Table 1).

All of the subjects were able to function independently (ADL evaluation: Barthel Index), and none choked during the study measurements.

2. Measurements

1) Measurement of average bolus volume

The measurements were performed between July 2012 and March 2013. They were performed at a room temperature of 22 ± 4° C (18-20° C in winter, 26-28° C in summer). The food article used in the study was the commercially available bottled drinking water Mori no Mizu Dayori ®, which was maintained at a temperature of 15-20° C during the measurements [7]. The measurement was performed for each subject individually and, together with the preliminary interview and explanation of the swallowing method, took approximately 10 min.

The interview was used to confirm that the subject was not feeling stomach fullness, hunger, or thirst. The swallowing method involved swallowing with the mouth empty immediately before ingestion and, from a cup containing 50 g of drinking water, ingesting the amount that the subject could drink with a single swallow. The subject was asked to return to the cup any water that they could not ingest and that remained in the oral cavity. The measurement was performed 10 times with the subject seated, as described by Ojima et al. [8]

The amount of water remaining in the cup was subtracted from 50 g to determine the average bolus volume. The average bolus volume for the individual was determined as the mean of the 7 measurements remaining after the initial, minimum, and maximum values were excluded from the 10 measurement values.

2) Factors in average bolus volume variation

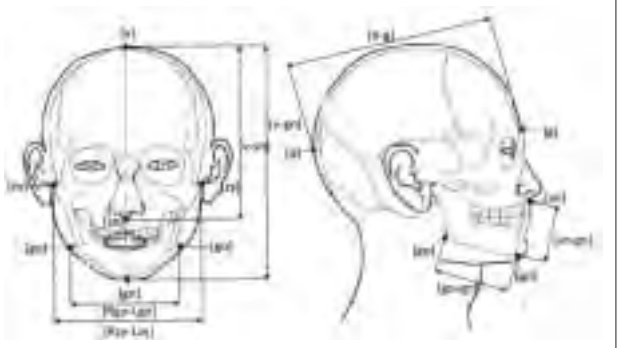
As a measure of intraindividual variation, the coefficient of variation (CV%) was calculated from the 7 measurements of average bolus volume.

To examine interindividual variation, subject height and weight and oral cavity factors [9-12] that have been found to be correlated with these indices of body type were measured. The measurements were performed after the measurement of average bolus volume and took approximately 20 min, including the explanation provided to the subject.

Height and weight measurements obtained by their most recent physical checkup. The body mass index (BMI) was calculated. A Martin anthropometer [9] was used to measure parameters of face size as followed: the total head height, distance from the vertex to the subnasal point, zygomatic arch width, width from left to right gonial angles, mandibular length (mean of left and right mandibular lengths), maximum head length, and distance from the subnasal point to the gnathion (Fig. 1).

Table 1 Number of subjects by age and gender groups

Age(y)	Men	Women	Total
20-29	16	18	34
30-39	15	16	31
40-49	16	15	31
50-59	17	15	32
60-69	19	24	43
70-79	16	27	43
80-89	15	14	29
Total	114	129	243



Reference point

v: vertex
gn: the gnathion point
sn: the subnasal point
go: gonial angle point
zy: zygomatic arch
o: occipital point
g: the glabella point

Orofacial measurements

v-gn: total head height (mm)
v-sn: the vertex to subnasal point width (mm)
Rgo-Lgo: right to left gonial angle point width (mm)
Rzy-Lzy: width of zygomatic arch (mm)
R(go-gn): width of right mandibular (mm)
sn-gn: subnasal point to gnathion width (mm)
o-g: width of maximum head (mm)

Wda: width of the dental arch (mm)
Dda: depth of the dental arch (mm)

Fig.1 Measurement points of the lower dental arch and facial

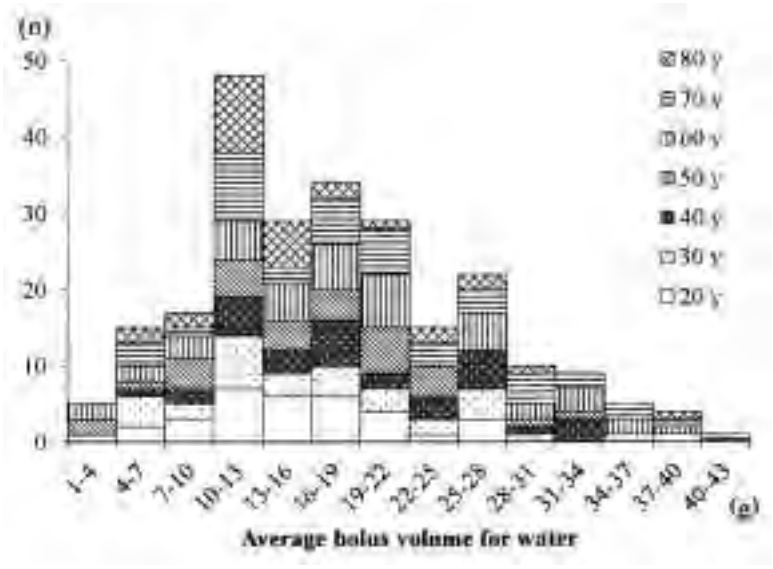


Fig.2 The distribution of average bolus volume for water

The width and length [10] of dental arch were measured by determining the lingual contact points of the left and right first molars and anterior teeth contact points using occlusal adjustment wax (Fig. 1). In addition, the area of the dental arch triangle was approximated from the width and length and used as the basal plane area.

For maximum oral cavity volume, the maximum amount of drinking water the subject could retain in the oral cavity immediately before swallowing was measured using the closed-position water content method described by Mogi et al. [11] The tip of a tube connected to a syringe filled with 120 g of drinking water was inserted through the center of the lips or corner of the mouth, and the water was gently injected into the oral cavity. When the oral cavity became completely filled with water, the subject spit the water into a cup, and the amount in the cup was determined using an electronic balance. The mean of 3 such measurements was used as the maximum oral cavity volume.

Three measurements were performed using the JMS tongue pressure measurement device ® [12] which measures the force applied in squashing a balloon inserted between the tongue and palate, and the mean of the 3 measurements was considered the maximum tongue pressure.

3. Statistical analysis

Genders and age groups were compared using Student's t-test and a one-way analysis of variance, and correlation and regression analyses were performed for the average bolus volume and variation factors. The statistical software used for the analysis was the Statistical Package for Social Science (SPSS, version 14.0 J). A 5% level of significance was used.

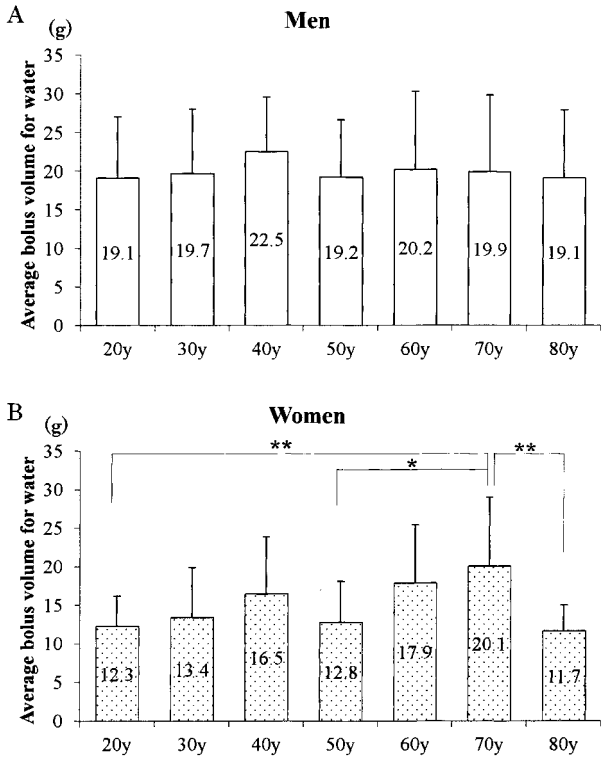


Fig.3 Average bolus volume of both men (A) and women (B) among age groups

Each column and ber shows the mean value and standard deviation.

*p<0.05 **p<0.01 by ANOVA

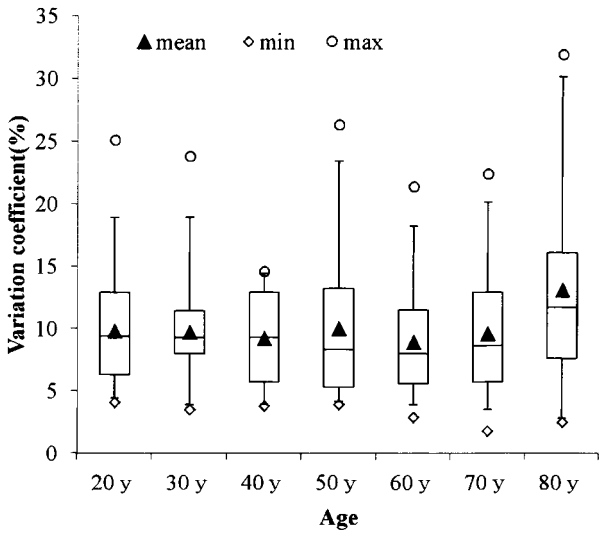


Fig.4 The average variation coefficient (%) of among age groups

Box chart shows the mean value and interquartile range and min and max.

Table 2-1 Measurement result of the factors contributing to average bolus volume for water in each age and gender group (n=243)

	Height (cm)			Weight (kg)			BMI		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
Total	169.0 (6.4)	155.6 (6.6)	***	66.0 (10.7)	52.7 (7.7)	***	23.1 (3.3)	21.7 (3.0)	***
20 y	170.1 (5.3)	157.8 (4.3)	***	62.6 (8.9)	50.7 (6.0)	***	21.6 (2.9)	20.3 (2.1)	
30 y	173.5 (4.8)	162.0 (5.8)	***	70.4 (7.7)	52.4 (7.6)	***	23.4 (3.2)	19.8 (2.2)	***
40 y	172.4 (4.8)	159.9 (4.7)	***	76.6 (15.9)	55.2 (7.6)	***	25.6 (5.0)	21.6 (2.8)	**
50 y	170.6 (6.9)	158.0 (5.5)	***	68.0 (8.8)	56.9 (10.7)	***	23.2 (2.5)	22.7 (4.0)	
60 y	167.6 (4.9)	153.7 (4.9)	***	63.7 (8.1)	51.9 (6.2)	***	22.6 (2.4)	21.1 (3.2)	
70 y	165.7 (5.7)	152.2 (5.0)	***	63.7 (8.4)	52.8 (8.3)	***	23.1 (2.7)	22.6 (3.0)	
80 y	160.8 (5.3)	148.5 (6.8)	***	59.5 (9.7)	49.3 (5.5)	**	23.2 (3.9)	22.3 (2.3)	
	v-gn (mm)			v-sn (mm)			Rzy-Lzy (mm)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
Total	243.5 (7.6)	229.3 (7.6)	***	191.7 (8.3)	179.1 (8.4)	***	145.7 (5.8)	138.9 (5.3)	***
20 y	245.7 (8.7)	228.4 (7.0)	***	196.4 (10.2)	177.4 (9.5)	***	144.9 (6.0)	138.5 (5.6)	**
30 y	247.0 (7.6)	230.6 (8.8)	***	194.3 (8.6)	181.0 (10.2)	***	146.4 (4.6)	138.4 (5.2)	***
40 y	244.1 (7.0)	228.5 (8.4)	***	191.6 (9.3)	179.8 (10.1)	**	147.7 (7.2)	140.6 (3.8)	**
50 y	242.9 (7.9)	228.0 (7.4)	***	190.2 (8.0)	176.4 (6.3)	***	146.6 (5.2)	139.3 (6.8)	**
60 y	244.1 (6.5)	231.5 (6.5)	***	192.8 (6.3)	181.8 (6.7)	***	145.8 (4.5)	139.3 (4.8)	***
70 y	240.8 (7.4)	230.5 (7.9)	***	190.9 (6.2)	180.0 (8.0)	***	145.3 (6.3)	138.5 (5.5)	**
80 y	239.5 (7.0)	224.8 (6.2)	***	185.3 (5.2)	175.3 (6.9)	***	143.3 (6.6)	137.8 (6.0)	*
	Rgo-Lgo (mm)			go-gn (mm)			o-g (mm)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
Total	116.6 (6.2)	111.2 (5.3)	***	98.1 (4.9)	92.5 (4.4)	***	191.4 (7.1)	180.9 (6.5)	***
20 y	113.3 (4.1)	109.2 (5.4)	*	96.3 (5.6)	90.5 (4.5)	**	197.3 (7.9)	180.9 (5.8)	***
30 y	115.1 (6.0)	110.4 (5.1)	*	98.2 (3.3)	93.3 (2.8)	***	192.6 (6.5)	185.0 (7.1)	**
40 y	115.9 (6.5)	111.8 (4.3)	*	99.1 (4.2)	90.6 (3.3)	***	189.9 (4.7)	180.5 (6.2)	***
50 y	116.5 (6.0)	109.7 (4.3)	**	99.6 (4.3)	92.5 (4.4)	***	191.6 (6.5)	182.7 (8.7)	**
60 y	117.9 (5.8)	112.5 (5.0)	**	96.4 (6.1)	92.4 (5.3)	*	190.5 (6.2)	180.6 (5.9)	***
70 y	119.2 (5.7)	112.2 (6.1)	**	98.2 (4.9)	94.2 (4.2)	*	188.6 (9.1)	178.4 (5.7)	**
80 y	118.4 (7.7)	111.6 (5.7)	*	99.2 (4.9)	92.9 (4.1)	**	189.4 (5.7)	179.9 (5.4)	***

Notes; BMI: body mass index

The values are Mean (SD). The *p* values are related to the comparison between men and women.

*$p < 0.05$, ** $p < 0.01$, ***$p < 0.001$ by T-test

4. Ethical considerations

The study was approved in advance by the research ethics committee of the School of Comprehensive Rehabilitation, Graduate School of Comprehensive Rehabilitation, Osaka Prefecture University (Approval no. 2012-NT02).

Ⅲ. Results

1. Average bolus volume

The monomodal normal distribution for average bolus volume is shown in Fig. 2. The results for average bolus volume according to gender and age group are shown in Fig. 3. The overall average bolus volume for water was 17.6 ± 8.2 g.

By gender, men had the higher average bolus volume, 20.0 ± 8.5 g, as compared with 15.6 ± 7.5 g for women ($p < 0.01$). However, no significant difference was seen between men and women in the 60- and 70-year-old age groups.

The results by age group showed no significant differences between the age groups for men. In women, the average bolus volume showed a trend toward higher values in the upper age groups, although the volume was lower among women in their 80s than among those in their 70s ($p < 0.01$).

Table 2-2 Measurement result of the factors contributing to average bolus volume for water in each age and gender group (n=243)

	sn-gn (mm)			Wda (mm)			Dda (mm)		
	Men	Women	*p*	Men	Women	*p*	Men	Women	*p*
Total	71.7 (5.3)	67.2 (4.4)	***	38.3 (3.0)	36.1 (3.2)	***	32.6 (3.0)	31.4 (2.8)	**
20 y	72.0 (4.7)	66.3 (4.6)	**	38.5 (2.7)	34.0 (3.4)	***	34.5 (3.0)	32.8 (2.5)	
30 y	74.2 (3.9)	68.9 (5.2)	**	39.5 (3.1)	35.5 (2.3)	**	33.3 (2.3)	33.0 (2.6)	
40 y	73.1 (4.6)	68.8 (4.9)	*	37.7 (3.5)	36.4 (3.5)		34.1 (2.3)	32.3 (1.9)	*
50 y	71.8 (4.5)	69.0 (4.4)		37.2 (2.4)	35.2 (2.6)		33.8 (1.6)	32.6 (2.0)	
60 y	69.8 (6.0)	66.2 (3.8)	*	37.9 (2.8)	37.3 (2.9)		32.1 (2.7)	30.7 (2.3)	
70 y	70.0 (7.0)	66.5 (3.9)		38.6 (3.3)	36.3 (3.1)	*	30.3 (2.6)	30.1 (3.1)	
80 y	71.8 (5.3)	65.3 (3.6)	**	38.6 (3.1)	37.2 (3.7)		29.8 (3.2)	29.1 (3.0)	
	Basal plane area (mm^2)			Maximum oral cavity volume (g)			Maximum tongue pressure (kPa)		
	Men	Women	*p*	Men	Women	*p*	Menv	Women	*p*
Total	622.6 (72.7)	565.7 (71.7)	***	80.6 (19.3)	61.3 (17.6)	***	38.2 (10.1)	32.4 (6.9)	***
20 y	662.4 (72.8)	557.5 (70.9)	***	90.2 (17.2)	56.5 (13.0)	***	42.3 (8.1)	30.1 (9.2)	**
30 y	656.6 (62.7)	586.3 (67.4)	**	87.1 (16.4)	71.9 (19.9)	*	42.2 (7.5)	33.1 (8.0)	**
40 y	643.7 (73.7)	587.4 (68.5)	*	94.3 (19.4)	66.5 (14.0)	***	44.9 (10.0)	34.7 (6.9)	**
50 y	628.4 (42.2)	571.9 (42.9)	*	79.7 (16.9)	67.9 (14.2)	*	41.5 (7.4)	34.9 (8.1)	*
60 y	610.1 (80.2)	572.6 (64.8)		78.1 (18.8)	61.1 (20.0)	**	33.3 (10.9)	33.1 (5.2)	
70 y	583.8 (55.7)	549.3 (85.1)		67.7 (13.8)	60.6 (16.4)		32.6 (8.3)	32.4 (5.1)	
80 y	576.2 (73.5)	542.1 (86.1)		67.4 (16.5)	44.0 (11.3)	***	30.8 (8.7)	27.7 (4.6)	

Notes; BMI: body mass index
The values are Mean (SD). The *p* values are related to the comparison between men and women.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$ by T-test

Table 3 The results of multiple regression analysis for average bolus volume for water

Independent variable (range)	Coefficient (B)	Standardized estimate(β)	*t*-ratio	*p*-value
Intercept	-20.13		-2.257	0.025
Maximum oral cavity volume (22.3-122.1g)	0.116	0.291	4.133	<0.001
Mandibular length (82-108.5mm)	0.273	0.178	2.671	0.008
Age (20 -88 y)	0.065	0.151	2.281	0.023
Multiple correlation coefficient (R)	0.39			<0.001
Adjusted R-square	0.141			
F-value	13.9			
n	243			

Notes: The vertical line shows multiple regression. n: Number of subjects

2. Intraindividual coefficient of variation for average bolus volume

The results for intraindividual coefficient of variation (%) are shown according to age group in Fig. 4. The overall mean intraindividual coefficient of variation was 9.9 ± 5.1, and the mean according to age group was 9.8 ± 4.4 for the 20s, 9.7 ± 4.0 for the 30s, 9.2 ± 3.5 for the 40s, 10.0 ± 5.9 for the 50s, 8.9 ± 4.4 for the 60s, 9.6 ± 5.0 for the 70s, and 13.1 ± 7.3 for the 80s. Thus, the mean coefficient of variation was higher in subjects in their 80s than in those in the other age groups. No differences were seen between men and women in any of the age groups.

3. Interindividual variation factors for average bolus volume

The measurement results for the variation factors are shown according to gender and age group in Table 2-1, 2-2. The values were generally higher in men than in women. However, there were no differences between men and women in oral cavity area and maximum tongue pressure among subjects in their 60s, 70s, or 80s or in maximum oral cavity volume among subjects in their 70s. In men, negative correlations were seen between age and height, weight, vertex to subnasal point distance, maximum head length, dental arch length, basal plane area, maximum oral cavity volume, and maximum tongue pressure, the values for subjects in their 70s and 80s being lower than those for subjects in their 20s-40s. In women, negative correlations were seen between age and height, maximum head length, dental arch length, and maximum oral cavity volume, the values for subjects in their 80s being the lowest among the age groups.

Analysis of the correlations between average bolus volume and the variation factors showed positive correlations with mandibular length and maximum oral cavity volume in men and with age, maximum oral cavity volume, and maximum tongue pressure in women.

A stepwise multiple regression analysis was performed with average bolus volume as the response variable and the following variation factors as explanatory variables: age, gender, height, weight, BMI, total head height, vertex to subnasal point distance, zygomatic arch width, width from left to right gonial angles, mandibular length, maximum head length, subnasal point to gnathion distance, dental arch width, dental arch length, basal plane area, maximum oral cavity volume, and maximum tongue pressure. A significant regression equation (R^2 of 0.141, $p < 0.001$) was obtained for average bolus volume with maximum oral cavity volume, mandibular length, and age as explanatory variables (Table 3).

Ⅳ. Discussion

1. Average bolus volume

The water content of the body is lower in elderly individuals than in younger adults, and the elderly are prone to dehydration, making fluid intake essential. However, liquids that are highly fluid readily enter the pharynx, and the potential for such liquids to be ingested in quantities that exceed the average bolus volume is high. Consequently, the risk of aspiration is higher for water than for solid food. If the individual ingests an amount smaller than the average bolus volume out of fear of aspiration and this elicits a weak swallowing reflex, the deglutition does not proceed smoothly [2,13]. Deglutition apnea may occur repeatedly, and the individual may become fatigued and not ingest the amount of fluid needed. To prevent aspiration and ensure that fluids are ingested in the required amounts, it is necessary to know the average water bolus volume for the elderly. However, there have been no reports of previous studies in elderly individuals greater than 70 years of age.

Hiraba et al. [14] found the average bolus volume for water in 6 Japanese men and women aged 27-42 years to be 38.8 ± 11.4 mL. Okuno et al. [15] found the average bolus volume for green tea to be 17.5 ± 5.5 mL in 10 men and women with a mean age of 25 years, and Miyaoka et al. [16] reported an average bolus volume for oolong tea of 17.9 ± 1.58 mL in 28 women aged approximately 20 years.

Using gum syrup, Ojima et al. [8] determined the average bolus volume to be 23.9 ± 14.1 mL in 7 men and women with a mean age of 26 years. These previous studies used measurement methods similar to that used in the present study, and the textural characteristics of the test foods -- such as hardness, adhesiveness, and agglutination -- also were comparable. Although the flavors differed, these findings are currently considered reference values for average bolus volumes in Japanese adults. However, although the average bolus volume for water obtained for the 206 men and women under the age of 75 years in this study, 18.0 ± 8.3 g, was comparable to results obtained in the previous studies, the value obtained for men and woman aged 75 years or greater was smaller, 15.5 ± 7.9 g. Consequently, the current reference value may result in ingestion of quantities that are too large for elderly individuals aged 75 years or greater.

Adnerhill et al. [17] found no correlation between average bolus volume and age in 60 men and women aged 30-79 years, and Lawless et al. [6] reported finding no effect of age on average bolus volume in non-elderly men and women (50 subjects aged 18-54 years) and elderly men and women (22 subjects aged 60-94 years). No correlation with age was seen in the total of 243

men and women in the present study, and no differences were seen between the age groups in men. In women, however, a trend toward an increase in average bolus volume with age was seen through the 70s, while the average bolus volume was lower in subjects in their 80s ($p < 0.01$).

Regarding gender differences, Nilsson et al.[18] found the average bolus volume to be higher in males (28.1 ± 9.1 mL) than in females (21.6 ± 5.5 mL) among 292 adult males and females aged 15-64 years. Adnerhill et al. [17] and Lawless et al. [6] also reported higher average bolus volumes for men than for women. The results of present study, which showed a higher average bolus volume in men (20.0 ± 8.5 g) than in women (15.6 ± 7.5 g, $p < 0.01$) when the total study population was considered, lent support to those of the previous studies. However, no differences were seen between men and women in their 60s and 70s, indicating that gender differences tended to vary according to age. Because some of the findings of interindividual variation in bolus volume for water supported the results of the previous studies while others did not, it was concluded that further examination of the factors involved in interindividual variation would be necessary.

2. Intraindividual variation

The single intake amount of solid food that requires chewing varies little and is constant for the same individual and food, even if chewing ability and circumstances (e.g., number of teeth) differs between individuals [4].

However, we have found no consistent perspective regarding liquids such as water, which do not require chewing. Lawless et al. [6] found that the first of the 5 measurements yielded the highest value and the values gradually decreased subsequently, and Nilsson et al. [18] reported intraindividual variation with repeated swallowing, including the finding that the measurement values for 3 consecutive swallows were lower than the value for a single swallow. Moreover, Nilsson et al. [18] and Hiraba et al. [14] reported that the coefficient of variation for consecutive swallowing decreased if subjects were instructed to swallow at a certain pace, such as being told to swallow as quickly as possible.

In the present study, the measurement was performed 10 times with the subjects asked to swallow a bolus of a size that would normally enable them to swallow and no instructions given regarding the pace of ingestion. Although the pace of swallowing varied depending on the subject, intraindividual variation was small for subjects in their 20s-70s regardless of swallowing pace, indicating that, as with solid food, the liquid was ingested in a constant amount that was suitable for the individual. However, a trend toward much greater intraindividual variation was seen in subjects in their 80s than in the other age groups. Although we have found no previous studies that have addressed variation in individuals in their 80s and this is therefore merely conjecture based on the measurements, this variation may be related to skilled motor activities of fingers, such as moving the cup to the mouth and tilting it, and to the sensitivity and motor function of the tongue and lips to take liquid into the mouth. Fujishima [19] found that eating and swallowing are greatly affected by the steps that occur before swallowing, such as recognizing the food, taking it into the mouth, and chewing, and further investigation of the intraindividual variation in eating and swallowing among individuals in their 80s is needed.

3. Interindividual variation

There have been very few reports on interindividual variation in the average bolus volume for water. Lawless et al. [6] found it to be positively correlated with oral cavity volume, and Izuhara [20] reported no positive correlations with height, weight, and BMI, but thorough observations have not been delineated.

The present study found no relationship between body type and average bolus volume in men or women, with no positive correlation found with height, weight, or BMI. However, a positive correlation was found with maximum oral cavity volume, consistent with the finding of Lawless et al. [6] Although the maximum oral cavity volume was smaller in elderly subjects than in young and middle-aged subjects, no differences between the age groups were seen in men, and a trend toward an increase in the volume with increasing age was seen in women. Consequently, factors that have been found in recent years to be related to aspiration [21, 23] -- such as maximum tongue pressure, body type, and oral cavity volume -- were analyzed. The analysis detected maximum oral cavity volume, mandibular length, and age as factors that strongly affected interindividual variation in the average bolus volume for water (R^2 of 0.141).

Tachimura [22] reported that the bolus volume that can be processed in the mouth affected by the oral cavity volume, consistent with the detecting maximum oral cavity volume and mandibular length. With normal aging, the anatomical changes laryngoptosis and delayed swallowing initiation are seen [23] and it is surmised that water, which is highly fluid, enters the pharynx rapidly and that the amount that enters at one time is large. However, it has been surmised that a decrease in the strength of these muscles reduces the amount of water that can be taken in at one time. The finding that subjects in their 80s had the lowest average bolus volume was attributed to the fact that the maximum oral cavity volume was smaller in this group than in the other age groups. The maximum oral cavity volume

in their 80s is reduced by narrowing of the oral cavity resulting from a decrease in alveolar bone caused by tooth loss or from the use of dentures and by decreased perioral muscle strength. These results suggested the possibility that the average water bolus volume for a healthy individual can be predicted using a regression equation with maximum oral cavity volume, mandibular length, and age as explanatory variables.

V. Conclusions

The average bolus volume for water was measured in healthy adults in their 20s-80s, and intra- and interindividual variation in the average bolus volume was examined. The conclusions were as follows.

1. Although the overall average bolus volume for water was 17.6 ± 8.2 g, the appropriate volume varied according to gender and age group.
2. Intraindividual variation in the average bolus volume for water was small and constant in subjects in their 20s-70s but greater in subjects in their 80s.
3. The results suggest that interindividual variation in the average bolus volume for water was affected by the maximum oral cavity volume, mandibular length, and age.

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