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Factors associated with masticatory performance in community-dwelling older adults: a cross-sectional study

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Keiko Motokawa, Ayako Edahiro, Takayuki Ueda, Tomofumi Takano and Kaoru Sakurai contributed to interpretation of data.

Yu Taniguchi, Akihiko Kitamura, Shoji Shinkai and Hirohiko Hirano contributed to acquisition and analysis of data.

Conflict of interest statement

The authors declare that they have no conflicts of interest.

Abstract

Background

Decreased masticatory performance leads to deterioration of overall health among older adults. However, maintaining and improving masticatory performance by ways other than maintenance of natural teeth and appropriate prosthodontic treatment, remains unclear. If the factors related to the mixing and shearing abilities for the masticatory performance are clarified, it may be possible to maintain and improve the masticatory performance of older adults. We aimed to clarify the association among mixing ability, shearing ability, and masticatory performance-related factors.

Methods

Of the 707 community-dwelling older adults in Kusatsu Town, Japan, 344 who had been treated for any dental defects were enrolled in this study. Masticatory performance was evaluated based on mixing ability and shearing ability. The number of present teeth and artificial teeth, occlusal force, tongue pressure, and oral diadochokinesis /ta/ were measured as masticatory performance-related factors. Their relationship with mixing ability, shearing ability, and masticatory performance-related factors were examined by Spearman's rank correlation coefficient and path analysis.

Results

Among masticatory performance-related factors, the number of present teeth, occlusal force, and tongue pressure were directly associated with both mixing ability and shearing ability. Moreover, mixing ability was also directly associated with shearing ability.

Conclusions

Tongue pressure, which can be improved by training, is a masticatory performance-related factor associated with both mixing and shearing abilities.

Practical implications

Training for tongue pressure after proper prosthetic treatment may provide an effective means of maintaining and improving masticatory performance in older adults.

Keywords:

mastication; oral health; occlusal force; tongue pressure; mixing ability; shearing ability

1 Introduction

Recently, the decrease in masticatory performance among older adults has been reported to be one of the risk factors for metabolic syndrome, sarcopenia, and physical frailty.[1-3] These conditions are defined according to the 2009 Joint Interim Statement,[1] Asian Working Group for Sarcopenia (AWGS)[2], and the Cardiovascular Health Study index criteria,[2,3] respectively. Thus, a decrease in masticatory performance appears to be associated with overall health deterioration. Regular evaluation and efforts to maintain and improve the masticatory performance in older adults may lead to an improvement in overall health.

Masticatory performance has been evaluated using a variety of masticatory samples. These samples include peanuts,[4] silicone,[5] paraffin wax,[6] color-changeable chewing gum,[7] and gummy jelly.[8] In particular, the color-changeable chewing gum[7,9-13] and test gummy jelly[8,11,14-18] are most widely used in both research and clinical practice; of these, the color-changeable chewing gum is used to evaluate the patient's ability to mix food with saliva, while the test gummy jelly is used to evaluate the patient's ability to shear food. Thus, in masticatory performance, these items are used to evaluate different abilities such as mixing ability and shearing ability.[11]

Previous studies have reported that factors (masticatory performance-related factors) such as number of natural teeth,[16] occlusal force,[16,17,19] tongue pressure,[17,18,20] and oral diadochokinesis (ODK)[17,18,20] are associated with masticatory performance among older adults. However, studies that investigate factors related to the mixing ability and shearing ability, which are a part of masticatory performance, are limited. Therefore, effective factors for maintaining and improving mixing ability and

shearing ability are not yet clear. By clarifying these factors, it should be possible to maintain and improve masticatory performance among older adults. We hypothesized that a decrease in masticatory performance-related factors would be associated with a decrease in mixing ability and shearing ability. In this study, we aimed to clarify associations among mixing ability, shearing ability, and masticatory performance-related factors.

2 Materials and methods

2.1 Participants

This study included 707 older adults over 65 years living in Kusatsu town, Gunma Prefecture, who participated in a comprehensive geriatric health examination. Participants were informed in writing and verbally about the purpose and content of the health screening, and their consent to participate was obtained in writing. Health screening was conducted at the General Health and Welfare Center for five days in early July 2017. Of the participants, 99 (14.0%) older adults with deficits in masticatory performance examination data were excluded. Additionally, 264 (37.3%) patients who had not been treated for dental defects were excluded from the analysis in line with reports from previous studies[17,18] to exclude the effect of dental defects on masticatory performance.[21] As a result, 344 (48.7%) older adults (127 male adults and 217 female adults; mean age 76.3 ± 6.5 years) who had a complete dentition or all dental defects treated prosthodontically were included. Those who usually wore removable dentures were screened while wearing these dentures. This study was approved by the Ethics Committee of the Tokyo Metropolitan Institute of Gerontology (Approval No. 3 in 2008 and No. 23 in 2017).

2.2 Masticatory performance

The mixing ability was evaluated using a color-changeable chewing gum (Masticatory Performance Evaluating Gum XYLITOL, Lotte Co., Ltd., Tokyo, Japan).[7,10] Participants chewed the gum freely, in 60 chewing cycles. After chewing, the gum was transferred to a transparent plastic bag and compressed to a thickness of 1.5 mm. Subsequently, a* representing redness was measured randomly at three points using a color-difference meter (CR-20 Color Reader, KONICA MINOLTA, Tokyo, Japan), and the mean was defined as the mixing ability.[9,13] Mixing ability was assessed by four dentists who were pre-trained in the evaluation criteria.

Shearing ability was also assessed using test gummy jelly (Test gummy jelly for evaluating masticatory performance, UHA Mikakuto Co., Ltd., Osaka, Japan.).[8] The gummy jelly was chewed freely in 30 chewing cycles and collected on gauze. The chewed gummy jelly was visually compared with the score chart by Yashui et al. and shearing ability was evaluated in 10 stages.[14] The shearing ability was assessed by two dentists pre-trained in the evaluation criteria.

2.3 Masticatory performance-related factors

The number of present teeth and artificial teeth, presence of removable dentures, occlusal force, tongue pressure, and ODK /ta/ were measured as masticatory performance-related factors. Occlusal force was evaluated using pressure-sensitive sheets (Dental Prescale 50 H R type; Fuji Film Co., Tokyo, Japan).[22] The pressure sensitive sheet was interposed between the maxillary and mandibular dental arches and clenched with maximum occlusal force for 3 seconds in the intercuspal position according to the

evaluator's instructions. Tongue pressure was evaluated using a tongue pressure measurement device (JMS tongue pressure device; JMS Co., Ltd., Hiroshima, Japan).[23] The balloon of the tongue pressure probe was positioned on the anterior palate and compressed onto the palate with the tongue for approximately 7 seconds. Maximal tongue pressures were recorded three times at 30-second intervals, and the mean was recorded as tongue pressure. ODK was evaluated using an oral function measurement device (KENKOU-KUN Handy; Takei Scientific Instruments Co., Ltd., Niigata, Japan).[24] ODK was evaluated using the articulatory velocity of /ta/.[17] /ta/ was repeated as fast as possible for 5 seconds, and the number of syllables produced per second was calculated. Masticatory performance-related factors were evaluated by six dentists who had been trained in advance and who standardized evaluation criteria.

2.4 Other recorded variables

In order to understand the characteristics of the participants, handgrip strength and gait speed,[25] skeletal muscle mass index (SMI)[26] (a muscle mass assessment), body mass index (BMI), Japan Science and Technology Agency Index of Competence (JST-IC)[27] (to assess competence), Geriatric Depression Scale (GDS)-short version[28] (to assess depression), and the Mini-Mental State Examination (MMSE)[29] (to assess cognitive status), among other survey items, were evaluated. In addition, sarcopenia was adjudged from the values of handgrip strength (male: <26.0 kg, female: <18.0 kg), gait speed (≦0.8 m/s), and SMI (male: <7.0 kg/m^2, female: <5.7 kg/m^2) according to the criteria of the AWGS[30] to evaluate the physical functions of the participants. The results were evaluated by 12 nurses and clinical psychologists who had been trained in advance and who used standardized evaluation criteria.

2.5 Chewing syndrome

"Chewing syndrome," proposed by Nasu,[31] is defined as a condition involving difficulty in bolus formation related to chewing caused by malfunctioning of one or more organs, from the lip through the oral cavity proper to the upper part of the epiglottis.

2.6 Statistical analysis

First, Spearman's correlation analyses were performed to evaluate the correlations among mixing ability, shearing ability, and masticatory performance-related factors. Next, we referred to the "chewing syndrome,"[31] proposed by Nasu, to hypothesize pathways leading to decreased mixing ability and shearing ability (Figure 1). Finally, path analysis was performed with reference to the results of the Spearman's correlation analysis to estimate the relationship among a set of observed variables. The variables at the base of the arrow are considered to affect the variables at the tip of the arrow. The Bentler–Bonett normed fit index (NFI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA) were used as fit indices of the path diagram. All analyses were performed using SPSS version 22 (IBM Corp., Armonk, NY, USA). SPSS AMOS Version 20 (IBM) was used for path analysis. The significance level was set at $\alpha = 0.05$.

3 Results

3.1 Participant characteristics

The number of present teeth and artificial teeth were found to be 12.1±11.0 and 15.2±11.3, respectively (Table 1). There were 262 (76.2%) removable denture users, and Eichner index was the largest in class C

with 179 (52.0%). Mixing ability score was 17.0 ± 6.0 and that of shearing ability was 3.4 ± 2.5. During the course of sarcopenia evaluation according to the criteria of the AWGS[30], 95 (27.6%) of the participants were found to have low handgrip strength, 10 (2.9%) had low gait speed, and 0 had low SMI. None of the three elements of the diagnostic criteria for sarcopenia were met.

3.2 Spearman's correlation analysis

Spearman's correlation analysis showed that the correlation coefficients between mixing ability and shearing ability were significantly and positively correlated at r = 0.516. Both mixing and shearing abilities were significantly correlated with the number of natural and artificial teeth, removable denture use, occlusal force, and tongue pressure among the masticatory performance-related factors (Table 2). ODK /ta/ showed a significant correlation only with shearing ability. The correlation coefficient between the number of present teeth and the number of artificial teeth was -0.973 among the participants, while that between the number of present teeth and removable denture use was -0.697.

3.3 Path analysis

Path analysis with reference to the Spearman's correlation analysis is shown in Figure 2. From multiple hypothesis models, the best fit was adopted. Among masticatory performance-related factors, the number of present teeth, occlusal force, and tongue pressure were directly associated with mixing ability and shearing ability. Moreover, it was shown that the mixing ability was directly associated with shearing ability. The fit of the path diagram was 0.978 for NFI, 0.992 for CFI, and 0.039 for RMSEA.

4 Discussion

A decrease in masticatory performance among older adults is associated with the risk of deterioration in overall health.[1-3] Our results suggest that maintaining and improving masticatory performance may improve overall health. Prevention of tooth loss and prosthetic replacement of missing teeth are the main factors to accomplish this goal.[31] However, recently in Japan, there has been a decreasing trend in the number of missing teeth in older adults who are not treating tooth-related defects.[32] To maintain and improve the masticatory performance of aging adults whose dental defects have been treated, it is necessary to evaluate its association with mixing ability, shearing ability, and other masticatory performance-related factors. Appropriate countermeasures should also be continued, including those related to masticatory performance factors from the early stages of decline. Therefore, in this study, the masticatory performance decline pathway was estimated using path analysis to highlight the association among mixing ability, shearing ability, and other masticatory performance-related factors in community dwelling older adults.

The evaluation of participants' physical function with the diagnostic criteria of sarcopenia[30] revealed no applicable participants, indicating that the physical functions of the participants in this study were maintained. MMSE and GDS short-version scores also showed that most participants did not show a severe decrease in cognitive function or severe depressive tendencies.

The model of the path analysis is referred to as the “chewing syndrome”' and was proposed by Nasu.[31] Path analysis showed that a decrease in the number of present teeth leads directly to a decrease in

occlusal force and indirectly to a decrease in occlusal force via the use of removable dentures, and may lead directly to a decrease in mixing ability and shearing ability.

Previous studies have shown that a decrease in the number of present teeth is associated with a decrease in occlusal force and masticatory performance even if the defects were replaced by removable prostheses.[15,20] Our results also support this claim. Another pathway showed an association between age and tongue pressure. Tongue pressure was shown to decrease with age, similar to findings from previous studies.[33] Occlusal force was shown to be associated with the number of present teeth and sex, and these results are also supported by previous studies.[34] Although both tongue pressure and occlusal force are masticatory performance-related factors representing muscular strength, the reason for the differences in their associated factors were due to tongue pressure being minimally affected by the number of present teeth. The results of Spearman's correlation analysis showed a correlation between shearing ability and ODK /ta/, whereas path analysis did not show any association between both mixing ability and shearing ability with ODK /ta/. Several previous studies have reported an association between masticatory performance and ODK /ta/ among older adults.[17,18] In contrast, in a study of young people, both mixing ability and shearing ability have not been found to be associated with ODK /ta/.[11] The relationship among masticatory performance, tongue dexterity, and motor speed should be further investigated.

This study showed that a decrease in the number of present teeth, occlusal force, and tongue pressure among masticatory performance-related factors may lead to a decrease in mixing ability and shearing ability. Among masticatory performance-related factors, occlusal force, which is considered to

represent muscle strength, is affected by sex and number of present teeth, while tongue pressure is considered to be affected by aging. In order to maintain and improve masticatory performance, we should identify declining muscle strength in its early stages by assessing tongue pressure.

Mastication proceeds in the order of shearing food and mixing it with saliva. Based on clinical experience indicating that the influence of tooth loss is more pronounced on shearing ability than mixing ability, we hypothesized that a decrease in shearing ability contributes to a decrease in mixing ability. However, the path diagram showed results that were contrary to our hypothesis, suggesting the possibility that a decrease in mixing ability may lead to a decrease in shearing ability instead. Previous studies have reported that tongue muscle force and speed of tongue movement are associated with masticatory performance.[17,18] Our results suggest that a decrease in tongue-centered coordinated movement, which mixes food with saliva, can result in a decrease in the movement of transporting food to the occlusal surface, leading to a decrease in shearing ability.

It is clear that masticatory performance is affected by tooth loss[21]. In this study, those who had untreated missing teeth other than the third molar were excluded in order to evaluate masticatory performance in patients who had received prosthodontic treatment for all their missing teeth.[17,18] In other words, all missing teeth of the participants had been replaced with dental prostheses. Therefore, our results are not applicable to those who have untreated tooth loss. This study showed that tongue pressure was associated with both mixing ability and shearing ability in participants with appropriate prosthodontic treatment.

Previous studies have reported that tongue pressure improves with training.[35] These results suggest that training to improve tongue pressure contributes to the maintenance and improvement of masticatory performance, and we believe these are clinically meaningful results.

In this study, the selected masticatory performance-related factor associated with removable dentures was not the number of artificial teeth but the presence or absence of removable dentures, to avoid multicollinearity of the number of present teeth and number of artificial teeth.

There are some limitations in this study. We did not evaluate the occlusion and fit of dentures, so the effect of removable denture quality on masticatory performance could not be assessed. However, considering the fit of the path diagram, we consider that the association between masticatory performance and removable dentures can be adequately evaluated among older adults whose tooth-related defects have been treated. Since the study was conducted at a single clinical site, evaluation of the masticatory performance factors of older adults was limited to a small population. In addition, the mean number of present teeth of the participants (mean age of 76.3) was 12.1, which was less than the mean number of present teeth (18.0) in Japan for those aged 75-79 years.[36] This selection bias limits the generalization of our findings, and it cannot be claimed that the results represent the mean population of older Japanese adults. However, clarification of the factors affecting masticatory performance is one of the important findings of this study, and this may lead to better maintenance or improvements in masticatory performance of older adults.

Salivary flow has been reported to be associated with masticatory performance,[16] however, it was

not evaluated this study. In a previous study in which color-changeable chewing gum was used, it was reported that chewing-stimulated salivary flow affected the results.[12] The evaluation of the mixing ability by using color-changeable chewing gum used in this study may have indirectly evaluated the effect of salivary flow as well; however, it is necessary to critically evaluate this in future research.

Since this was a cross-sectional study, it could not determine causal relationships. However, since the goodness of the fit of the path diagram was sufficient, we consider it an adequate representation of the association among the shearing ability, mixing ability, and masticatory performance-related factors. As shown in the path diagram, a decrease in masticatory performance may be due to a decrease in both the number of present teeth, and muscle strength characterized by occlusal force and tongue pressure. Previous studies have only revealed factors associated with masticatory performance.[16-20] Although limited by its cross-sectional design, here, we used path analysis to estimate the relationship among certain factors, enabling us to produce results that represent advancements over those of previous studies. The novel aspect of this study was that after excluding the effect of dental defects on masticatory performance, path analysis was used to identify factors that could lead to a decrease in this measure.

As a means of maintaining and improving masticatory performance, prevention of loss of teeth and appropriate prosthetic treatment have been the main interventions offered to patients.[31] This study suggests that training of the tongue after proper prosthetic treatment is another effective means of maintaining or improving masticatory performance. Dentists may want to evaluate tongue pressure using one of the several types of a dedicated device such as JMS tongue pressure device[23] or the Iowa Oral Performance

Instrument[37] for patients who have undergone prosthetic treatment for dental defects to help prevent a decrease in masticatory performance. When low tongue pressures are identified, the dentist may want to train or refer these patients for training on how to improve their pressures.

5 Conclusion

Among masticatory performance-related factors, the number of present teeth, occlusal force, and tongue pressure were associated with the mixing ability in community-dwelling older adults. Moreover, shearing ability was also associated with mixing ability. Tongue pressure was found to be associated with both mixing ability and shearing ability in masticatory performance and may be one of the most important factors involved in maintaining or improving masticatory performance among older adults.

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Figure legends

Figure 1. Pathways to a decrease in masticatory performance as hypothesized in this study.

The pathway leading to a decrease in masticatory performance has been hypothesized in this study. The decreased number of present teeth is considered as the main cause of the decline in masticatory performance. Even in the presence of a full complement of present teeth, muscle strength and dexterity decrease with age. We hypothesized that a decrease in the number of present teeth, muscle strength, and dexterity lead to a decrease in the ability to perform combined movements, such as mixing and shearing, which ultimately lead to a decrease in masticatory performance. Reproduced with permission from Nasu.[31]

Figure 2. Path analysis of factors associated with masticatory performance.

Tongue pressure, number of present teeth, and occlusal force were directly associated with mixing ability and shearing ability. Mixing ability was also directly associated with shearing ability.

Sex (0: women, 1: man), Removable denture use (0: no, 1: yes)

Figure 1

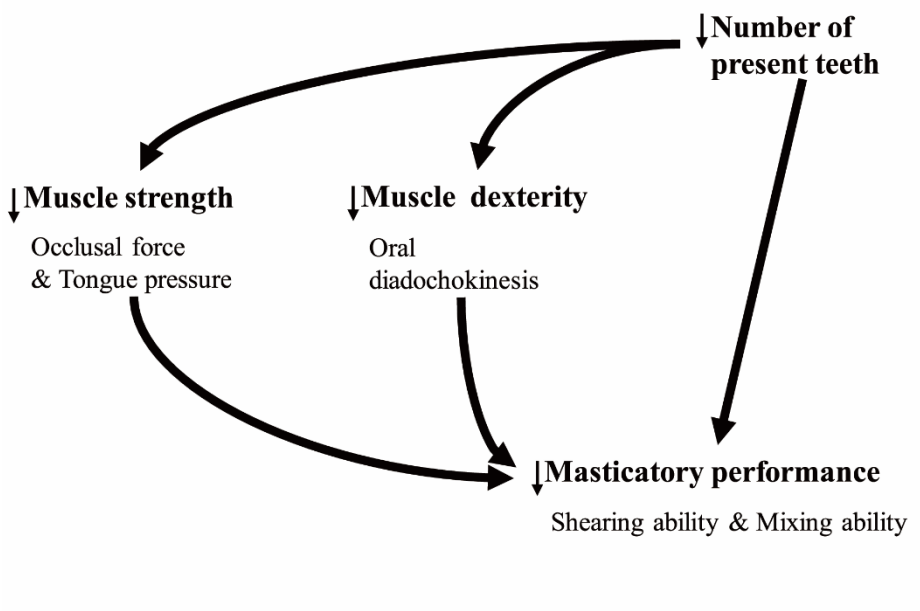


Figure 2

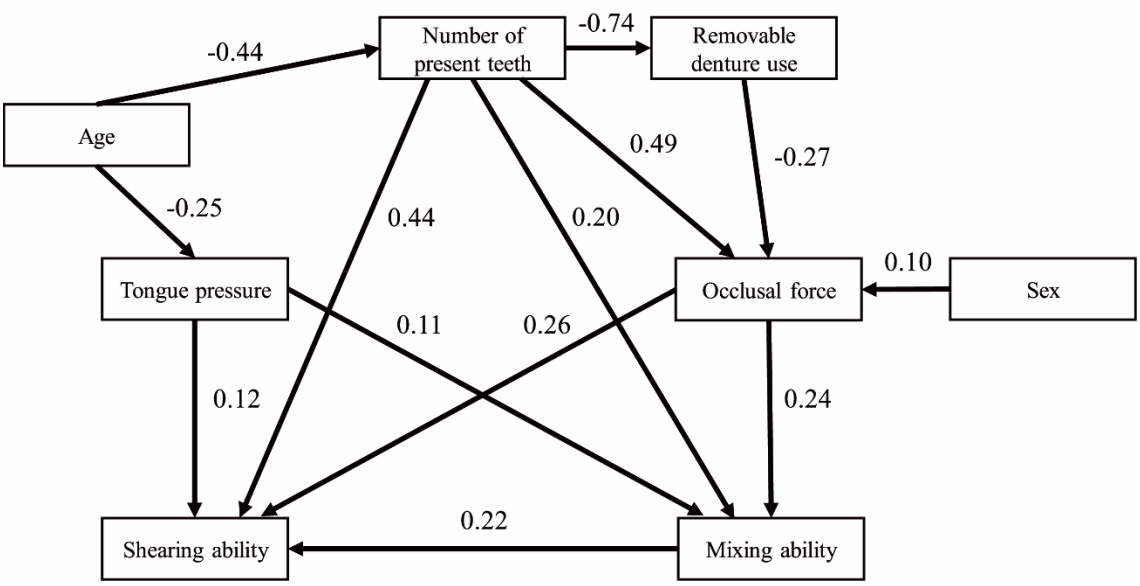


Table 1: Results of survey items

		Overall (n=344)		Male (n=127)		Female (n=217)	
		Mean, (SD)	Median, (Q1, Q3)	Mean, (SD)	Median, (Q1, Q3)	Mean, (SD)	Median, (Q1, Q3)
Age (years)		76.3, (6.5)	75.0, (71.0, 81.0)	75.4, (6.1)	75.0, (71.0, 80.0)	76.8, (6.7)	76.0, (72.0, 81.0)
Number of present teeth		12.1, (11)	9.0, (1.0, 24.0)	12.7, (11.1)	10.0, (2.0, 26.0)	11.8, (10.9)	8.0, (0.0, 23.0)
Number of artificial teeth		15.2, (11.3)	18.0, (2.0, 27.0)	14.6, (11.3)	17.0, (0.0, 26.0)	15.6, (11.3)	19.0, (2.5.0, 28.0)
Occlusal force (N)		271.3, (249.5)	194.6, (98.1, 374.6)	311.5, (296.3)	216.4, (105.3, 414.6)	247.7, (214.7)	176.7, (92.2, 369.7)
Mixing ability		17.0, (6.0)	17.0, (12.7, 21.3)	17.5, (6.1)	17.7, (13.0, 21.4)	16.6, (5.9)	16.5, (12.6, 20.9)
Shearing ability		3.4, (2.5)	3.0, (1.0, 5.0)	3.8, (2.5)	4.0, (2.0, 6.0)	3.2, (2.5)	3.0, (1.0, 5.0)
Tongue pressure (kPa)		28.3, (8.4)	29.5, (23.8, 33.6)	29.2, (8.5)	30.3, (24.2, 33.8)	27.7, (8.4)	28.9, (23.3, 33.4)
ODK /ta/ (time/s)		6.1, (0.8)	6.2, (5.6, 6.6)	6.0, (0.8)	6.0, (5.6, 6.6)	6.1, (0.8)	6.2, (5.6, 6.6)
Handgrip strength (kg)		25.0, (8.7)	22.5, (19.0, 31.5)	33.6, (7.4)	33.0, (30.0, 39.0)	19.9, (4.4)	20.0, (16.6, 22.5)
Gait speed (m/s)		1.3, (0.2)	1.4, (1.1, 1.5)	1.3, (0.2)	1.3, (1.2, 1.5)	1.3, (0.3)	1.4, (1.1, 1.5)
Skeletal muscle mass index (kg/m^2)		8.6, (1.1)	8.4, (7.7, 9.4)	9.6, (1.0)	9.6, (8.9, 10.2)	8.0, (0.7)	8.0, (7.5, 8.4)
Body mass index (kg/m^2)		23.0, (3.3)	22.7, (20.5, 25.1)	23.7, (3.1)	23.7, (21.6, 25.7)	22.5, (3.4)	22.2, (20.2, 24.6)
JST-IC score		10.6, (3.5)	11.0, (8.3, 13.0)	11.2, (3.2)	11.0, (9.0, 14.0)	10.2, (3.7)	10.0, (8.0, 13.0)
GDS Short-version score		3.2, (3.1)	2.0, (1.0, 5.0)	3.7, (3.4)	3.0, (1.0, 6.0)	3.0, (3.0)	2.0, (1.0, 4.0)
MMSE score		27.8, (2.4)	28.0, (27.0, 30.0)	27.7, (2.6)	28.0, (27.0, 30.0)	27.9, (2.3)	28.5, (27.0, 30.0)
		n	%	n	%	n	%
Eichner index	A	88	25.6	36.0	28.3	52	24.0
	B	77	22.4	29.0	22.8	48	22.1

	C	179	52.0	62.0	48.8	117	53.9
Removable denture	no	82	23.8	32.0	25.2	50	23.0
use	yes	262	76.2	95.0	74.8	167	77.0

SD: standard deviation, Q1: First quartile, Q3: Third quartile, ODK: oral diadochokinesis, JST-IC: Japan Science and Technology Agency Index of Competence,

GDS: Geriatric Depression Scale, MMSE: Mini-Mental State Examination

Table 2: Spearman's correlation analysis of mixing ability and shearing ability using survey items

	Mixing ability		Shearing ability	
	R	P-value	R	P-value
Age (years)	-0.169	0.002*	-0.389	<0.001*
Sex (0: female, 1: male)	0.073	0.177	0.114	0.035*
Number of present teeth	0.364	<0.001*	0.671	<0.001*
Number of artificial teeth	-0.389	<0.001*	-0.704	<0.001*
Removable denture use (0: no, 1: yes)	-0.366	<0.001*	-0.588	<0.001*
Occlusal force (N)	0.404	<0.001*	0.673	<0.001*
Tongue pressure (kPa)	0.174	0.001*	0.266	<0.001*
ODK /ta/ (time/s)	0.016	0.766	0.214	<0.001*
Handgrip strength (kg)	0.202	0.001*	0.314	<0.001*
Gait speed (m/s)	0.189	0.001*	0.287	<0.001*
Skeletal muscle mass index (kg/m^2)	0.148	0.006*	0.258	<0.001*
Body mass index (kg/m^2)	-0.028	0.602	0.088	0.104
JST-IC score	0.048	0.374	0.207	<0.001*
GDS short-version score	-0.028	0.609	-0.074	0.172

MMSE score	0.144	0.017*	0.212	<0.001*

* P < 0.05.

ODK: oral diadochokinesis, JST-IC: Japan Science and Technology Agency Index of Competence, GDS: Geriatric Depression Scale, MMSE: Mini-Mental State Examination