

Factors affecting subjective and objective masticatory function in older adults: Importance of an integrated approach

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ABSTRACT

Objectives: This study aimed to subjectively and objectively assess masticatory function and identify related factors in older adults.

Methods: From July 2017 to September 2018, we enrolled 115 healthy participants aged between 65 and 86 years. They underwent oral examination, and their stimulated salivary secretion rate and masseter muscle tone and biomechanical properties were assessed. Masticatory performance with two-colored chewing wax was objectively evaluated using the mixing ability index (MAI). Key food intake ability (KFIA) was subjectively assessed using a questionnaire.

Results: The MAI score was significantly associated with the number of remaining teeth ($r = 0.524, p < 0.001$) and the tone ($r = -0.222, p = 0.017$), elasticity ($r = -0.242, p = 0.009$), and dynamic stiffness ($r = -0.265, p = 0.004$) of the masseter muscles. In contrast, the KFIA score was only significantly associated with the number of remaining teeth ($r = 0.450, p < 0.001$). A weak association between the MAI and KFIA scores was observed ($r = 0.304, p = 0.001$).

Conclusions: A combination of objective and subjective methods should be used to accurately assess masticatory function in older adults. In addition to physical factors such as the number of remaining teeth, properties of the masticatory muscles should be evaluated to improve the masticatory function of older adults.

Clinical significance: In addition to dental problems, various maxillofacial and oral factors must be considered when establishing management strategies for the improvement of masticatory function in older adults.

1. Introduction

The recent global trend toward population aging has increased interest in the maintenance of functional abilities and the well-being of older adults. Balanced nutrient intake is vital for the management of older adults' health. However, older adults' masticatory function may affect their dietary patterns. In a previous study, adults older than 65 years had poorer nutrition and food intake than those aged between 50 and 64 years. Furthermore, edentulous individuals had low and excessive intake of fat and carbohydrates, respectively [1]. Masticatory dysfunction may result in imbalanced nutrient intake, leading to systemic diseases [2], including impaired postural control [3], decreased neural activity and blood flow in the maxillofacial and oral regions, cognitive impairment, and neuropsychiatric symptoms including depression and dementia [4-6]. Therefore, successful management of

masticatory dysfunction is important for maintaining good oral and general health in older adults.

Proper evaluation of older adults' masticatory function is necessary for its proper management. Masticatory function can be evaluated using both objective and subjective measures. The mixing ability test is the standard method for objectively evaluating masticatory performance. In this test, a two-colored wax cube is masticated, and the degree of color mixing is analyzed to calculate the mixing ability index (MAI), which reflects dynamic masticatory performance. Sato *et al.* [7] reported a higher validity for masticatory performance assessment for the mixing ability test than the conventionally used sieving method. In addition, Ikebe *et al.* [8] found that the mixing ability test has good construct validity for evaluating masticatory performance. In contrast, subjective assessment of masticatory ability is generally conducted using a food intake questionnaire, which evaluates the food intake ability (FIA) of an

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individual based on questions related to their ability to chew foods of varying hardness. Sakurai *et al.* [9] evaluated participants' masticatory ability for 31 food items using an FIA test and reported its usefulness in guiding oral health education and clinical practice. Koshino *et al.* [10] reported the validity and reliability of a questionnaire on the intake of 25 food items for evaluating masticatory ability. Kim *et al.* [11] suggested that scores of an FIA questionnaire for five key food items was strongly correlated with maximal bite force.

Mastication includes various actions such as biting, cutting, chewing, and crushing. Integrated functioning of the teeth, orofacial tissue, temporomandibular joints, and neuromuscular system is required for mastication. A decreased number of remaining teeth, decreased occlusal force, decreased salivation, and maxillofacial and oral pain have been found to be associated with decreased masticatory ability [12, 13]. Additionally, impaired masticatory muscle function can affect the masticatory performance of older adults [14]. Murakami *et al.* [15] reported that decreased skeletal muscle strength may be a risk factor for decreased chewing ability in older adults. However, there has been no detailed study on the effects of masticatory function on masticatory muscle strength. Furthermore, comprehensive research is lacking on the factors affecting subjective and objective masticatory function. Therefore, it is important to assess the objective and subjective masticatory function of older adults to identify related factors and explore strategies to improve the chewing ability of this population; this study aimed to examine these issues. The null hypothesis is that the MAI or key FIA (KFIA) scores, properties of the masseter muscles, and number of remaining teeth are not interrelated.

2. Materials and methods

2.1. Ethical considerations

This study was approved by the Institutional Review Board of our institution. All procedures performed in this study were in accordance with the ethical principles for medical research involving human participants as stipulated in the Declaration of Helsinki (2013 version) by the World Medical Association. The manuscript was prepared according to the Strengthening of Reporting of Observational Studies in Epidemiology guidelines [16]. Participants were informed of the purpose and methods of the study in detail, and those who provided informed consent were included.

2.2. Participants

The sample size was calculated based on a multiple linear regression model using G*power 3.1 (Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany). The required sample size was 107 based on an effect size (f^2) of 0.15, an alpha level of 0.05, and 95% power. After accounting for a 20% dropout rate, 128 participants were recruited from July 2017 to September 2018, of whom 115 were enrolled based on the inclusion and exclusion criteria. We included healthy participants aged between 65 and 86 years with permanent dentition (excluding the third molars). The exclusion criteria were related to factors that could hinder masticatory evaluation, such as painful dental caries, a score of 4 or higher on the World Health Organization's Community Periodontal Index, orofacial pain, complete denture (CD) use, planned dental treatment, and poor literacy.

2.3. Oral examination

All oral examinations were performed with the participant in a dental chair by a single trained dental hygienist. Each participant's dentition was examined. Remaining teeth referred to all teeth (except the third molars) capable of masticating food, including natural teeth and fixed prosthesis with intact roots and excluding pontic and implant-supported teeth. Stimulated salivary secretion was evaluated by

instructing the participants to chew on paraffin wax for 5 min and collecting the stimulated whole saliva in a 50 mL tube. The salivary secretion rate (mL/min) was determined based on the amount of saliva collected.

2.4. Assessment of masseter muscle tone and biomechanical properties

Participants were asked to place their mandible in the physiologic rest position while seated upright in a dental chair. This mandible position was comfortably maintained with a freeway space of 2–3 mm. The point of maximum masseter muscle contraction during biting with maximum force with the teeth in the centric occlusion position was marked. The probe of a handheld myotonometer Myoton® PRO device (MyotonPRO, Myoton AS, Tallinn, Estonia) was placed perpendicular to the skin surface overlying the muscle, and pressure was exerted with an initial force of 0.18 N. Subsequently, the device delivered an additional force of 0.4 N for 15 ms on the underlying soft tissues, causing muscle deformation. The resultant damped natural oscillations, which were due to the viscoelastic properties of the biological tissue, were recorded using a built-in accelerometer at a sampling rate of 3,200 Hz. In this manner, measurements were performed at identical points bilaterally, with each masseter muscle being measured five times. Masseter muscle tone and biomechanical properties were calculated using the MyotonPRO software (MyotonPRO, Myoton AS.). Muscle tone refers to the damped natural oscillation frequency (Hz), which indicates the intrinsic tension of the muscle. The higher the oscillation frequency, the greater the muscle tension, and muscle tension increases during muscle contraction [17]. Biomechanical properties of the muscle, including elasticity and dynamic stiffness, were assessed. Muscle elasticity is characterized by the logarithmic decrement of a muscle's natural oscillation and represents the muscle's ability to recover its initial shape after deformation. A lower decrement value indicates smaller dissipation of mechanical energy and better muscle elasticity [17]. Dynamic muscle stiffness is the ability to resist contraction or external forces that modify the muscle's initial shape. The higher the value, the stiffer the muscle [17], and the greater the stiffness, the less the muscle relaxes. The device used to assess the mechanical properties of masseter muscles in this study has good to excellent inter-rater (intraclass correlation coefficient (ICC) = 0.76–0.88) and intra-rater (ICC = 0.72–0.82) reliability [18, 19].

2.5. Assessment of objective masticatory performance

Masticatory performance was objectively assessed using the mixing ability test. We used a 12 × 12 × 12 mm wax cube (Fig. 1A) created by arranging red and green utility wax rods (Daedong Industrial Co., Ltd, Daegu, South Korea) without overlap [20]. Participants were asked to masticate one wax cube ten times with the right-side teeth. They subsequently masticated another cube ten times with the left-side teeth (Fig. 1B). The opposite sides of the masticated specimens were photographed using a digital camera (Canon EOS 500D, Canon Korea Consumer Imaging Inc., Seoul, Korea) while maintaining a uniform distance between the lens and the specimen. The camera settings were ISO: 100, shutter speed: 1/40, and aperture: 5.6. The specimen images were saved

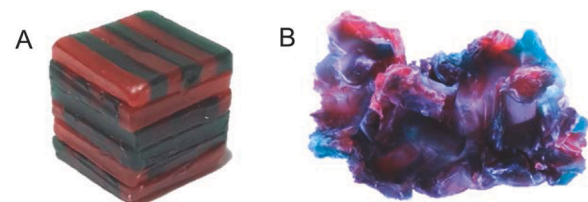


Fig. 1. Wax specimen used for mixing ability index assessment. (A) Before mastication. (B) After being masticated ten times.

as JPEG files, and an image-processing program (Image-pro 10.0, Media Cybernetics Inc., Silver Spring, MD, USA) was used to analyze the total projection area (TPA, mm²), projection area thinner than 50 µm (P, mm²), maximum length (ML, mm), maximum breadth (MB, mm), red area (RA), and green area (GA). The following variables were calculated using these values: the ratio of the area with color mixing (MIX) = $100 - (RA + GA)/P \times 100$, the ratio of the area thinner than 50 µm to TPA (TR) = $100 - P/TPA \times 100$, the ratio of maximum length to maximum breadth (LB) = ML/MB , and the shape factor, which showed how flat the sample was (FF) = $ML^2 \times \pi/4 \times TPA \times 100$. Additionally, four variables (MIX, TR, LB, and FF) were used to calculate the MAI [20, 21]. The mean MAI value of two sides of each masticated wax specimen was used to calculate the total MAI for that specimen. Each participant's MAI was calculated as the mean MAI of the two wax specimens. The calculated MAIs were converted to scores on a 0–100-point scale. The higher the MAI score, the better the masticatory performance.

2.6. Assessment of subjective chewing ability

The KFIA questionnaire was used to subjectively evaluate the participants' chewing ability [11]. Considering the age of the participants, a visual analogue scale of faces was used to assess chewing ability for five key food items (dried cuttlefish, raw carrot, dried peanut, cubed white radish kimchi, and caramel; Fig. 2) [22]. The visual analogue scale of faces consisted of seven facial expressions that indicated chewing ability ranging from "cannot chew at all" (0 points) to "unencumbered chewing" (6 points). The total KFIA score for all five food items ranged from 0 to 30 points. The higher the KFIA score, the higher the masticatory ability.

2.7. Statistical analyses

The Shapiro–Wilk test was used to examine the normality of the data. Pearson's correlation analysis was performed to identify variables related to the MAI and KFIA scores and investigate the correlation between the MAI and KFIA scores. The chi-square test was used to assess the relationship between the mean MAI and KFIA scores. Multiple linear regression analyses were performed to test each factor's relationship with the MAI and KFIA scores after controlling for other factors. All factors (i.e., age, number of remaining teeth, salivary secretion rate, tone, elasticity, and dynamic stiffness) were entered into the model using a stepwise method. All statistical analyses were performed using SPSS version 25 (IBM Corp., Armonk, NY, USA). *p* values < 0.05 were considered statistically significant.

3. Results

The mean age of the participants (*n* = 115; men, 55; women, 60) was 73.58 ± 5.41 years. The combinations that make up the participants' dentition are as shown in Table 1. Twenty-three participants (20%) reported partial denture use (data not shown). The oral and maxillofacial factors affecting masticatory function are shown in Table 2. The participants' mean stimulated salivary secretion rate was 1.81 ± 0.73 mL/

Table 1

Number of participants according to the dentition status that can affect MAI or KFIA scores (*N* = 115).

Combinations of remaining teeth and various prosthetics	Number of participants (%)
Only remaining teeth including natural teeth and fixed prosthesis	93 (80.87)
Remaining teeth and artificial teeth type I (pontic and fixed prosthesis with intact roots)	15 (13.04)
Remaining teeth and artificial teeth type II (implant-supported teeth)	4 (3.48)
Remaining teeth, artificial teeth type I, and artificial teeth type II	3 (2.61)

Table 2

Factors that may affect masticatory function (*N* = 115).

Variables	Mean ± standard deviation	Minimum	Maximum
Number of remaining teeth	17.77 ± 4.89	4	27
Mixing ability index score	72.15 ± 13.25	41.32	96.80
Key food intake ability score	19.59 ± 5.02	8	30
Salivary secretion rate (mL/min)	1.81 ± 0.73	0.80	3.70
Masseter muscle tone (frequency, Hz)	18.52 ± 3.59	10.45	28.95
Masseter muscle elasticity (log decrement)	1.36 ± 0.50	0.04	2.46
Masseter muscle dynamic stiffness (N/m)	334.02 ± 53.67	240.50	505.00

min. Eighteen participants (15.7%) had a salivary secretion rate lower than 1.0 mL/min (data not shown) and none had hyposalivation (< 0.7 mL/min).

Correlation analysis showed that the MAI score was significantly associated with the number of remaining teeth ($r = 0.524$, $p < 0.001$) and the tone ($r = -0.222$, $p = 0.017$), elasticity ($r = -0.242$, $p = 0.009$), and dynamic stiffness ($r = -0.265$, $p = 0.004$) of the masseter muscles (Table 3). In contrast, the KFIA score was only significantly associated with the number of remaining teeth ($r = 0.450$, $p < 0.001$). A weak association between the MAI and KFIA scores with a variance of 40% was also observed ($r = 0.304$, $p = 0.001$; Table 3, Fig. 3). The MAI score was lower and KFIA score was higher than the respective mean scores in 26 (22.61%) participants; in contrast, the MAI score was higher and KFIA score was lower than the respective mean scores in 20 (17.39%) participants (Table 4).

Different factors affected the MAI and KFIA scores (Table 5). The MAI score was affected by the number of remaining teeth (standardized $\beta = 0.479$, $p < 0.001$), masseter muscle dynamic stiffness (standardized $\beta = -0.208$, $p = 0.008$), and masseter muscle tone (standardized $\beta = -0.170$, $p = 0.030$). However, the KFIA score was only affected by the number of remaining teeth (standardized $\beta = 0.450$, $p < 0.001$).

							
Scores	6	5	4	3	2	1	0
Explanation	Unencumbered chewing	Able to chew well	Can chew a little bit	Neutral	Struggling to chew	Difficulties in chewing well	Cannot chew at all

Fig. 2. Visual analogue scale of faces used to measure chewing ability for key foods.

Table 3

Pearson's correlation coefficients for the associations of various factors with MAI or KFIA score and between the MAI and KFIA scores.

Variables	MAI score		KFIA score	
	r	p-value	r	p-value
MAI score	1		0.304	0.001**
KFIA score	0.304	0.001**	1	
Age	-0.037	0.696	-0.104	0.267
Salivary secretion rate (mL/min)	0.002	0.980	0.118	0.208
Number of remaining teeth	0.524	< 0.001**	0.450	< 0.001**
Masseter muscle tone (frequency, Hz)	-0.222	0.017*	-0.130	0.066
Masseter muscle elasticity (log decrement)	-0.242	0.009**	-0.052	0.581
Masseter muscle dynamic stiffness (N/m)	-0.265	0.004**	-0.099	0.290

KFIA, Key food intake ability; MAI, mixing ability index

Pearson correlation analysis

* $p < 0.05$

** $p < 0.01$

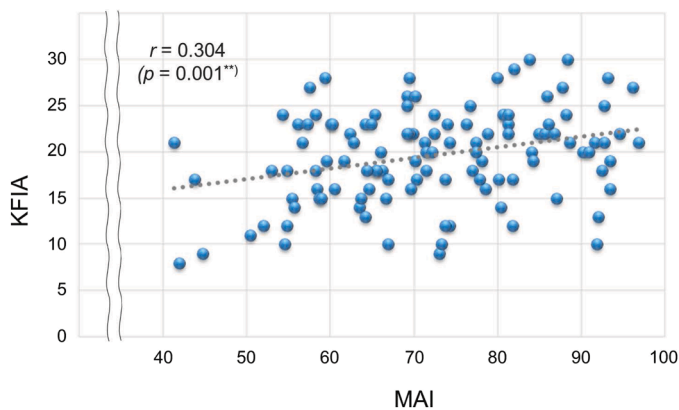


Fig. 3. Correlation between the mixing ability index (MAI) and key food intake ability (KFIA) scores. r: Pearson's correlation coefficient. ** $p < 0.01$

Table 4

Comparisons between objective and subjective measures of masticatory function.

	MAI score		Total	p-value*
	< 72.15	≥ 72.15		
KFIA score	< 19.59	33 (28.70)	20 (17.39)	0.047
	≥ 19.59	26 (22.61)	36 (31.30)	
Total	59 (51.30)	56 (48.70)	115 (100.00)	

Data are presented as N (%).

KFIA, Key food intake ability; MAI, mixing ability index

* p-values denote differences between groups determined using the chi-squared test.

Table 5

Results of multiple linear regression analysis of factors associated with masticatory function (final multivariate model).

Outcome variables	Predictorvariables	B	Standardized β	t	p-values	VIF values
MAI score	Constant	77.840		7.933	< 0.001	
	Number of remaining teeth	1.300	0.479	6.146	< 0.001	1.029
	Masseter muscle dynamic stiffness (N/m)	-0.051	-0.208	-2.685	0.008	1.016
	Masseter muscle tone (frequency, Hz)	-0.629	-0.170	-2.200	0.030	1.014
F = 19.423 ($p < 0.001$); R^2 , 0.344; adjusted R^2 , 0.327						
KFIA score	Constant	11.375				
	Number of remaining teeth	0.462	0.450	5.359	< 0.001	1.000
F = 28.723 ($p < 0.001$); R^2 , 0.203; adjusted R^2 , 0.196						

Stepwise multiple regression analysis was performed with $\alpha = 0.05$.

KFIA, key food intake ability; MAI, mixing ability index; VIF, variance inflation factor

4. Discussion

The masticatory function of older adults limits their food choices, which can have significant negative effects on their health. It is crucial to accurately assess the masticatory function of older adults and identify factors that affect it to establish health management strategies. This may be important for promoting successful aging and reducing morbidity in older adults. Therefore, this study evaluated the masticatory function of healthy adults older than 65 years through subjective and objective methods and assessed factors affecting masticatory function. The null hypothesis of this study has been rejected. As the number of remaining teeth increased, so did the MAI and KFIA scores. This was consistent with the findings of previous studies showing that the masticatory function of older adults was closely related to the number of remaining teeth [13, 23–25]. The participants of our study had an average of 17.77 ± 4.89 remaining teeth. It is known that at least 20 natural teeth with nine to 10 pairs of occluding teeth are required to maintain normal masticatory function [25, 26], and individuals with fewer than 20 teeth show decreased protein and micronutrient intake and increased carbohydrate intake [27]. Therefore, the participants of this study may have had difficulty in mastication, which may have led to imbalanced nutrition intake.

Moreover, we observed that the MAI score significantly decreased as the tone and dynamic stiffness of the masseter muscles increased and its elasticity decreased. Several studies have found strong associations of masticatory performance with grip strength, tongue thickness, tongue strength [28–30], and decreased skeletal muscle mass [15]. However, a direct association between masticatory performance and masticatory muscle properties was not reported in these studies. We found that the mixing ability of older adults was significantly associated with the tone and biomechanical properties of the masseter muscles. Daboul *et al.* [31] found that masseter muscle thickness decreased significantly as the number of missing teeth increased. Furthermore, Tissue [32] reported that maximum bite force had a significant effect on masseter muscle performance. Therefore, it is reasonable to assume that the tension, elasticity, and stiffness of the masseter muscles during the grinding and crushing phases of mastication may affect the MAI score.

We also observed a weak correlation between the MAI and KFIA scores. Several studies have reported that the results of objective and subjective evaluation of masticatory function are not strongly related to each other [33–35]. We observed an inconsistency of 40.00% between the MAI and KFIA scores. Takagi *et al.* [34] reported an inconsistency of 24.2% between objective and subjective evaluations of masticatory function in older adults. Kimura *et al.* [15] reported an inconsistency of approximately 39%. This could be because objective measures only evaluate the crushing and mixing of food, while subjective measures assess older adults' perception of various chewing and swallowing processes. However, a more likely explanation for the inconsistency may be the slow adaptation of older adults to persistent physical changes such as tooth loss and impairment of orofacial functions. As a result, participants may have overestimated their subjective masticatory ability. The high inconsistency between different methods of masticatory

function evaluation indicates that factors affecting masticatory function in older adults may vary according to the evaluation method. We assessed the factors affecting the MAI and KFIA scores to delineate this phenomenon.

The MAI score was affected by the number of remaining teeth and dynamic stiffness and tone of the masseter muscles. With aging, mastication is inevitably affected by the number of remaining teeth [36]; however, masticatory performance should not be evaluated based solely on the number of remaining teeth, as the chewing movement is coordinated by the functional occlusion system, which includes the teeth, temporomandibular joints, and masticatory muscles [14]. In particular, the masticatory muscles undergo dynamic contraction, which involves alternate isotonic and isometric contractions [37]. However, aging leads to abnormalities in masticatory muscle contraction and induces muscle atrophy. This could lead to increased tension and stiffness and decreased elasticity of muscles [38]. Thus, increased masseter muscle stiffness or tension indicates muscle atrophy, which may reduce the MAI. Ikebe *et al.* [39] suggested that the number of remaining teeth may significantly affect the masticatory performance of older adults with posterior occlusal support. However, they also reported that masticatory muscles play a more important role in masticatory performance than the number of remaining teeth in older adults who were partial denture wearers because of loss of posterior occlusal support. This supports our finding that decreased number of remaining teeth and increased stiffness and tone of the masseter muscles may negatively affect the mixing ability.

The KFIA questionnaire used in this study assessed chewing ability for five hard and tough food items that have the greatest correlation with bite force [11]. Okiyama *et al.* [40] reported better masticatory performance with hard foods compared to soft foods. Nevertheless, the number of remaining teeth was the only factor that affected the KFIA. This may be because complex psychological factors led to satisfaction with and gradual adaptation to declined masseter muscle function in our participants.

We observed that there may be significant differences between the results of objective (using the MAI) and subjective (using the KFIA) assessment of masticatory function. Moreover, these methods of assessment were not affected by the same factors. Older adults experience dynamic physical and psychological changes, resulting in impaired masticatory function that may affect health and decrease quality of life. According to Montgomery *et al.* [41], the diet of older adults gradually becomes monotonous and has a low energy and nutrient content with deficiencies in calcium, zinc, magnesium, iron, vitamin D, vitamin B6, vitamin B12, vitamin E, thiamin, retinol, carotenes, and folic acid. Friedlander *et al.* [42] reported that older adults with masticatory dysfunction have a decreased intake of fresh fruits and vegetables and well-done meat, and they prefer soft, eat-to-chew food with greater-than-recommended amounts of sugar and fat. Additionally, decreased masticatory function with aging causes decreased sensory input and central nervous system activity [4]. Mastication is controlled by a brainstem central-pattern generator [43], which is a repository of neurons controlling rhythmic muscle activities involved in functions such as breathing, walking, and chewing [6]. Momose *et al.* [44] showed increased regional cerebral blood flow during mastication in the bilateral Rolandic areas, which control the sensorimotor activities, and the flow immediately decreases on cessation of mastication. This is probably attributable to the motor system controlling the movements of the jaw muscles [44]. Therefore, changes in sensory input caused by decreased masticatory function may negatively affect physical performance and lead to decreased cerebral blood flow and impaired systemic function in older adults [45].

Hwang *et al.* [21] reported that older adults with low masticatory performance had worse dynamic balance than those with high masticatory performance; this increased the risk of falls in those with low masticatory performance. Bae and Park [46] showed that older adults who used dentures had significantly lower neck muscle strength than those who did not; thus, denture wearers with poor masticatory

performance may have a forward head posture. Other studies reported that masticatory performance was associated with cognitive processing speed [40], reaction time [41], and cerebral blood oxygen-dependent signals [42]. These findings suggest that improvement of masticatory performance can lead to improvement of both oral and whole-body health. In fact, Kim *et al.* [47] demonstrated significant improvement in the MAI after eight weeks of simple oral exercise, and Morita *et al.* [30] reported that masticatory performance is associated with whole-body muscle strength. Thus, improving masticatory muscle function may not only improve the masticatory ability [48], but also increase the physical performance of older adults [2].

This study has some limitations. First, CD wearers were excluded from this study because the support, retention, and stability of the CD greatly affect chewing ability performance. Furthermore, severe changes in occlusal and ridge morphology may occur depending on the duration of CD use. However, these factors are difficult to control and may act as confounding factors for the outcome. Second, the number of functional tooth units (FTUs) was not evaluated. Although the mastication status of older adults is directly related to the number of remaining teeth, masticatory performance may change depending on tooth distribution [49]. Therefore, future studies should assess the number of FTUs. Finally, this was a cross-sectional study. Therefore, it was not possible to determine the causal relationships between masticatory function and the factors affecting it.

Our results suggested that masticatory performance may be affected by the number of remaining teeth and tension and biomechanical properties of the masticatory muscles. Moreover, we evaluated masticatory function through objective and subjective methods to comprehensively analyze the factors affecting it. In addition to dental problems, various maxillofacial and oral factors must be considered to establish management strategies for improvement of masticatory function in older adults.

5. Conclusion

A combination of objective and subjective methods should be used to accurately assess masticatory function in older adults. In addition to physical factors, such as the number of remaining teeth, the properties of the masticatory muscles should be evaluated to improve the masticatory performance of older adults as they experience gradual muscle atrophy.

Declaration of Competing Interest

There are no conflicts of interest to declare.

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