Association of Masticatory Performance with Age, Posterior Occlusal Contacts, Occlusal Force, and Salivary Flow in Older Adults

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Purpose: This study aimed to investigate the effect of age, posterior occlusal contacts, occlusal force, and salivary flow on masticatory performance in older adults. ***Materials and Methods:*** The study sample consisted of 328 independently living people over the age of 60 years. Masticatory performance was determined by the concentration of dissolved glucose obtained from test gummy jellies, which are the standardized food developed for measuring masticatory performance. Bilateral maximal occlusal force in the intercuspal position was measured with pressure-sensitive sheets. Stimulated whole saliva was collected using the mastication method. Subjects were grouped into 3 categories by posterior occlusal contacts according to the Eichner Index. ***Results:*** The multiple linear regression analysis showed that, with other variables controlled, masticatory performance was significantly associated with posterior occlusal contacts ($\beta = -.24$, $P < .001$ for Eichner group B; $\beta = -.52$, $P < .001$ for Eichner group C), occlusal force ($\beta = .28$, $P < .001$), and hyposalivation ($\beta = -.08$, $P < .046$) ($R^2 = 0.49$). Within the groups classified by the Eichner Index, occlusal force was significantly associated with masticatory performance; however, age was not. For salivary flow rate, hyposalivation had a significant relationship with masticatory performance in group C ($P = .003$) and group B ($P = .047$), but no significant relationship in group A. ***Conclusion:*** A decline of posterior occlusal contacts, occlusal force, and hyposalivation appear to be associated with masticatory performance with aging in older adults. *Int J Prosthodont 2006;19:475–481.*

A primary goal of dental treatment is to restore oral function, especially masticatory function, which is considered the first link in the chain for proper digestion and absorption of nutrients.

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Factors reported to affect masticatory performance include loss and restoration of posterior teeth,[1–4] occlusal force,[4–6] sensory activity,[7–9] salivary flow,[10–12] and oral motor function.[13]

Masticatory function may commonly be affected in older adults. Previous studies have demonstrated that age per se is not necessarily associated with a loss of masticatory function.[2,4,6] Therefore, it is necessary to study other factors that may be linked to the aging process, eg, salivary flow. Although experimental studies with dentate young adults have indicated that drug-induced oral dryness impairs masticatory function,[10,12] there are no epidemiologic studies of the relationship between salivary flow and masticatory performance in older people.

The hypothesis was that age-related hyposalivation, as well as loss of posterior occlusal contacts and/or reduced occlusal force, are associated with a decline of masticatory performance. To test this hypothesis, a cross-sectional study using multiple variable regression analysis was conducted.

Materials and Methods

The subjects were participants of the Senior Citizens' College of Osaka prefecture in 2000 and 2001 who were community-dwelling, independently living elderly people over the age of 60 years.[14] An oral health lecture was given to the participants of the senior citizens' college, at the end of which the purpose and procedures of this study were explained to the audience. Volunteers for this study were asked to return for a dental examination on a later date. The final volunteer study population participated in the dental as well as the oral examination. The population comprised 328 individuals (173 men and 155 women) with a mean age of 66.2 (SD = 4.1) years. The protocol of this study was approved by the Institutional Review Board of Osaka University Graduate School of Dentistry. All participants gave written informed consent.

The dental examinations were conducted by 5 calibrated dentists. Measurements of masticatory performance, occlusal force, and stimulated salivary flow rate were taken. Individuals with partially or fully edentulous arches without a prosthesis were excluded from the study. As a result, all study participants with a loss of teeth used a removable denture. Participants who wore removable prostheses kept their dentures in place during all measurements.

Posterior Occlusal Contacts

Posterior occlusal contacts were recorded according to the Eichner Index,[15] based on existing natural tooth contacts between the maxilla and mandible in the bilateral premolar and molar regions. According to the Eichner Index, a dentition restored with a fixed partial denture was recorded as if it were natural dentition. The molar and premolar contacts of the remaining teeth define the classification. Group A has contacts in 4 support zones; group B has contact in 1 to 3 zones or contact in the anterior region only; and group C has no support zone at all, although a few teeth may still remain.

Maximal Occlusal Force

Bilateral maximal occlusal force was measured with pressure-sensitive sheets, 97 μm in thickness (Dental Prescale 50H R type, Fuji Film).[16,17] The subjects performed maximal clenching in the intercuspal position with a sheet placed between the maxillary and mandibular dental arch.

Based on the results of the clenching test, subjects were divided into 4 groups. Low and high occlusal force were identified in less than 25% and more than 75% of subjects, respectively.[18]

Masticatory Performance

Masticatory performance was determined by the concentration of dissolved glucose obtained from test gummy jellies, which are the standardized food developed for measuring masticatory performance.[19] The subjects were instructed to chew the gummy jelly using 30 chewing strokes on their preferred chewing side (left, right, or both) and to expectorate the bolus of comminuted particles as thoroughly as possible. The collected particles of the comminuted jelly were rinsed with running water for more than 30 seconds to obtain an accurate value. If any adherent glucose remained after mastication, the surface area might be overestimated.

Next, the particles were soaked in 15 mL of distilled water and stirred. The supernatant fluid of the solution was sampled, and the concentration of dissolved glucose from the comminuted gummy jelly was measured with a portable blood glucose meter (Glutest, Sanwa Chemical Laboratory).[20] According to the manufacturer, the value of glucose concentration using this meter has a high reproducibility (coefficient of variation $< 2.5\%$) and a high accuracy, such that the correlation coefficient to the value using a precious blood glucose meter (glucose analyzer GA-1150; Arkray Co)[21,22] is 0.998.

A linear regression analysis showed that the concentration of glucose had a significantly high correlation to the surface area (mm^2) of the comminuted jelly ($r = 0.993$, $P < .01$). Masticatory performance was assessed by calculating the surface area of particles (mm^2) from the glucose concentration, using linear regression.

Stimulated Salivary Flow Rate

Stimulated whole saliva was collected using the mastication method. The subjects were asked to swallow all the saliva in their mouths, chew a measured amount of paraffin wax (Orion Diagnostica) for 2 minutes at their own pace, and then spit into a graduated tube.[23] All saliva specimens were collected between 10:00 am and 3:00 pm. Subjects were classified into 2 groups according to their salivary flow rates. Subjects whose stimulated salivary flow rate was less than 0.5 mL/min were placed in the hyposalivation group, and the remaining subjects were designated as the normal salivary flow group.[24]

Data Analysis

Data analyses were done using the SPSS version 13.0 for Windows (SPSS). The masticatory performance with regard to each of the individual explanatory vari-

Table 1 Bivariate Analysis of Masticatory Performance in Relation to Explanatory Variables

Explanatory variables	n	Mean (mm^2)	SE (mm^2)	Subgroup[§]	*P*
Gender*					
Male	173	2359	74.4		.604
Female	155	2304	76.3		
Age (y)[†]					
60–64	125	2530	75.9	A	.001
65–69	133	2332	85.0	A	
70+	70	1984	124.0	B	
Occlusal support[†]					
Eichner A	172	2826	49.5	A	< .001
Eichner B	103	2144	86.2	B	
Eichner C	53	1101	100.0	C	
Occlusal force[†,‡]					
Low 25%	82	1428	96.3	A	< .001
Medium 50%	164	2533	65.6	B	
High 25%	82	2839	70.1	C	
Stimulated salivary flow rate*					
≥ 0.5 mL/min	267	2415	55.2		.006
< 0.5mL/min	61	1977	146.0		
Total	328	2333	53.2		

*_t_ test for difference between means.
[†]One-way ANOVA for difference between means.
[‡]Occlusal force: low 25% = less than 225 N; medium 50% = 225 to 690 N; high 25% = more than 690 N.
[§]Tukey multiple range test: means with the same letter are not significantly different from each other ($P > .05$).

ables was compared using a Student *t* test and a 1-way analysis of variance (ANOVA), followed by a Tukey multiple range test. Statistical significance was set at $P \leq .05$.

A multiple linear regression analysis was carried out to test each explanatory variable's relationship with the outcome variable after controlling for the other factors. The outcome variable was masticatory performance.

For explanatory variables, age and occlusal force were used as continuous variables. Posterior occlusal contacts had 3 categories, from which dummy variables were created. In the regression analysis, group A was the reference category. Gender and hyposalivation, which had only 2 categories each, were scored as follows: female = 0, male = 1; normal salivation = 0, hyposalivation = 1. All explanatory variables were entered into the model. Variance inflation factors for each of the explanatory variables in the regression model were calculated to test for the presence of highly correlated explanatory variables.

Finally, the relationship between age, occlusal force, or stimulated salivary flow rate and masticatory performance for subjects stratified by the Eichner classification was investigated using both the Student *t* test and 1-way ANOVA.

Results

The mean for masticatory performance was 2,333 (SE = 53) mm^2. Masticatory performance was significantly associated with age, posterior occlusal contacts, occlusal force, and stimulated salivary flow rate (Table 1). Participants in group A had the highest masticatory performance among the 3 groups. The masticatory performance values of groups B and C were found to be 76% and 39% of those of group A, respectively. There was no significant difference in masticatory performance based on gender.

The multiple linear regression analysis showed that, with other variables controlled, masticatory performance was significantly associated with posterior occlusal contacts (β (standardized partial regression coefficient) = –.24, $P < .001$ for group B; β = –.52, $P < .001$ for group C), with occlusal force (β = .28, $P < .001$) and with hyposalivation (β = –.08, $P = .046$) (Table 2). The multivariate coefficient of determination of the model was 0.49, indicating that about half of the variation in masticatory performance could be statistically explained by this model.

Because posterior occlusal contacts, according to the Eichner Index, were the most significant contributor in the model, the subjects were analyzed separately in each of the 3 classes. Within the groups classified by the Eichner Index, occlusal force was significantly associated with masticatory performance; however, age was not (Table 3). For salivary flow rate, hyposalivation had a significant relationship with masticatory performance in group C ($P = .003$) and group B ($P = .047$), but not in group A.

Table 2 Multiple Linear Regression Analysis for Masticatory Performance (n = 328)*

Explanatory variables†	B	SE	β	*P*	VIF
Age (y)‡	-3.63	10.44	–.02	.728	1.22
Gender¶	28.8	80.9	.01	.722	1.11
Eichner B§	-505	91	–.24	< .001	1.22
Eichner C	-1369	125	–.52	< .001	1.44
Occlusal force (N)‡	0.80	0.13	.28	< .001	1.36
Hyposalivation mL/min#	-202	101	–.08	.046	1.05
(Constant)	2585	697		< .001	

*Multiple regression coefficient = 0.70; R^2 = 0.49; F = 51.1; P < .001.
†Outcome variable: masticatory performance.
‡Continuous variables.
¶Females = 0, males = 1.
§Eichner A is the reference category.
#0.5 mL/min and over = 0; less than 0.5 mL/min = 1.
B = partial regression coefficient.
β = Standardized partial regression coefficient.
VIF = variance inflation factors.

Table 3 Bivariate Analysis of the Masticatory Performance in Relation to Age, Occlusal Force, and Salivary Flow Rate Within Eichner Groups

Explanatory variables	n	Mean (mm^2)	SE (mm^2)	Subgroup*	*P*
Eichner A					
Age (y)†					
60-64	83	2802	67		.888
65-69	69	2846	85		
70+	20	2862	133		
Occlusal force†,‡					
Low 25%	14	2277	167	A	.003
Medium 50%	95	2839	67	B	
High 25%	63	2930	75	B	
Salivary flow rate (mL/min)§					
≥ 0.5	147	2815	55		.548
< 0.5	25	2891	112		
Eichner B					
Age (y)†					
60-64	33	2245	147		.725
65-69	44	2103	125		
70+	26	2084	197		
Occlusal force (N)†,‡					
Low 25%	34	1596	152	A	< .001
Medium 50%	51	2385	107	B	
High 25%	18	2494	158	B	
Salivary flow rate (mL/min)§					
≥ 0.5	81	2249	89		.047
< 0.5	22	1755	220		
Eichner C					
Age (y)†					
60-64	9	1070	322		.931
65-69	20	1064	166		
70+	24	1143	132		
Occlusal force (N)†,‡					
Low 25%	34	911	96	A	< .001
Medium 50%	18	1334	180	B	
High 25%	1	3351			
Salivary flow rate (mL/min)§					
≥ 0.5	39	1248	120		.003
< 0.5	14	692	127		

*Tukey multiple range test: means with the same letter are not significantly different from each other (P > .05).
†One-way ANOVA for difference between means.
‡Occlusal force: low 25% = less than 225 N; medium 50% = 225 to 690 N; high 25% = more than 690 N.
§*t* test for difference between means.

Discussion

This cross-sectional study evaluated a sample of functionally independent older urban adults who volunteered for an educational program. How representative these individuals are of elderly Japanese is not precisely known. However, in Japan, most elderly people (95.5% of those 75 to 79 years) are functionally independent and have no limitations in their daily activities.[25] Therefore, it is important to understand the oral health of these independent elderly people, who appear to represent a majority of the elderly Japanese population.

Masticatory performance, which is the ability to break down foods into discrete portions by chewing to permit swallowing, is usually assessed by measuring the size of test food samples that have been chewed for a specific number of chewing cycles.[26] Since 1950,[27] fractional sieving, with various natural and artificial foods,[28] has been used as a technique of separating food after chewing to measure masticatory performance. The authors found a positive correlation in masticatory performance between the present test with gummy jelly and the sieving method with peanuts ($n = 10$, Spearman correlation coefficient $= 0.56$, $P = .09$). However, it has been reported that masticatory performance values assessed by calculating the area of the gelatin particles has a wider range than the sieving method; thus, it is possible to differentiate between subjects.[29] Because of significant advantages such as speed and accuracy of measurement and discriminating ability, the gummy jelly is the preferred food for measuring masticatory performance.[14,19]

If dental status of the study participants is used as an explanatory variable, the classification becomes more unbalanced and complicated because dental status was classified separately by maxilla and mandible. Natural dentition, a removable partial denture, and a complete denture in both the maxilla and mandible formed 9 groups. In this study population, the subpopulation in 6 groups became less than 10%, and complete denture wearers in both the maxilla and mandible were only 5.5%. This grouping is very statistically unbalanced.

In addition, for example, a removable partial denture replacing only a central incisor must have different significance from a removable partial denture for 13 teeth except for a central incisor, and yet, both dental statuses are grouped into the same category of removable partial dentures.

The classification of partially edentulous arches using the Eichner Index[30] is characterized by the number of occlusal contacts of the natural dentition. These groups also represent the course of tooth loss regarding the functional value of the natural dentition.[31] Thus, this classification provides a standard for the degree of morbidity of the dentition and is suitable for application in studies on morbidity statistics.

Posterior occlusal contacts of the remaining dentition and occlusal force were confirmed as key predictors of reduction of masticatory performance in an earlier study.[4] Extensive research has demonstrated that replacing missing teeth with a removable prosthesis cannot approach the efficiency of a complete natural dentition.[32] These results suggest that the preservation of posterior functional teeth may be of primary importance for masticatory performance. Although the masticatory performance of denture wearers is seriously handicapped, removable partial denture wearers with posterior occlusal contacts of natural teeth maintain better masticatory performance than those without these occlusal contacts.[3]

In an experimental study, it was reported that the occlusal morphology of artificial teeth influenced masticatory performance.[33] However, more recent studies showed that the type of artificial teeth did not significantly affect masticatory performance.[34,35] A series of controlled studies showed a relatively limited influence of denture factors, such as retention, stability, and occlusal relation, on oral function.[36–42] In addition, in an epidemiologic study, it is very difficult to determine a clinically adequate denture, specifically when such factors as retention, stability, occlusal morphology, and ridge morphology are examined. Validation of the evaluation of these denture factors is very poor. Therefore, the clinical adequacy of dentures was excluded from the factors for evaluation in this study.

In addition, logistic regression analysis showed that stimulated salivary flow was significantly associated with masticatory performance after controlling for other factors. In analyzing the association of stimulated salivary flow rate, dichotomization of the explanatory variable with a cut-off value of 0.5 mL/min was reasonable, because the *P* value for stimulated salivary flow rate was not found to be significant when the values were used as a continuous variable in the regression model (data not shown). This suggests that salivary flow rate is not linearly associated with masticatory performance. The results suggest that there is a critical level of salivary flow for masticatory disorders.

Interestingly, in group C, which had removable dentures without natural posterior occlusal contact, salivary flow was significantly related to masticatory performance. However, in group A, which had almost a complete natural dentition, salivary flow was not as important to masticatory performance. In group B, the relationship was significant and intermediate.

Xerostomia and other dysfunctions related to salivary supply may negatively influence the masticatory process by making it impossible for subjects to gather food into a bolus before swallowing.[32] An experimen-

tal study showed that the masticatory ability of 15 nondysphagic volunteers with complete natural dentitions was not influenced by experimental oral dryness.[10] This agrees with the results obtained from group A. The results of this study suggest that salivary flow is critical for masticatory function, especially in denture wearers with a lack of posterior occlusal contacts, whose masticatory performance is likely to be lower. The results indicate that altered masticatory performance is a multifactorial problem. In the future, longitudinal studies are needed to confirm the causal relationships and refine this model.

In fact, as the age of the subjects increased, the masticatory performance decreased. However, age did not exert a direct effect on masticatory performance within the same posterior occlusal contacts group. This suggests that age-related masticatory performance need not decline with age if posterior occlusal contacts are maintained. The influence of age is currently viewed as the result of an accumulation of insults to orofacial structures and function.[43]

As in other investigations,[4,44] gender was not found to have an effect on masticatory performance. The results of this study indicate that occlusal force in women was significantly lower than in men.[14] Regarding mastication, women might compensate for their low muscle strength by increased coordination of other motor and sensory functions.

Conclusions

The results of this study show that decline in posterior occlusal contacts, occlusal force, and hyposalivation appear to be associated with reduction of masticatory performance with aging in older adults. With increasing age, maintenance of an adequate number of healthy natural teeth, combined with the ability to stimulate a reasonable salivary flow, is the best way to maintain adequate masticatory ability.

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Literature Abstract

The use of digital imaging for colour matching and communication in restorative dentistry

The purpose of this in vitro study was to compare the percentage accuracy of shade matching between 2 sets of Vita Lumin shade guides using 2 methods of shade matching: a conventional visual method and a newly developed computer shade-matching procedure. A secondary purpose was to compare the actual CIELAB values of the shade tabs used in the study with one measured using a spectrophotometer. For the computer shade-matching procedure, each digital image of the selected shade tab to be matched in the phantom head was overlaid with images of all 16 Vita Lumin shade tabs. Ten observers participated in this study to match 9 Vita Lumin shade tabs, from a full Vita Lumin shade guide (16 shade tabs). One tab was positioned in the maxillary left central incisor position. For each matching method, each observer carried out the shade matching 3 times in 2 sessions in a crossover design, with observers split into 2 groups. The order of shade matching was random, without any time limit imposed on the shade matching. Chi-squared contingency analysis revealed a statistically significant difference ($P < .001$) between the accuracy of the conventional method and the computer method of shade matching. The percentage correct for the conventional visual method was 43%, compared to 61.1% for the newly developed computer method. Statistically significant high correlations of the CIELAB values were found between both color measurement methods ($P < .001$) using Spearman correlation, but R values were only fairly acceptable: L* = 0.846, A* = 0.92, B* = 0.961. The conclusion that the digital camera can be used as a means of color measurement in the dental clinic is questionable, as the optical configuration of their spectrophotometric "gold standard" for color measurements of the translucent shade tabs is not appropriate.

Jarad FD, Russell MD, Moss BW. *Br Dent J* 2005;199:43–49. **References:** 21. **Reprints:** Dr Fadi Jarad, Restorative Dentistry, Liverpool University Dental Hospital, Pembroke Place, Liverpool L3 5PS, United Kingdom. E-mail: f.jarad@liverpool.ac.uk—*Alvin G. Wee, OSU College of Dentistry, Columbus, OH*