CLINICAL RESEARCH

Factors Associated with Masticatory Performance in Unilateral Distal Extension Removable Partial Denture Patients

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Purpose: **Masticatory performance of denture patients is an outcome of the intricate interrelationship between patient characteristics and denture construction. This study aimed to identify both patient- and denture-related factors associated with masticatory performance in unilateral distal extension removable partial denture patients (RPDs).**

Materials and Methods: **Seventy-two patients (25 male and 47 female, mean age 63.4 ± 6.7 years) with unilateral distal extension RPDs were included in the study. The Mixing Ability Index (MAI) obtained from a chewing test using standard two-colored wax cubes, determined masticatory performance. The effect of each evaluated factor on masticatory performance was first determined by an independent *t*-test or one-way analysis of variance. The statistically significant factors were entered in a model of multivariate linear regression analysis to estimate the independent effect on MAI.**

Results: **The MAI ranged from −3.06 to 0.80 (Mean −0.71 ± 0.86). Univariate analyses identified male gender, high maximum bite force, more functional tooth units, and natural dentition opposing RPDs as patient factors increasing the MAI. Multivariate analysis (adjusted $R^2 = 0.346$) revealed that gender ($p < 0.001$), maximum bite force ($p = 0.02$), and number of functional tooth units ($p = 0.03$) were independent predictors for masticatory performance. None of the denture-related factors had a significant influence on MAI.**

Conclusion: **Gender, maximum bite force, and number of functional tooth units were the main factors influencing masticatory performance of unilateral distal extension RPD patients.**

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INDEX WORDS: mastication, bite force, functional tooth units, gender

REHABILITATION OF missing teeth with removable partial dentures (RPDs) is often used to achieve an acceptable level of masticatory function, possibly leading to better digestion and absorption of nutrients; however, the key factors that influence masticatory performance in RPD patients remain unclear.

In both partially edentulous and edentulous patients, masticatory function involves both selection and fragmentation of food particles.[1] Masticatory function is commonly evaluated using objective measures of masticatory performance.[2] Determinants of masticatory performance tend to vary depending on the dental characteristics of the studied populations. A number of studies conducted on people with natural dentitions have demonstrated that the number of functional tooth units (i.e., pairs of occluding posterior natural teeth) and bite force are the two major factors affecting their masticatory performance.[3-6] Greater bite force has been noted to correspond with more occluding teeth, together facilitating better food breakage by the posterior teeth. Gender has also been shown to have a significant effect on masticatory performance, with higher bite force[3,7,8] seen

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in males compared with females.[3-5,9] Although age has also been reported to significantly impact masticatory performance,[4,5,10] other reports have indicated little change when dentition status and health have been controlled.[3,11-13]

In complete denture patients, masticatory performance was also influenced mainly by anatomical structures of the stomatognathic system. The quality of the residual ridge (shape and size of the overall ridge, keratinized tissue resiliency, and location of border tissue attachment), which directly modulates retention and the stability of dentures, is seen through its effects on masticatory performance.[11,14-16] Bite force[11] and age[9] have been found to have a very limited effect on complete denture patients.

Due to a wide variety of possible combinations of teeth and edentulous spaces in partially edentulous arches, which have complicated study designs, most investigators tended to exclude RPD patients from their studies. In a study by Yamashita et al,[9] RPD patients were only divided into two groups based on the presence of functional tooth units, regardless of the classifications of RPDs. Results suggested that the presence of functional tooth units, adjacent to the RPDs, was important to preserve patients' masticatory performance. Gender was also found not to affect masticatory performance in this study.[9]

Even when missing teeth are replaced in partially edentulous patients, they exhibited lower masticatory performance than people with complete natural dentitions.[9,12,17] Nevertheless, the factors that limit the masticatory performance of RPD patients remain unclear. The purpose of this study was to identify the factors associated with masticatory performance in patients with unilateral distal extension RPDs.

Materials and Methods

Subjects

Seventy-two Kennedy class II patients (25 males and 47 females) were randomly recruited from routine follow-up patients, who attended the Removable Prosthodontics Clinic of Tokyo Medical and Dental University between April 2002 and October 2003, for inclusion in this cross-sectional study. The mean age of patients was 63.4 ± 6.7 years (range 47 to 76 years). All subjects had received unilateral distal extension RPDs from the above clinic and had used them for at least 3 months (mean 14.4 ± 5.7 months) before investigation. At the time of investigation, the dentures showed satisfactory retention (the clasps offered resistance when the denture was removed in the direction opposite to that of insertion) and acceptable stability (the denture could not be rocked to any appreciable extent by gentle digital pressure against the first molar on the denture bases).[18] By using a modified version of the questionnaire by Kapur,[19] denture satisfaction was rated by patients. All dentures were rated at least acceptable. All patients were using their dentures regularly, during daytime and when eating, and were thus considered to be well adapted to wearing dentures. Patients were excluded if the abutment teeth had greater than grade 1 mobility (more than +19 Periotest value) evaluated by Periotest® (Siemens, Bensheim, Germany), or the patients had any signs or symptoms of temporomandibular joint disorders evaluated by screening questionnaires and clinical examinations.[20] In cases where patients had unilateral distal extension RPDs in both maxilla and mandible, the investigator randomly selected one denture. The sample consisted of 53 Kennedy class II dentures (restored 2.7 ± 0.8 teeth) and 19 Kennedy class II-mod. 1 dentures (restored 5.7 ± 1.5 teeth). The Ethics Committee of Tokyo Medical and Dental University approved the protocol. Prior to inclusion, written informed consent was obtained from the subjects after a detailed explanation of the study.

Experimental Procedures and Considered Factors

Preoperatively, comprehensive oral and denture examinations, and evaluations of masticatory performance,[21] maximum bite force, and denture-supporting tissues were carried out. The independent factors were categorized into two groups: patient and denture-related factors. Gender, age, number of functional tooth units, maximum bite force, RPD-restored arch, type of opposing dentition, and quality of denture-supporting tissues were considered as patient factors. Extent of replaced missing teeth, presence of modification areas, and type of denture materials were considered as denture-related factors. The categories of patient factors and denture-related factors used in this study are shown in Tables 1a and 1b, respectively. The functional tooth units were defined as pairs of occluding natural, restored, or fixed prosthetic posterior teeth (premolars = 1 unit, molars = 2 units).[22] All factors and testing procedures were investigated only on the unilateral distal extension side.

Masticatory Performance

In this study, Mixing Ability Index (MAI) was obtained from a chewing test with a standard two-colored wax

Table 1a. Distribution of Patient Factors and Comparison Analyses Between Categories of Each Factor ($n = 72$)

Factors	*Number (%)*	*MAI**	*P-value*
Gender†			<0.001
Males	25 (34.7)	−0.14 ± 0.51	
Females	47 (65.3)	−1.02 ± 0.85	
Age† (years)			0.69
Adults (≤60)	27 (37.5)	−0.66 ± 0.71	
Elderly (>60)	45 (62.5)	−0.74 ± 0.94	
Functional tooth units‡,§			0.04
0 unit	22 (30.6)	−0.96 ± 0.80	
1 unit	17 (23.6)	−0.96 ± 0.97	
2 units	33 (45.8)	−0.44 ± 0.77	
Maximum bite force† (N)			<0.001
Low (≤175 N)	35 (48.6)	−1.07 ± 0.87	
High (>175 N)	37 (51.4)	−0.38 ± 0.70	
Removable partial denture-restored arch†			0.82
Maxilla	32 (44.4)	−0.74 ± 0.91	
Mandible	40 (55.6)	−0.69 ± 0.83	
Opposing dentition†			0.04
Natural dentition¶	54 (75.0)	−0.60 ± 0.86	
Removable partial denture	18 (25.0)	−1.06 ± 0.77	
Quality of denture-supporting tissues‡			0.11
Good (total score higher than 8)	14 (19.5)	−0.27 ± 0.73	
Fair (total score of 7 or 8)	34 (47.2)	−0.82 ± 0.92	
Poor (total score lower than 7)	24 (33.3)	−0.81 ± 0.78	

*Mean ± SD of MAI.
†Analysis was performed with *t*-test.
‡Analysis was performed with ANOVA.
§Counted only on the distal extension side.
¶Fixed restorations were included.

cube that determined masticatory performance.[21] The details of the technique,[21] as well as its reliability and concurrent validity to the original comminuted sieving method,[17] have been described previously. In the present study, the patients were asked to chew a wax cube on the RPD side for 10 strokes. Prior to the actual test, all subjects were trained until they fully understood the testing procedures. The mean of three chewing tests represented the MAI for each patient.

Maximum Bite Force

Maximum bite force was measured unilaterally on the occlusal surface of the artificial first molar of the RPDs

Table 1b. Distribution of Denture-Related Factors and Comparison Analyses Between Categories of Each Factor ($n = 72$)

Factors	*Number (%)*	*MAI**	*P-value*
Extent of replaced missing teeth			0.34
Premolar and molar teeth	33 (45.8)	−0.82 ± 0.78	
Molar teeth only	39 (54.2)	−0.62 ± 0.92	
Modification area			0.67
Presence	19 (26.4)	−0.79 ± 0.70	
Absence	53 (73.6)	−0.69 ± 0.91	
Denture material			0.56
Metal alloy framework†	48 (66.7)	−0.76 ± 0.84	
No framework (acrylic resin denture)	24 (33.3)	−0.63 ± 0.91	

All analyses were performed with *t*-test.
*Mean ± SD of MAI.
†Au-Pt or Co-Cr.

using a force transducer, Occlusal Force Meter (GM-10, Nagano keiki, Tokyo, Japan), with the patient seated upright in a dental chair. The patients were trained before the actual test to create confidence. The bite force was measured 3 times, with 1 minute rest between measurements. The highest recorded value represented the maximum bite force for each patient. The Intraclass Correlation Coefficient for the test-retest consistency, determined after the test was performed again at one month in 21 randomly selected patients, was 0.95.

Quality of the Denture-Supported Tissues

The residual ridge shape, tissue resiliency, and location of border tissue attachment of the denture-supporting tissues were assessed by intra-oral examination and from diagnostic casts made from irreversible hydrocolloid impressions (Aroma fine DF III, GC, Tokyo, Japan). One experienced and blinded prosthodontist scored the tissues according to Kapur scoring method,[23] which was modified for application in the RPD patients in this study. The total denture-supporting tissues score, which ranged from 3 (the worst quality) to 10 (the best quality), was calculated only from the tissues in distal extension areas. The kappa values for test-retest consistency of each component scoring, after one month, were more than 0.8 ($n = 21$).

Statistical Analysis

Independent *t*-tests or one-way analysis of variance (ANOVA) with Tukey test as a post hoc test were performed to compare MAI with independent variables. Age and maximum bite force were categorized as binary variables (cut-off points were 60 years and 175 N,[24] respectively). Univariate linear regression analysis was performed for each interval or ordinal variable (age, maximum bite force, and denture-supporting tissue score) to confirm the results obtained from the comparison analyses. Multivariate analysis, in a stepwise linear regression model, was used to estimate the independent effect on MAI. The variables that the univariate analyses had shown as statistically significant were entered in this model. All tests were 2-tailed and the probability level was set at $p < 0.05$. Data were analyzed using SPSS version 10.0J (SPSS Japan Inc., Tokyo, Japan).

Results

The MAIs obtained from the unilateral distal extension RPD sides of all patients varied from −3.06 to 0.80 (mean −0.71 ± 0.86), while the maximum bite force varied from 42 N to 806 N (mean 208 ± 141 N). The distribution of all considered factors and the results of comparison analysis of each patient factor and denture-related factor are shown in Tables 1a and 1b, respectively. The MAIs obtained from males were significantly higher than those from females ($p < 0.001$). Patients with high maximum bite force (>175 N) showed significantly higher MAIs than those with low maximum bite force (≤175 N, $p < 0.001$). Patients with two remaining functional tooth units in the distal extended arch side demonstrated significantly higher MAIs than those with fewer remaining functional tooth units ($p = 0.04$). The MAIs were significantly higher in patients who had natural teeth opposing the RPDs than those who had RPDs in both jaws ($p = 0.04$). The remaining patient factors (age, RPD-restored arch, and quality of denture-supporting tissues) and all denture-related factors (extent of replaced missing teeth, presence of modification area, and denture material) did not have any significant effect on the MAIs. The same results were obtained when univariate linear regression analysis was performed for each interval or ordinal variable (Table 2).

Results from the stepwise multivariate linear regression analysis are shown in Table 3. With an adjusted $R^2 = 0.346$, the MAI was significantly associated with gender ($p < 0.001$), maximum bite force ($p = 0.02$), and a number of functional tooth units (2 units) ($p = 0.03$). Male patients with unilateral distal extension RPDs, who had at least two remaining functional tooth units in the RPD extended arches and high maximum bite force demonstrated the highest MAIs, i.e., the best masticatory performance.

Discussion

Masticatory performance was intentionally assessed in unilateral distal extension RPD patients by investigating the patient and denture-related factors that could affect the patients' masticatory performances with dentures. This was determined by the MAI obtained from chewing tests. The present study revealed that maximum bite force, gender, and number of remaining functional tooth units in partially edentulous dentitions restored with Kennedy class II RPDs were factors predicting masticatory performance. Previous studies reported correlations between maximum bite force and masticatory performance in adults with natural dentitions.[3-6] A significant correlation

Table 2. Univariate Linear Regression Analyses of the Association Between the Mixing Ability Index and Interval or Ordinal Variables ($n = 72$)

Factors	*Intercept*	*Coefficient Estimate*	*P-value*	R^2
Age	−1.22 (0.47)	−0.01 (0.02)	0.46	0.01
Maximum bite force	−1.31 (0.16)	0.003 (0.01)	<0.001	0.22
Denture-supporting tissues score	−1.06 (0.43)	0.05 (0.06)	0.41	0.01

Numbers in parentheses are standard errors.

between maximum bite force and masticatory performance was also found in this study in RPD patients. Nevertheless, the previous study conducted on complete denture patients reported fewer (in high residual ridge patients) correlations between these two factors.[11]

As masticatory function has been defined as the combined process of fragmentation and selection of food particles,[1] the lower retention and stability of complete dentures when compared with the designs of RPDs could affect the selection process of food particles and in turn, reduce masticatory performance in edentulous patients. This may be explained by the fact that the masticatory performance of complete denture wearers is more likely to be influenced by the quality and quantity of the residual ridge rather than bite force,[11,14] as in the case for RPD wearers. So even though complete denture patients with a low residual ridge (mandibular symphyseal bone height $\leq$15 mm) exhibited bite force comparable to those with high residual ridges (mandibular symphyseal bone height $\geq$16 mm), it would not be surprising to observe significantly low masticatory performance in the low residual ridge group.[11]

It is of interest that along with maximum bite force, gender was also related to masticatory performance in our subjects. These findings were similar to those reported in subjects with natural dentitions.[3-5,9] According to a previous study, such a correlation could not be observed in complete denture patients;[9] however, in dentate people, gender has been determined to be the most important factor affecting bite force, which in turn plays a direct role with masticatory performance.[3] In the previous studies mentioned above, males with natural dentitions tended to have higher bite force than females.[3,7,8] This is consistent with this current finding from RPD patients (male: 294 ± 187 N, female: 163 ± 79 N, $p < 0.001$). This in turn may have caused the higher masticatory performances observed in male RPD patients than in female patients.

The number of functional tooth units, defined as pairs of occluding posterior teeth, was another factor associated with masticatory performance. A previous study suggested the importance of functional tooth units in preserving masticatory performance of RPD patients.[9] The number of functional tooth units was also important. The results of the present study demonstrated that RPD patients with two remaining functional occluding tooth units had better masticatory performance than those with one or no functional tooth units; however, the extent of replaced missing teeth did not show an effect on masticatory performance. The mean MAIs observed in patients who had premolars and molars replaced with RPDs were not different from those observed in patients who had only molars replaced. This indicates the importance of the number of functional tooth units remaining rather than the extent of replaced missing teeth in masticatory performances of RPD patients. Furthermore, under comparison analysis, the RPD patients who had natural teeth opposing the RPDs had significantly higher MAIs than those who had dentures opposing the RPDs. This is in agreement with the report by Sato et al.[17] Hence, this factor may play a role in masticatory performance, but is less significant compared with

Table 3. Stepwise Multivariate Linear Regression Analysis of Predictive Characterisitcs of the Mixing Ability Index ($n = 72$)

Characteristics	*Parameter Estimate*	*Standard Error*	*P-value*
Intercept	−1.36	0.14	<0.001
Male gender	0.77	0.18	<0.001
High maximum bite force	0.41	0.18	0.02
Functional tooth units (2 units)	0.37	0.17	0.03

Adjusted $R^2 = 0.346$.

maximum bite force, gender, and number of functional tooth units.

Similar to other reports,[3,11-13] no association was observed in this study between the age of patients and masticatory performance; however, this does not correspond with the data reported by studies that included and compared patients in completely different age groups.[4,5,19] The differences in bite force exertion among age groups, which is influenced by human growth and/or aging,[10] cannot be overlooked. The subjects in our study were of similar age. Although MAIs obtained from patients with good quality denture-supporting tissues tended to be higher than other groups, the quality of denture-supporting tissues and denture-restored arches did not significantly affect the masticatory performance. Nevertheless, these factors would affect the masticatory performances in complete denture patients,[11,14–16] as masticatory performance relies on the retention and stability of dentures. Further studies will be carried out to determine factors affecting patients using tooth-supported RPDs. Finally, most of the determinants investigated in this study seemed to influence the fragmentation of food particles. Additional studies are necessary in order to identify other possible determinants that influence the selection of food particles in denture wearing patients.

Conclusion

The results of this study suggest that the masticatory performance of partially edentulous patients who replace their missing posterior teeth with RPDs is influenced by bite force, gender, and number of functional tooth units. Preserving two functional occluding tooth units on the distal extension side is recommended to maintain masticatory performance in patients with unilateral distal extension RPDs.

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References

1. van der Bilt A, Olthoff LW, van der Glas HW, et al: A mathematical description of the comminution of food during mastication in man. Arch Oral Biol 1987;32:579-586
2. Boretti G, Bickel M, Geering AH: A review of masticatory ability and efficiency. J Prosthet Dent 1995;74:400-403
3. Hatch JP, Shinkai RS, Sakai S, et al: Determinants of masticatory performance in dentate adults. Arch Oral Biol 2001;46:641-648
4. Julien KC, Buschang PH, Thorckmorton GS, et al: Normal masticatory performance in young adults and children. Arch Oral Biol 1996;41:69-75
5. Akeel R, Nilner M, Nilner K: Masticatory efficiency in individuals with natural dentition. Swed Dent J 1992;16:191-198
6. Okiyama S, Ikebe K, Nokubi T: Association between masticatory performance and maximal occlusal force in young men. J Oral Rehabil 2003;30:278-282
7. Youssef RE, Throckmorton GS, Ellis E III, et al: Comparison of habitual masticatory patterns in men and women using a custom computer program. J Prosthet Dent 1997;78:179-186
8. Shinogaya T, Bakke M, Thomsen CE, et al: Effects of ethnicity, gender and age on clenching force and load distribution. Clin Oral Investig 2001;5:63-68
9. Yamashita S, Sakai S, Hatch JP, et al: Relationship between oral function and occlusal support in denture wearers. J Oral Rehabil 2000;27:881-886
10. Kohyama K, Mioche L, Bourdiol P: Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples. Gerodontology 2003;20:15-23
11. Fontijn-Tekamp FA, Slagter AP, van der Bilt A, et al: Biting and chewing in overdentures, full dentures, and natural dentitions. J Dent Res 2000;79:1519-1524
12. Carlssson GE: Masticatory efficiency: the effect of age, the loss of teeth and prosthetic rehabilitation. Int Dent J 1984;34:93-97
13. Wayler AH, Kapur KK, Feldman RS, et al: Effects of age and dentition status on measures of food acceptability. J Gerontol 1982;37:294-299
14. Koshino H, Hirai T, Ishijima T, et al: Influence of mandibular residual ridge shape on masticatory efficiency in complete denture wearers. Int J Prosthodont 2002;15:295-298
15. Fujimori T, Hirano S, Hayakawa I: Effects of a denture adhesive on masticatory functions for complete denture wearers: consideration for the condition of denture-bearing tissues. J Med Dent Sci 2002;49:151-156
16. Kapur KK, Soman S: The effect of denture factors on masticatory performance. II. Influence of the polished surface contour of denture base. J Prosthet Dent 1965; 15:231-240
17. Sato S, Fueki K, Sato H, et al: Validity and reliability of a newly developed method for evaluating masticatory function using discriminant analysis. J Oral Rehabil 2003;30:146-151
18. Bergman B, Hugoson A, Olsson CO: Periodontal and prosthetic conditions in patients treated with removable partial dentures and artificial crowns. A longitudinal two-year study. Acta Odontol Scand 1971;29:621-638
19. Kapur KK: Veterans Administration Cooperative Dental Implant Study.Comparisons between fixed partial dentures supported by blade-vent implants and removable

partial dentures. Part IV: comparisons of patient satisfaction between two treatment modalities. J Prosthet Dent 1991;66:517-530
20. Delcanho R: Screening for temporomandibular disorders in dental practice. Aust Dent J 1994;39:222-227
21. Sato H, Fueki K, Sueda S, et al: A new and simple method for evaluating masticatory function using newly developed artificial test food. J Oral Rehabil 2003;30:68-73
22. Kayser AF: Shortened dental arches and oral function. J Oral Rehabil 1981;8:457-462
23. Kapur KK: A clinical evaluation of denture adhesives. J Prosthet Dent 1967;18:550-558
24. Miyaura K, Morita M, Matsuka Y, et al: Rehabilitation of biting abilities in patients with different types of dental prostheses. J Oral Rehabil 2000;27:1073-1076