Influence of Length of Occlusal Support on Masticatory Function of Free-End Removable Partial Dentures

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Purpose: The aim of this study was to determine the influence of occlusal support length (OSL) of free-end removable partial dentures (RPDs) on masticatory function. ***Materials and Methods:*** Twenty-three subjects (mean age: 55.2 ± 8.4 years) who were edentulous in the maxilla and classified as Kennedy Class I in the mandible were selected. Subjects received new maxillary complete dentures and mandibular RPDs. Five OSL conditions were determined by RPD artificial tooth wear: full occlusal support (L1, control), OSL to first molar (L2), OSL to second premolar (L3), OSL to first premolar (L4), and absence of occlusal support (L5). Masticatory performance and efficiency were evaluated using the sieve method. Chewing rate was defined as the number of masticatory cycles per minute. Bolus selection opportunities and bolus breakage function were evaluated using the one-chew method. Qualitative and quantitative measurements of masticatory cycle patterns were recorded kinesiographically. Data were analyzed using repeated-measures analysis of variance and Friedman and Fisher exact tests ($\alpha = .05$). ***Results:*** Masticatory performance and efficiency decreased ($P < .05$) from L1 (5.46 ± 0.64 mm and 51.21% ± 19.44%, respectively) to L5 (6.24 ± 0.44 mm and 24.50% ± 15.98%, respectively). Chewing rate was higher for L4 than L1 ($P < .05$). Bolus selection chances and bolus breakage function decreased as OSL was reduced ($P < .05$); however, there were no differences in masticatory cycle pattern among the OSL conditions ($P > .05$). ***Conclusion:*** Reduction of OSL altered masticatory function, thereby decreasing masticatory performance and efficiency resulting from a lower capacity to select and break down food. *Int J Prosthodont 2012;25:472–479.*

The main goal of prosthetic rehabilitation is to replace lost teeth to restore a sufficient number of occlusal surfaces and promote occlusal support and efficient mastication.[1] The functional improvement of partially edentulous subjects through rehabilitation with removable partial dentures (RPDs) is not clear,[2] and there are still no evidence-based indications to justify their prescription.[3] This may be the result of a lack of data regarding the influence of occlusal support on masticatory function, given that artificial teeth are considered a nonspecific splinted grinding tool.[4,5] Reduction of the occlusal support length (OSL) of free-end RPDs has been suggested to preserve and decrease overload on the residual ridges and abutment teeth during mastication.[6] According to the shortened arch concept, the rehabilitation of occlusal support can be restricted to restoring the arches only to the level of the second premolars.[7–9]

The influence of occlusal support on masticatory function can be described through masticatory performance and efficiency tests, which determine the comminution degree in terms of median particle size and percentage of efficiency, respectively.[10] The results of both tests depend on the individual chewing rate applied during mastication,[11] which can be modified by oral or food characteristics.[12] Reduction in occlusal support of molar unilateral free-end RPDs occluding on natural teeth can decrease the capacity to mix and knead food.[4,5] However, to date, there are no published studies describing the influence of the free-end length of RPDs on masticatory performance or examining the chewing efficiency of subjects who have lost bilateral occlusal support in both arches.

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During mastication, each cycle starts with the selection process of viable particles to be broken down and ends when a breakage process has been completed.[8] Any alteration in selection or breakage can affect masticatory performance and efficiency, according to the constantly changing properties of food particles after each masticatory cycle.[13] Selection chance is the probability that food particles are captured by the teeth. Breakage function is the process by which selected particles are fractured into fragments of different sizes. Studies have shown that complete denture wearers present smaller values for both selection chance and breakage function.[14,15] However, there are no data available for RPD wearers.

Masticatory function of subjects rehabilitated with RPDs can also be evaluated by analyses of trajectories, maximum excursions, and areas of mandibular movements during mastication.[16] Mandibular movements are connected with hyoid and tongue movements and therefore with food transport in the mouth,[17] which can also be altered according to a loss of occlusal support.[8] Tallgren et al[16] found that complete maxillary and partial mandibular Kennedy Class I denture wearers are characterized by more regular and some narrowed sagittal masticatory cycles, presenting an increased maximum vertical opening, which characterizes the mastication of a food bolus in the posterior region of rehabilitated dental arches.[18]

Given that any prosthodontic procedure should be justified biologically, the objective of this study was to evaluate the immediate influence of reducing OSL on masticatory performance and efficiency, chewing rate, selection chance, breakage function, and patterns of the masticatory cycle of subjects with free-end RPDs. Clearly defining the values of such properties will establish the improvement afforded by this type of rehabilitation.

Materials and Methods

Sixty-three partially dentate subjects were initially recruited from the Piracicaba Dental School, State University of Campinas, Piracicaba, São Paulo, Brazil. After clinical examination, 23 subjects (5 men and 18 women, mean age: 55.2 ± 8.4 years) were selected to participate. Subjects were required to meet the following criteria: complete edentulism in the maxilla and partial edentulism in the mandible (classified as Kennedy Class I) with canines and incisors present and slight or moderate bone resorption of the residual ridges. Subjects with neuromuscular diseases or who presented with symptoms of temporomandibular disorder, parafunctional habits, xerostomy, or severe periodontal disease were excluded. The research protocol was approved by the ethics committee of Piracicaba Dental School, State University of Campinas, and written consent was obtained from all participants.

All selected subjects received general dental treatment including periodontal and dental care of the remaining teeth and prosthetic rehabilitation with conventional complete dentures in the maxilla and free-end RPDs in the mandible. The RPDs were manufactured using cobalt-chromium metal frameworks, and depending on the height from the floor of the mouth to the free gingival margins, lingual plates or bars were used as the major connectors. The direct retainers were circumferential or bar clasps based on the retention and contour of the abutment teeth. Heat-cured acrylic resin (Dental Vipi) was used to process the denture bases. Occlusal support was established through the second molars (Dentsply Industria), and a bilateral balanced occlusal scheme was employed. This occlusal scheme had been prior achieved through artificial tooth adjustments on wax rims during functional and esthetic try-in for the maxillary and mandibular dentures. After denture processing, any necessary adjustments were made based on the wear of artificial teeth from the complete denture. All prosthetic treatments were performed by the same operator. After insertion of the new dentures, the subjects had a 2-month period of adaptation before evaluating masticatory function.

Evaluation of Masticatory Performance, Masticatory Efficiency, and Chewing Rate

Optocal artificial test food based on Optosil polydimethylsiloxane putty (Optosil Comfort, Heraeus Kulzer) was used to prepare cubes measuring 5.6 mm on each edge.[15,19] Portions of 17 cubes (approximately 3 cm^3 and 3.7 g) were offered to the subjects, who were instructed to chew them in a habitual manner. After 20 chewing strokes, counted by the examiner, the particles were expectorated on a paper filter sitting in a glass container, and the patients rinsed with 200 mL of water to complete cleansing of the oral cavity. The comminuted particles were recovered and dried at room temperature for 1 week and then sieved in a sieving machine (Bertel Indústria Metalúrgica) through a stack of up to 10 sieves for 20 minutes using mesh sizes gradually decreasing from 5.6 to 0.5 mm. The particles retained on each sieve and in the bottom pans were weighed on a 0.001-g analytical balance (Mark, BEL Engineering).

Masticatory performance was determined according to the median particle size (X50) calculated using the Rosin-Rammler cumulative function.[10]

Masticatory efficiency was calculated as the weight percentage of the fractioned material that passed through the 5.6-mm mesh.[15] When recording the subjects' masticatory cycles, the time to complete 20 masticatory cycles was registered, and the chewing rate was defined as the number of masticatory cycles performed per minute.[11]

Selection Chance and Breakage Function of Bolus

Selection chance and bolus breakage function for different particle sizes were determined by the one-chew experiment.[20] Three sizes of Optocal cubes with edges measuring 8.0, 4.8, and 2.4 mm were prepared as described previously.[21] Each subject was simultaneously offered 3 cubes with 8.0-mm edges, 12 cubes with 4.8-mm edges, and 68 cubes with 2.4-mm edges.[19,22] Subjects first made pseudo-chewing movements to obtain a natural dispersion of the particles in the mouth and to produce saliva. Thereafter, they were instructed to carry out a real chew.[21] The particles were then expectorated into a filter paper and the mouth was rinsed with 200 mL of water to complete cleansing of the oral cavity. Since all particles initially had regular shapes, the nondamaged (nonselected) particles were distinguished from damaged and broken (selected) ones by visual inspection.[20] The weight of the selected particles divided by the total weight of damaged and nondamaged particles corresponds to the selection chance of each size. After sieving and weighing the particles, breakage function was defined through a cumulative distribution function, which establishes the degree of fragmentation (r).[20–22]

Masticatory Cycle Pattern

Masticatory cycle patterns were recorded simultaneously with masticatory performance and efficiency evaluations over 20 cycles using a kinesiograph (K6-I Evaluation System, Myotronics-Noromed). Subjects were seated on a chair with the Frankfort plane parallel to the ground; a small magnet was attached to their mandibular central incisors, and the mandibular scanner was placed on the subjects' heads. Trajectories of mandibular movements were assessed and classified in the frontal plane as teardrop (type I), hemioval (type II), or sliver (type III).[23] In the sagittal plane, mandibular movements were classified according to the maximum anteroposterior width between opening and closing path configurations as either less than 2 mm (type I) or more than 2 mm (type II).[23] Maximum frontal, horizontal, and anteroposterior excursions (mm) and frontal and sagittal areas (mm^2) of the masticatory cycle were recorded and defined as quantitative measurements, which were analyzed using ImageTool Software (University of Texas Health Science Center).

Occlusal Support Length and Periods of Evaluation

Variables were first measured 2 months after insertion of the new dentures with full OSL up to the second molars (L1, control). After L1 evaluation, the OSL of the mandibular RPDs was reduced to the first molars (L2) and all variables were reevaluated. The sequential evaluations were carried out weekly at three additional sessions in which the OSL was reduced to the second premolars (L3), first premolars (L4), and finally, reduced completely (L5). The reduction of OSL was performed by artificial wearing of the teeth using a low-speed cylindric tungsten bur (Maxi Cut). All evaluations were carried out immediately after each tooth removal, and no time was allowed for the subjects to adapt to the new occlusal condition. After each evaluation, another artificial tooth was replaced infraocclusally at the denture base level.

Statistical Analysis

Assumptions of parametric analysis were tested with respect to the additivity model, homogeneity of variances, and normality of residuals through guided data analysis using SAS statistical software (SAS Institute). Masticatory performance was transformed to square, and logarithmic transformation was applied to data from the frontal and sagittal areas as well as the chewing rate. Analyses of variance for repeated measures and post hoc Tukey tests were applied for the mentioned variables and for the maximum excursion data. Selection chance and breakage functions did not meet the assumptions necessary for parametric analysis and were therefore evaluated using the Friedman test and nonparametric multiple comparisons tests. The qualitative measurements of masticatory cycle patterns were analyzed using the Fisher exact test. All statistical analyses were performed assuming a 5% level of significance.

Results

Masticatory performance (X50) and masticatory efficiency (%) gradually decreased (from 5.46 ± 0.64 mm to 6.24 ± 0.44 mm and from 51.21% ± 19.44% to 24.50% ± 15.98%, respectively) as RPDs with full OSL (L1) were degraded to having no occlusal support (L5). Significant differences ($P < .05$) were

Table 1 Masticatory Assessments (Mean ± Standard Deviation)*

OSL	Masticatory performance (mm)	Masticatory efficiency (%)	Chewing rate (cycles/min)
L1	5.46 ± 0.64[a]	51.21 ± 19.44[a]	82.21 ± 14.68[a]
L2	5.84 ± 0.55[b]	39.33 ± 17.59[b]	83.81 ± 14.72[a,b]
L3	5.91 ± 0.54[b]	36.33 ± 19.25[b]	88.16 ± 17.80[a,b]
L4	6.11 ± 0.52[b,c]	29.67 ± 19.86[b,c]	89.45 ± 18.89[b]
L5	6.24 ± 0.44[c]	24.50 ± 15.98[c]	87.27 ± 15.26[a,b]

*Different letters indicate statistically different values among OSLs ($P < .05$).

Table 2 Selection Chance and Breakage Function Values According to Cube Size (Mean ± Standard Deviation)*

	Selection chance			Breakage function (r)		
OSL	8.0 mm	4.8 mm	2.4 mm	8.0 mm	4.8 mm	2.4 mm
L1	0.90 ± 0.16[a]	0.41 ± 0.10[a]	0.07 ± 0.02[a]	0.39 ± 0.10[a]	0.19 ± 0.08[a]	0.05 ± 0.03[a]
L2	0.77 ± 0.19[a,b]	0.28 ± 0.09[a,b]	0.04 ± 0.01[a,b]	0.38 ± 0.12[a,b]	0.13 ± 0.06[a,b]	0.03 ± 0.03[a]
L3	0.52 ± 0.17[b,c]	0.18 ± 0.09[b,c]	0.03 ± 0.02[b,c]	0.27 ± 0.17[b,c]	0.09 ± 0.05[b]	0.03 ± 0.04[a]
L4	0.43 ± 0.21[c,d]	0.11 ± 0.10[c,d]	0.01 ± 0.03[c,d]	0.19 ± 0.16[c,d]	0.02 ± 0.04[c]	0.00 ± 0.00[b]
L5	0.33 ± 0.10[d]	0.05 ± 0.09[d]	0.00 ± 0.00[d]	0.02 ± 0.06[d]	0.00 ± 0.00[c]	0.00 ± 0.00[b]

*Different letters indicate statistically different values among OSLs ($P < .05$).

Table 3 Patterns of Mandibular Movements by No. of Patients Recorded Using Kinesiography

	Frontal plane (%)			Sagittal plane (%)	
OSL	Type 1	Type 2	Type 3	Type 1	Type 2
L1	20 (87.0)	3 (13.0)	0 (0.0)	0 (0.0)	23 (100.0)
L2	19 (82.6)	4 (17.4)	0 (0.0)	0 (0.0)	23 (100.0)
L3	18 (78.3)	5 (21.7)	0 (0.0)	1 (4.4)	22 (95.6)
L4	21 (91.3)	2 (8.7)	0 (0.0)	0 (0.0)	23 (100.0)
L5	20 (87.0)	3 (13.0)	0 (0.0)	0 (0.0)	23 (100.0)

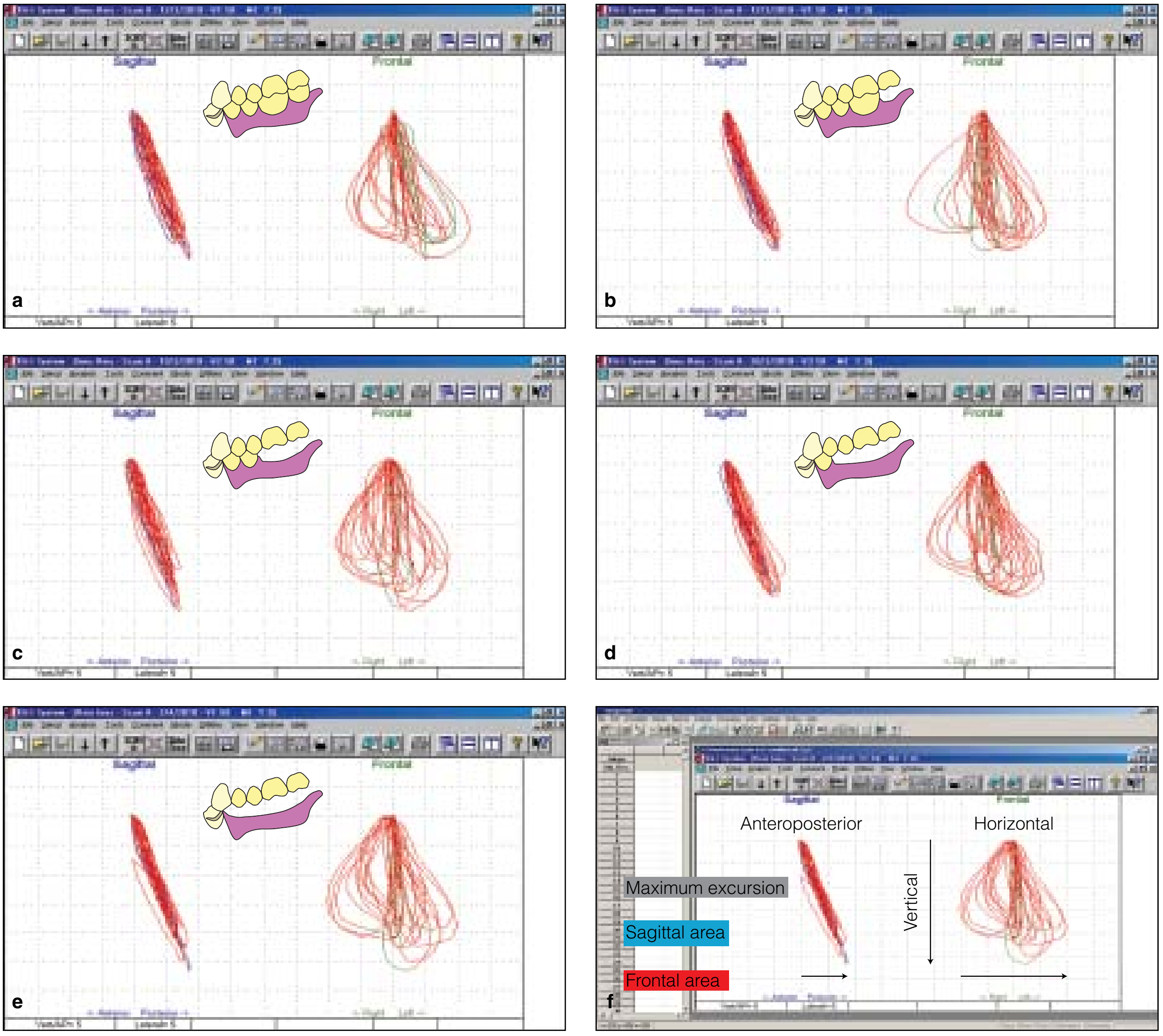
noted among L1 (full support), L4, and L5 conditions (Table 1). However, chewing rate generally did not differ with changing OSL ($P > .05$), with the exception of L1 versus L4 ($P < .05$), which yielded the lowest and highest chewing rates, respectively (Table 1).

The percentage of selection chance for 8.0-, 4.8-, and 2.4-mm cubes decreased when the OSL was reduced (Table 2). There were differences ($P < .05$) among L1, L3, and L5, with the lowest values presented by subjects in the last condition. It can also be noted that subjects in L2 showed a greater chance of selecting particles than subjects in the L4 and L5 conditions ($P < .05$). The pattern of results from the breakage function test with 8.0-mm cubes was similar to that seen for the selection chance data. However, differences ($P <. 05$) between OSL conditions were apparent in the breakage function tests with the 4.8- and 2.4-mm cubes, though the L4 and L5 conditions remained clearly inferior to the greater support conditions (Table 2).

The pattern of mandibular movements during mastication did not differ between the OSL conditions ($P > .05$) in either the frontal or sagittal planes (Table 3 and Fig 1). Similarly, quantitative values measured for masticatory cycles showed no differences among the five OSL conditions ($P > .05$, Table 4).

Discussion

Masticatory performance and efficiency showed decreased values when subjects chewed using free-end RPDs with reduced OSL. Although no studies have examined the influence of artificial premolars and molars on the masticatory performance and



Figs 1a to 1f Masticatory cycle patterns observed for each OSL. **(a)** L1 = full support; **(b)** L2 = support to the first molars; **(c)** L3 = support to the second premolars; **(d)** L4 = support to the first premolars; **(e)** L5 = no occlusal support. **(f)** Analysis performed using ImageTool Software.

Table 4 Quantitative Masticatory Cycle Measurements (Mean ± Standard Deviation)

	Maximum excursions (mm)			Area (mm^2)	
OSL	Vertical	Horizontal	Anteroposterior	Frontal	Sagittal
L1	18.16 ± 4.49	11.54 ± 3.12	6.63 ± 1.64	126.30 ± 59.35	59.63 ± 19.56
L2	18.30 ± 4.74	12.37 ± 3.28	7.02 ± 2.04	139.50 ± 72.56	63.26 ± 24.09
L3	18.04 ± 3.86	11.43 ± 2.87	6.76 ± 2.11	128.71 ± 61.65	59.28 ± 21.08
L4	18.16 ± 4.06	11.22 ± 3.00	6.81 ± 1.84	125.90 ± 59.63	59.89 ± 21.54
L5	18.19 ± 4.57	10.88 ± 3.28	6.78 ± 1.78	118.46 ± 69.97	57.93 ± 21.28

efficiency of RPD wearers, the results of this study are in agreement with those from Yanagawa et al,[4] who observed decreased masticatory performance when the length of the food platform in Kennedy Class II free-end RPDs was reduced to 10 mm. Similarly, the masticatory performance in overdenture wearers has previously been reported to decrease after reduction of OSL to the second and first premolars.[24]

In this study, masticatory function was affected by removal of the second molars from the free-end RPDs (L2). A decrease in the capacity to comminute test food could be the result of loss of occlusal contact and reduced transmission of masticatory force,[25,26] which are the main determinants of masticatory function.[27] Loss of molar teeth results in decreased comminution of particles that are approximately 4.8 mm or smaller, which influences the cumulative weight distribution during median particle size estimation.[28] However, no differences were noted among subjects in conditions L2, L3, and L4, pointing to the probable importance of the presence of the second molars when processing mandibular free-end RPDs. The lack of differences among these conditions may be attributable to the gradual increase in occlusal force at second and first premolars after loss of contact at the first molar and second premolar levels, respectively,[29] which could improve comminution capacity. However, despite the greater force on the remaining teeth, the total occlusal force or the sum of the occlusal load distributed over the dentition decreases because of the fewer number of occluding antagonist teeth,[30] explaining the higher masticatory performance and efficiency values exhibited in the control condition (L1, full occlusal support). Moreover, since a reduced OSL also implies a reduction in the total occlusal table area,[31] an increased occlusal force by a greater local stress to indent or crack a food bolus for the same applied muscular load[28] may be considered mainly for harder foods.[28] Nevertheless, a smaller number of antagonist teeth also decreases one's capacity to select particles and the number of available breakage sites,[14] limiting the use of increased occlusal force with the remaining teeth.

Despite the observed differences in masticatory tests, subjects generally presented a similar chewing rate across the different OSLs, with the exception of L1 versus L4. The duration of each masticatory cycle depends on the ease with which food is being broken down,[12,32] and comminution capacity is high when a slow chewing rate is used.[11] Subjects with reduced OSL compress fewer food particles between their artificial teeth, indicating that reduced OSL is associated with lower resistance to reach maximum intercuspation.[32] As a consequence, the velocity for completion of each masticatory cycle may be increased.

Given that premolars provide preliminary breakdown for large- and medium-sized particles and that molars reduce the particle size further,[28] the presence of all premolars in conditions L2 and L3 probably leads to the absence of alteration of the chewing rate. In addition, the lack of differences in chewing rates measured for conditions L1 and L5 could be the result of an anteriorized chewing strategy being employed when individuals lack occlusal support.[18] Without posterior contacts (L5), the occlusal force of anterior teeth increases and is similar to that in the molar region when occlusal support is intact.[30] Although occlusal force was not measured in this study, the authors believe that it is likely that this compensatory mechanism was at work, thereby attenuating alterations in the chewing rate in condition L5.

The selection chance of 8.0-, 4.8-, and 2.4-mm cubes also decreased as the OSL was reduced. Selection chance is determined by tongue and cheek actions, tooth shape, occlusal area, and the size and quantity of food particles.[22] There are no reports regarding selection chance in free-end RPD wearers, but it is possible that the reduced occlusal area—a consequence of the progressive reduction of occlusal support—leads to a lack of coordination among the tongue, cheeks, and artificial and remaining teeth. As previously mentioned, this condition could indicate that the food particles cannot be selected, decreasing the quantity of food particles trapped between the teeth able to escape between occlusal surfaces without breakage during mastication.[14]

Breakage function depends on cusp form, masticatory force, and fracture characteristics of food.[20] Thus, after a gradual reduction of OSL, breakage could be decreased by the fewer particles that were previously selected[14,15] and lower transmission of masticatory force through the remaining teeth.[29,30] Decline of breakage function was more critical for 4.8- and 2.4-mm cubes, which showed values near zero. van den Braber et al[20] also found that subjects with poor masticatory performance resulting from altered occlusion showed more difficulty in selecting and breaking Optosil cubes, which may explain why these subjects increase the number of masticatory cycles before swallowing or swallow larger particles.[33] The decreased oral sensory perception and feedback presented by edentulous subjects, even after rehabilitation, could also have contributed to the lower values of selection chance and breakage function observed in this study.[34] According to the results, selection chance and breakage function reflected the masticatory performance and efficiency values reached by subjects in the different occlusal support conditions.

The pattern of mandibular movements during chewing did not differ among the OSLs on the frontal or sagittal planes. Similar results were obtained for maximum mandibular excursions and masticatory cycle areas. These findings are in agreement with those of Nissan et al,[35] who found that factors such as missing teeth, type of occlusion, lateral guidance, sex, and use of implant-supported restorations or complete dentures do not affect the trajectory of the masticatory cycle. Apparently there are other factors besides occlusal support that can influence mandibular movement during mastication in subjects with free-end RPDs. These factors could be related to musculoskeletal features[36] such as articular kinematics[37] and muscle lines of action[38] as well as variations in the central control of the masticatory cycle.[39]

Although occlusal support is a structural feature that should be rehabilitated during prosthetic treatment,[24,27] it should be considered that subjects can adapt their mastication to new occlusal conditions without oral discomfort, occlusal instability, temporomandibular signs and symptoms, or other issues.[7] However, in this study, masticatory function was evaluated immediately after each change in OSL, precluding the possibility for an adaptation period. If an adaptive period had been included, the cumulative contribution of each restored artificial tooth could not have been determined since compensatory mechanisms can alter the results. Undoubtedly, controlled studies evaluating rational adaptive periods need to be conducted to determine the adaptation degree of subjects and whether such adaptation can be sustained temporarily without masticatory system fatigue.

Conclusions

Within the limitations of this study, it can be concluded that any reduction in OSL for subjects with free-end RPDs can influence masticatory function, resulting in decreased masticatory performance and efficiency because of a reduced capacity to select and break down food. However, the mandibular movement pattern exhibited by these subjects during mastication was unaffected by changes in OSL.

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Literature Abstract

Wear at the titanium-zirconia implant-abutment interface: A pilot study

The purpose of this study was to use a clinical simulation to determine whether wear of the internal surface of a titanium implant was greater following connection and loading of a one-piece zirconia implant abutment or a titanium implant abutment. Two internal-connection titanium implants (grade IV, 4.5 × 9 mm; Astra Tech) received a zirconia abutment (3 mm ZirDesign, Astra Tech) and two similar implants received titanium abutments (3 mm TiDesign, Astra Tech). The implants were secured into four fiber-reinforced epoxy resin disks that had been prepared to receive the internal-connection implants. The assemblies were cyclically loaded off axis for a total of 1,000,000 cycles. At various intervals, the abutments were removed, photographed, examined using scanning electron microscopy (SEM), and returned to the implant for further testing. The area of the titanium transfer from the implants to the abutments observed in the SEM image was quantified using image analysis software. The analysis demonstrated that there was considerably more wear associated with the zirconia abutments but the rate of wear slowed after 250,000 cycles. Parabolic curves were fit to the data. The projected mean ± standard deviation maximum area (wear) values associated with the titanium and zirconia abutments were $15.8 \pm 3.3 \times 10^3$ μm^2 and $131.8 \pm 14.5 \times 10^3$ μm^2, respectively, and the difference was statistically significant ($P = .0081$). Although this was a pilot study involving four implants only, it demonstrated that implants with the zirconia abutments showed a greater initial rate of wear and more total wear than the implants with the titanium abutments following cyclic loading. The amount of titanium transfer seen on the zirconia abutment increased with the number of loading cycles but appeared to be self-limiting. The clinical ramifications of this finding are unknown at this time, and more research is required to ascertain the potential for screw loosening and subsequent fracture.

Klotz MW, Taylor TD, Goldberg AJ. *Int J Oral and Maxillofac Implants* 2011;26:970–975. **References:** 15. **Reprints:** Dr A. Jon Goldberg, Center for Biomaterials, Department of Reconstructive Sciences MC1615, University of CT School of Dental Medicine, 263 Farmington Ave, Farmington, CT 06030-1615. Fax: +860-679-1370. Email: goldberg@uchc.edu—*Tee-Khin Neo, Singapore*