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ORIGINAL ARTICLE

Factors affecting wear of composite resin denture teeth—24-month results from a clinical study

Thomas Stober · Andreas Geiger · Stefan Rues · Jens Dreyhaupt · Peter Rammelsberg · Brigitte Ohlmann

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Abstract The objectives of this study were to measure the occlusal wear of composite resin denture teeth in patients wearing a complete denture and to evaluate factors affecting wear. Fifty participants provided with complete dentures in at least one jaw were included. Gypsum casts were made from preliminary vinyl polysiloxane impressions 4 weeks after insertion, then after 6 (t_1), 12 (t_2), and 24 months (t_3). Three-hundred and three posterior denture teeth were evaluated after 24 months. Wear was measured indirectly, from the casts, by means of a three-dimensional laser scanner device. Sequential images of the occlusal surfaces were digitized and superimposed (occlusal matching). Statistical analysis was performed by the use of mixed regression models, with the patient being a random effect. Mean wear (median, interquartile range; micrometer) of the entire occlusal surface was 8 (19) at t_1, 18 (34) at t_2, and 40 (61) at t_3. Maximum vertical loss (median, interquartile range; micrometer) was 92 (112) at t_1, 146 (148) at t_2, and 226 (184) at t_3. The dental status of the opposing jaw and the nature of the opposing material significantly affected the wear of denture teeth at t_3. Gender, daily wearing time, jaw, and type of tooth had no significant effects on the extent of wear. Clinically relevant vertical loss of composite resin denture teeth occurs after 24 months. Considering the limitations of this study, wear of denture teeth was affected by dental status and opposing material. The results suggest that wear of composite resin denture teeth exceeds that of enamel.

Keywords Wear · Occlusal wear · Clinical wear · Composite resin denture teeth · Artificial teeth

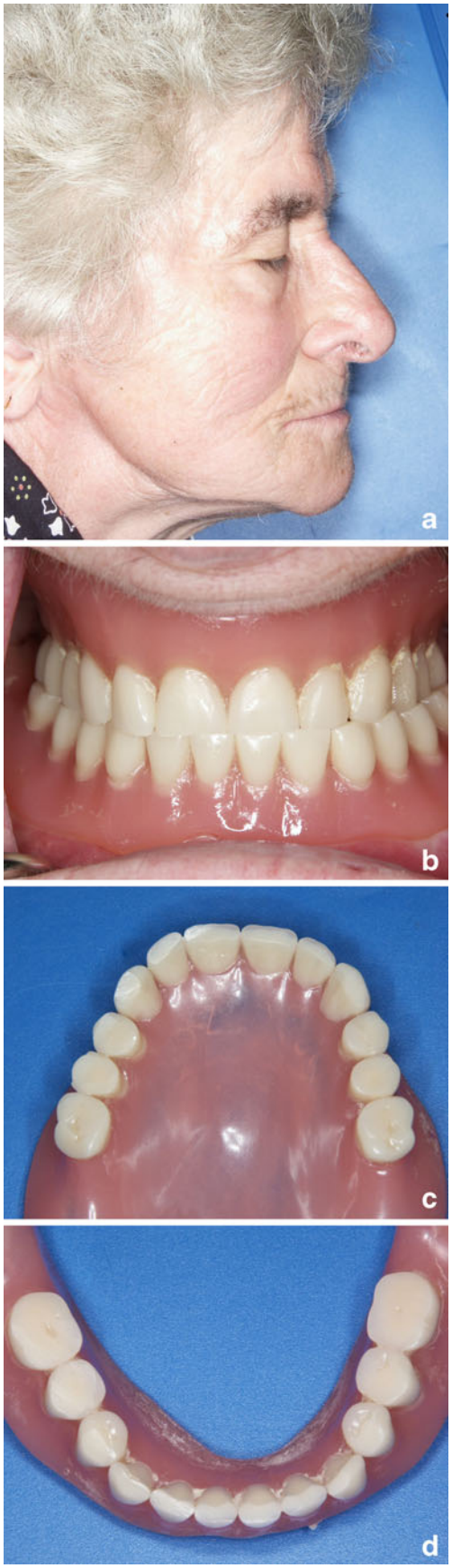
T. Stober (✉) · A. Geiger · S. Rues · P. Rammelsberg · B. Ohlmann
Department of Prosthodontics, Heidelberg University Hospital, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany
e-mail: thomas_stober@med.uni-heidelberg.de

J. Dreyhaupt
Institute of Biometrics, Ulm University, Ulm, Germany

Introduction

The lifetime of removable partial dentures or complete dentures is partly dependent on the wear resistance of the artificial teeth. Loss of vertical dimension, reduced masticatory efficiency, and esthetic impairment may result if denture teeth have insufficient wear resistance (Fig. 1). For this reason, in the last decade, many manufacturers have developed resin materials for which they claim high wear resistance.

Basic approaches used to improve mechanical properties and wear resistance are production of modified resin materials with more cross-linking between the polymers and the addition of special pre-polymers or inorganic fillers to the polymer matrix [1–3]. Whether these developments have resulted in a substantial increase in clinical wear resistance has not yet been clearly answered, despite many in vitro [2, 4–15] and in vivo [1, 16–20] investigations. In vitro testing of resin denture teeth with inorganic fillers, so-called composite resin teeth, revealed increased wear resistance in most studies [5–8, 10, 11, 14, 15] but there are also contradictory reports [2, 6, 9]. However, laboratory investigations of wear have the shortcoming of evaluation of wear behavior by simulation of only one or two wear mechanisms under limited chewing simulation conditions. There is no evidence that any wear simulator provides wear data, which correlate with those obtained clinically [21, 22]. Clinical studies may produce very different results because



◀**Fig. 1 a–d** Example of a patient with severe occlusal wear of composite resin denture teeth after 3 years of clinical service. **a** Side face with signs of changes in the jaw relations, **b** esthetic impairments and insufficient posterior tooth support in consequence of occlusal wear, **c** view on the upper denture with severe occlusal wear, **d** view on the lower denture with severe occlusal wear

wear processes in the oral cavity result from a complex interaction of mechanical forces and a variety of other factors (e.g., erosion and corrosion processes, nutritional habits, etc.), the effect of which on the extent of wear may differ greatly from person to person.

In summary, few clinical data only are available on the wear behavior of denture teeth. In a clinical study by Ogle et al., resin teeth with high cross-linking proved advantageous in terms of wear behavior compared with conventional acrylic resin teeth [16]. Other clinical investigations, however, have not revealed any statistically significant difference between wear behavior of resin denture teeth with high cross-linking or with inorganic fillers and that of conventional acrylic resin teeth [1, 17, 18, 20]. One clinical wear study suggested a correlation between diet preference (hard foods, raw vegetables) and wear of resin denture teeth in complete dentures [1]. The same authors found that wear of maxillary teeth was higher than that of mandibular teeth [1].

Although knowledge of factors affecting the wear of artificial teeth would be helpful for dentists attempting to select appropriate denture teeth for the individual patient, little information is available. A recent clinical study revealed high variability of wear of resin denture teeth in patients with complete dentures and reported that primary factors affecting wear were the subject, the age of the subject, and the type of tooth [20]. Ogle et al. reported that resin denture teeth wore by approximately the same amount whether they opposed artificial teeth or natural teeth [16]. In their pilot study, Ohlmann et al. found indications that gender, type of denture, and antagonist material significantly affected the wear of resin denture teeth [19].

The objective of this study was to determine the occlusal wear of composite resin denture teeth over a period of 24 months for patients wearing a complete denture in at least one jaw. The effect on wear of gender, daily wearing time, jaw, type of tooth, dental status of the opposing jaw, and opposing antagonist material would also be evaluated. The null hypothesis was that wear would not be affected by these factors.

Materials and methods

The participants in this study were 50 patients who were edentulous in one or both jaws. The mean age of the patients was 66.3 years (SD 11.6, range 45–87) and 48.1%

were male. Depending on their dental status, 27 patients received a complete denture in the maxilla only, 2 in the mandible only, and 21 in the maxilla and mandible. All participants were required to sign a consent form. The study protocol was approved by the local university review board (ethical approval no. 295/2003).

The participants received dentures of either a heat-pressed denture base material (Pala-X-Press; Heraeus Kulzer, Hanau, Germany) or a hypoallergenic denture base polymer (Versyo.com; Heraeus Kulzer). All dentures were made according to the usual routines of complete denture treatment in centric occlusion. If patients received complete dentures in both jaws, the dentures were adjusted according to the principle of bilateral balanced occlusion. The artificial teeth were composite resin denture teeth with a matrix of poly(methyl methacrylate) and 14% inorganic fillers (highly dispersed silica) (Vitapan; VITA Zahnfabrik, Bad Säckingen, Germany). After incorporation of the dentures, necessary occlusal adjustments or removal of pressure spots was performed within 4 weeks.

To evaluate wear, extra-oral impressions of the dentures were made 4 weeks after insertion (t_0), then after 6 (t_1), 12 (t_2), and 24 months (t_3), with vinyl polysiloxane, by the use of the dual viscosity technique (Flexitime Putty and Flexitime Correct Flow; Heraeus Kulzer). Before taking impressions, the dentures were inspected for stains, calculus, and foreign debris and, if necessary, cleaned in an ultrasonic cleaner. The impressions were poured with gypsum type IV dental stone (GC Fujirock EP Pearl White; Leuven, Belgium). Wear was determined indirectly by the use of the casts with a commercially available laser scanner device (Laserscan 3D, Willytec/SD Mechantronic, Feldkirchen-Westerham, Germany). The method, first described by Mehl et al. [23], has been proven to be suitable in a variety of previous clinical studies of wear [19, 20, 24–26] and is regarded as the preferred method for measurement of clinical wear [27].

First, the occlusal surfaces of the casts were digitized with the laser scanner device. Each denture tooth was scanned separately (Fig. 2). The settings for this scanning process, preset by the manufacturer, were adjusted by increasing the number of read-in light lines from 400 to 700 with a step distance of 30 μm. The data sets obtained in this way were then checked for surface changes (wear), by the use of a surface analysis software (Match 3D, Version 1.6, Willytec/SD Mechantronic). The extent of wear was calculated by superimposing the baseline and follow-up scans (occlusal matching). An automated superimposition process without reference points was used, as described by Mehl et al. [23]. This technique enables measurement of surface changes with an accuracy of approximately 10 μm [23]. The objective of the occlusal matching was to match the surface points of recall casts with those of the baseline cast as precisely as possible. The number of calculation steps executed until termination of the calculation process was preset to 20,000. The minimum number of image points used for matching was 800. To prevent surface changes as a result of wear or artifacts in the casts (voids, blebs) from impairing the superimposition process, a threshold value of −30 μm was defined. This means that all areas of the follow-up cast which differed from the baseline cast by more than 30 μm in the negative direction were not included in the matching process. Matching was accepted if the standard deviations between the two occlusal surfaces were less than 20 μm. Details of the mathematical algorithms used for this occlusal matching have been published elsewhere [23]. The results of this matching process were differential images showing surface changes (wear zones) in red, in a false color representation.

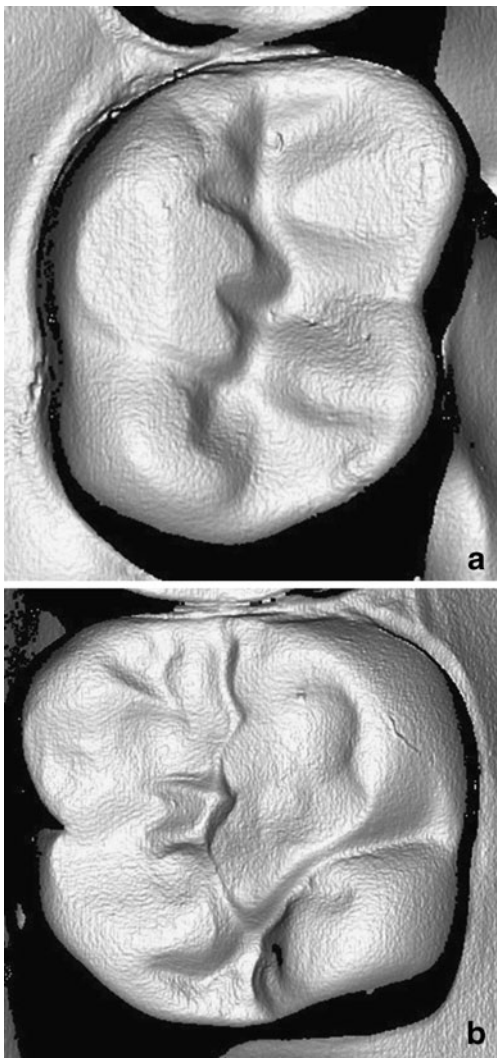


Fig. 2 **a**, **b** Examples of scanned denture teeth with clear signs of occlusal wear. **a** Upper right first molar after 24 months of clinical service with resin denture teeth antagonists, **b** upper left first molar after 24 months of clinical service with ceramic crown antagonists

For each posterior denture tooth, the entire surface involved in occlusion was evaluated. The maximum vertical loss (to eliminate outliers, the 2% quantile was used) and the mean wear of the entire occlusal surface of the posterior denture teeth were calculated by the use of the surface analysis software.

For further statistical evaluation, the data were analyzed with SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Figures were created using R (Version 2.11.0). Because the distribution of the wear data was skewed, the data were log-transformed to furnish normal distribution. To evaluate the effects of gender, daily wearing time, jaw, type of tooth, antagonistic situation, and antagonistic material on the extent of wear, univariate mixed-effects regression models (SAS PROC MIXED) were used, with the patient being a random effect. The "difference between wear for t_1, t_2, and t_3" was also tested by the use of mixed regression models. A p value less than 0.05 was regarded as significant. Because of the explorative nature of this study, no adjustment was made for multiple testing.

Results

The results from the evaluation of wear were based upon 44 participants (407 denture teeth) after 6 months (t_1), 37 participants (340 denture teeth) after 12 months (t_2), and 32 participants (303 denture teeth) after 24 months (t_3) of wearing time. The mean vertical loss (median, interquartile range in parentheses) from the entire occlusal surface for all the denture teeth was 8 (19) μm at t_1, 18 (34) μm at t_2, and 40 (61) μm at t_3. The maximum vertical loss of denture teeth (median, interquartile range) was 92 (112) μm at t_1, 146 (148) μm at t_2, and 226 (184) μm at t_3.

Regression analysis for gender, daily wearing time, jaw, type of tooth, dental status of the opposing jaw, and antagonistic material was based on mean vertical loss of 303 posterior denture teeth of 32 participants, which could be evaluated at t_3 (24 months). For evaluation of differences in wear rate between the time points (t_1 vs. t_2, t_1 vs. t_3, t_2 vs. t_3), all available teeth were included. Details of gender, daily wearing time, jaw, type of tooth, dental status, and antagonistic material for the participants and the denture teeth included in the statistical analysis are shown in Table 1. The reasons for dropout of 195 denture teeth at t_3 were 18 participants (with 156 denture teeth) who moved or withdrew from the study, 35 denture teeth which could not be matched because of artifacts in the casts (voids, blebs), and 4 denture teeth which needed occlusal adjustments after baseline impression at t_0.

Differences between mean unadjusted wear at t_1, t_2, and t_3 were statistically significant (Table 2). Statistically significant effects of gender, daily wearing time, jaw, and type of tooth on the extent of wear could not be shown (Table 2). However, the dental status of the opposing jaw had a significant effect on wear at t_3 (Table 2). Wear of denture teeth with an antagonistic natural tooth, crown, or fixed partial denture was higher than for denture teeth with an antagonistic removable partial denture or complete denture. Wear was lowest for four denture teeth without antagonists (Table 1, Fig. 3).

The occlusal material of the antagonists also significantly affected wear at t_3 (Table 2). Wear was greater for denture teeth occluding with metal alloy crowns or resin veneering material from telescopic crowns than for denture teeth occluding with resin denture teeth. Again, wear was lowest for the four denture teeth without antagonists (Table 1, Fig. 4).

Discussion

The main findings of this study were the significant effect of the dental status of the opposing jaw and of the nature of the opposing material on the wear of composite resin denture teeth. Consequently, the null hypothesis had to be rejected. Considering the small sample sizes in some categories (e.g., six metal alloy crown and eight ceramic crown antagonists), however, the results of this study must be interpreted with caution. Furthermore, because of the explorative nature of this study, no adjustment was made for multiple testing. Therefore, all results should be interpreted in an exploratory sense and not as proof of efficacy.

A second important finding of this study was that the vertical loss from composite resin denture teeth for complete denture wearers increased continuously over 24 months up to a median vertical loss of 226 (171) μm after 24 months. These results can aid further interpretation of in vitro wear studies and are in accordance with the results of two previous clinical studies using the same method for evaluation of wear [19, 20]. Schmid-Schwap et al. measured median vertical loss for posterior denture teeth of 121–221 μm after 1 year of clinical service [20]. Another study found an average of 19 μm of wear of posterior teeth for complete dentures after 6 months [19]. In that study, however, the mean vertical loss was calculated for the entire occlusal surface area and must, therefore, be compared with the mean wear of 8 (19) μm after 6 months in this study. In contrast, older studies of the wear of denture teeth described less vertical loss, with annual wear of 58–85 [16] and 90 μm [17]. The main reason for the apparently lower wear resistance of the composite resin teeth used in this study may be a different, more objective, and more accurate method of evaluation.

Table 1 Characteristics and wear data for posterior resin denture teeth from 32 participants evaluated at t_3 (24 months) with details of gender, daily wearing time, jaw, type of tooth, antagonistic situation, and antagonistic material

Parameter	Characteristic	Number of denture teeth	Mean vertical wear (medians and, in parentheses, interquartile ranges, μm)
Total		303	40 (61)
Gender	Male	113	54 (81)
	Female	190	37 (53)
Daily wearing time	<24 h	162	43 (55)
	24 h	141	40 (65)
Jaw	Maxilla	209	44 (65)
	Mandible	94	38 (51)
Type of tooth	Premolar	171	43 (57)
	Molar	132	39 (68)
Antagonistic situation	No antagonist	4	17 (52)[a]
	Complete denture	189	36 (53)[b]
	Removable partial denture	74	47 (66)[c]
	Natural tooth, crown, or fixed partial denture	36	97 (178)[a,b,c]
Antagonistic material	No antagonist	4	17 (52)[u,w,x]
	Enamel	9	36 (51)
	Metal alloy (crown)	6	117 (97)[u,y]
	Ceramic (crown)	8	304 (341)[w]
	Resin denture tooth	262	39 (55)[y,z]
	Resin veneering material (telescopic crown)	14	115 (87)[x,z]

The same superscript letter indicates statistically significantly different wear based on mixed regression models (for details, see Table 2)

The observed effects of dental status of the opposing jaw and of the antagonistic occlusal material on wear of composite resin denture teeth are in agreement with a previous clinical pilot study [19]. Ohlmann et al. found indications that the interaction of antagonistic material and type of denture is a factor affecting wear of denture teeth in removable partial dentures, overdentures, and complete dentures [19]. The effect of dental status on wear, i.e., whether the occluding antagonists were natural teeth (or crowns) or partial or complete dentures, can be explained on the basis of different biting forces. It has been shown that the biting forces of wearers of removable partial dentures and complete dentures are much less than those of subjects with natural dentition [28, 29]. Another reason for less wear in subjects with dentures and who lack periodontal receptors may be that they prefer softer, less abrasive food.

Multiple in vitro studies concluded that wear is substantially affected by the opposing material. In general, ceramic antagonists caused the most vertical wear of resin denture teeth [11, 13, 14, 30, 31]. Our clinical study could not prove these previous in vitro results. Although wear was much higher if denture teeth were opposed by ceramic crowns than if they were opposed by metal crowns, resin-veneered telescopic crowns, resin denture teeth, or natural teeth, the differences were not statistically significant, probably because of the small sample size in the subgroups. Furthermore, it should be considered that the samples of some tested subgroups are only from two (ceramic crown antagonist, enamel antagonist) or three patients (no antagonist, metal alloy crown antagonist). Nevertheless, the results of this study apparently suggest that metal crowns and resin-veneered telescopic crowns cause significantly more wear of resin denture teeth than denture teeth as opposed to other denture teeth. However, these findings also should be interpreted with caution. The greater wear of denture teeth as opposed to metal crowns and resin-veneered telescopic crowns was probably a result of the different dental status of the opposing jaw and the coherent effects (different biting forces, different nutrition) described above. On the other hand, for denture teeth as opposed to enamel, the amount of wear was nearly the same as for denture teeth as opposed to denture teeth. This result confirms a previous clinical report that wear of resin denture teeth was approximately the same whether they were opposed to resin denture teeth or natural teeth (enamel), although that study was based on eight patients only [16].

Table 2 Results from statistical analysis with mixed regression models (including patient as random effect)

Variable		*p* value	Regression coefficient (95% confidence interval)
Evaluation	t_1 vs. t_2 (n=303)	<0.01	−0.20 (−0.26; −0.14)
	t_1 vs. t_3 (n=303)	<0.01	−0.53 (−0.59; −0.46)
	t_2 vs. t_3 (n=303)	<0.01	−0.33 (−0.39; −0.26)
Gender	Male (n=113) vs. female (n=190)	0.11	−0.29 (−0.07; 0.65)
Daily wearing time	24 h (n=162) vs. <24 h (n=141)	0.83	−0.03 (−0.34; 0.27)
Jaw	Maxilla (n=209) vs. mandible (n=94)	0.47	−0.04 (−0.15; 0.07)
Type of tooth	Premolar (n=171) vs. molar (n=132)	0.08	0.08 (−0.01; 0.17)
Antagonistic situation	0 (n=4) vs. 1 (n=189)	0.20	−0.27 (−0.67; 0.14)
	0 (n=4) vs. 2 (n=74)	0.07	−0.47 (−0.99; 0.05)
	0 (n=4) vs. 3 (n=36)	<0.01	−0.77 (−1.31; −0.23)
	1 (n=189) vs. 2 (n=74)	0.22	−0.21 (−0.54; 0.12)
	1 (n=189) vs. 3 (n=36)	<0.01	−0.50 (−0.86; −0.14)
	2 (n=74) vs. 3 (n=36)	<0.01	−0.30 (−0.52; −0.07)
Antagonistic material	1 (n=9) vs. 0 (n=4)	0.19	0.39 (−0.20; 0.99)
	2 (n=6) vs. 0 (n=4)	0.02	0.68 (0.11; 1.25)
	3 (n=8) vs. 0 (n=4)	0.02	0.82 (0.13; 1.51)
	4 (n=262) vs. 0 (n=4)	0.19	0.27 (−0.14; 0.68)
	5 (n=14) vs. 0 (n=4)	<0.01	0.65 (0.16; 1.14)
	1 (n=9) vs. 2 (n=6)	0.25	−0.29 (−0.78; 0.20)
	1 (n=9) vs. 3 (n=8)	0.14	−0.43 (−1.00; 0.14)
	1 (n=9) vs. 4 (n=262)	0.58	0.12 (−0.31; 0.55)
	1 (n=9) vs. 5 (n=14)	0.30	−0.26 (−0.74; 0.23)
	2 (n=6) vs. 3 (n=8)	0.65	−0.14 (−0.74; 0.46)
	2 (n=6) vs. 4 (n=262)	0.04	0.41 (0.01; 0.80)
	2 (n=6) vs. 5 (n=14)	0.88	0.03 (−0.39; 0.45)
	3 (n=8) vs. 4 (n=262)	0.06	0.55 (−0.01; 1.11)
	3 (n=8) vs. 5 (n=14)	0.58	0.17 (−0.43; 0.77)
	4 (n=262) vs. 5 (n=14)	<0.01	−0.38 (−0.64; −0.11)

The reference category in each regression model is the second (i.e., that category which is mentioned after the "vs.")

Antagonistic situation: no antagonist (0); complete denture (1); removable partial denture (2); natural tooth, crown, or fixed partial denture (3)

Antagonistic material: no antagonist (0), enamel (1), metal alloy (crown) (2), ceramic (crown) (3), resin denture tooth (4), resin veneering material (telescopic crown) (5)

When discussing the effect of different antagonistic materials on wear, it should be kept in mind that the surface roughness of the antagonistic material may strongly affect the amount of wear [32, 33]. On the basis of the results from their in vitro study, Ghazal and Kern recommended that ceramics should be highly polished to minimize their abrasive effect [33]. According to Oh et al. ceramic-caused wear processes seem to be more closely related to the microstructure and surface roughness of the ceramic and to environmental effects (pH, parafunctional habits, etc.) than to hardness [32].

Although there was a tendency of more wear of dentures worn by males, no statistically significant effect of gender on wear was found in this study. This finding is supported by the clinical investigation of Schmid-Schwap et al., who found no differences between wear of denture teeth for male and female wearers of complete dentures [20]. In clinical wear studies with fixed polymer crowns, also, no significant effect of gender on wear was found [24, 25]. In contrast, another study demonstrated that wear of resin denture teeth was significantly greater for male denture wearers than for females [19]. An explanation of these different results could be that not only complete dentures but also removable partial dentures were included in the study of Ohlmann et al. [19]. In previous studies, occlusal forces were lower for women than for men, whereas in edentulous subjects, no effect of gender on occlusal biting force has been found [28].

According to Schmid-Schwap et al., wear tended to be less for dentures which were worn at night than for those which

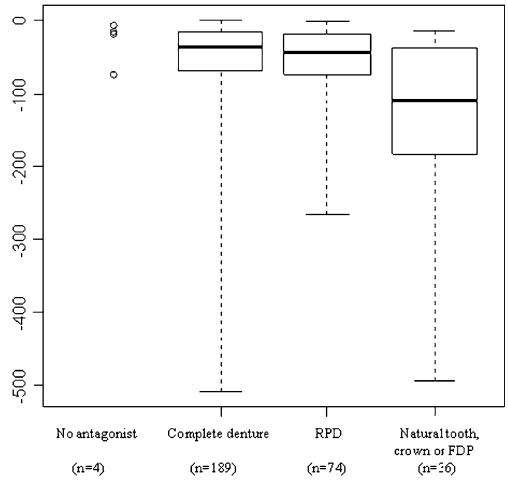


Fig. 3 Effect of dental status of opposing jaw on mean vertical loss of resin denture teeth at t_3 (wear rates in micrometer). *Box* includes 50% of all measurements with lower quartile, median (*black lines*), and upper quartile. *Whiskers* depict the highest and lowest values. For $n<10$, only the single values are provided

were not [20]. This observation was not fully confirmed by our results because we found a tendency to more wear in subjects with a daily wearing time of 24 h, i.e., when dentures were worn at night. In both studies, however, daily denture wearing time had no significant effect on wear.

Two previous studies of complete denture wearers proved a significant effect of jaw on wear rate. It was found that wear was systematically greater for maxillary denture teeth than for denture teeth in the mandible [1, 20]. In contrast, our study could not prove a significant effect of jaw on wear, although teeth in the maxilla had a tendency to wear more than teeth in the mandible.

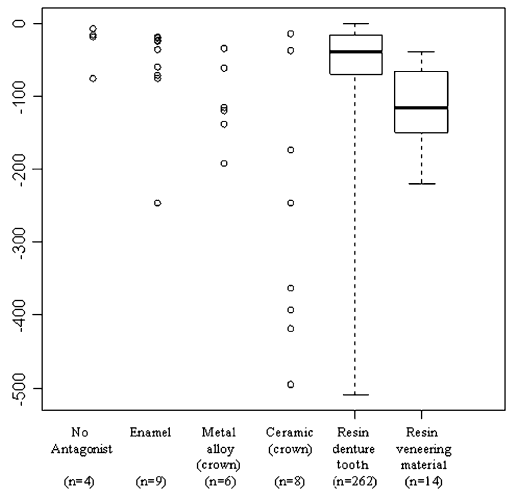


Fig. 4 Effect of antagonistic material on mean vertical loss of resin denture teeth at t_3 (micrometer). *Box* includes 50% of all measurements with lower quartile, median (*black lines*), and upper quartile. *Whiskers* depict the highest and lowest values. For $n<10$, only the single values are provided

Finally, the type of tooth (molar vs. premolar) did not significantly affect wear in our study, which partly contradicts the results from a previous work [20, 25]. For denture teeth, Schmid-Schwap et al. found that volumetric wear depended on tooth type (molars, premolars, incisors, canines), but differences diminished substantially after wear was adjusted for tooth surface [20]. A significant effect on wear, with wear greater for molars than for premolars, was also reported after clinical studies on fixed polymer crowns and enamel [25, 34]. The reasons for these contradictory results may be differences between bite force, chewing patterns, and food preferences of edentulous and dentate subjects [28, 29].

All already mentioned, previous clinical studies have one result in common—the large effect of the individual subject on wear [1, 16–20]. The wear measured in our investigation also varied substantially, which may be attributable to subject variation and the possibility of error in the measurement of wear. Although the method of measurement used in this study was characterized by good reproducibility and accuracy of 10–15 μm [23], it tends to underestimate the actual vertical loss because negative and positive values were considered in the matching process when calculating the mean negative differences.

The strengths of the study were the relatively long follow-up period of 24 months after denture placement in a prospective study design and the adequate number of participants at the beginning of the study. Wear measurements were, furthermore, performed with an objective, noncontact, optical scanning device which is currently regarded as the most accurate, effective, and successful technique for clinical wear analysis [20, 35]. The weaknesses of the study were the relatively high dropout of 18 patients (36%) after 24 months and matching problems because of poor quality of impressions and/or casts leading to only 303 evaluable teeth at t_3. Another weakness was the low sample sizes in some tested subgroups. Because this reduced the power of the statistical analysis, the results should be interpreted with caution and there may be significant factors which remained undetected.

Multicenter studies which involve a larger number of participants are proposed for future investigation of clinical wear. Efforts must also be made to improve the quality of impressions and casts for wear measurements. Finally, because occlusion has an important effect on wear processes, patient-related factors, for example bite force, parafunctional habits, and nutritional aspects, should be monitored in future clinical studies.

Conclusion

Clinically relevant vertical loss was observed after 24 months for the composite resin denture teeth evaluated.

This suggests that the wear resistance of composite resin denture teeth does not match with that of natural enamel [34]. Considering the limitations of this study, it can be concluded that the dental status distinctly affects wear of denture teeth. Moreover, the results suggest that wear of denture teeth is influenced by the nature of the opposing antagonistic material. These findings should be taken into account when providing patients with complete or removable partial dentures. In general, denture teeth with high wear resistance are recommended, especially when opposed to natural teeth, crowns, fixed partial dentures, or restorations with ceramic occlusal surfaces.

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Conflict of interest The financial support of Heraeus Kulzer was used to compensate the patients for their additional effort attending recalls. The authors have no other financially beneficial arrangements with Heraeus Kulzer. The authors declare that they have no conflict of interest.

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