

## Effect of contact area size on enamel and composite wear

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### Abstract

The effect of contact area dimensions on the wear of composite specimens and their opposing enamel cusps was evaluated in vitro. Thirty-six standardized cylindrical composite specimens were placed into metal cavities (8 mm x 2 mm) and divided randomly into five groups. The composite used was a fine-particle hybrid and was stressed as follows: storage in 75% aqueous ethanol solution for 24 h, toothbrush/toothpaste-abrasion for 30 min, followed by 300 thermal cycles in water ranging from 5 degrees to 55 degrees C and simultaneous 120,000 occlusal chewing loads at a frequency of 1.7 Hz at 53 N maximum force. In group 1 (n = 12), the occlusal chewing loads were applied by palatal cusps of extracted human maxillary molars with natural morphology. In groups 2 to 5 (n = 6), the cusp tips had standardized contact area dimensions of 0.26, 0.38, 1.18, and 4.10 mm<sup>2</sup>, respectively. Wear of composite specimens and antagonistic enamel cusps (means +/- SD) was assessed in microns by means of a 3-D scanner. Additionally, the contact surfaces of the restorations and of the antagonistic enamel cusps were evaluated by SEM. Increases in [...]

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# Effect of Contact Area Size on Enamel and Composite Wear

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The effect of contact area dimensions on the wear of composite specimens and their opposing enamel cusps was evaluated *in vitro*. Thirty-six standardized cylindrical composite specimens were placed into metal cavities (8 mm x 2 mm) and divided randomly into five groups. The composite used was a fine-particle hybrid and was stressed as follows: storage in 75% aqueous ethanol solution for 24 h, toothbrush/toothpaste-abrasion for 30 min, followed by 300 thermal cycles in water ranging from 5° to 55°C and simultaneous 120,000 occlusal chewing loads at a frequency of 1.7 Hz at 53 N maximum force. In group 1 (n = 12), the occlusal chewing loads were applied by palatal cusps of extracted human maxillary molars with natural morphology. In groups 2 to 5 (n = 6), the cusp tips had standardized contact area dimensions of 0.26, 0.38, 1.18, and 4.10 mm<sup>2</sup>, respectively. Wear of composite specimens and antagonistic enamel cusps (means ± SD) was assessed in µm by means of a 3-D scanner. Additionally, the contact surfaces of the restorations and of the antagonistic enamel cusps were evaluated by SEM. Increases in enamel contact areas after being loaded were measured by means of a digitizer and expressed in percent of the initial size before stress exposure. The wear of the composite specimens varied from 69.8 ± 19.9 to 9.5 ± 3.6 µm, and that of antagonistic enamel cusps from 31.3 ± 3.4 to 8.8 ± 1.5 µm. The increase in contact area varied between 27.8 and 0.1%. Composite and antagonistic enamel wore significantly (p < 0.001, ANOVA, Scheffé) less with increased contact area dimensions. The most severe disintegration of the composite was found in specimens occluding with the smallest enamel contact area. The extent of wear and the wear mechanisms were related to the chewing pressure, which in turn was governed by the contact area dimension.

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## Introduction.

Enamel-like wear resistance is one of the major requirements for posterior composite restorations (Lutz, 1980; Roulet, 1988a; Vanherle *et al.*, 1989). Because simple *in vitro* wear tests do not convincingly correlate with clinical wear behavior, it is claimed that the only relevant trial for the testing of wear is a clinical study (Roulet, 1988b). However, wide variations in clinical results make it difficult for significant differences among materials to be found. These variations are related to patient-specific factors such as diet or chewing forces (Craig, 1989). Chewing pressure, which is defined as the force applied *per* unit area, may be a dominating factor in the wear of occlusal contact points. The purpose of the present study was to evaluate the influence of the size and shape of the contact areas on the wear rates of a specific composite material and on the antagonistic enamel cusps in a clinically relevant *in vitro* wear test (Krejci *et al.*, 1990a,b; Krejci and Lutz, 1990) by use of a constant occlusal force.

## Materials and methods.

Thirty-six standardized cylindrical cavities, 8 mm wide and 2 mm deep, were cut in metal sample-holders and filled with a light-cured hybrid composite (Brilliant Enamel, Lot No. 100589-16, Coltene

AG, Altstätten, Switzerland). For reduction of porosities, Mylar strips were placed on the composite surfaces and pressed with a glass slab while curing. After a 60-second irradiation with visible light (Elipar II, Espe, Seefeld, Germany), the Mylar strips were removed, and another 60-second light-curing period was initiated. The composite surfaces were flattened and polished by wet-grinding with 800/1000-grit SiC paper at 150 rpm. Custom-made measuring brackets, serving as a reference plane, were attached to the peripheries of the metal sample-holders (Krejci *et al.*, 1990a). Thereafter, the composite specimens were randomly split into five experimental groups. In group 1 (n = 12), natural palatal cusps of extracted human upper first molars were used as antagonists. In groups 2 to 5 (n = 6), the enamel cusps were standardized in shape and size. For this purpose, the mean inclination of the cuspal walls was initially evaluated. The palatal cusps of 24 unworn extracted human upper first molars were sectioned occlusocervically. Photographs of the sections were evaluated at 7x magnification with a digitizer screen (HP 9874A Digitizer, Hewlett Packard Co., Sunnyvale, CA), and the angles between the cusp slopes were measured. A mean value of 90.2° ± 7.4° was found. Based on these findings, a 45° angle of the cuspal slopes to the long axes of the cusps was chosen for the main experiment. This was produced by the wet-grinding of the enamel cusps in a custom-made lathe with 15-µm diamond burs. The appropriate sizes of the contact point areas were precisely established by the flattening of the cuspal tips at 90° to their long axes with wet 1000-grit SiC paper at 150 rpm. The resulting contact areas were checked at 7x magnification with the digitizer. The sizes of the standardized occlusal contact areas are listed in the Table. Finally, brackets were bonded to all enamel cusps for quantitation of their vertical loss.

The wear test consisted of (1) chemical disintegration by immersion in 75% aqueous ethanol solution for 24 h; (2) toothbrushing with a dentifrice slurry for 30 min [2 parts dentifrice (RDA 90) to 1 part water] at a brushing force of 2 N; (3) attrition by the enamel cusp antagonist by 120,000 chewing cycles with a maximum load of 53 N run at a frequency of 1.7 Hz and with a lateral slide of 0.2 mm; and (4) thermal stressing between 5 and 55°C, consisting of 300 cold and 300 warm cycles of two minutes' duration. Stresses 3 and 4 ran simultaneously in a computer-controlled masticator (Krejci *et al.*, 1990a).

After the stress cycles were completed, the vertical losses of composite material and opposing enamel cusps were separately recorded and calculated in a 3-D scanner (Roulet, 1987; Krejci *et al.*, 1990a,b). The cuspal occlusal tip areas were digitized. The quantitative wear results and the increase in cuspal occlusal tip areas were statistically analyzed by means of ANOVA and the Scheffé test. The surface micromorphology of the occluding areas of the composites and of the enamel cusp tips was evaluated by SEM (Amray 1810/T, Amray, Bedford, MA) at various magnifications.

## Results.

The mean wear values with the appropriate standard deviations of the composite are shown in Fig. 1. The extents of wear of the composite samples in group 1 and group 2 were very similar (p > 0.05). However, the extents of wear of the pertinent antagonistic enamel cusps were significantly different (p < 0.05). Fig. 2 shows the extent of wear of the composite samples loaded by standardized opposing cusps in relation to the initial contact area size. The wear

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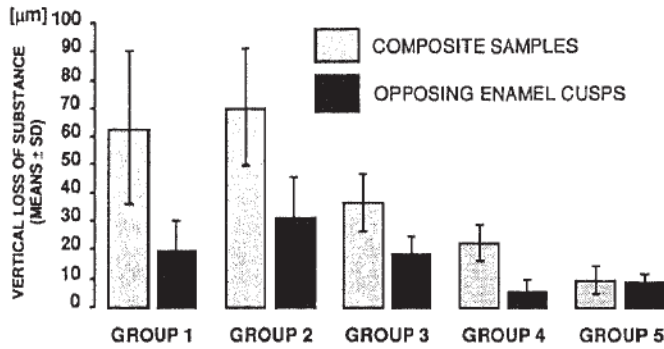


Fig. 1—Wear of composite samples and opposing enamel cusps at the end of the wear test (maximal vertical loss in the occlusal contact area; means ± standard deviations) for groups 1 to 5.

decreased exponentially with increasing contact area. The corresponding results for the antagonistic enamel cusps are summarized in Fig. 3. They show a distribution pattern analogous to that of the restorations. Fig. 4 illustrates the increase in enamel contact point areas after the wear test, expressed as a percentage of the initial values. The smallest initial contact point area showed the largest increase after wear-testing. The smallest contact area was associated with the highest total vertical loss of substance, having the highest deviation of measurements.

**Discussion.**

The exact wear mechanism in the occlusal contact area of dental restorations is not completely understood. It is assumed to be a combination of abrasion, adhesion, chemical disintegration, and surface fatigue (Burwell, 1957/58; Roulet, 1987). The wear test used in this experiment simulated these four wear types in a combination. The good correlation with *in vivo* wear measurements and the similarity of the micromorphological wear patterns in the loaded occlusal areas to *in vivo* findings suggest that this test comes close to the clinical situation (Krejci and Lutz, 1990).

The results showed that occlusal contact wear of posterior restorative materials was inversely related to the contact area size of the antagonistic cusps. A significant decrease of wear was recorded when the contact area increased from 0.26 to 0.38 and to 1.18 mm<sup>2</sup>. No significant difference in the extent of wear was found between areas of 1.18 and 4.10 mm<sup>2</sup>. These findings imply a constant coefficient of wear for groups 4 and 5, leading to a linear

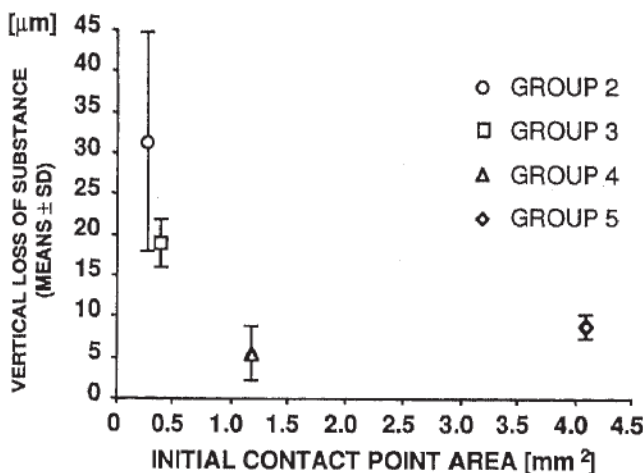


Fig. 3—Wear of opposing enamel (groups 2 to 5) cusps at the end of the wear test (maximal vertical loss in the occlusal contact area; means ± standard deviations) in relation to the initial contact area sizes.

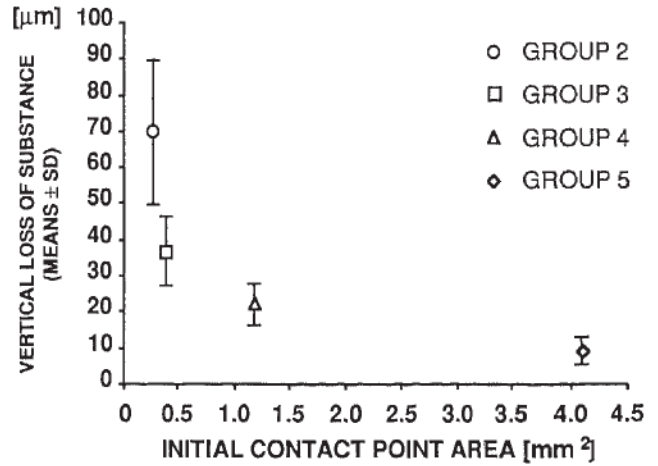


Fig. 2—Wear of composite samples (groups 2 to 5) at the end of the wear test (maximal vertical loss in the occlusal contact area; means ± standard deviations) in relation to the initial contact area sizes.

decrease of the wear rate with decreasing chewing pressure. According to SEM observations, the main wear mechanisms in these two groups were abrasion and adhesion, induced by the sliding motion of the enamel antagonists, without noticeable subsurface damage. In groups 2 and 3, the coefficient of wear was apparently different, as expressed by the nonlinear decrease of the wear rate with decreasing chewing pressure. In the SEM, microscopic damage was detected in the occlusal areas of these two groups. According to the literature (McKinney and Wu, 1982; Olver et al., 1986), plastic deformation leading to compressive or tensile fatigue is responsible for subsurface disintegration of composite materials. This indicates that these mechanisms contributed to the wear process in groups 2 and 3. The quantitative wear behavior of the opposing enamel cusps was similar to that of the composite samples. Although signs of fatigue were not obvious in the microscopic wear patterns in groups 2 and 3, the decrease in wear of the enamel cusps was also nonlinear. There is no plausible explanation for this wear behavior. A more detailed analysis of enamel wear should be the subject of future studies.

The similar results seen in groups 1 and 2 indicate that natural cusps have a rather small occlusal contact area, which results in both high chewing pressure and high wear rate. *In vivo*, this may particularly be the case with freshly placed restorations, because the enamel cusps do not fit the occlusal contact area of the restora-

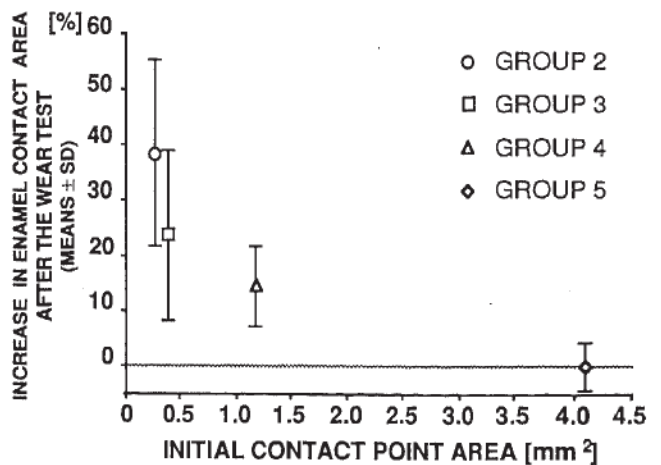


Fig. 4—Increase of the size of the occlusal contact point area of opposing enamel cusps after the wear test (in percent of the initial values).



TABLE  
EXPERIMENTAL GROUPS USED IN THE STUDY

	n	Initial Contact Area of Enamel Antagonists	Surface Polishing
Group 1	12	not standardized (natural human cusps)	none
Group 2	6	0.26 ± 0.02 mm <sup>2</sup>	1000-grit
Group 3	6	0.38 ± 0.02 mm <sup>2</sup>	1000-grit
Group 4	6	1.18 ± 0.04 mm <sup>2</sup>	1000-grit
Group 5	6	4.10 ± 0.21 mm <sup>2</sup>	1000-grit

tion perfectly. Therefore, the initial contact between the restoration and the antagonistic enamel cusp is rather punctiform. The significantly greater extent of enamel wear in group 2 compared with that in group 1 may be explained by the grinding procedure, which exposed less dense and softer enamel layers, and by differences in the shapes of the enamel cusps.

The size of the contact area governs chewing pressure and consequently the extent and mechanism of wear. This may be of significance for future clinical trials. Besides the influences of the restorative materials, different batches, measuring methods, or finishing techniques, differing results between clinical studies with the same material (Meier and Lutz, 1980; Roulet *et al.*, 1980; Lambrechts, 1983) may be related to differences in chewing pressures. For deviations of the wear results to be reduced in future studies, an attempt should be made to standardize this parameter. To a certain degree, this may be accomplished by the use of occlusal foils and the Vishay apparatus (Vishay Medical System Group, Malvern, PA) (Zwicky, 1991). In addition, patients with excessive wear facets, bruxism, or malocclusion should be excluded from clinical trials. Chewing pressure is also influenced by occlusal force, which varies not only from patient to patient, but also among different tooth locations in the same mouth. Therefore, test restorations, preferably MOD's, should be placed in the lower first molars, where chewing forces are reported to be the highest (Craig, 1989).

In addition, this study has consequences on *in vitro* wear testing in occlusal contact areas. The shapes of the enamel antagonists influenced the wear of both the restorations and the enamel cusps, as seen in groups 1 and 2. Therefore, the standardized enamel antagonists must not have a flat uniform contact surface, but, rather, should have a cupola-like shape. The exact cupola radius of palatal cusps, mirroring natural teeth and the average of a large population, must also be determined in further studies.

At higher chewing pressures (groups 2 and 3), antagonistic cusps were abraded by the restorative material, although a fine hybrid composite (Lutz and Phillips, 1983) with a smooth surface was used in this study. Because of the conical shapes of the enamel cusps, this process led to an increase in the contact area. The decrease of wear rates over time observed with some restorative materials in the occlusal contact area *in vivo* (Meier and Lutz, 1979; Roulet *et al.*, 1980) and in clinically relevant *in vitro* tests (Sakaguchi *et al.*, 1986; Krejci *et al.*, 1990c) may be explained by the increasing contact area, which reduces the chewing pressure. The reduction in chewing pressure may be far more important than other factors often mentioned as causes for nonlinear wear behavior, such as a soft superficial composite layer, destructive finishing, or loss of contact. The reason for this assumption lies in the fact that nonlinear wear curves are observed in studies with natural enamel fossae opposed by natural enamel cusps (Krejci *et al.*, 1990c), where neither destructive finishing nor soft superficial layers were involved, and

loss of contact was totally compensated for by a constant repositioning of the occluding teeth (Krejci *et al.*, 1990a).

In some clinical trials with quantitative wear measurements in the occlusal contact area, nonlinear wear behavior has not been reported (Braem *et al.*, 1986; Vanherle *et al.*, 1989). This may be a result of the special conditions pertinent to those studies. Large old fillings were usually present in adult patients, the teeth had already experienced wear, and the opposing cusps were very likely abraded. This situation corresponds to the one in groups 4 and 5 of this study, where the enlargement of the occluding areas induced only a linear increase in wear. Another explanation may be the fact that wear measurements were not initiated at point zero, but about one month after the placement of the restorations. During this initial period, high wear of the nonlinear type may have taken place (Meier and Lutz, 1979). In the *in vitro* studies mentioned above (Sakaguchi *et al.*, 1986; Krejci *et al.*, 1990c), unerupted teeth with nonabraded cusps were used as antagonists, and wear measurements were initiated without a preceding wear-in period.

It is important to note that the results of this study apply only to the occlusal contact area. Unfortunately, most clinical measurements are confined to contact-free wear (Leinfelder, 1987; Wilson *et al.*, 1988; Dietschi and Holz, 1990), where fatigue does not play a major role (McCabe and Ogden, 1987). In these studies, the explanations for the shapes of the wear curves may be different.

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