Wear of opposing teeth by posterior composite wear resins —Evaluation of newly developed wear test methods—

Tatsuto SHIMANE, Kazuhiko ENDO, Jing Hong ZHENG, Tomochika YANAGI and Hiroki OHNO

Division of Biomaterials and Bioengineering, Department of Oral Rehabilitation, School of Dentistry, Health Sciences University of Hokkaido, 1757 Kanazawa, Ishikari-Tobetsu, Hokkaido 061-0293, Japan

Corresponding author, Hiroki OHNO; E-mail: ohno@hoku-iryo-u.ac.jp

In the present study, enamel wear against indirect composite resins was evaluated using two newly designed wear test methods: a rotating sliding wear test and a buff wear test. For the composite resins investigated in this study, their surface morphologies were examined using a scanning probe microscope after buff-polishing. After the wear tests, enamel was worn down by hard fillers that protruded from the abraded resin matrices. Notably, enamel wear was induced by composite materials with a Vickers hardness number (VHN) greater than 45 and that the amount of enamel wear increased with increasing hardness of the composite material. Therefore, 45 VHN was the critical hardness value for composite resins at which antagonistic enamel wear would occur. Besides, the D-value obtained from the buff wear test indicated not only the relative wear resistance of the composite resin itself, but also its potential risk to induce antagonistic enamel wear.

Keywords: Enamel wear, Posterior composite resin, Scanning probe microscope

INTRODUCTION

Dental porcelains are highly favored for their strength, esthetics, and biological compatibility. However, a major drawback is their abrasiveness on the opposing natural dentition. Many clinical reports on this phenomenon have been published: one was on extensive wear of mandibular anterior teeth and gold crowns caused by porcelain crowns and denture teeth, while another report was on mismatch of materials that resulted in porcelain wearing out gold crowns. The potentially destructive character of porcelain was also highlighted in another study, which then recommended that porcelain should never be placed on occlusal surfaces because the restorative materials used should also preserve function and occluding surface integrity. Although metal restorations are superior to dental porcelain in preserving natural opposing teeth, metal-free restorations are extensively used to avoid metal allergies and to restore the esthetics and function of teeth.

Further on metal-free restorations, many brands of resin composite products —claimed to be safe and effective substitutes for porcelain— have appeared on the dental market. They are widely used as molar restorative materials because of improved physical and mechanical properties achieved via innovations in filler composition, morphology and particle size. However, the increasing use of composite resins on occlusal surfaces has resurrected the problem of considerable wear to the opposing enamel cusps.

On the wear of human enamel by modern posterior composite resins, conflicting reports have emerged. One view is that posterior composite resins do not cause excessive wear of human enamel since the rate of enamel attrition is comparable to the occlusal contact area wear rate of composite resins. On the other hand, there exists the opposing view that the natural dentition is abraded by posterior composite resins because of twofold factors: the high wear resistance of composite resins and the exacerbated surface roughness with coarse filler particles protruding from the abraded resin matrix. Some researchers have urged extreme care when using composite resins for the occlusal surfaces of posterior teeth because of the incidence of severe attrition of opposing natural dentition by composite restorations. It seemed that contradicting results have arisen from different studies because of the different kinds of composite products used. Consequently, the amount of induced enamel wear differed due to the different characteristics of the fillers used in the composite resins —in terms of filler shape, size, hardness, and content.

In the present study, two newly designed test methods were assessed if they were useful in determining dentitionally friendly posterior composite resins (i.e., posterior composite resins that do not abrade enamel). In our first novel method, a rotating sliding wear machine was devised to quantitatively evaluate enamel wear by composite resins within a short time with good reproducibility. In our second test method, a buff wear test was developed to evaluate the relative wear resistance of a composite resin with respect to human dentin and enamel. Moreover, since differing degrees of enamel wear were purportedly effects of the different filler properties in composite resins, the surface morphologies of five commercially available posterior composite resins after polishing were observed using a scanning probe microscope and their influence on enamel wear thereby discussed.

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MATERIALS AND METHODS

Indirect posterior composite resins

Five commercially available indirect posterior composite resins were used for in vitro wear testing in this study. Table 1 lists their monomer and filler compositions, as well as their respective filler contents as reported in published literature\(^9,10\). Table 2 then lists their mechanical properties as reported by their manufacturers.

Human enamel specimens

Human enamel was used in this study for in vitro wear testing against the composite materials. All teeth were stored in water at 4°C and used within three months of extraction. To obtain flat enamel surfaces, the buccal surfaces of tooth crowns were ground with #600 silicon carbide paper under running water and then polished to a mirror-like finish on a buff with an abrasive slurry of alumina paste and distilled water. Human enamel specimens of 1×6×3 mm\(^3\) in size were cut from the polished, flat tooth surfaces using a diamond saw (Isomet, Buehler Ltd., IL, USA).

Rotating sliding wear test

1. Test setup

Figure 1 is a schematic illustration of the rotating sliding wear machine newly devised in this study, which comprised a rotation rod and a specimen holder. The 18-mm-diameter rotation rod had a groove of 10 mm width and 1 mm depth, in which a paste of the posterior composite resin was applied and cured as instructed by the manufacturer. At one end of the vertical-moving rod was a specimen holder to which a human enamel specimen was attached using an adhesive (Model Repair II Blue, Dentsply-Sankin, Tokyo, Japan) (Fig. 2a).

The applied sliding load could be varied by changing the weight on the loading platform of the vertical rod. Figure 2b shows the rotation rod joined to a synchronizing motor by a universal joint. The synchronizing motor operated at 25 rpm, and the number of rotations during each wear test was recorded.

Table 1  Indirect posterior composite resins used for in vitro wear testing

<table>
<thead>
<tr>
<th>Brand name</th>
<th>Manufacturer</th>
<th>Main matrix monomers</th>
<th>Main fillers</th>
<th>Filler content (mass%)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estenia</td>
<td>Kuraray</td>
<td>UTMA</td>
<td>SiO(_2), BaO, Al(_2)O(_3), La(_2)O(_3)</td>
<td>92</td>
<td>ES</td>
</tr>
<tr>
<td>Belle Glass</td>
<td>Sybron</td>
<td>Bis-GMA EDMA</td>
<td>SiO(_2)</td>
<td>74</td>
<td>BL</td>
</tr>
<tr>
<td>Artglass</td>
<td>Kulzer</td>
<td>UDMA</td>
<td>SiO(_2), BaO</td>
<td>69</td>
<td>AT</td>
</tr>
<tr>
<td>Solidex</td>
<td>Shofu</td>
<td>UDMA</td>
<td>SiO(_2)</td>
<td>54</td>
<td>SD</td>
</tr>
<tr>
<td>Infis</td>
<td>Sun Medical</td>
<td>UDMA TEGDMA</td>
<td>SiO(_2)</td>
<td>43</td>
<td>IN</td>
</tr>
</tbody>
</table>

Table 2  Mechanical properties of indirect posterior composite resins used for in vitro wear testing

<table>
<thead>
<tr>
<th>Material</th>
<th>Compressive strength (MPa)</th>
<th>Bending strength (MPa)</th>
<th>Hardness (VHN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES</td>
<td>613</td>
<td>202</td>
<td>190</td>
</tr>
<tr>
<td>BL</td>
<td>540</td>
<td>151</td>
<td>72</td>
</tr>
<tr>
<td>AT</td>
<td>660</td>
<td>110</td>
<td>50</td>
</tr>
<tr>
<td>SD</td>
<td>314</td>
<td>75</td>
<td>43</td>
</tr>
<tr>
<td>IN</td>
<td>430</td>
<td>91</td>
<td>26</td>
</tr>
</tbody>
</table>
by a counter.

2. Specimen preparation for rotating sliding wear test
Before wear testing, the cured composite resin surface were rounded off using silicon carbide papers (#240, #400, #600) to produce a round-shaped specimen, 18 mm in diameter. Each specimen was then polished to a mirror-like finish by buff polishing with 3-µm alumina paste.

3. Enamel wear profile measurement
The rotating sliding wear test with two-body abrasion was conducted using a 1 kg load. After wear testing, the amount of enamel wear was measured using a surface texture measuring instrument (Surfcom, Tokyo Seimitsu, Tokyo, Japan). Figure 3 shows a typical example of an enamel wear profile as measured by the surface texture measuring instrument after a rotating sliding wear test. The amount of enamel wear was derived from the maximum wear depth of enamel. For each investigated posterior composite resin, three enamel wear profiles were obtained for 300 rotations, 600 rotations, and 900 rotations.

Buff wear test
1. Test purpose and setup
The rotating sliding wear test had a limitation: it could not be used to evaluate cases where the posterior composite resin was worn more than the enamel. To this end, a buff wear test was devised.

As shown in Fig. 4, a posterior composite resin was tightly adhered to a block of human dentin and enamel specimens (1×1×2 mm²) with 4-META resin (Super-Bond C&B, Sun Medical, Tokyo, Japan). This entire test piece block was then embedded in a resin (Model Repair II Blue, Dentsply-Sankin, Tokyo, Japan), which in turn was embedded in a 6-mm-diameter hole with 4-META resin in an aluminum holder of 1 inch diameter. Six aluminum holders were mechanically fixed in the stainless steel specimen holder of a polishing machine (ECOMET 2, Buehler Ltd., IL, USA).

The buff wear test specimens were ground using silicon carbide papers (#240, #400, #600). This was followed by buff-polishing finish with an abrasive slurry of alumina paste (3 µm) and distilled water for 60 seconds at a rotation speed of 120 rpm and a load of 100 g for one aluminum holder. Differences in the surface levels of the composite resin, enamel, and dentin were measured using a surface texture measuring instrument after buff-polishing.

2. Wear profile measurement
Figure 5 shows a schematic illustration of the wear...
profile of a buff wear test specimen made up of composite resin and human dentin and enamel. The difference in surface levels between the composite ($D_M$) and human enamel ($D_E$) is defined as the $D$-value — an indicator of the relative wear resistance of a composite resin with respect to human enamel and dentin. The buff wear test was carried out in triplicate for each composite resin.

Observation of fillers protruding from composite resins by scanning probe microscopy

The material properties of fillers — in terms of composition, shape, and content — differ from product to product and they greatly influence the wear resistance of composite resins and the degree of antagonist enamel wear. For this reason, the morphologies of the protruding fillers from the surfaces of cured composite resin specimens after buff-polishing with 3-µm alumina paste were observed using a scanning probe microscope (SPM-9500, Shimadzu Co., Kyoto, Japan).

RESULTS

Results of five commercially available indirect posterior composite resins

Figures 6 to 10 show the results of indirect posterior composite resins (ES, BL, AT, SD, IN) obtained in this study: (a) scanning probe microscope image of the surface morphology of each composite resin after buff-polishing; (b) enamel wear profiles after 300 rotations (12 minutes), 600 rotations (24 minutes), and 900 rotations (36 minutes) in the rotating sliding wear test; and (c) profile of the differences in surface levels among the composite resin and human dentin and enamel.
after buff wear test.

1. Product Estenia (ES)
In Fig. 6(a), in which the scales of X, Y, and Z are 30 µm, 30 µm and 1.3 µm respectively, filler particles were observed to protrude to a magnitude not exceeding 10 µm. Figure 6(b) shows that the maximum depth of enamel wear after 900 rotations was 48 µm. In Fig. 6(c), buff wear test revealed that product ES was less worn than the enamel, suggesting that the wear resistance of ES to alumina abrasive was higher than that of human enamel. The D-value indicating the difference in surface levels between the composite resin and enamel was 4.0 µm.

2. Product Belle Glass (BL)
Figure 7(a) shows that the filler particles of product BL protruded to a magnitude of several microns. Figure 7(b) shows that the maximum depth of enamel wear after 900 rotations was ca. 6 µm. In this case, enamel wear was hardly visible to the naked eye. In Fig. 7(c), buff wear test revealed that product BL was less worn than the enamel. D-value was 2.5 µm, indicating that the wear resistance of BL against alumina abrasive was slightly higher than that of human enamel.

3. Product Artglass (AT)
Results obtained for product AT were quite similar to those of BL. Figure 8(a) shows that the filler particles protruded to a magnitude of several microns. In Fig. 8(b), the maximum depth of enamel wear after 900 rotations was ca. 5 µm. In Fig. 8(c), D-value was found to be 1.3 µm.

4. Product Solidex (SD)
Figure 9(a) shows that the SD surface after buff-polishing was flatter than those of BL and AT. Enamel wear could not be observed for product SD (Fig. 9(b)). The D-value obtained from buff wear test, as shown in Fig. 9(c), was almost zero, suggesting that the wear resistance of SD to alumina abrasive was identical to that of human enamel.

5. Product Infis (IN)
Figure 10(a) shows that the IN surface after buff-polishing was flatter than those of BL and AT. Enamel wear could not be observed for product IN (Fig. 10(b)). In Fig. 10(c), buff wear test revealed that product IN was more worn than the enamel, hence yielding a negative D-value of −1.3 µm.

Impact of hardness on enamel wear depth and D-value
Figure 11(a) shows the relationship between the hardness of posterior composite resins and the maximum enamel wear depth obtained from the rotating sliding wear test after 900 rotations, while Fig. 11(b) shows the relationship between hardness and the...
D-value obtained from the buff wear test. Although there was lack of data between hardness (VHN) values of 72 and 190, there were apparent trends to indicate that enamel wear and the relative wear resistance of composite resins with respect to human enamel increased with increasing hardness of the composite resin.

**DISCUSSION**

Mechanism of human enamel wear by composite resins

In general, softer materials wear more easily than harder materials when two materials come into contact with each other. This is the reason why the hardness number is considered as an indicator of wear. Based on this viewpoint, the composite resins listed Table 1 would not induce antagonistic enamel wear since these materials had lower hardness numbers than enamel (VHN 350). The rotating sliding wear tests, however, demonstrated that human enamel specimens were abraded by composite resins ES, BL, and AT (Figs. 6(c), 7(c), and 8(c)). These results suggested that incidence of antagonistic enamel wear could not be estimated by a simplistic comparison of the average hardness number of a composite resin against that of human enamel.

Following the initial abrasion of resin composites, filler particles protruded from the abraded resin matrices, as shown in Figs. 6(a)–10(a), thereby resulting in increased surface roughness. Consequently, the rough surfaces and protruding hard filler particles induced enamel wear although the average hardness values of the composite resins were much lower than that of human enamel. Moreover, the extent of enamel wear seemed to depend on the hardness, shape, size, and content of the filler particles, as suggested by Suzuki and Leinfelder⁴.

In the present study, a scanning probe microscope was used to observe the surface morphology of composite materials after buff-polishing, by which the resin matrix was removed with an alumina abrasive, resulting in protrusion of hard fillers. Figure 12 schematically illustrates the three types of surface textures observed in the present study after buff-polishing of the composite materials. Product ES was classified into type (a), products BL and AT into type
human enamel also increased with increasing hardness of the composite resins (Fig. 11(b)). Hence, as the extent of enamel wear depended on the size, shape, hardness, and content of the filler particles, such a direct relationship was also found between the filler properties and the average hardness and wear resistance of composite resins.

Interestingly, it was also demonstrated in Figs. 11(a) and (b) that when the hardness of a composite resin exceeded 45 VHN, its wear resistance would be higher than that of human enamel, thereby leading to antagonistic enamel wear by the composite resin. Within the limits of the composite resins examined in this study, it was thus concluded that 45 VHN is the critical value at which composite resins would induce enamel wear.

**Evaluation of posterior composite resins for restoration of occlusal surfaces from viewpoint of enamel wear**

ES was developed as an esthetic restoration material for molar crowns in place of porcelain. It has 92 mass% filler content with a microfiller particle size smaller than 10 µm and a submicron filler of 0.02 µm; its resin matrix was composed of urethane tetramethacrylate (UTMA). Nishino reported that this indirect composite resin caused less enamel wear than porcelain restorations. Nonetheless, protruding 10 µm filler particles, as revealed in this study (Fig. 6(a)), induced significant enamel wear.

BL and AT had approximately 1 µm, hard SiO₂ particles as filler and caused enamel wear (Figs. 7 and 8), but the amount of enamel wear was smaller than that of ES. AT was reported to induce enamel wear in the oral cavity after 3 years, a finding consistent with the experimental data obtained in the present study.

SD and IN had smooth surfaces after buff-polishing and caused no excessive enamel wear in the rotating sliding wear test (Figs. 9 and 10). Buff wear test also demonstrated that the wear resistance of SD was identical to that of enamel, but the wear resistance of IN was lower than that of enamel. These results suggested that SD was a dentitionally friendly composite resin. Thus, among the indirect composite resins examined in this study, SD emerged as the most suitable restorative material for the occlusal surfaces of posterior teeth.

**Key features of the two novel test methods developed for evaluating enamel wear by composite resins**

Abe et al. have pointed out that evaluation by means of simultaneous colliding and sliding movements during articulation is not a suitable method to evaluate wear. This was because the collision point during occlusion did not match the sliding part, making it necessary to measure the effects of collision and sliding movements separately.

In the rotating sliding wear test of the present study, the simple sliding movement of the wear machine was performed in conjunction with a rotating movement afforded by a rotation rod. The tip of a

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**Fig. 12 Three types of surface textures of composite resins as observed by scanning probe microscopy after buff-polishing.**

(b), and products SD and IN into type (c). Together with enamel wear profiles shown in Figs. 6(b)–10(b), it was clear that significant enamel wear was induced by composite resins with protruding large filler particles (i.e., type(a)), whereas enamel wear became reduced when the size of protruding filler particles decreased.

**Relations of average hardness and wear resistance of composite resins with enamel wear**

Although the hardness values of the posterior composite resins investigated in this study were markedly lower than that of enamel, enamel wear was found to increase with increasing hardness of the composite resins, as shown in Fig. 11(a). The relative wear resistance of the composite resins with respect to
human enamel specimen was pressed by a constant load against a round-shaped composite resin specimen, the latter being placed in the groove of the rotation rod which rotated at a speed of 25 rpm. With this newly developed wear machine, enamel wear by composite resins could be evaluated quantitatively within a short time (ca. 0.5 hour) with good reproducibility by simply measuring the maximum wear depth of the enamel specimen.

In addition to the rotating sliding wear test, we also developed a buff wear test —using alumina abrasive—to evaluate the relative wear resistance of a composite resin with respect to human dentin and enamel. The $D$-value, which corresponded to the difference in surface levels between the composite resin and human enamel after buff-polishing, indicated the relative wear resistance of the composite resin to enamel. Based on the experimental results shown in Figs. 6–10, it was clear that the $D$-value obtained from the buff wear test could be a good indicator of antagonistic enamel wear. A composite resin with positive $D$-value induced enamel wear, whereas one with $D$-value less than zero induced no enamel wear. Nonetheless, despite the presence of a positive correlation between the $D$-value and maximum enamel wear depth, a further study is needed to prove and confirm the quantitative relationship between the $D$-value and the extent of enamel wear.

**CONCLUSIONS**

A rotating wear test machine was developed to examine enamel wear by composite resins, and a buff wear test was also developed to evaluate the relative wear resistance of a composite resin with respect to human dentin and enamel. The wear profiles of all test specimens were measured using a surface texture measuring instrument after each test was performed. In addition, the surfaces of all the investigated posterior composite resins after buff-polishing with an alumina slurry were observed by scanning probe microscopy.

Within the limitations of the current study, the following conclusions were drawn:

1. Significant enamel wear was induced by composite resins with large protruding filler particles and that enamel wear became reduced with decrease in protruding filler size.
2. The critical hardness value of composite resins is 45 VHN —beyond which antagonistic enamel wear would occur.
3. The $D$-value obtained from the buff wear test indicated not only the relative wear resistance of a composite resin, but also its potential risk to induce antagonistic enamel wear.
4. A combination of the rotating sliding wear test and buff wear test developed in the present study was useful and efficacious in evaluating the wear resistance of posterior composite resins and their potential risk towards inducing antagonistic enamel wear.

**REFERENCES**