Erosion and abrasion of tooth-colored restorative materials and human enamel

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Running title: Erosion and abrasion of dental materials and enamel

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Key words: Erosion; abrasion; restorative material; human enamel
Abstract

Objectives. The aim of this study was to investigate the effects of erosion and toothbrush abrasion on different restorative materials and human enamel.

Methods. Human enamel and 5 kinds of tooth-colored restorative materials were used. The restorative materials included three composite resins (Filtek Silorane, Tetric EvoCeram, Tetric EvoFlow), a polyacid-modified composite (Dyract Extra), and a conventional glass-ionomer cement (Ketac Fil Plus). For each type of the material, 40 specimens were prepared and embedded in ceramic moulds and divided into four groups (n=10): control group (C), erosion group (E), abrasion group (A), and erosion-abrasion group (EA). The specimens were subjected to six daily erosive attacks (groups E and EA; citric acid, pH 2.3, 1 min) and/or six abrasive attacks (groups A and EA; toothbrush abrasion, 100 strokes, 1 min), while the control specimens (group C) were maintained in artificial saliva. After 10-day treatment, the substance loss and surface changes were determined by surface profilometry and scanning electron microscopy.

Results. Human enamel presented higher substance loss when compared to restorative materials. Generally, combined erosion-abrasion (EA) caused the highest substance loss, followed by erosion, abrasion, and storage in artificial saliva. Composite resin presented highest durability under erosive and/or abrasive attacks. Enamel and restorative materials showed degradation in groups E and EA through SEM observation.

Conclusions. Toothbrush abrasion has a synergistic effect with erosion on substance
loss of human enamel, polyacid-modified composite and glass-ionomer cement. The acid- and abrasive-resistance of human enamel was lower compared to restorative materials.
Introduction

Despite the fact that there is limited information regarding the prevalence of dental erosion in the general population, evidence shows that the presence of dental erosion is growing steadily in the last few decades. In the literature, dental erosion can be attributed to either exogenous or endogenous factors. Exogenous factors contribute to dental erosion usually involve excessive consuming of soft drinks and fruit juices, while endogenous factors are mainly associated with frequent exposure of teeth to gastric juice.

Dental erosion leads to an irreversible loss of the enamel and dentin surface and softening of the tooth surface. It was shown that patients suffering from erosion had a median of 36.5 μm of tooth wear (range 17.6 -108.2 μm) over 6 months. Furthermore, the softened zone of eroded enamel surfaces is highly susceptible to physical forces, which normally have minor effects on native enamel surfaces. Toothbrush abrasion and erosion appear to act synergistically in wear processes on enamel.

Clinical performance of restorative materials is affected by erosion as well. Previous studies reported that acidic challenge had detrimental effects on wear, surface and physical properties of glass-ionomer cements, polyacid-modified composites, and composite resins. Although restorative materials are less susceptible to erosion compared to enamel, the erosive attack can induce, at least to some extent, the degradation of the matrix and fillers of restorative materials. Thus, it could be hypothesized that toothbrush abrasion and erosion would have a synergic
effect on the substance loss of dental materials. However, no information published is available regarding the potential effects of erosion combined with toothbrush abrasion on different tooth-colored restorative materials. This knowledge would be important to dentists in planning which kind of restorative materials to use for restoration of teeth which might be exposed frequently to erosion and/or abrasion.

Therefore, the objective of the present study was to investigate the effects of erosion and abrasion on tooth-colored restorative materials and human enamel. Two hypotheses were proposed: 1) erosion and abrasion have effects on the restorative materials; 2) restorative materials and human enamel behave differently under erosion, abrasion, and combined erosion-abrasion conditions.

**Materials and Methods**

Human enamel and 5 kinds of tooth-colored restorative materials were employed in this *in vitro* study. The restorative materials used were three composite resins (a micro-hybrid, a flowable, a nano-hybrid), a polyacid-modified composite (compomer), and a conventional glass-ionomer cement (CGIC). Shade A2 was selected for all the restorative materials. The details of the restorative materials used in this study are listed in Table 1.

**Study design**

The specimens of each type of materials tested were divided into four groups (n=10): control group (C), erosion group (E), abrasion group (A), and erosion-abrasion group
Over the experimental period, specimens of group E, A, and EA were subjected to a 10-day erosive/abrasive cycling regimen. The cyclic treatment procedure included 6 daily erosive acid attacks (groups E and EA) and/or toothbrush abrasion (groups A and EA). Thus, in total, 60 min erosion and/or 6000 toothbrush strokes were performed on each sample. The group C specimens remained stored in artificial saliva throughout the whole experimental period. Surface profilometry and scanning electron microscopy (SEM) were used to evaluate substance loss and changes of surface morphology.

**Specimen preparation**

40 enamel samples (3 mm in diameter) were obtained from the labial and palatal surfaces of 20 previously extracted, caries-free human molar teeth. The samples were embedded in ring-shaped ceramic moulds (3 mm diameter, 3 mm thickness) with acrylic resin (Paladur, Heraeus Kulzer, Wehrheim, Germany). The ceramic moulds were cut from a ceramic tube (Degussit, Friatec/Degussa, Düsseldorf, Germany) using a water-cooled low speed saw (Isomet, Buehler, Lake Bluff, IL, USA). The embedded specimens were ground flat and polished with water-cooled carborundum discs (1200, 2400 and 4000 grit (FEPA-P), Water proof silicon carbide paper, Stuers, Erkrat, Germany). This procedure resulted in the removal of about 200 µm depth of enamel, which was controlled with a digital micrometer (Holex, Nuremberg, Germany).

As to the restorative materials, 40 specimens were fabricated for each kind of material according to the manufacturers’ instructions. The ceramic moulds were positioned on a glass plate and then slightly overfilled with the material, and pressed
flat with a microscopic glass slide to extrude the excess material. Dyract, Flow, Ceram, Silorane specimens were light-polymerized with a LED curing light (Bluephase, Ivoclar Vivadent, Schaan, Liechtenstein). The specimens were light cured from both sides for 40 s. For Ketac, the material was mixed in accordance with the manufacturer's direction, prepared as previously described, and left undisturbed for 8 min. Following removal of the glass plate, the surface of glass-ionomer cement was coated with a resin bonding agent (Heliobond, Ivoclar Vivadent, Schaan, Liechtenstein) and light cured for 20 s. All restorative material specimens were stored in distilled water for 24 h. After storage in distilled water, all the specimens were wet polished with carborundum discs progressively (FEPA-P 1200, 2400 and 4000) as described above.

The polished specimens were cleaned in distilled water in an ultrasonic cleaner for 1 min to remove any debris. Prior to the tests, all the specimens were stored in distilled water for 7 days.¹¹

**Erosion/abrasion cycling model**

For groups E, A and EA, the respective cycling regimen was performed 6 times daily. For group E, the samples were first eroded by immersion in 5 ml of citric acid (pH=2.3) for 1 min. After erosion the samples were rinsed for 10 s with distilled water and stored for 30 min in 5 ml of artificial saliva until the next erosion challenge. The artificial saliva was mixed according to the formulation given by Klimek et al.¹² In group A, the specimens were brushed in toothpaste slurry for 1 min (100 strokes) with a load of 250 g using an automatic brushing machine¹³, rinsed with distilled water for 10 s, followed
by exposure to 5 ml of artificial saliva for 30 min. A toothbrush with medium bristle stiffness (Paro M43, Esro, Kilchberg, Switzerland) was used. The toothpaste slurry was prepared with fluoridated dentifrice (Elmex, GABA, Therwil, Switzerland) and distilled water in the proportion 1:3 (w/w). The toothpaste slurry and toothbrushes were changed everyday. For group EA, the samples were first soaked in 5 ml of citric acid (pH=2.3) for 1 min. After 10 s rinsing with distilled water, the specimens were stored in artificial saliva for 30 min. Subsequently, the samples were cleaned with distilled water for 10s and subjected to brushing procedure in the same manner as described above. Subsequently, the specimens were stored in artificial saliva (30 min) until the next erosive-abrasive attack.

After 6 daily cycles, specimens of groups A, E and EA were stored in artificial saliva overnight. Specimens in group C were maintained in artificial saliva for the entire experimental period. The artificial saliva for storage was renewed every day.

**Measurement of substance loss**

A stylus profilometer (Perthometer S2/GD 25, Mahr, Göttingen, Germany) placed on a pneumatic stone desk, which has been described in detail elsewhere, was used. The device was equipped with a custom-made jig for repositioning of samples for successive measurements. Substance loss was calculated based on the differences between pre- and post-treatment profiles with customized software. Five profiles were performed on each specimen via scanning from the reference (ceramic mould) surface to the treated surface. An average of these five readings (μm) was obtained and used for
data analysis.

**Scanning electron microscopy**

After 10-day treatment, 3 specimens from each group (12 specimens for each material) were randomly selected for SEM observation. The specimens were mounted on aluminum stubs and sputter coated with platinum, and then examined using a Supra 50 VP Scanning Electron Microscope (Carl Zeiss NTS, Oberkochen, Germany) with an acceleration voltage of 10 kV. The secondary electron SEM images were captured at the magnification of 5000x. Four images were taken from the representative area of each sample.

**Statistical analysis**

The assumption of the approximate normal distribution of the data was investigated by Kolmogorov-Smirnov test. First, two-way analysis of variance (ANOVA) was used to analyze the material loss caused by erosive and/or abrasive attack. Interaction between erosion and abrasion was also analyzed by means of the multiple linear regressions with and without interaction term. If any significant interaction exists, the modes of these interactions (infra-additive or supra-additive interactions\(^\text{15}\)) would be determined by the following rules: if erosion-abrasion causes a substance loss greater than would be expected under additive influence of erosion only and abrasion only, it would be regarded as a supra-additive interaction (as the combined treatment enhances the substance loss). Otherwise, it would be regarded as an infra-additive
interaction. Next, one-way ANOVA was applied to treatment and material groups separately. The \(p\)-values of multiple comparisons were adjusted by the Student-Newman-Keuls correction. The data was analyzed using the SPSS statistical software package (SPSS 13.0 for Windows, SPSS, Chicago, IL, USA). All statistical analyses were carried out at a significance level of 0.05.

Results

Substance loss

The results of the Kolmogorov-Smirnov test were non-significant, indicating that the assumption of the normal distribution of the data is not violated. The substance loss of all the materials tested is presented in Table 2. Statistically significant supra-additive interaction was found between the erosive attack and abrasive attack on the substance loss for enamel \((p<0.001)\), Dyract \((p<0.001)\), and Ketac \((p<0.001)\). For enamel the mean substance loss expected, under the additive influence of erosive and abrasive attacks (performed independently), should be equal to 28.8 \(\mu m\) on the basis of multiple linear regressions without interaction term. This expected value is smaller as compared with the observed mean substance loss due to the combined erosive and abrasive treatment (32.7 \(\mu m\)). Similarly, the mean expected substance loss of Dyract and Ketac under the additive influence of erosive and abrasive attacks (performed independently) should be equal to 3.3 \(\mu m\) and 16.7 \(\mu m\), respectively. These values are smaller than the actually detected mean substance loss of Dyract (3.8 \(\mu m\)) and Ketac (18.0 \(\mu m\)). In these groups (enamel, Dyract, Ketac), combined erosive and abrasive treatments showed a
synergistic effect on the substance loss. Further, statistically significant infra-additive interaction was found between the erosive attack and abrasive attack for Silorane ($p=0.013$). The observed mean substance loss in the group EA (0.28 µm) was smaller than the expected mean substance loss (0.35 µm). In other words, for Silorane, combined erosive and abrasive treatments had an antagonistic effect on the substance loss.

A comparison of the wear of the six materials due to different treatments is shown in Table 3. Overall, composite resin had better resistance to the acid and/or abrasive attacks (with lower substance loss) than compomer, CGIC and human enamel. Although human enamel presented the same abrasive resistance compared with compomer and CGIC, it showed the greatest wear due to erosion and erosion-abrasion as compared to the restorative materials.

Table 4 shows significant differences in substance loss in terms of different treatments for each material. Generally, the substance loss produced by each treatment was different for each material. The substance loss induced by abrasion only (A) was significantly lowest as compared to both the erosion (E) and erosion–abrasion (EA) treatment. The combination of erosion and abrasion (EA) caused the significantly highest substance loss. Moreover, the specimens of group E had more substance loss than those of group A except for one composite resin (Ceram).

**Scanning electron microscopy**

In general, the sample surfaces of the four groups revealed observable differences from
each other (Figures 1-6). All control specimens showed a relatively smooth surface.

For the restorative materials, brushing traces and exposed filler particles were observed in the samples of group A and EA. In the group E, all the samples presented more accentuated matrix degradation as well as more voids and cracks compared to those in the group C. After the combination of erosive and abrasive attacks, damage on the material was evident showing a smoother surface compared to the respective acid-treated samples. Among the 5 restorative materials tested, the most severe changes in the surface morphology were found in Dyract and Ketac caused by erosive and erosive-abrasive attacks.

For human enamel, the control samples appeared smooth and structureless under SEM. As to the sample of group A, linear brushing traces were found. Dissolution of prism cores and boundary regions could be observed after erosion. For the specimens of group EA, the etched prisms were brushed away due to the abrasive challenge, thereby resulting in a smoother surface as compared with those of group E.

Based on the above results, the hypotheses that erosion and abrasion have effects on the restorative materials and that the restorative materials and human enamel behave differently under the testing conditions were therefore confirmed.

**Discussion**

Given that dental caries has declined in developed countries, the potential of dental erosion should receive more attention from both the dentists and patients.\(^\text{16}\) Efforts have been made to assess the erosive and abrasive effects on dental enamel and dentine.
However, information, regarding the effects of erosion and abrasion on restorative materials and possible differences in these effects between dental enamel and restorative materials, is limited. The present study could be considered the first investigation considering both, erosion and abrasion on different restorative materials and human enamel.

In previous studies, substrates usually contacted acidic solution for a prolonged period of time or did not account for the role of saliva.\textsuperscript{17-19} The current study was designed to overlap the above-mentioned limitation of \textit{in vitro} studies and simulate the clinical situation maximally. Citric acid was selected on the basis of its common existence in the citrus fruit, juices and carbonated beverages. The pH value of the citric acid chosen is representative of the common pH of soft drinks and acidic beverages.\textsuperscript{20} The ceramic moulds were used to provide an unchangeable reference surface in the profilometrical assessment\textsuperscript{14,21}. Further, the ceramic moulds were employed to minimize the possible shrinkage effects of the materials on the results of the present study\textsuperscript{14}. Based on the data showing that the pH of oral fluids returned to neutral 1-3 min after one single sip of an acidic beverage\textsuperscript{22}, the 1 min erosion for each cycle was selected. It has been stated that the detection limits of our surface profilometer, under the same condition, is $\pm 0.105 \, \mu m$.\textsuperscript{14} This may explain the finding that some groups having minimum wear presented relative high standard deviations.

Assuming a maximum contact time for one tooth of 10 s during daily toothbrushing\textsuperscript{23}, the total brushing time of 60 min is approximately equivalent to 1 year of toothbrushing. It could be concluded that abrasion under the present experimental
setting has merely no effect (all <1 µm) on wear of all the materials tested, which is consistent with previous findings. Immersion of the restorative material samples in artificial saliva resulted in a small gain of surface profile (shown as negative values in Table 2). This effect could be attributed to a water sorption of the materials.

As expected, the citric acid promoted significant wear of dental enamel, and storage in artificial saliva did not provide enamel alterations. With the focus on the restorative materials, after the erosive attack, the CGIC showed the highest wear and surface change among the restorative materials, followed by compomer and composite resin. These results could be explained by the matrix dissolution peripheral to glass particles of CGIC, which could result from dissolution of the siliceous hydrogel layer. On the other hand, acid could also attack the resin, to a lesser extent, resulting in a possible degradation of the surrounding resin matrix or silane coupling agent and loss of filler particles of compomer and composite resin. The SEM images, showing the degraded polymer matrix and loss of fillers due to erosion, corroborate this hypothesis. The facts that CGIC exhibited significantly higher wear rates and greater surface changes than the composite resin and compomer may be due to the higher acid resistance of polymer matrices in resin based materials.

In accordance with previous studies, the wear due to erosion and erosion-abrasion of human enamel is remarkably higher than those of the restorative materials (especially for compomer and composite resin). It has been shown that unpolished enamel surface is less susceptible to erosion because of a higher degree of mineralization than polished surface. Thus, the enamel data measured on polished
samples may overestimate the amount of material loss compared to the situation *in vivo*. It might be speculated that the erosive and erosive-abrasive effects on native human enamel would be similar to those effects on CGIC. The findings of a previous *in vitro* study could add some support to this hypothesis.\(^3^3\)

The eroded enamel was found to be highly susceptible to toothbrush abrasion, which is in agreement with the findings of Wiegand et al.\(^3^4\) Considering the statistically significant interaction between erosion and abrasion, it suggested that erosion and abrasion act synergistically to produce wear of human enamel. This phenomenon might result from erosion causing both bulk loss of hard tissues and surface softening. This softened tissue appears to be more susceptible to mechanical forces than the native hard tissue.\(^3^3\) Similar synergic (or so-called supra-additive) effects were found in compomer and CGIC. The possible explanation could be that citric acid caused the matrix dissolution as described above, and this degraded layer can be easily removed by toothbrush abrasion. The findings of SEM observation, showing a relatively smoother sample surface after erosion-abrasion compared to the acid-treated surface, support this hypothesis. Interestingly, an infra-additive interaction was found in Silorane. Although there is a lack of information regarding the effects of fluoride on restorative material erosion, it has been stated that fluoridated toothpaste had a protective effect on enamel erosion progression.\(^3^5\) Considering the minor effects of erosive and/or abrasive attack on Silorane, this sub-additive effect might be due to the following explanations: 1) the protective effects of fluoride in the erosion process; 2) Silorane has an unique silorane-based resin matrix without methacrylates (manufacturer’s data), which is
different from the common composite resins. These may account for the sub-additive effect found in the present study. However, further studies are needed to clarify these findings.

The SEM images, correlating well with the profilometrical evaluation, showed that all the materials presented surface changes after erosive and/or abrasive attack. These findings are in agreement with previous studies.\textsuperscript{28,36} Moreover, the predominant etching pattern of enamel was pattern 2\textsuperscript{37}, which shows the preferentially etched prism boundary and relatively unaffected prism cores.

In the current study, the 5 restorative materials were more resistant than human enamel to acid and toothbrush, with the composite resin demonstrating the lowest susceptibility to acid erosion and toothbrush abrasion. This result highlights the need to control factors that contribute to enamel loss by erosive and abrasive challenge prior to restoration, or to resort to full-coverage restorations under extreme situation (for example: patients with endogenous erosion problem, or the exogenous erosive habits are difficult to control). Importantly, it must be noted that, at least in the case of human enamel, the results of the present study must be interpreted with caution because the erosion and abrasion process might be influenced by the presence of pellicle and saliva in the oral cavity.

**Conclusion**

Within the limitation of the present study, it suggests that toothbrush abrasion has a synergistic effect with erosion on substance loss of human enamel, compomer and
CGIC. The susceptibility to citric acid and/or toothbrush abrasion of human enamel was higher compared to restorative materials. Furthermore, composite resin has the best resistance to erosion and/or abrasion among all the materials tested.

References


Fig 1

Fig 2
Fig 5

Fig 6
<table>
<thead>
<tr>
<th>Materials</th>
<th>Type</th>
<th>Main composition</th>
<th>Manufacturer</th>
<th>Lot</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetric EvoCeram</td>
<td>Nano-hybrid composite resin</td>
<td>Dimethacrylates, barium glass, ytterbium trifluoride, mixed oxide, prepolymer</td>
<td>Ivoclar Vivadent AG, Schaan, Liechtenstein</td>
<td>L49346</td>
<td>Ceram</td>
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<tr>
<td>Tetric EvoFlow</td>
<td>Flowable composite resin</td>
<td>Dimethacrylates, barium glass, ytterbium trifluoride, highly dispersed silicon dioxide, mixed oxide, copolymer</td>
<td>Ivoclar Vivadent AG, Schaan, Liechtenstein</td>
<td>L42806</td>
<td>Flow</td>
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<tr>
<td>Filtek Silorane</td>
<td>Micro-hybrid composite resin</td>
<td>Silorane-based hydrophobic resin matrix, camphorquinone, fine quartz filler, yttrium fluoride</td>
<td>3M ESPE, St. Paul, MN, USA</td>
<td>8AN</td>
<td>Silorane</td>
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<td>Dyract Extra</td>
<td>polyacid-modified composite</td>
<td>Urethane dimethacrylate, carboxylic acid modified dimethacrylate, triethyleneglycol dimethacrylate, trimethacrylate resin, highly dispersed silicon dioxide, strontium-alumino-sodium-fluoro-phosphor-silicate glass, strontium fluoride</td>
<td>Dentsply DeTrey GmbH, Konstanz, Germany</td>
<td>8100002492</td>
<td>Dyract</td>
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<td>Ketac Fil Plus</td>
<td>Conventional glass-ionomer cement</td>
<td>Aluminium-calcium-lanthanum fluorosilicate glass, polycarboxylic acid</td>
<td>3M ESPE AG, Seefeld, Germany</td>
<td>351620</td>
<td>Ketac</td>
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Table 2 Means and standard deviations (SD) of substance loss (µm) for each material and treatment

<table>
<thead>
<tr>
<th>Materials</th>
<th>Control</th>
<th>Abrasion</th>
<th>Erosion</th>
<th>Erosion-abrasion</th>
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</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>0.21(0.11) A,a</td>
<td>0.61(0.25) A,a</td>
<td>16.62(1.20) B,a</td>
<td>32.74(1.89) C,a</td>
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<tr>
<td>Dyract</td>
<td>-0.19(0.11) A,b</td>
<td>0.50(0.22) B,a</td>
<td>1.12(0.23) C,b</td>
<td>3.76(0.52) D,b</td>
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<tr>
<td>Silorane</td>
<td>-0.68(0.22) A,c</td>
<td>-0.22(0.23) B,b</td>
<td>0.11(0.10) C,c</td>
<td>0.28(0.14) D,c</td>
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<td>Flow</td>
<td>-0.77(0.20) A,c</td>
<td>-0.42(0.17) B,c</td>
<td>0.21(0.10) C,c</td>
<td>0.56(0.13) D,c</td>
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<tr>
<td>Ceram</td>
<td>-0.35(0.21) A,b</td>
<td>-0.12(0.11) B,b</td>
<td>-0.13(0.16) B,c</td>
<td>0.15(0.07) C,c</td>
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<tr>
<td>Ketac</td>
<td>-0.26(0.23) A,b</td>
<td>0.54(0.18) A,a</td>
<td>11.83(1.18) B,d</td>
<td>18.05(2.04) C,d</td>
</tr>
</tbody>
</table>

Positive values indicate a substance loss of the respective materials. Negative values indicate a volume expansion of the respective materials.

Within the same material, values marked with same capital letter were not significantly different.

Within the same treatment, values marked with the same small letter were not significantly different.

Table 3 Results of comparisons based on groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>Substance loss</th>
</tr>
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<tr>
<td>Control</td>
<td>Flow, Silorane &lt; Ceram, Ketac, Dyract &lt; Enamel</td>
</tr>
<tr>
<td>Abrasion</td>
<td>Flow &lt; Silorane, Ceram &lt; Dyract, Ketac, Enamel</td>
</tr>
<tr>
<td>Erosion</td>
<td>Ceram, Silorane, Flow &lt; Dyract &lt; Ketac &lt; Enamel</td>
</tr>
<tr>
<td>Erosion-abrasion</td>
<td>Ceram, Silorane, Flow &lt; Dyract &lt; Ketac &lt; Enamel</td>
</tr>
</tbody>
</table>

<indicates statistical significance

Table 4 Results of comparisons based on materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Substance loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>Control, Abrasion &lt; Erosion &lt; Erosion-abrasion</td>
</tr>
<tr>
<td>Dyract</td>
<td>Control &lt; Abrasion &lt; Erosion &lt; Erosion-abrasion</td>
</tr>
<tr>
<td>Silorane</td>
<td>Control &lt; Abrasion &lt; Erosion &lt; Erosion-abrasion</td>
</tr>
<tr>
<td>Flow</td>
<td>Control &lt; Abrasion &lt; Erosion &lt; Erosion-abrasion</td>
</tr>
<tr>
<td>Ceram</td>
<td>Control &lt; Abrasion, Erosion &lt; Erosion-abrasion</td>
</tr>
<tr>
<td>Ketac</td>
<td>Control, Abrasion &lt; Erosion &lt; Erosion-abrasion</td>
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</tbody>
</table>

<indicates statistical significance