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Enamel wear by antagonistic restorative materials under erosive conditions

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Abstract

Objectives: This study aimed to analyse loss of enamel worn against composite, leucite glass ceramic or enamel antagonists under non-erosive and alternating or simultanuous erosive-attritive conditions.

Materials and Methods: Flat human enamel specimens were loaded (1Hz, 300g loading weight, each subgroup n=12) with antagonists made from a hybrid-composite (Z250, 3M Espe), a nano-composite (Filtek Supreme XTE, 3M Espe), leucite glass ceramic (IPS Empress CAD LT, Ivoclar Vivadent) or enamel. Specimens were either submitted to mechanical loading in mineral solution (60s) or to loading under alternating or simultaneous erosive conditions. For alternating erosion-attrition, specimens were eroded by citric acid (pH 2.6, 60s) and then loaded with the respective antagonist for 60s. For simultaneous erosion-attrition, specimens were loaded with the respective antagonist while being immersed in citric acid (pH 2.6, 60s). After each cycle, specimens were stored in water for 1 h. After 18 cycles, enamel loss was calculated profilometrically and statistically analysed by two-way ANOVA and Tukey's post-hoc tests ($p<0.05$).

Results: Enamel loss (µm, mean±standard deviation) was significantly highest for simultaneous erosion-attrition (ceramic: 9.4±1.1, hybrid-composite: 8.3±0.7, nano-composite: 7.8±1.2, enamel: 7.4±0.8) followed by alternating erosion-attrition (ceramic: 3.5±0.5, hybrid-composite: 2.1± 0.8, nano-composite: 1.0±0.2, enamel: 2.5 ± 0.7) and attrition in mineral solution (ceramic: 0.5±0.3, hybrid composite: 0.3±0.1, nano composite: 0.1± 0.2, enamel: 0.1±0.1). Ceramic antagonists resulted in significantly higher loss than the remaining antagonistic materials when alternating or simultaneous erosion-attrition was performed.

Conclusion: Erosive conditions had a massive impact on enamel worn against different antagonistic materials, with simultaneous erosive-attritive conditions being more detrimental than alternating erosive-attritive conditions.

Clinical Relevance: Enamel wear by antagonistic restorative materials is significantly influenced by erosive conditions.

Keywords: Erosion, Attrition, Composite, Ceramic, Profilometry

Introduction

It is well known that eroded enamel presents a demineralised and softened surface layer, which can be at least partially removed by mechanical forces [1-3]. Abrasion of eroded dental hard tissues, especially the effect of toothbrushing, has been intensively studied over the past years (for review see [4]).

Comparatively little information is available in the scientific literature on the interaction of erosion and attrition. The effects of pH and load on wear between opposing tooth surfaces seem to be very complex. Initial studies by Eisenburger & Addy [5,6] showed that enamel-to-enamel wear is significantly reduced under acidic compared to neutral conditions, probably due to smoothening effects of erosion on contacting surfaces. Also, wear of opposing enamel-to-dentin surfaces is affected by the pH of the environment. While enamel and dentin attrition was significantly increased at severe erosive (pH 1.2) compared to moderate (pH 3.0) or almost neutral (pH 6.1) conditions, no differences in wear were observed between pH 3.0 and 6.1 [7].

However, if erosion and attrition are not performed simultaneously but successively, attrition of eroded enamel or dentin by enamel antagonists significantly increased overall wear [8,9]. While numerous studies investigated the interplay between opposing tooth surfaces and different restorative materials, wear performance under erosive conditions was hardly analysed so far [10,11]. This subject is of high clinical relevance in patients suffering from erosive tooth wear, when restorations or antagonistic tooth surfaces come in contact with severely eroded teeth. Compared to enamel and dentin, composite and ceramic materials are considerably resistant against erosion and erosion/abrasion [12], indicating that under erosive conditions the effects of composite or ceramic antagonists on enamel might be quite different from tooth-to-tooth contacts.

This study aimed to analyse loss of enamel worn against composite, ceramic or enamel antagonists under either simultaneous or alternating erosive-attritive conditions. The null hypothesis was that enamel wear by opposing restorative materials is not different from enamel-to-enamel wear under both conditions.

Methods

Specimen preparation

Intact human front teeth from the lower jaw (n = 144) were selected from the department's collection of extracted teeth (Department of Preventive Dentistry, Periodontology and Cariology, University of Zurich). The research compiled with the use of anonymized biological material according to the local ethics committee. The teeth had been extracted during routine dental treatment and stored in water. After removal of the roots, the crowns were embedded in acrylic resin (Paladur, Heraeus Kulzer, Wehrheim, Germany) and fixed to stainless steel carriers. The labial surfaces were ground flat and polished under water cooling (Planopol-2, Struers, Denmark) with silicone carbide paper (1200, 2400 and 4000 grit, Stuers, Erkrat, Germany) until approximately 200 µm of the outermost enamel were removed. Two parallel identification marks (scratches) were prepared on the surface at a distance of 3 mm to allow for exact superimposition of the profiles during profilometric measurement. To avoid any damage of the identification marks, the scratches were covered by adhesive tape (tesafilm, tesa, Germany) resulting in a test surface of 1.5 mm width in between.

Smooth enamel specimens were randomly assigned to 12 groups (n = 12 per group) according to the kind of antagonist (enamel, nanofiller composite, microhybrid composite, and leucite glass ceramic) and the experimental condition (no erosion, alternating erosion-attrition, simultaneous erosion-attrition).

Antagonistic cusps were either prepared from enamel or from composite or ceramic materials (each n = 36). Enamel antagonists were obtained from the palatal cusps of upper wisdom teeth. They were fixed with amalgam on custom-made stainless steel specimen carriers (PPK, Zurich, Switzerland) [13]. The cusps were adjusted to a spherical shape (diameter: 3 mm) by grinding with a stainless steel stylus with concave hemispherical diamond tips (40 µm and 8 µm particle size). Subsequently, the tips of the spherical-shaped cusps were manually fine-polished for 5 s with 4000-grit silicon carbide paper by one operator (AC) to standardize the polishing procedure. Ceramic antagonists were prepared from leucite glass ceramic blocks (IPS Empress CAD LT, Ivoclar Vivadent, Schaan, Liechtenstein). The ceramic blocks were cut under water-cooling with a low-speed cutting wheel (Struers MOD 10, Struers, Ballerup, Denmark) into specimens of 6 mm x 6 mm x 7 mm. Composite antagonists were made from a nanofiller (Filtek Supreme XTE, 3M Espe) or a microhybrid (Z250, 3M Espe) composite. The composite was filled into prefabricated silicone moulds in increments of 2 mm, each light cured for 60 s (Bluephase G2, Ivoclar Vivadent, Schaan, Liechtenstein). Ceramic and composite cusps were also fixed on stainless steel carriers and standardized cusps were prepared as described above.

Antagonists of enamel, composite and ceramic were randomly assigned to 3 groups with each n = 12 antagonists.

Experimental procedure

Loading of flat human enamel specimens was performed in a custom-made power driven wear device, in which linear attrition (track length: 3 mm) could be simulated (Figure 1). The six antagonists were mounted at 90° to the enamel surface with a loading weight of 300 g [9]. In all groups, the wear process was conducted in 18 cycles, each cycling treatment followed by storage in mineral solution [14] for 1 h. After each 6 cycles, enamel specimens and antagonists were stored in mineral solution [14] over night. Enamel specimens were either submitted to mechanical loading by the respective antagonist only or to loading under alternating or simultaneous erosive conditions. In each cycle, specimens were worn with 60 linear strokes (1 Hz) [9]. Enamel specimens submitted to alternating erosion-attrition conditions were immersed in citric acid (pH 2.6, 5 ml) for 60 s, rinsed with tap water and loaded with the respective antagonist while being immersed in mineral solution (5 ml). Enamel specimens submitted to simultaneous erosion-attrition were loaded with the respective antagonist while being immersed in citric acid (pH 2.6, 0.0125 mol/L, 5 ml, 60 s). After loading, the specimens and antagonists were removed from the wear device, rinsed with tap water and immersed in mineral solution for 1 h.

Profilometry

Enamel loss was analysed with a stylus profilometer (Perthometer S2, Mahr, Göttingen, Germany). Ten profiles were performed on each specimen via scanning from the reference surfaces to the test surface. Mean substance loss was calculated based on the differences between pre- and post-treatment profiles with a custom-designed software (4D Client, University Zurich, Zurich, Switzerland). Depth of erosion (if applicable) and combined erosion-attrition was calculated separately (Figure 2). Values of 10 profiles per specimes were averaged and submitted to the statistical analysis.

Statistical analysis

Enamel loss was quantified for each subgroup. Data were submitted to Shapiro-Wilk-tests to check normal distribution. Normal distribution was found in 10 of 12 subgroups, thus, a normal distribution assumption was employed.

Two-way ANOVAs followed by Tukey's post-hoc tests (STATISTICA 13.0, StatSoft) were applied to analyse and compare total enamel loss and loss by erosion (if applicable), separately. Factors were the kind of antagonistic material and the experimental conditions. The level of significance was set at $p < 0.05$.

Results

Two-way ANOVA revealed both the kind of antagonistic material, the experimental conditions (attrition without erosion, alternating erosion-attrition, simultaneous erosion-attrition) and the interaction among both factors significant with respect to total enamel loss. Generally, total enamel loss was highest for simultaneous erosion-attrition followed by alternating erosion-attrition and attrition in mineral solution. While no significant differences between the antagonistic materials were observed when pure attrition was performed, ceramic antagonists resulted in significantly higher loss than the remaining antagonistic materials when alternating or simultaneous erosion-attrition was performed (Table 1).

Considering erosion depth only, two-way ANOVA revealed significant differences between alternating and simultaneous erosion-attrition with the latter being approximately fourfold higher, but no significant differences among the materials.

Discussion

The setting used to characterize enamel loss by restorative materials and enamel under alternating or simultaneous erosion-attrition is similar to previous studies dealing with the interplay of opposing tooth surfaces under neutral and acidic conditions. The attrition experiments were performed using a load of 300 g, which is considered within the range of forces produced during the physiological masticatory cycle, but towards the lower end [15]. Even though maximum bite forces in the molar region might be distinctly higher, the chosen loading is in the range (200-600 g) of previous in vitro studies on erosion-attrition [5,6,8,9] and might be suited to determine relative differences in enamel wear caused by different antogonistic materials. Erosion was performed with citric acid at pH 2.6, which is commonly used to simulate an acidic diet. Citric acid is commonly present in citrus fruits or beverages; the pH value was chosen as it is representative for the pH-value of soft drinks. In contrast to previous *in vitro* studies, cyclic loading and erosion was limited to a short time period per cycle to reflect clinical conditions with short-term erosive episodes [16] and short tooth-to-tooth contacts [17]. Specimens were stored in mineral solution intermittently in all groups and during loading in all groups except for specimens submitted to simultaneous erosion-attrition. However, as this kind of artificial saliva did not contain any mucins or other salivary macromolecules that might reduce frictional forces, wear is probably increased compared to the clinical situation. On the other hand, artificial saliva – like human saliva or water – can keep potential detachted particles of enamel or restorative restorative materials (e.g. composite fillers) in suspension, which can act as abrasive particles. As a consequence, two-body wear by tooth-to-tooth or tooth-to-restoration contacts, respectively, is changed to three-body-abrasion [18].

As expected, enamel loss by different antagonists under non-erosive conditions was comparatively small. Antagonistic wear was not measured in this study, but is also relevant under clinical conditions. Previous studies showed that under neutral conditions enamel and leucite ceramic antagonists were worn off to a similar amount [19], while an opposing nano-composite was shown to be hardly affected by wear [20].

Total enamel wear was significantly higher under alternating and simultaneous erosive-attritive conditions compared with attrition in mineral solution. In case of alternating erosion-attrition, citric acid erosion might dissolve enamel completely up to few hundred nanometer depth [21] and demineralise the surface beneath up to around 200-300 nm depth [1,3,21]. If erosion proceeds, the demineralised surface is completely dissolved and the demineralisation front moves forward [21]. Under conditions of alternating erosion-attrition, net erosion amounted to around 1 micron (Table 1). However, if the softened surface is loaded, the demineralised surface layer can be partly removed mechanically prior to the next acid contact. Depending on the kind of antagonist, enamel loss was increased by 1.2 to 2.1 microns, except for Filtek Supreme XTE, which caused no detectable additional surface loss. According to the manufacturer, the fillers of Filtek Supreme XTE are a combination of non-aggregated nanoparticles and nanoclusters consisting of loosely bound aggregates of nanofiller particles. Probably, other than conventional filler particles, nanofillers detached during loading were not able to induce relevant three-body abrasion.

Interestingly, depths of erosion and additional attrition were increased approximately 3-5 fold and 2-fold, respectively, by simultaneous erosion-attrition compared to alternating erosion-attrition. Probably, loss by erosion was significantly increased compared to alternating conditions, as the acid was constantly moved during movement of the antagonist. Due to the enhanced fluid movement at the enamel surface, dissolved minerals were removed and further dissolution was increased [22-24]. Additionally, the superficial enamel was removed by attrition as soon as a critical degree of softening was reached, so that direct access of the acid to the underlying sound enamel became possible resulting in continuous removal of enamel. When attrition was perfomed after erosion, the dissolution of the enamel surface was only diffusion controlled [23].

Again, additional attrition was highest for IPS Empress CAD LT; enamel and composite antagonists resulted in a similar amount of attrition. Compared to enamel and composite, the leucite glass ceramic is much harder and resistant against acids, so that the ceramic antagonist probably remained unaltered during attrition in the acidic medium. In contrast, the enamel antagonists might be demineralised to the same amount as the enamel specimens, indicating that smoothening effects at the enamel surfaces resulted in a reduction of frictional forces at the opposing enamel-to-enamel surfaces. To a lesser extent, the acid contact and continuous loading might also attack and degrade the resin matrix of the composites [12]. However, further studies have to elucidate antagonistic wear under acidic conditions.

Under the limitations of the present *in vitro* study, it can be concluded that erosive conditions have a massive impact on enamel worn against different antagonistic materials, with simultaneous erosive-attritive conditions being more detrimental than alternating erosive-attritive conditions. Under acidic conditions, composite materials cause lower wear on opposing enamel surfaces than ceramic, which should be considered in the selection of restorative materials for patients suffering from dental erosion.

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors. The research compiled with the use of anonymized biological material according to the ethics committee of the University of Zurich.

Informed consent: For this type of study, formal consent is not required.

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Table 1. Enamel loss (µm, mean ± standard deviation) by different antagonists under different experimental conditions (attrition without erosion, alternating erosion-attrition, simultanuous erosion-attrition).

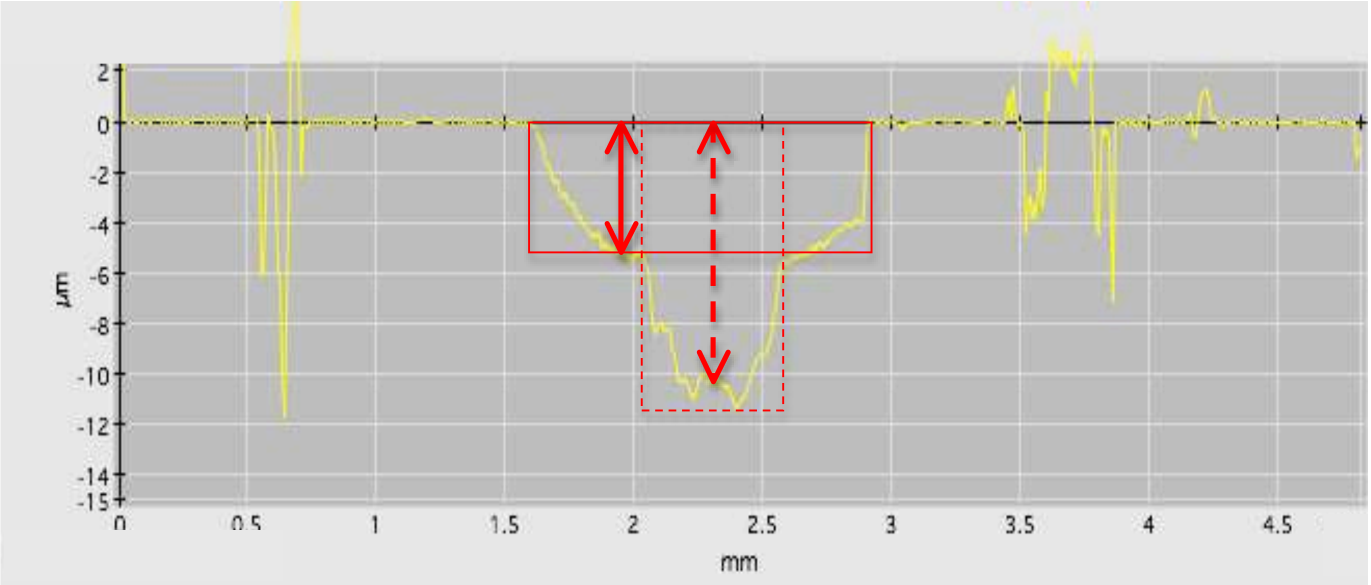
Material antagonist	Attrition only	Alternating erosion - attrition		Simultanous erosion - attrition	
		erosion	**total**	erosion	**total**
Enamel	0.1 ± 0.1^{a,A}	1.3 ± 0.3	2.5 ± 0.7^{b,B}	4.6 ± 0.4	7.4 ± 0.8^{c,A}
Nano-composite	0.1 ± 0.2^{a,A}	1.0 ± 0.2	1.0 ± 0.2^{b,A}	5.4 ± 0.7	7.8 ± 1.2^{c,AB}
Hybrid-composite	0.3 ± 0.2^{a,A}	0.8 ± 0.5	2.3 ± 0.3^{b,B}	5.3 ± 0.8	8.3 ± 0.7^{c,B}
Ceramic	0.5 ± 0.3^{a,A}	1.3 ± 0.3	3.5 ± 0.4^{b,C}	4.7 ± 0.5	9.4 ± 1.1^{c,C}

With regard to total enamel loss, significant differences between different conditions within the same kind of antagonist are marked by different small letters. Significant differences between antagonistic materials within the same experimental condition are marked with different captial letters. Note that two-way ANOVA revealed no significant effect among the antagonist materials when considering loss by erosion only.

Figure 1: Contact between enamel specimen and antagonist

Example of the contact between enamel specimens and antagonist. Track length of linear attrition amounted to 3 mm. For better visibility, the adhesive tape covering the identification marks and limiting the test surface for erosion to 1.5 mm width was removed.

Figure 2: Analysis of erosion and erosion-attrition



Example of a difference profile (simultaneous erosion-attrition, ceramic antagonist) after superimposition of pre- and post-treatment profiles. The test surface submitted to erosion was 1.5 mm wide, while the area submitted to additional attrition was smaller due to the point shaped contact area of the antagonistic cusp with the enamel surface. Mean depth of erosion (if applicable, continuous line) and mean depth of erosion-attrition (dashed line) were calculated separately.