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Bioactive Materials Subjected to Erosion/Abrasion and Their Influence on Dental Tissues

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Clinical Relevance

When restorations are needed in patients with high risk of erosive tooth wear, resin-modified GICs may be considered an alternative. Although they are susceptible to wear under erosion/abrasion, they are capable of reducing enamel loss adjacent to the restorative material.

SUMMARY

Objective: The objective of this study was to evaluate the effect of erosion or erosion-abrasion on bioactive materials and adjacent enamel/dentin areas.

Methods and Materials: Enamel and dentin blocks (4×4×2 mm) were embedded side by side in acrylic resin, and a standardized cavity (1.2×4×1.5 mm) was prepared between them. Preparations were restored with the following materials: composite resin (Filtek Z350, control); experimental composite containing dicalcium phosphate dihydrate particles (DCPD); Giomer (Beautifil II), high viscosity glass ionomer cement (GIC, Fuji IX); and a resin-modified GIC (Fuji II LC). The specimens were submitted to two cycling models (n=10): erosion or erosion-abrasion. The challenges consisted of five-minute immersion in 0.3% citric acid solution, followed by 60-minute exposure to artificial saliva. Toothbrushing was carried out twice daily, 30 minutes after the first and last exposures to acid. Dental and material surface loss (SL, in µm) were determined by optical profilometry. Data were analyzed with Kruskal-Wallis and Dunn tests (α=0.05).

Results: Under erosion, for enamel, only the GIC groups presented lower SL values than Z350 (*p*<0.001 for Fuji IX and *p*=0.018 for Fuji

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II LC). For dentin, none of the materials showed significantly lower SL values than Z350 ($p>0.05$). For material, the GICs had significantly higher SL values than those of Z350 ($p<0.001$ for Fuji IX and $p=0.002$ for Fuji II LC). Under erosion-abrasion, the enamel SL value was significantly lower around Fuji II LC compared with the other materials ($p<0.05$). No significant differences were observed among groups for dentin SL ($p=0.063$). The GICs and Giomer showed higher SL values than Z350 ($p<0.001$ for the GICs and $p=0.041$ for Giomer).

Conclusion: Both GIC-based materials were susceptible to erosive wear; however, they promoted the lowest erosive loss of adjacent enamel. Against erosion-abrasion, only Fuji II LC was able to reduce enamel loss. For dentin, none of the materials exhibited a significant protective effect.

INTRODUCTION

Erosive tooth wear (ETW) is a condition causing growing concern among dental professionals.[1] Tissue loss caused by ETW is usually an interplay between acid demineralization and mechanical wear through attrition and abrasion.[2] It has an estimated prevalence of approximately 30% in the permanent teeth of children and adolescents.[3-5] When in the initial stages, ETW lesions appear as shallow defects with a dull surface. As the process continues, concavities and rounding of the cusps become evident. In advanced stages, the morphology of the tooth can be completely affected. If there are restorations present, they look as though they have risen above the adjacent tooth structure, resembling islands of restorative material. This occurs because erosive acids do not affect restorative materials in the same way as they affect dental tissues.[6,7]

In addition to controlling the etiologic factors and implementing specific preventive measures,[8,9] dentists may recommend the restoration of worn tissues when there is considerable loss of tooth structure, to protect the remaining tissues, reduce the risk of pulp exposure, and control dentin hypersensitivity. Additional purposes of performing restorations are to reestablish the esthetic appearance of teeth and recover the vertical occlusal dimension.[10,11] In general, the longevity of these restorations depends on the properties of the restorative material, including the material's resistance to wear, the integrity of the tooth-restoration interface, and extent of dental destruction.[12] Frequent erosive challenges can compromise the mechanical properties of restorative materials, thereby reducing their longevity.[13]

Among the restorative materials available for direct restorations, conventional or resin-modified glass ionomer cements (GICs) and composite resins are those most frequently used to restore erosive lesions.[14] The following are some of the beneficial properties of GICs: their chemical bond to enamel and dentin, coefficient of thermal expansion similar to the tooth structure, and fluoride release.[15] The latter is an important characteristic that can reduce the effects of erosion on the adjacent dental hard tissues.[13] However, studies have shown that this material can undergo a higher degree of degradation than composite resins when exposed to erosive challenges.[13,14,16]

The incorporation of bioactive components into composite resins may be an advantageous alternative for restorations in patients frequently exposed to erosive challenges, due to the release of ions that could play a relevant role in the ETW process. Calcium orthophosphates have been extensively studied due to their role in the mineralization of bones and teeth.[17] Recently, the synthesis of dicalcium phosphate dihydrate (DCPD) particles demonstrated promising results in the remineralization of carious lesions *in vitro*[18] and *in situ*.[19] Considering the positive results obtained with this material, in the context of caries disease, its possible protective effect against erosion also deserves to be explored.

Giomers are resin-based materials containing prereacted glass-ionomer fillers prepared by surface reaction (S-PRG), which are capable of releasing various ions, such as fluoride, silicate, borate, and strontium.[20] They are hybrid materials that were developed to provide resin composites with the cariostatic properties of GICs.[21] Fluoride and strontium, for example, may form an acid-resistant layer and reinforce tooth structure by inducing the formation of fluoride-apatite[22,23] and strontium-apatite[24] complexes. Because Giomers have the ability to neutralize acids and prevent demineralization,[25] they may also be an option to protect the dental hard tissues adjacent to restorations against erosive challenges, but this effect has not yet been thoroughly studied.

The aim of this laboratory study was to evaluate the effect of erosion or erosion-abrasion on fluoride- or calcium-containing restorative materials and on surrounding dental hard tissues (enamel and dentin) through evaluation of surface loss (SL). The null hypotheses were as follows: 1) restorative materials

Table 1: *Specifications of the Restorative Dental Materials Tested*

Material/Group	Manufacturer/Lot Number	Composition
Microhybrid resin composite (Filtek Z350, Shade A2B)	3M-ESPE, St Paul, MN, USA/1635100182	Bis-GMA, UDMA, bis-EMA, TEGDMA, and PEGDMA. 78 wt% (or 59 vol%) of zirconia/silica particles and nonagglomerated silica particles
Experimental material (60% DCPD)	—	Bis-GMA, TEGDMA, CQ, EDMAB, DCPD functionalized with DEGDMA
Giomer (Beautifil II, Shade A2O)	Shofu Dental Corporation, San Marcos, CA, USA/061618	Bis-GMA, UDMA, Bis-MPEPP, TEGDMA 83.3 wt% fluorosilicate glass
High-viscosity GIC (Fuji IX, Shade A2)	GC Corporation, Tokyo, Japan/1610031	Polyacrylic acid, fluoroaluminosilicate glass, polybasic carboxylic acid
RMGI (Fuji II LC, Shade A2)	GC Corporation/1611251	2-Hydroxyethyl methacrylate, polyacrylic acid, and water; 58 wt% fluoroaluminumsilicate

Abbreviations: bis-EMA, ethoxylated bisphenol A dimethacrylate; bis-GMA, bisphenol-A glycidyl dimethacrylate; bis-MPEPP, bisphenol A polyethoxy methacrylate; CQ, camphorquinone; DCPD, di-calcium phosphate dihydrate; EDMAB, ethyl-4-dimethylamino benzoate; PEGDMA, polyethylene glycol dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

subjected to erosion or erosion-abrasion would show similar SL values, and 2) surrounding enamel and dentin SL after erosion or erosion-abrasion would not be influenced by the restorative material.

METHODS AND MATERIALS

Study Design

This study was based on a completely randomized design, with restorative material as the main factor, at five levels, as described in Table 1. All the groups were compared with the (nonbioactive material) Z350, because it does not release ions. One hundred specimens were prepared, each one containing one enamel and one dentin slab. Between the two slabs, a standardized cavity was prepared and subsequently filled with one of the tested materials (n=20). The specimens were then submitted to erosion (n=10) or erosion-abrasion (n=10) challenges. At the end of cycling, the SL values (in μm) of the three substrates (enamel, dentin, and restorative material) were determined.

Specimen Preparation

The crowns of bovine incisors were separated from the roots using a double-side diamond disc (KG Sorensen, Barueri, SP, Brazil). Slabs of enamel and dentin (4×4×2 mm) were obtained from their crowns and roots, respectively, using an automatic sectioning machine (Isomet, Buehler, Lake Bluff, IL, USA). A silicone mold was used to position one dentin and one enamel slab 0.5-0.8 mm apart from each other, and, subsequently, they were embedded in acrylic resin (Varidur, Buehler).[13] The embedded enamel-dentin pairs were ground flat with 240-grit paper for five seconds, under constant cooling, to remove any acrylic residue, randomly allocated into five experimental groups according to the restorative materials (n=20), and were then stored under relative humidity condition, at 4°C.

Experimental Composite Formulation

The experimental resin-based material had an organic phase composed of 1:1 in moles of bisphenol-A glycidyl dimethacrylate (BisGMA) and triethylene glycol dimethacrylate (TEGDMA), plus 0.5 wt% of camphorquinone and ethyl-4-dimethylamino benzoate (EDMAB, all components from Sigma–Aldrich, St Louis, MO, USA) as photoinitiators. The filler was composed of 60% di-calcium phosphate dihydrate (DCPD) particles functionalized with TEGDMA. The material was mechanically mixed under vacuum (Speedmixer DAC 150.1 FVZ-K, FlackTek Inc, Landrum, SC, USA) and kept under refrigeration until two hours before use.[26]

Application of Restorative Materials

A standardized cavity (1.2×4×1.5 mm) was prepared between the enamel and dentin fragments using a cylindrical diamond bur (2292, KG Sorensen) in a high-speed handpiece under water cooling, by a single trained operator.[13,14] The cavity dimensions were in accordance with the active tip of the bur. The cavity depth (1.5 mm) was standardized by the stop device of the bur. The cavities were filled with the respective restorative materials, in accordance with the different manufacturers' recommendations. When required, light activation was carried out using a second-generation LED light curing unit (Radii-cal, SDI, Bayswater, VIC, Australia), with an irradiance of 1200 mW/cm^2, which was monitored by radiometer. The specimens were kept under relative humidity for one week prior to testing to allow post irradiation hardening of composite restorations and

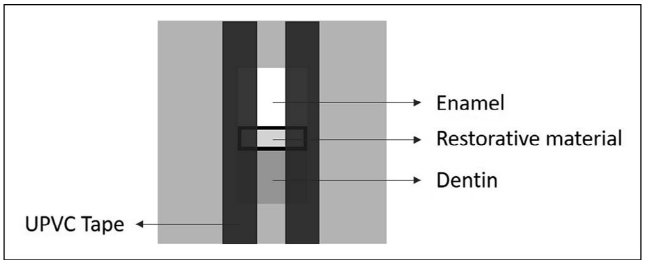

Figure 1. *Representative image of a specimen used in the study. A silicone mold was used to position one dentin and one enamel slab 0.5-0.8 mm apart from each other. Between the slabs, a standard cavity was made and restored with its respective material. After polishing, tape was placed on the specimen's surface, leaving a central area exposed to subsequent testing.*

complete setting of the GIC restorations. Specimens were finished and polished with Al_2O_3 abrasive discs (400-, 600-, 1200-, and 4000-grit, Buehler) under water-cooling, to ensure that the restorative material was at the same level as the enamel and dentin fragments. This procedure allowed the specimens to be evaluated by optical profilometry, as plain and polished surfaces improve the accuracy and sensitivity of the measurements.[27] Specimens were then sonicated for three minutes with distilled water.

The initial curvatures of the enamel, dentin, and restorative fragments were evaluated with an optical profilometer (Proscan 2100, Scantron, Venture Way, Tauton, United Kingdom). Fragments with curvature greater than 0.4 μm and specimens with cracks or surface defects were discarded. Unplasticized polyvinyl chloride (UPVC)-type adhesive tape was applied to the surface of the specimens, leaving approximately 1 mm exposed (Figure 1). The specimens were kept in 100% relative humidity until the next stage of the study.

Erosion and Erosion-Abrasion Cycling

For the erosion cycling, half of the specimens of each group (n=10) were immersed in 0.3% citric acid solution (pH=2.6) for five minutes, followed by immersion in artificial saliva[28] ($CaCl_2 \times 2\ H_2O$ 0.213 g/L, KH_2PO_4 0.738 g/L, KCl 1.114 g/L, NaCl 0.381 g/L, Tris buffer 12 g/L, pH=7) for 60 minutes. This procedure was repeated four times a day for five days. For erosion-abrasion cycling, the other half of the specimens (n=10) were submitted to the same procedures, but the specimens were also brushed in a toothbrushing simulator (MEV-2T Odeme Equipamentos Médicos e Odontológicos Ltda, Joaçaba, SC, Brazil). Brushing was performed twice a day (45 cycles/150g/15 seconds), 30 minutes after the first and fourth erosive challenges, with a suspension of a standard toothpaste (Colgate Total 12 Mint Clean, Colgate-Palmolive, São Bernardo do Campo, SP, Brazil; 1450 ppm F, as NaF) and distilled water, in a ratio of 1:3. The specimens were exposed to the slurries for a total time of two minutes. All procedures were conducted at room temperature (~24°C). At the end of each cycling day, the specimens were stored at 100% relative humidity. The erosive solution and artificial saliva were renewed after each exposure. At the end of the cycling procedures, the specimens were maintained in 100% relative humidity condition at 4°C until the profilometric test was performed.

Surface Loss Measurements

After five days of cycling, the tape was removed from the specimens, and an area 2 mm long (x) × 1 mm wide (y) was scanned at the center of the substrates. This readout covered the eroded area and the reference areas on enamel and dentin. On the x-axis, the step size was set to 0.01 mm and the number of steps was 200. On the y-axis, these values were 0.1 mm and 10, respectively. The depth of the eroded area was calculated based on subtracting the mean height of the test area from the mean height of the two reference areas, using the system software (Proscan Application software v. 2.0.17, Scantron, Venture Way, Tauton, United Kingdom). The specimens were scanned moist to avoid retraction of the eroded dentin collagen matrix.[29]

Statistics

For each model (erosion and erosion-abrasion), the data of surface loss of enamel, dentin, and restoration were analyzed independently. Considering that the data of enamel after erosion and restorative material after both challenges did not follow a normal distribution, data were analyzed by the Kruskal-Wallis and Dunn's tests, adopting the level of significance of 5%. Sigma Plot 13.0 software (Systat Sotware Inc, Chicago, IL, USA) was used for calculations.

RESULTS

The medians (interquartile intervals) of material surface loss obtained in both erosive and erosive-abrasive challenges are presented in Table 2. For erosion, Fuji IX presented the highest material loss value ($p<0.001$ for Z350; $p<0.001$ for Beautifil II; and $p=0.050$ for DCPD), statistically similar to that of Fuji II LC only ($p=0.727$). The composite containing DCPD showed values similar to those of Fuji II LC ($p=1.000$) and to those of the commercial

Table 2: *Medians (Interquartile Intervals) of Material Surface Loss (in μm) for Erosion and Erosion-Abrasion Models[a]*

Groups	Erosion	Erosion-Abrasion
DCPD	1.31 (0.88-1.87) BC	0.57 (0.32-1.01) BC
Z350	0.29 (0.13-0.44) C	0.26 (0.19-0.35) C
Beautifil II	0.34 (0.07-0.60) C	1.59 (1.42-2.29) B
Fuji II LC	2.35 (1.99-2.58) AB	2.86 (2.29-4.12) AB
Fuji IX	16.60 (14.42-17.09) A	13.39 (11.98-15.25) A

[a] *Different letters in columns imply significant difference among groups ($p<0.05$).*

composite ($p=0.066$). For erosion-abrasion, Fuji IX again presented the highest material loss ($p<0.001$ for Z350; $p<0.001$ for DCPD; and $p=0.022$ for Beautifil II), with values statistically similar to those of Fuji II LC ($p=0.657$). The Giomer and the DCPD-containing composite both showed values similar to those of Fuji II LC ($p=1.000$ and $p=1.000$, respectively), whereas the values of the latter were significantly higher than those of Z350 ($p<0.001$). The medians (interquartile intervals) of enamel surface loss obtained in both challenge conditions are presented in Table 3. For erosion, the enamel adjacent to Fuji IX and Fuji II LC showed the lowest surface loss values ($p<0.05$), without significant difference between them ($p=1.000$). The use of Beautifil II resulted in enamel loss value similar to those of both Fuji II LC ($p=0.135$) and the other two resin-based materials ($p=1.000$ for Z350 and $p=1.000$ for DCPD). For erosion-abrasion, the enamel adjacent to Fuji II LC presented the lowest surface loss values ($p=0.001$ for DCPD; $p=0.009$ for Fuji IX; $p=0.011$ for Z350; and $p=0.020$ for Beautifil II) that differed significantly from those of all the other groups, which showed no significant differences among them ($p>0.05$).

The medians (interquartile intervals) of dentin surface loss obtained in both challenge conditions are presented in Table 4. For erosion, Fuji IX and Fuji II LC presented the lowest SL values that did not differ significantly from those of Z350 ($p=0.886$ and $p=1.000$, respectively), which in turn did not differ from those of Beautifil II ($p=0.858$). DCPD showed the highest SL values ($p<0.001$ for Fuji IX, $p<0.001$ for Fuji II LC; and $p=0.014$ for Z350) that did not differ from those of Beautifil II ($p=0.100$). For erosion-abrasion, there were no significant differences among the groups ($p=0.063$).

Table 3: *Medians (Interquartile Intervals) of Enamel Surface Loss (in μm) Adjacent to Studied Materials for Erosion and Erosion-Abrasion Models[a]*

Groups	Erosion	Erosion-Abrasion
DCPD	16.36 (14.22-18.12) A	10.84 (10.20-11.96) A
Z350	13.95 (12.88-14.50) A	10.63 (10.13-11.36) A
Beautifil II	13.44 (12.13-13.78) AB	10.76 (8.51-11.57) A
Fuji II LC	10.01 (9.26-11.10) BC	8.02 (7.23-8.81) B
Fuji IX	9.27 (8.76-9.67) C	10.54 (10.16-11.84) A

[a] *Different letters imply significant difference among groups, in columns ($p<0.05$).*

Table 4: *Medians (Interquartile Intervals) of Dentin Surface Loss (in μm) Adjacent to Studied Materials for Erosion and Erosion-Abrasion Models[a]*

Groups	Erosion	Erosion-Abrasion
DCPD	18.77 (18.10-22.40) A	5.85 (4.65-7.74) A
Z350	14.74 (13.34-15.80) BC	8.69 (7.56-9.49) A
Beautifil II	16.83 (15.52-18.10) AB	7.77 (6.86-9.51) A
Fuji II LC	12.48 (11.03-12.93) C	8.63 (6.23-9.27) A
Fuji IX	12.11 (8.25-13.02) C	8.85 (6.60-10.48) A

[a] *Different letters in columns imply significant difference among groups ($p<0.05$).*

DISCUSSION

After analyzing the data, the first study hypothesis was rejected, as the restorative materials did not present a similar degree of SL after the erosive or erosive-abrasive challenges. This result was expected, because different categories of restorative materials were tested. In agreement with previous investigations, the GICs presented the highest SL values after erosive cycling.[13,14] This could be explained by the dissolution of the peripheral silicate hydrogel lattice of their glass particles.[30,31] It should be also considered that, because of their composition, GICs are also known to have an inherent increased solubility in aqueous medium.[32] However, there were no significant differences in surface loss between the GICs. It was hypothesized that the acid challenges would affect the glass ionomer portion of the material with a higher level of intensity than it would affect its resin component; thus, conventional GICs would present significant higher susceptibility to erosion than resin-modified GICs[16]; however, this was not observed in the present study. Although there was a great numerical difference between these groups (median and interquartile interval of 16.60 and 14.42-17.09 for Fuji IX and 2.35 and 1.99-2.58 for Fuji II LC, respectively), a significant difference could not be detected with the nonparametric approach used.

Although studies have suggested that composites could also be affected by erosive challenges, which would degrade the resin matrix or the silane-coupling agent, resulting in the loss of filler particles,[33,34] the composite Z350 was only minimally impacted by the acid challenges, also in agreement with previous investigations.[13,14,35] Although the surface loss from DCPD did not significantly differ from that of Z350, it also did not differ from that of Fuji II LC, probably due to the absence of reinforcing particles and the higher solubility of DCPD in acidic environments.[36] The Giomer exhibited similar behavior to that of Z350 under erosion. This could be attributed to high filler content (78% wt and 83.3% wt of Z350 and Giomer, respectively), whereas, for resin-based materials, a linear relationship between wear resistance by acids and the filler volume has previously been observed.[33] In addition, the authors could suggest that the buffering capacity promoted by the ions released by the S-PRG fillers of Giomer[25] reduced the effect of the acid on the material. However, a previous study observed that the Giomer has higher susceptibility to reduction in hardness under citric acid challenge than a microhybrid composite resin with nanoparticles has.[37] The authors related this fact to the type of filler in the Giomer–alumino-fluoro-borosilicate glass, which was found to be more susceptible to degradation by weak acids than the zirconia-silicate filler of the composite. These different results could be explained by the lower contact time with the acid in the present study when compared with the seven days of acid exposure of this previously cited investigation, which might have reduced the effect of the acid on the Giomer. Furthermore, in our study, the impact of the acid on the materials was evaluated by means of surface loss and not hardness; therefore, to clearly see some effect, a prolonged exposure time would be required.

In the erosion-abrasion model, Fuji IX again underwent the highest level of wear, but it was no different from Fuji II LC and Giomer. It could be hypothesized that the citric acid negatively affected the hardness of Giomer, leaving the material more vulnerable to the mechanical action of toothbrushing.[38] For the composites, it was shown that prolonged toothbrushing could result in the wear of the polymeric matrix and the loosening of the filler particles.[39] Nevertheless, when considering only a few brushing cycles, as was the case of the present study, this should not be an issue.[40]

The restorative materials selected for this study contained either fluoride or calcium phosphate in their formulations. These are relevant compounds for caries prevention, which may also positively act on the dental erosion process. Fluoride products can induce the formation of fluor-hydroxyapatite (a less soluble mineral) and the precipitation of CaF_2-like compounds, which will protect the underlying dental tissues against erosive acids and serve as a fluoride deposit.[41] Additionally, fluoride has the ability to form a nonspecific adsorbed fluoride phase over hydroxyapatite,[42] which can make this ion readily available to influence demineralization and remineralization.[43] However, it is questionable whether fluoride-releasing materials would induce the precipitation of CaF_2-like material, due to their low amount of fluoride release.[44,45] Moreover, it should be taken into account that remineralization is a limited process in dental erosion, most probably confined to the softened eroded layer.[46] Calcium phosphates can promote tooth remineralization, acting as an external source of calcium and phosphate ions, which will deposit in the empty spaces of the demineralized structure, resulting in mineral gain.[47] In the context of erosion, the presence of these ions in the tooth surroundings at the time of the acid challenge could potentially contribute to reducing the demineralization rate.

The resin-modified glass ionomer cement Fuji II LC was the only material able to protect the enamel adjacent to the restorations against the erosive and erosive-abrasive challenges; therefore, the second null hypothesis of this study was also rejected. Although fluoride release from the materials were not evaluated in the present investigation, based on a previous report, this result could be related to the higher quantity of fluoride release of Fuji II LC when compared with the other materials.[44] Studies have stated that fluoride release was affected by the formulation, solubility, and porosity of the material. The resin-modified GICs showed an initial burst of fluoride release, which was possibly induced by a superficial rinsing effect. During the subsequent days, the fluoride release was lower and attributed to its ability to diffuse through the cement pores and cracks.[48] The hydroxyethylmethacrylate (HEMA) present in the resin-modified GICs composition is thought to slowly absorb water and allow the diffusion of fluoride.[49] This result is in agreement with a previous investigation, in which not only the resin-modified GIC, but also a high viscosity GIC, was able to reduce enamel loss by erosion in the areas adjacent to the restoration.[13] Nevertheless, the aggressiveness of the erosive challenges must also be considered, because with lower exposure to the acidic solution, no protective effect on enamel adjacent to resin-modified GICs could be observed.[50] This could be related to correlation between the ability of GICs to release fluoride and the acid erosion.[51] The fluoride release of Giomer was observed to be lower than that of other fluoride-containing materials, such as Fuji II LC, with no effect of initial burst of fluoride release.[44] This may justify the lack of erosion or erosion-abrasion protection provided by the Giomer.

Unlike the results obtained for dental caries, in which a DCPD-containing experimental composite was able to provide protection in the surroundings of the restoration, resulting in enamel remineralization,[18] no significant effect against erosive wear was observed in the present investigation. Although in erosion, rehardening is a process limited to the softened layer,[52] we hypothesized that the release of these ions would help to improve the mineral gain of the enamel and dentin surface after each erosive episode, which would result in a lower surface loss in the end of cycling. Additionally, and more importantly, these ions would also act during the erosive challenge, by increasing the saturation in relation to tooth minerals in the tooth surroundings, thereby reducing demineralization. Nevertheless, the results suggested that the experimental composite had insufficient calcium release for producing this type of effect.

None of the materials showed a protective effect on dentin, which may be explained by the high aggressiveness of the erosive challenges used; this was in agreement with the outcomes of a previous report.[53] It should be noted that significant protection against dentin erosion was observed at the margins of GIC restorations when milder erosive challenges were used.[13]

Unexpectedly, the surface loss values for enamel and dentin were not higher under erosion-abrasion condition compared with erosion only.[54] Although the data from both challenges were not compared (because they were independent experiments), this could be attributed to the use of fluoridated toothpaste during toothbrushing, which may have offered some protection against erosive wear.[55] It has also to be taken into account that in the erosion-abrasion condition, the presence of fluoride in the toothpaste may have masked the effect of the nonactive material Z350, by providing it with a false protective action. One option to avoid this issue would be to perform the brushing with a nonfluoridated dentifrice. However, this would not be a realistic representation of what happens in the clinic, as the use of fluoride toothpastes is recommended from the time that the first deciduous tooth erupts. It should be mentioned that, as other erosion-abrasion studies, specimens from bovine teeth were used as replacement for human teeth.[13,53,56] Although there are some reported structural differences between substrates,[57] it was concluded that the use of bovine teeth is acceptable, especially for the comparison of the relative effect of agents or materials.[58] Another point is the use of optical profilometry to measure surface loss from eroded dentin without the removal of the organic matrix. Although the presence of the organic matrix could interfere with the readings, care was taken to perform the readings in standardized moist conditions, thus avoiding its shrinkage.[29]

Ideally, restorative materials should be able to withstand all adverse conditions present at the oral environment, such as acid challenges, brushing and masticatory forces, increasing the longevity of the restoration. In patients with erosive wear, if the implementation of preventive measures is not established, the progression of the lesion is more likely to occur. Hence, for these patients, the search for a material that can protect the dental tissues at the vicinity of the restoration and, at the same time, be resistant to constant chemical and mechanical challenges is desirable. Despite the greater surface loss under the challenges and the lower mechanical resistance than composites,[59,60] Fuji II LC presented promising results regarding the protection of substrates in both proposed models. This material can thus be used in a temporary restoration, during the transitional period in which the patient is changing his/her habits or treating a medical condition. Later on, replacement with a resin composite could be performed, because this material was more resistant to surface wear.

CONCLUSIONS

According to the findings of this laboratory study, it was concluded that the resin-modified GIC (Fuji II LC) was the restorative material associated with the lowest loss of adjacent enamel due to erosion and erosion-abrasion challenges. However, it was one of the materials that underwent higher surface loss in the face of both challenges. For dentin, none of the materials exhibited a significant protective effect.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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References

1. Lussi A & Carvalho TS (2014) Erosive tooth wear: A multifactorial condition of growing concern and increasing knowledge *Monographs in Oral Science* **25** 1-15.
2. Shellis RP & Addy M (2014) The interactions between attrition, abrasion and erosion in tooth wear *Monographs in Oral Science* **25** 32-45.
3. Salas MMS, Nascimento GG, Huysmans MC, & Demarco FF (2015) Estimated prevalence of erosive tooth wear in permanent teeth of children and adolescents: an epidemiological systematic review and meta-regression analysis *Journal of Dentistry* **43(1)** 42-50.
4. Bartlett DW, Lussi A, West NX, Bouchard P, Sanz M, & Bourgeois D (2013) Prevalence of tooth wear on buccal and lingual surfaces and possible risk factors in young European adults *Journal of Dentistry* **41(11)** 1007-1013.
5. Loomans B & Opdam N (2018) A guide to managing tooth wear: the Radboud philosophy *British Dental Journal* **224(5)** 348-356.
6. Lussi A, Schlueter N, Rakhmatullina E, & Ganss C (2011) Dental erosion: an overview with emphasis on chemical and histopathological aspects *Caries Research* **45(Supplement 1)** 2-12.
7. Schlueter N, Jaeggi T, & Lussi A (2012) Is dental erosion really a problem *Advances in Dental Research* **24(2)** 68-71.
8. Magalhães AC, Wiegand A, Rios D, Honório HM, & Buzalaf MAR (2009) Insights into preventive measures for dental erosion *Journal of Applied Oral Science* **17(2)** 75-86.
9. Carvalho JC, Scaramucci T, Aimée NR, Mestrinho HD, & Hara AT (2018) Early diagnosis and daily practice management of erosive tooth wear lesions *British Dental Journal* **224(5)** 311-318.
10. Lambrechts P, Van Meerbeek B, Perdigão J, Gladys S, Braem M, & Vanherle G (1996) Restorative therapy for erosive lesions *European Journal of Oral Science* **104(2 Pt 2)** 229-240.
11. Varma S, Preiskel A, & Bartlett D (2018) The management of tooth wear with crowns and indirect restorations *British Dental Journal* **224(5)** 343-347.
12. Peutzfeldt A, Jaeggi T, & Lussi A (2014) Restorative therapy of erosive lesions *Monographs in Oral Science* **25** 253-261.
13. Alghilan MA, Cook NB, Platt JA, Eckert GJ, & Hara AT (2015) Susceptibility of restorations and adjacent enamel/dentine to erosion under different salivary flow conditions *Journal of Dentistry* **43(12)** 1476-1482.
14. Honório HM, Rios D, Francisconi LF, Magalhães AC, Machado MAAM, & Buzalaf MAR (2008) Effect of prolonged erosive pH cycling on different restorative materials *Journal of Oral Rehabilitation* **35(12)** 947-953.
15. Hu JY, Li YQ, Smales RJ, & Yip KHK (2002) Restoration of teeth with more-viscous glass ionomer cements following radiation-induced caries *International Dental Journal* **52(6)** 445-448.
16. Soares LES, Lima LR, Vieira LDS, Do Espírito Santo AM, & Martin AA (2012) Erosion effects on chemical composition and morphology of dental materials and root dentin *Microscopy Research and Technique* **75(6)** 703-710.
17. Dickens SH, Flaim GM, & Takagi S (2003) Mechanical properties and biochemical activity of remineralizing resin-based Ca-PO4 cements *Dental Materials* **19(6)** 558-566.
18. Alania Y, Natale LC, Nesadal D, Vilela H, Magalhães AC, & Braga RR (2019) In vitro remineralization of artificial enamel caries with resin composites containing calcium phosphate particles *Journal of Biomedical Materials Research. Part B, Applied Biomaterials* **107(5)** 1542-1550.
19. Melo MAS, Weir MD, Rodrigues LKA, & Xu HHK (2013) Novel calcium phosphate nanocomposite with caries-inhibition in a human in situ model *Dental Materials* **29(2)** 231-240.
20. Fujimoto Y, Iwasa M, Murayama R, Miyazaki M, Nagafuji A, & Nakatsuka T (2010) Detection of ions released from S-PRG fillers and their modulation effect *Dental Materials Journal* **29(4)** 392-397.
21. Nedeljkovic I, De Munck J, Slomka V, Van Meerbeek B, Teughels W, & Van Landuyt KL (2016) Lack of buffering by composites promotes shift to more cariogenic bacteria *Journal of Dental Research* **95(8)** 875-881.
22. Cochrane NJ, Saranathan S, Cai F, Cross KJ, & Reynolds EC (2008) Enamel subsurface lesion remineralisation with casein phosphopeptide stabilised solutions of calcium, phosphate and fluoride *Caries Research* **42(2)** 88-97.
23. Jima Y & Koulourides T (1989) Fluoride incorporation into and retention in remineralized enamel *Journal of Dental Research* **68(8)** 1289-1292.
24. Dedhiya MG, Young F, & Higuchi WI (1973) Mechanism for the retardation of the acid dissolution rate of hydroxapatite by strontium *Journal of Dental Research* **52(5)** 1097-1109.
25. Kaga M, Kakuda S, Ida Y, Toshima H, Hashimoto M, Endo K, & Sano H (2014) Inhibition of enamel demineralization by buffering effect of S-PRG filler-containing dental sealant *European Journal of Oral Science* **122(1)** 78-83.
26. Rodrigues MC, Natale LC, Arana-Chaves VE, & Braga RR (2015) Calcium and phosphate release from resin-based materials containing different calcium orthophosphate nanoparticles *Journal of Biomedical Materials Research. Part B, Applied Biomaterials* **103(8)** 1670-1678.
27. Schlueter N, Hara A, Shellis RP, & Ganss C (2011) Methods for the measurement and characterization of

erosion in enamel and dentine *Caries Research* **45(1)** 13-23.

28. Scaramucci T, Hara AT, Zero DT, Ferreira SS, Aoki I V, & Sobral MAP (2011) In vitro evaluation of the erosive potential of orange juice modified by food additives in enamel and dentine *Journal of Dentistry* **39(12)** 841-848.

29. Attin T, Becker K, Roos M, Attin R, & Paqué F (2009) Impact of storage conditions on profilometry of eroded dental hard tissue *Clinical Oral Investigations* **13(4)** 473-478.

30. Turssi CP, Hara AT, Serra MC, & Rodrigues AL (2002) Effect of storage media upon the surface micromorphology of resin-based restorative materials *Journal of Oral Rehabilitation* **29(9)** 864-871.

31. El-Badrawy WA & McComb D (1998) Effect of home-use fluoride gels on resin-modified glass-ionomer cements *Operative Dentistry* **23(1)** 2-9.

32. Kuhn AT & Wilson AD (1985) The dissolution mechanisms of silicate and glass-ionomer dental cements *Biomaterials* **6(6)** 378-382.

33. Han L, Okamoto A, Fukushima M, & Okiji T (2008) Evaluation of flowable resin composite surfaces eroded by acidic and alcoholic drinks *Dental Materials Journal* **27(3)** 455-465.

34. Lim BS, Ferracane JL, Condon JR, & Adey JD (2002) Effect of filler fraction and filler surface treatment on wear of microfilled composites *Dental Materials* **18(1)** 1-11.

35. Francisconi LF, Honório HM, Rios D, Magalhães AC, Machado MAAM, & Buzalaf MAR (2008) Effect of erosive pH cycling on different restorative materials and on enamel restored with these materials *Operative Dentistry* **33(2)** 203-208.

36. Xu HHK, Weir MD, & Sun L (2009) Calcium and phosphate ion releasing composite: effect of pH on release and mechanical properties *Dental Materials* **25(4)** 535-542.

37. Kooi TJM, Tan QZ, Yap AUJ, Guo W, Tay KJ, & Soh MS (2012) Effects of food-simulating liquids on surface properties of giomer restoratives *Operative Dentistry* **37(6)** 665-671.

38. Yu H, Wegehaupt FJ, Wiegand A, Roos M, Attin T, & Buchalla W (2009) Erosion and abrasion of tooth-colored restorative materials and human enamel *Journal of Dentistry* **37(12)** 913-922.

39. Al Khuraif AAA (2014) An in vitro evaluation of wear and surface roughness of particulate filler composite resin after tooth brushing *Acta Odontologica Scandinavica* **72(8)** 977-983.

40. Teixeira ECN, Thompson JL, Piascik JR, & Thompson JY (2005) In vitro toothbrush-dentifrice abrasion of two restorative composites *Journal of Esthetic and Restorative Dentistry* **17(3)** 172-180.

41. Magalhães AC, Wiegand A, Rios D, Buzalaf MAR, & Lussi A (2011) Fluoride in dental erosion *Monographs in Oral Science* **22** 158-170.

42. Wong L, Cutress TW, & Duncan JF (1987) The influence of incorporated and adsorbed fluoride on the dissolution of powdered and pelletized hydroxyapatite in fluoridated and non-fluoridated acid buffers *Journal of Dental Research* **66(12)** 1735-1741.

43. White DJ, Nelson DGA, & Faller RV (1994) Mode of action of fluoride: application of new techniques and test methods to the examination of the mechanism of action of topical fluoride *Advances in Dental Research* **8(2)** 166-174.

44. Garoushi S, Vallittu PK, & Lassila L (2018) Characterization of fluoride releasing restorative dental materials *Dental Materials Journal* **37(2)** 293-300.

45. Petzold M (2001) The influence of different fluoride compounds and treatment conditions on dental enamel: a descriptive in vitro study of the CaF(2) precipitation and microstructure *Caries Research* **35(Supplement 1)** 45-51.

46. Lussi A & Carvalho TS (2015) The future of fluorides and other protective agents in erosion prevention *Caries Research* **49(1)** 18-29.

47. Cochrane NJ, Cai F, Huq NL, Burrow MF, & Reynolds EC (2010) New approaches to enhanced remineralization of tooth enamel *Journal of Dental Research* **89(11)** 1187-1197.

48. Tiwari S, Kenchappa M, Bhayya D, Gupta S, Saxena S, Satyarth S, Singh A, & Gupta M (2016) Antibacterial activity and fluoride release of glass-ionomer cement, compomer and zirconia reinforced glass-ionomer cement *Journal of Clinical and Diagnostic Research* **10(4)** ZC90-ZC93.

49. Forsten L (1998) Fluoride release and uptake by glass-ionomers and related materials and its clinical effect *Biomaterials* **19(6)** 503-508.

50. Salas CFC, Guglielmi CAB, Raggio DP, & Mendes FM (2011) Mineral loss on adjacent enamel glass ionomer cements restorations after cariogenic and erosive challenges *Archives of Oral Bioliogy* **56(10)** 1014-1019.

51. Bueno LS, Silva RM, Magalhães APR, Navarro MFL, Pascotto RC, Buzalaf MAR, Nicholson JW, Sidhu SK, & Borges AFS (2019) Positive correlation between fluoride release and acid erosion of restorative glass-ionomer cements *Dental Materials* **35(1)** 135-143.

52. Ganss C, Lussi A, & Schlueter N (2014) The histological features and physical properties of eroded dental hard tissues *Monographs in Oral Science* **25** 99-107.

53. Turssi CP, Hara AT, Domiciano SJ, & Serra MC (2008) Study on the potential inhibition of root dentine wear adjacent to fluoride-containing restorations *Journal of Materials Science. Materials in Medicine* **19(1)** 47-51.

54. Scaramucci T, João-Souza SH, Lippert F, Eckert GJ, Aoki I V, & Hara AT (2016) Influence of toothbrushing on the antierosive effect of film-forming agents *Caries Research* **50(2)** 104-110.

55. Scaramucci T, Borges AB, Lippert F, Frank NE, & Hara AT (2013) Sodium fluoride effect on erosion-abrasion under hyposalivatory simulating conditions *Archives of Oral Biology* **58(10)** 1457-1463.

56. Bezerra SJC, João-Souza SH, Aoki IV, Borges AB, Hara AT, & Scaramucci T (2019) Anti-erosive effect of solutions

containing sodium fluoride, stannous chloride, and selected film-forming polymers *Caries Research* **53(3)** 305-313.

57. Yassen GH, Platt JA, & Hara AT (2011) Bovine teeth as substitute for human teeth in dental research: a review of literature *Journal of Oral Science* **53(3)** 273-282.

58. Shellis RP, Ganss C, Ren Y, Zero DT, & Lussi A (2011) Methodology and models in erosion research: discussion and conclusions *Caries Research* **45(Supplement 1)** 69-77.

59. Shabanian M & Richards LC (2002) In vitro wear rates of materials under different loads and varying pH *Journal of Prosthetic Dentistry* **87(6)** 650-656.

60. Attin T, Vataschki M, & Hellwig E (1996) Properties of resin-modified glass-ionomer restorative materials and two polyacid-modified resin composite materials *Quintessence International* **27(3)** 203-209.