Wear of an enhanced resin-modified glass-ionomer restorative material

RITIKA BANSAL, BDS, MS, JOHN O. BURGESS, DDS, MS & NATHANIEL C. LAWSON, DMD, PhD

ABSTRACT: Purpose: To compare the wear of an enhanced resin-modified glass-ionomer (RMGI) restorative material (ACTIVA BioACTIVE Restorative) to a resin composite (Filtek Supreme Ultra), RMGI (Fuji II LC), and glass-ionomer (GI) (Fuji IX) material. Methods: Specimens of each material (n=8) were prepared in a silicone mold. All specimens other than the GI material were light polymerized for 40 seconds. After 24-hour storage (H2O, 37°C), the specimens were loaded into the modified Alabama wear testing device. Freshly extracted cusps of human premolars were prepared as antagonists. Specimens were loaded with 20N for 100,000 cycles at 1 Hz. A 33% glycerin lubricant was cycled throughout testing. Specimens and enamel antagonists were scanned before and after wear testing with a non-contact optical profilometer and volumetric wear was measured with superimposition software. Representative specimens were examined with scanning electron microscopy. Data were analyzed with a 1-way ANOVA and Tukey post-hoc analysis (alpha= 0.05). Results: Significant differences were found between materials. Materials ranked in order of increasing wear: Filtek Supreme Ultra and ACTIVA BioACTIVE Restorative < Fuji II LC < Fuji IX. Micrographs revealed that Filtek Supreme Ultra and ACTIVA BioACTIVE Restorative underwent abrasive wear whereas Fuji II LC and Fuji IX underwent fatigue wear. (Am J Dent 2016;29:171-174).

CLINICAL SIGNIFICANCE: ACTIVA BioACTIVE Restorative had similar wear as a resin composite and therefore may have acceptable clinical performance in load bearing restorations.

Introduction

A meta-analysis1 of prospective clinical studies determined the annual failure rate of resin composite restorations in posterior teeth was 1.46% for the initial 5 years and 1.97% following 5 years of service. The primary causes of failure initially are bulk fracture, secondary caries, and marginal opening (in order of decreasing incidence) and long term failure is equally dependent on secondary caries and bulk fracture.1 Therefore, it is evident that improvements in resin composites should prevent the development of secondary caries while maintaining the strength of the material.

Fluoride release from glass-ionomer (GI) restorative materials has been credited for a 65% lower incidence of secondary caries surrounding GI restorations than amalgam restorations.2 However, the use of GI restorations is often contraindicated for posterior load bearing restorations3 due to the greater degree of wear of GIs than of resin composites.3 Resin-modified glass ionomers (RMGIs) are formulated by incorporating a small quantity of resin monomers and initiators into GIs in order to improve some of their mechanical properties. The clinical wear performance of RMGIs, however, remains inferior to resin composite materials.5

Several laboratory studies6-9 demonstrated that resin composites had significantly greater wear resistance than RMGI or GI materials. Resin composites differ from GI-based materials in that resin composite filler particles are bonded to the polymer matrix through a silane coupling agent. In GI-based materials, a bond is formed between polycarboxylic acids in the polymer matrix and aluminum and/or calcium ions in the filler. Unreacted filler or polymer material in GI and RMGI materials may constitute areas of poor wear resistance.9 Laboratory testing7,9-11 also demonstrated that RMGI materials had greater wear rates than GI materials, particularly at early time points. The proposed explanation is that GI materials develop strength through a time dependent acid-base setting reaction. The incorporation of resin into RMGI may interfere with that setting reaction, and delay the onset of adequate wear resistance.11

A novel restorative material has been developed constituting a RMGI enhanced with a blend of diurethane monomers modified by the insertion of a hydrogenated polybutadiene (a synthetic rubber) moiety and methacrylate-based monomers (ACTIVA BioACTIVE Restorative)6. The resin monomers added to ACTIVA BioACTIVE Restorative are claimed to impart resilience to the material to improve its resistance to wear, fracture, and marginal chipping. A previous study12 reported that the flexural strength of ACTIVA BioACTIVE Restorative was similar to flowable resin composites and significantly greater than RMGI or GI materials. The reported flexural strength (105.4 ± 14.3 MPa) was greater than the minimum value required for occlusal restorations by the International Standards Organization (80 MPa), and the authors concluded that this material may be suitable for stress bearing restorations.12 Due to the poor wear performance of RMGI materials, however, an analysis of the wear of ACTIVA BioACTIVE Restorative is warranted.

This study compared the wear of an enhanced-RMGI material to a conventional RMGI, a GI, and a resin composite material. The null hypothesis was that there would be no difference in the wear of any of the materials or their opposing enamel.

Materials and Methods

Representative resin composite, RMGI, and GI restorative materials were used in this study (Table 1). Eight flat disc-shaped specimens (diameter = 15 mm, height = 3.6 mm) were prepared for each material in a silicone mold. The materials were placed in one (enhanced-RMGI and GI) or two (resin...
Table 1. Materials used in this study.

<table>
<thead>
<tr>
<th>Material</th>
<th>Category</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTIVA BioACTIVE Restorative</td>
<td>Enhanced-RMGI material</td>
<td>Diurethane modified by the insertion of a hydrogenated polybutadiene and other methacrylate monomers, polyacrylic acid, silica, sodium fluoride</td>
</tr>
<tr>
<td>Fuji II LC³</td>
<td>Resin-modified glass-ionomer</td>
<td>Fluoroaluminoisilicate glass, polyacrylic acid, HEMA, triethylene glycol-dimethacrylate</td>
</tr>
<tr>
<td>Fuji IX³</td>
<td>Glass-ionomer</td>
<td>Fluoroaluminoisilicate glass, polyacrylic acid, HEMA</td>
</tr>
<tr>
<td>Filtek Supreme Ultra⁴</td>
<td>Resin composite</td>
<td>Dimethacrylate resins, CQ, EDMAB, silica and zirconia nanoparticles and silica/zirconia nanoclusters (78.5wt%; 66.3vol%)</td>
</tr>
</tbody>
</table>

![Graph 1](image1.jpg)  
**Fig. 1.** Wear of restorative materials.

![Graph 2](image2.jpg)  
**Fig. 2.** Wear of enamel antagonists.

composite and RMGI) increments, covered with a glass slide and light polymerized for 40 seconds with a Bluephase 20³ curing light (irradiance = 1,100 mW/cm²). The GI was not light cured. Specimens were mounted into brass holders with acrylic. The specimens were then wet polished in a rotational polisher with 600, 1,200 and 2,000 grit SiC paper and sonicated for 5 minutes to remove polishing debris. After fabrication, the specimens were stored in distilled water at 37°C for 24 hours.

Opposing enamel cusps (antagonists) were prepared from extracted caries-free maxillary premolars. The buccal and lingual cusps were standardized to a cone (5 mm diameter, 2 mm height) with a diamond bur (sintered diamond part #50140060U³). The cusp tips were not abraded by the standardizing bur and therefore represent uncut enamel. The antagonist surface was cleaned and polished with flour of pumice. Initial scans of the enamel cusps were obtained with a non-contact profilometer (Proscan 2000³) at 20 μm resolution. Enamel cusps were chosen to most closely simulate the oral environment. Despite the inherent variability in hardness from tooth to tooth, a previous study³ demonstrated similar variability in vitro composite wear measurements with natural enamel and standardized ceramic antagonists.

A modification of Leinfelder and Suzuki’s original Alabama wear device was used in this study. The mechanisms and testing parameters of the modified Alabama wear testing device have been described thoroughly in a previous publication.¹⁴ The machine operates by applying a vertical load from the antagonist onto the specimen, sliding horizontally, and then repeating the cycle, whereas the original Alabama wear machine applied a spring loaded force with a 30° rotation upon contact with the specimen. The specific parameters for this test were a 20 N load, 1 Hz frequency, 2 mm sliding distance, 33% glycerin lubricant, and 100,000 testing cycles. Following testing, 4 × 4 mm² areas of the specimens and the antagonists were scanned at 20 μm resolution in a non-contact light profilometer (Proscan 2000³). The scans obtained from baseline and 100,000 cycles of wear were superimposed and the volumetric material loss was measured with Proform³ software.

Representative specimens from each group were chosen for imaging with digital light microscopy (VHX-600³). The specimens were cleaned with acetone and the wear tracks were recorded at an original ×100 magnification.

The material and opposing enamel wear data were analyzed using a 1-way ANOVA, followed by a post-hoc test for any significant factor. A P<0.05 was considered statistically significant in two-tailed statistical tests. All analyses were conducted using SAS 9.4.⁵

### Results

The results of the material wear are presented in Fig. 1 and of opposing enamel wear in Fig. 2. Results of the 1-way ANOVAs are presented in Tables 2 and 3. For material wear, significant differences were found between materials (P<0.001). ACTIVA BioACTIVE Restorative demonstrated equivalent wear with Filtek Supreme Ultra and less wear than all other materials. Fuji II LC demonstrated significantly more wear than all other materials. For enamel wear, all materials produced statistically equivalent wear.

Wear tracks of the restorative materials are presented in Figs. 3A-D with the impact site located at the left side of the image. Observation of the wear pattern observed on Filtek Supreme Ultra and ACTIVA BioACTIVE Restorative material
Table 2. Results of 1-way ANOVA for material wear.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>3</td>
<td>15.202</td>
<td>5.067</td>
<td>104.6</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

*Denotes statistical significance at P<0.05.

Table 3. Results of 1-way ANOVA for enamel wear.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>DF</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>3</td>
<td>0.001</td>
<td>0.000</td>
<td>0.898</td>
<td>0.454</td>
</tr>
</tbody>
</table>

*Denotes statistical significance at P<0.05.

reveals a 1.5 mm abrasive track with light scratching along the track (Fig. 3A, D). The start of the wear track shows an impact area whereas the end of the wear track shows an area of sliding. The wear pattern observed on the Fuji II LC material shows a much deeper and wider wear track with chipping and cracks at the start of the track (Fig. 3B). Fuji IX shows a similar wear pattern as Fuji II LC; however, less chipping was observed at the start of the wear track (Fig. 3C).

Discussion

In this study, wear of an enhanced-RMGI material, ACTIVA BioACTIVE Restorative, was equivalent to the wear of the composite resin, Filtek Supreme Ultra. Additionally, the wear of the enhanced-RMGI material was significantly less than traditional RMGI and GI restorative materials. The wear of enamel opposing the bioactive material was equivalent to all other materials tested.

The results of this study are in agreement with previous studies that have reported lower wear resistance of RMGI and GI materials compared to resin composites, and lower wear resistance of conventional RMGI materials than GI materials.

The wear values of the composite reported in this study are similar in magnitude with the values reported in a previous study using the same wear device. Based on a previously determined clinical correlation with the original Alabama wear device, 100,000 cycles of wear simulation in the current study models approximately 9 months of clinical service. This correlation is merely an approximation; however, the original Alabama wear test used a higher load, rotational grinding, and a stainless steel antagonist. Although only a short period of time was modeled, these results should apply to longer wear times as the wear rates of RMGI and GI materials become constant after the initial wear-in stage.

The wear patterns observed on the restorative materials suggest that the materials underwent different mechanisms of wear. The resin composite and the enhanced-RMGI material produced similar wear tracks. The materials seem to have undergone predominantly abrasive wear as indicated by the area of sliding wear at the end of the wear tracks and the light scratching observed in the wear track (Fig. 3A, D). The RMGI and GI materials, on the other hand, produced evidence of fatigue wear as indicated by the cracking and chipping at the start of the wear track (Fig. 3B, C). Abrasive wear occurs in relatively brittle materials when microscopic surface peaks of the material are fractured due to shear forces applied by the antagonist. Fatigue wear occurs in more flexible materials as subsurface micro-cracks coalesce and fragments of the material are removed from its surface. The reported elastic modulus of the enhanced-RMGI material (4.45 GPa) is significantly higher than a RMGI (2.89 GPa) or GI (2.57 GPa) but significantly less than a resin composite (9.53 GPa). The low modulus of the RMGI and GI material explains their susceptibility to fatigue wear.

Another study reported that flexural fatigue of the enhanced-RMGI material is similar to a resin composite and higher than RMGI and GI materials. The high values of flexural fatigue imply that the material may withstand repeated cycles of applied stress prior to fracture. The high flexural fatigue of the enhanced-RMGI material explains the chipping resistance observed in this study at the impact site at the start of the wear track (Fig. 3A). The superior flexural fatigue of the enhanced-RMGI material is attributed to the resilience of its modified resin matrix.

No difference was seen in enamel antagonist wear for all materials. The hardness of resin composites and GIs has been reported previously to be in the range of 42-61 HV, whereas the hardness of enamel is approximately 315-357 HV. Since hardness of the enamel antagonist is approximately eight times greater than the restorative materials, the similarity in reported enamel antagonist wear was expected. The variability in the wear of the enamel antagonists is likely due to the variation in hardness of the natural teeth.

Limitations of this study include the relatively short time of simulated wear, the specificity of the wear mechanisms occurring in the testing device, and the lack of pH and thermal challenge during wear testing. A previous review suggested analyzing the results of more than one wear testing methodology to best assess the wear performance of new materials. Additional properties of this enhanced-RMGI material should be evaluated, particularly bond strength, moisture tolerance, shrinkage stress, ion release, color stability, and roughness. Based on the results of this study, ACTIVA BioACTIVE Restorative had sufficient wear performance for load bearing restorations; however, controlled clinical trials are needed for adequate prediction of the clinical behavior of this material.

Fig. 3. Light micrographs of A, ACTIVA BioACTIVE Restorative; B, Fuji II LC; C, Fuji IX; D, Filtek Supreme Ultra.

a. Pulpdent, Watertown, MA, USA.
References


